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A method for censusing the greater white-nosed monkey in northeastern Gabon using the population density gradient in relation to roads

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ABSTRACT. This paper presents a method for estimating monkey numbers in a large area of forest where there is a gradient of monkey densities. The method is illustrated using data collected in the northeastern forests of Gabon during an earlier project. These forests are sparsely populated and there are few roads. The density of *Cercopithecus nictitans* increases with distance from the nearest road. A geographic information system (GIS) divided the forest into bands of increasing distance from the nearest road. The number of monkeys in each band is the product of the monkey density in that band and the area of the band. Summing across bands gives the population estimate; the standard error can be estimated by bootstrapping. The optimum sample size can be estimated by simulation. Combining estimates of the density gradient with a GIS is a cost-effective method of censusing primates in extensive forests.

KEY WORDS: Census, forest, Gabon, gradient, methods, monkeys

INTRODUCTION

Monkeys are an important source of food for both rural and urban residents in central Africa (Colyn *et al*. 1987, Docky 1987, Lahm 1993a, Robineau 1971). Monkeys and apes are widespread in Gabon (Blom *et al*. 1992, Lahm 1986, 1996, Tutin & Fernandez 1984), but the forests of Gabon are changing rapidly

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as logging activities expand and roads spread further into the interior (Lahm 1993a, Tutin 1992, Tutin & Fernandez 1987). Increasing human activities in the forest zone combined with modern weapons cause greater hunting pressure on game populations, especially those of monkeys and duikers (Lahm 1993b). There is an increasing need for assessments of the status of monkey populations both within and outside protected areas. However, wildlife surveys in the equatorial forests are expensive because of the great distances to be traversed. Travel is usually by foot or canoe and is therefore slow. Biologists need to develop methods that can provide estimates of animal numbers in large blocks of forest but which are not too expensive. This requires the identification of the principal sources of variation in animal numbers over a large area, because otherwise the confidence limits of the estimate will be wide. In this paper we introduce a new method of designing monkey censuses in large areas of equatorial forest.

During a study of forest ecology in northeastern Gabon (Lahm 1993a, b) we noticed a gradient of increasing monkey densities as one moved away from roads. Later we realised that this relationship could be exploited to furnish estimates of monkey numbers. In this paper we describe the method, and illustrate it using data on the greater white-nosed monkey *Cercopithecus nictitans nictitans* L. previously collected by Lahm (1993a, b). First we establish the form of the density gradient in relation to roads. Then we combine the density gradient with the results from a Geographic Information System (GIS) analysis of forest area in relation to roads. This gives an estimate of monkey numbers. Next we show how the variance and confidence limits can be estimated, and then illustrate the estimation of optimum sample sizes. Finally, we suggest improvements to the method, and suggest how future censuses of *C. nictitans* in the central African forests should be designed.

STUDY AREA

Approximately 85% of Gabon is covered by lowland forest (Caballé 1983). The forest of Gabon is part of the Guinea-Congolian phytogeographic region (White 1983). It has been described by Breteler (1989), Caballé (1978, 1983), Reitsma (1988), Tutin (1992) and Wilks (1990). Caballé (1983) separated Gabon's forests into different types according to their floristic composition. Our study area is the vegetation zone defined by Caballé (1983) as 'forests without okoumé of the north-eastern plateaux.' This zone is characterised by many semi-deciduous species and the absence of *Aukoumea klaineana*. The annual rainfall is 1700–1800 mm (Reitsma 1988). The terrain is undulating and the altitude is 500–600 m.

There is a dense human population in the extreme NW corner of the study area associated with several towns and many roads (Figure 1). To the southeast of these towns is an expanse of uninhabited forest stretching towards the town

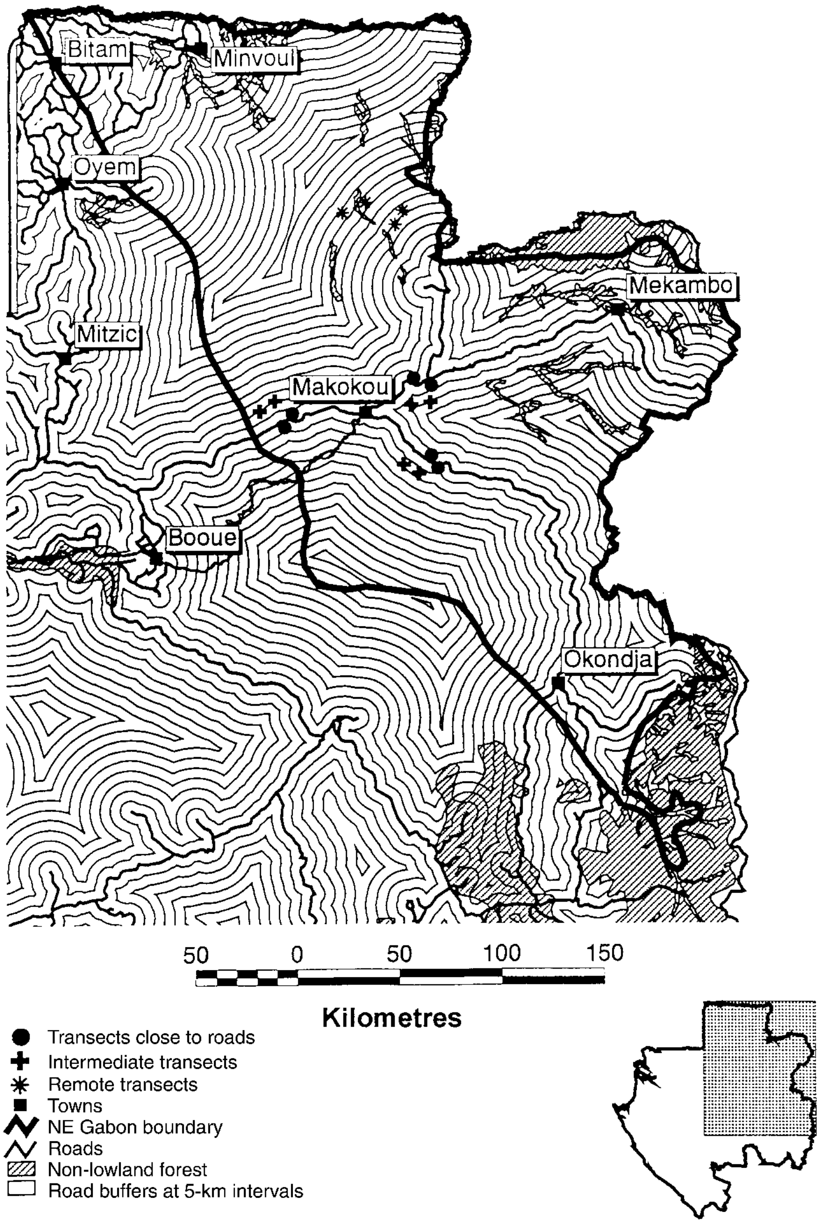

Figure 1. Map of northeastern Gabon. The inset shows the part of Gabon covered by this map. The thick black line represents the boundaries of the vegetation type defined by Caballé (1983). The contours (or buffers) were produced by the GIS and show distances (in 5-km increments) from the nearest road. Shaded areas are non-forest, either swamp forest in the study area or savanna outside the study area.

of Makokou (which had a population of 10,000 in 1990; Richard & Léonard 1993) in the centre of the study area. Three main roads radiate out from Makokou (Figure 1). Villages are scattered along the roads which thus form ribbons of human disturbance. Apart from roadside villages and the towns shown in Figure 1, and a few riverside villages and camps, the forests are uninhabited. These forests had not been logged at the time this field work was conducted. However, much of the forest had previously been occupied intermittently because most villages were semi-nomadic until the 1960s (Pourtier 1989). Thus patches of secondary forest of different ages are found throughout the area.

The forests support a wealth of wildlife (Blom *et al*. 1992, Dubost 1984, Emmons *et al*. 1983, Gautier-Hion 1978, Lahm 1993a, Tutin & Fernandez 1984). The villagers live by subsistence farming, hunting and fishing. Bushmeat is an important source of income (Lahm 1993b). *Cercopithecus nictitans* is the most common primate and is also the monkey most frequently killed by local people (Lahm 1993a).

METHODS

Field studies

Field work was conducted between 1988 and 1991 by the first author as part of a comprehensive study of the impact of hunting and trapping on wildlife (Lahm 1993a). Sixteen permanent transects, each 5 km long, were established. The starting point of each transect was selected at random. Six were close to villages (Figure 1); each one started at, and was oriented perpendicular to, a road. Six were cut deeper in the forest, starting 5 – 7 km from a road. Four were cut in remote forests (Figure 1).

Six replicate counts were made on each transect. Each count began between 06h30 and 08h00. Two observers walked slowly along the transect, pausing occasionally to listen. The average speed was *c*. 1–1.5 km h^{-1}.

The strip-transect method described by Whitesides *et al*. (1988) was employed. The width W of the transect was estimated by:

$$W = 2 \times (0.5G + D)$$

where G was the group spread and D was the detection distance (Whitesides *et al*. 1988). This gave a width of 140 m, so that each transect covered an area of 0.7 km^2 (Lahm 1993a).

The number of monkeys seen was recorded. For each transect, the mean monkey density (Y) was calculated from the six replicates. The variance tended to increase with the mean, indicating a slightly contagious or aggregated distribution (Southwood 1978). Applying Taylor's power law as recommended by Southwood (1978: page 10) indicated a square-root transformation ($\sqrt{Y}$).

Geographic information system

The African Elephant Database was established as a geographic information system (GIS) by Burrill & Douglas-Hamilton (1987) using the ARC/INFO software package. A GIS is a database management system designed for the analysis of spatial information (Burrough 1986, Star & Estes 1990). It may be envisaged as layers of geographic information (e.g. in this case separate layers of political boundaries, rivers and lakes, vegetation, roads) which are spatially referenced to each other.

We modified the African Elephant Database GIS for Gabon by re-digitizing the road layer using a 1 : 1 million map (IGN 1987), and by adding a layer showing the vegetation of Gabon (WCMC 1993).

A set of contours showing the distance from the nearest road was generated by the GIS. The interval between contours was 5 km. Next, we combined the GIS contour data layer with the vegetation layer to generate contours for the forests of northeastern Gabon. Then the GIS program calculated the area of forest in each band between the contours.

RESULTS

Field studies

Altogether there were 2,232 sightings of monkeys on the transects. Low densities of monkeys were recorded near the roads, but the densities increased with increasing distance away from roads (Figure 2). The relationship between monkey density and distance to the nearest road, X_{rd} was very significant ($P < 0.0001$). Since r^2 was 0.69, distance from the nearest road accounted for approximately two-thirds of the variation in the density of *C. nictitans*.

There was no correlation between the percentage of secondary forest, expressed as an arcsine transformation, and monkey density ($r = 0.28$, $P > 0.05$). Adding secondary forest to the regression of $\sqrt{Y}$ on $\log_e X_{rd}$ did not make a significant contribution to the explained variance ($t = 0.47$, $P > 0.05$).

Geographic information system

The GIS calculated the area of Caballe's (1983) 'forests without okoumé of the north-eastern plateaux' to be 55,541 km^2. If one took an imaginary circular forest and created concentric bands 5 km wide within the forest, the area of forest within each band would decrease with increasing distance from the forest edge. Similarly, Figure 3 shows how the area of forest in each of the 5-km-wide bands diminished with increasing distance from roads. The most remote forest was 80 km from the nearest road (Figure 3). Half of the study area lay within 20 km of a road, 75% lay within 40 km, and 95% lay within 65 km.

Estimate of monkey numbers

The ability to calculate the number of monkeys at a given distance from the road, combined with knowledge of the amount of forest at given distances from

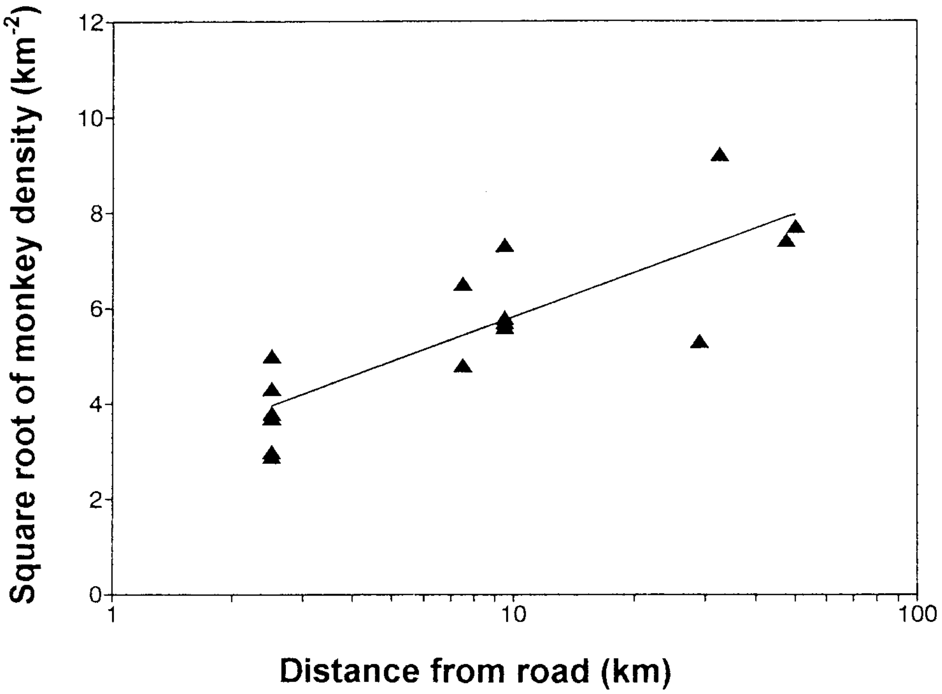

Figure 2. Plot of the square root of monkey density ($\sqrt{Y}$, where Y is expressed in numbers of monkeys per sq km) against distance to the nearest road (X_{rd}, expressed in km). $\sqrt{Y} = 2.73 + 1.34\log_e(X_{rd})$ $r = 0.831$, d.f. = 14, $P < 0.0001$.

the road, provides a new method for estimating monkey numbers in large forest blocks. We illustrate this for the northeastern forests.

For each band of forest defined by the contours, the monkey density Y at the midpoint of the band (i.e. at 2.5, 7.5 km . . . etc from the nearest road) was calculated from the regression equation $\sqrt{Y} = 2.73 + 1.34 \log_e(X_{rd})$ (Figure 2). This was used as an estimate of the mean monkey density in that band. The number of monkeys in the band was then the product of the monkey density and the area of that band.

The maximum distance from the nearest road (X_{rd}) for the 16 transects was 50 km, whereas the GIS analysis showed the most remote forest to be 80 km from a road. Calculating monkey densities beyond 55 km by extrapolating from the regression equation may not be justified. Therefore, to be conservative, we allocated the bands beyond 55 km the same density as that estimated for the 50–55 km band. This made a difference of only 1.2% to the total estimate compared with extrapolating up to 80 km.

The lowest monkey densities were in the roadside band, which covers the largest area (Figure 3). Similarly the highest densities were in the most distant forests which account for only a small proportion of the total area. Although

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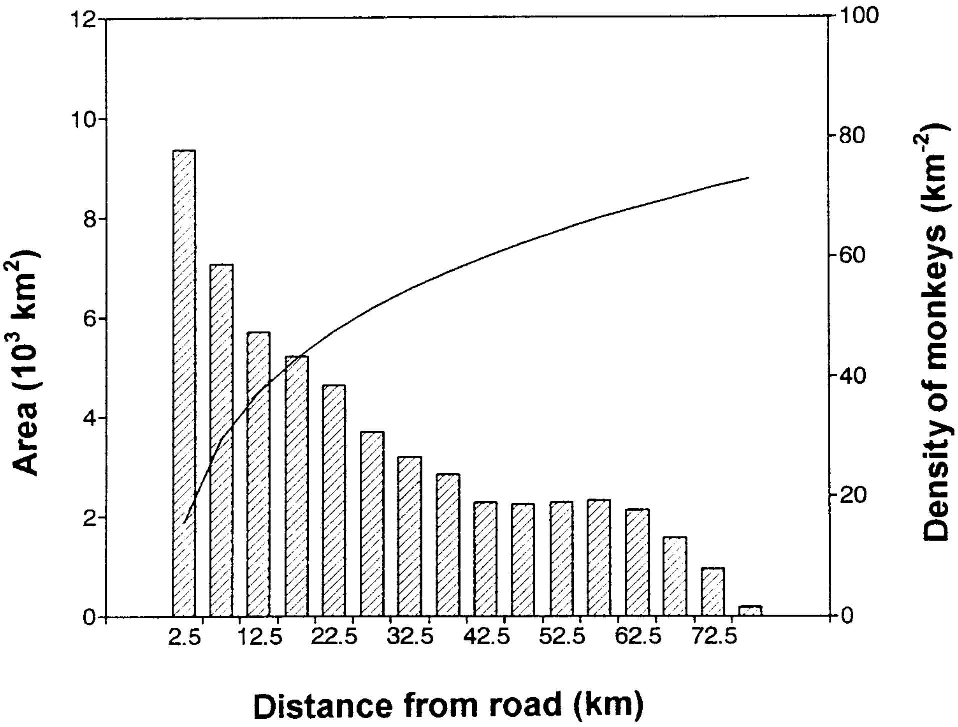

Figure 3. The histogram shows the area of forest in each band representing distance from the nearest road. The bands are 5 km wide. The line shows the mean monkey density in relation to distance from the nearest road.

monkey densities were low closer to the roads, the larger area of forest near the roads means that 50% of the monkeys were within 30 km of a road (i.e. readily accessible to hunters) and only 25% were more than 50 km from a road.

The estimated monkey population was obtained by summing monkey numbers across bands. The standard error was estimated by the following bootstrap procedure (Diaconis & Efron 1983, Efron & Tibshirani 1986). Sixteen $Y\text{-}X_{rd}$ data-pairs were randomly selected with replacement from the original sample to give a new set of $Y\text{-}X_{rd}$ pairs. The $\sqrt{Y}$ values were regressed upon the $\log_e(X_{rd})$ values to give a new regression equation. This was used to estimate the monkey density for each band. Summing across bands gave a new estimate of the monkey population. This procedure was repeated 1,000 times to give that number of estimates of the monkey population. The mean of these 1,000 estimates was 2,454,200 monkeys, with a SE of 312,476 and 95% confidence limits of ± 612,453 (or ± 25% of the mean). However, the estimates were not normally distributed, because there was a slight tail towards the higher values (Figure 4). The median was 2,427,651 and the 95 percentiles were 1,907,390 (–21%) and 3,200,894 (+32%). Therefore the best estimate is 2,427,651 monkeys with asymmetric confidence limits of 1,907,390 and 3,200,894.

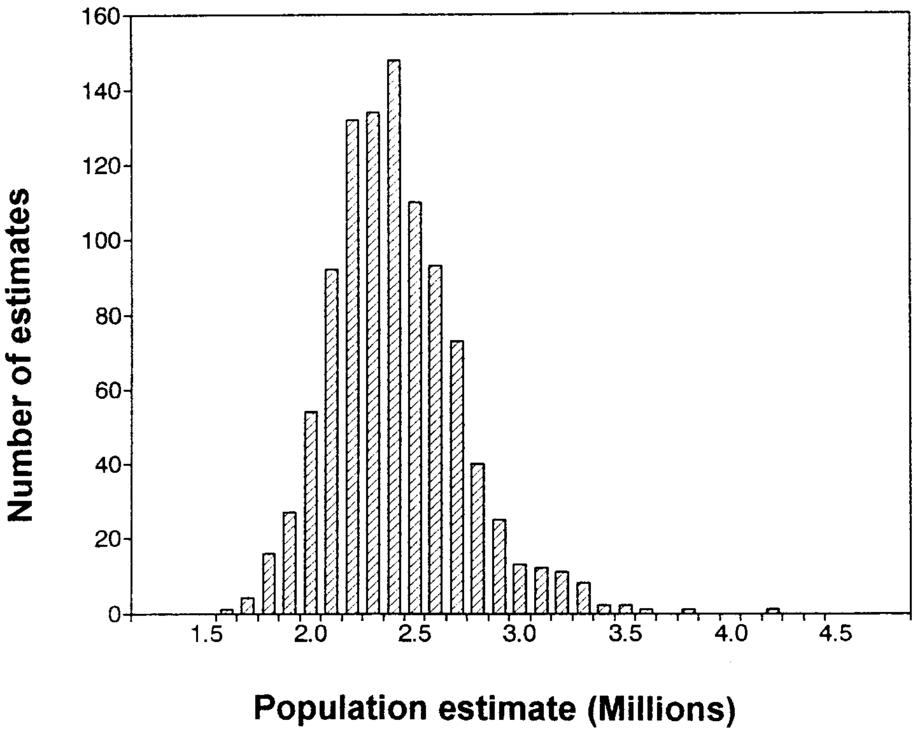

Figure 4. The frequency distribution of monkey population estimates from bootstrap resampling.

Optimum sample size

The ideal census gives an estimate that is both accurate, i.e. close to the true number of animals, and precise, i.e. small variance or narrow confidence limits (Norton-Griffiths 1978). The variance decreases with sample size, but the relationship is not linear, so a stage is reached where an increase in sample size is not matched by a corresponding decrease in variance (Norton-Griffiths 1978).

What is the optimum number of replicates for each transect? Ideally, the more replicates the better, but there has to be a trade-off between number of replicates and costs of field work. We answered this question by simulation. First, for each transect the density from the first replicate was calculated, and these densities were used to estimate the total monkey population by the method above. Then for each transect the mean density was calculated from the first two replicates and used to estimate the total monkey population. This was repeated for 3, 4, 5 and 6 replicates.

By chance, in four transects no monkeys were sighted in the first replicate. Thus using only one replicate for each transect gave a low estimate (Figure 5a). Using two replicates, or three replicates, gave a higher estimate. There was no change in the estimate after four replicates (Figure 5a), and so four appears to be the optimum.

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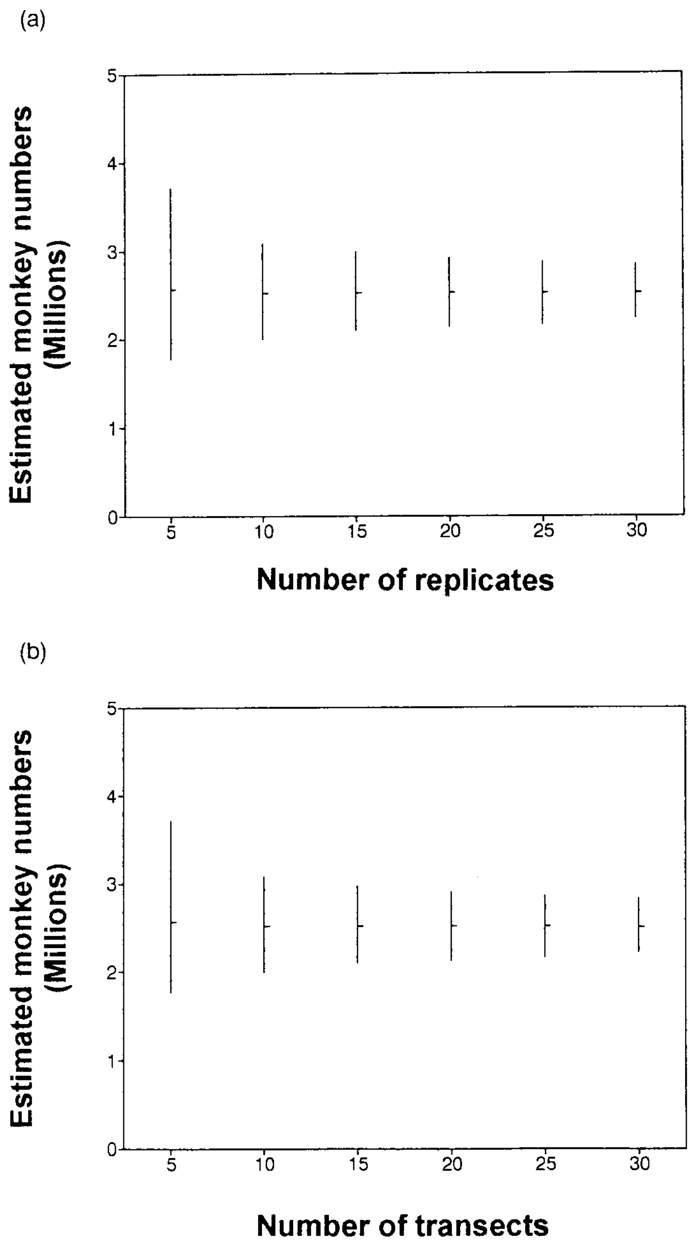

Figure 5. Results of the sample size trials. The median estimates of monkey numbers from the bootstrap resampling are shown. The vertical bars show the confidence limits. Relationships between the estimated number of monkeys and (a) the number of replicates for each transect and (b) and the number of transects.

Having determined the optimum number of *replicates* for each transect, what is the optimum number of *transects*? We first calculated the mean density for each of the 16 transects using four replicates. Then we calculated the regression of $\sqrt{Y}$ on $\log_e(X_{rd})$ and stored the residuals. The variance of the residuals

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was 1.2609. Next we imagined a study in which five transects were placed at regular distances from a road, e.g. at the midpoint of the 0–5, 10–15, 20–25, 30–35 and 40–45 km bands. These distances were represented in the simulation by X_{rd}. For each X_{rd} the computer calculated $\sqrt{Y}$ using the regression. Then to $\sqrt{Y}$ it added a random normal deviate drawn from a distribution with a mean of zero and a variance of 1.2609 . This gave a pseudo-value $\sqrt{Y^*}$ corresponding to each X_{rd}. These X_{rd}-$\sqrt{Y^*}$ pairs were entered into a new regression from which the monkey density in each band was calculated. Summing across bands gave the total monkey population for the study area. This was repeated 1,000 times, and the median estimate and confidence limits were calculated. We then imagined a second set of five transects, perhaps in a different part of the study area, giving a total sample of ten transects. The above procedure was repeated to give 1,000 estimates of monkey numbers from ten transects. It was then repeated with varying numbers of transects up to 30.

With only five transects the variance of the estimate was high, giving wide confidence limits (Figure 5b). In other words, the estimate was not precise (Norton-Griffiths 1978). Increasing the number of transects to ten, and then to 15, dramatically reduced the variance and therefore the width of the confidence limits (Figure 5b). However, samples larger than 15 transects resulted in little improvement in precision, and therefore 15 can be tentatively accepted as the optimum sample size.

DISCUSSION

Density gradients

Distance from road explains two-thirds of the variation in monkey numbers. The most likely explanation is hunting pressure because villages are concentrated along the main roads, leaving large areas of forest uninhabited. Until the 1950s the people lived in hamlets scattered throughout the study area. In the 1950s and 1960s the government resettled the rural population into villages located on the roads (Barnes *et al*. 1991, Lahm 1993a, Pourtier 1989). Patches of secondary forest now cover the former villages and plantations but there is no evidence that they have any effect upon the distribution of *C. nictitans*. It is possible that the roads were aligned to avoid marshes and swamps, and if *C. nictitans* preferred such areas then we would see the same density gradient in relation to roads. On the other hand, Barnes *et al*. (1991) found a positive correlation between elephant numbers and X_{rd} in this part of Gabon. They accounted for secondary vegetation and showed that marshes and wet (seasonally inundated) forest did not affect elephant distribution, at least in the wet season when they conducted their study. Therefore it seems most likely that both elephant and *C. nictitans* densities are high in the remotest parts of the forest because of the absence of human disturbance.

Logging changes the structure of the forest and can affect primate populations (Plumptre & Reynolds 1994, Skorupa 1986; Struhsaker 1975, 1997), but this area had not been logged at the time of the field work.

Gabon's northeastern corner is one of the most sparsely populated parts of equatorial Africa. Elsewhere in Gabon, where there are more people, and where there are also logging operations, hunting has an even greater impact upon monkeys. As human populations increase along roads and rural development increases, hunting pressure will spread deeper into the forest and the slope of the graph in Figure 2 will become less steep as monkeys diminish. Barnes *et al*. (1997) and Michelmore *et al*. (1994) have shown this effect for elephants suffering different hunting intensities. In order to fully understand the impact of the utilization of monkey populations by humans, estimates of the slope of the curve are needed for different conditions of human disturbance.

The gradient in *C. nictitans* densities in relation to roads is similar to that reported for elephants (*Loxodonta africana africana* Blumenbach and *L. a. cyclotis* Matschie) in northeastern Gabon and elsewhere in the equatorial forests (Alers *et al.* 1992, Barnes *et al*. 1991, Fay 1991, Fay & Agnagna 1991). For primates, Lahm (1993a) has demonstrated similar trends for *Cercocebus albigena* Gray, *Cercopithecus cephus* L., *C. pogonias* Bennett, and *Colobus guereza uellensis* Matschie in northeastern Gabon. Tutin & Fernandez (1984) recorded lower densities of gorillas (*Gorilla g. gorilla* Savage & Wyman) and chimpanzees (*Pan t. troglodytes* Blumenbach) near roads in Gabon. Kano & Asato (1994) demonstrated a gradient of increasing gorilla and chimpanzee densities with distance from the nearest village in northern Congo. Antelopes also seem to show the same effect in northeastern Gabon: *Cephalophus callipygus* Peters, *C. dorsalis* Gray, and *C. monticola* Thunberg (Lahm 1993a). The population density gradient in relation to human activities may therefore be a general rule governing large mammal abundance in the central African forests.

Importance of the density gradient

The variation in monkey abundance can be broken down into that explained by the gradient, that due to environmental factors such as the patchiness of the forest, and random error. Two-thirds of the variance in monkey densities was explained by distance from the nearest road. This is a very high proportion of the variance to be explained by only one variable. By accounting for this large source of variation, one can sample the forest more efficiently. If one did not account for the gradient, one would have to use many more transects to achieve the same level of precision.

This proposed new method of estimating monkey numbers takes advantage of three recent developments. The first is the discovery of the density gradient in relation to roads. The second is the evolution of geographic information systems which are now relatively cheap. The GIS is a powerful new tool for primate surveys, not only in the forest but also in more open habitats (Zinner & Torkler 1996, Smith *et al*. 1997). The third is the development of computer-intensive methods such as the bootstrap. Without the bootstrap it would have been difficult to estimate the precision of the estimate.

Census design

A problem with this type of study is in deciding when a road is important enough to be included. Our criterion was whether or not the road appeared on the latest edition of the 1 : 1 million map of Gabon. One could use different criteria, such as the mean number of vehicles passing per 24 h, or the mean number of people resident per unit length of road.

Although we used X_{rd} as the only predictor of monkey density, future studies should investigate the relationship between monkey abundance, distance to road and the level of human activity along the road. For example, monkey densities at 10 km from sparsely-populated roads (that is, roads lined with few villages) are likely to be higher than those at 10 km from heavily-populated roads. Thus a better model of monkey density might be:

$$\sqrt{Y} = a + b \log_e(X_{rd}) + cH$$

where a, b and c are regression constants, H is an index of human population density along the road, e.g. inhabitants per km of road, and X_{rd} is the distance of the transect from that road. Other mappable variables, such as marsh or swamp, might also be useful predictors of monkey abundance. Where villages are distributed through the forest, rather than along main roads, then distance to the nearest village will become an important predictor either instead of, or as well as, X_{rd}.

Roads are the main source of human disturbance in these forests, because villages are sited on the roads. However, there are a few villages and many small hunting camps along the rivers. At present these riverside habitations appear to have little effect upon monkeys because the river villagers concentrate on fishing, and the hunting camps are used intermittently (Lahm 1993a). Indeed, the highest monkey densities in this study were recorded on transects which started from the Ntsie and Nouna Rivers. However, as human pressures increase within the forests, there will be more and larger hunting camps along the rivers. Eventually primatologists will find that monkey densities in these forests will be determined by distance from both roads and rivers.

The forest biologist faces sampling problems similar to the political pollster. The population of the USA is 265 million, but pollsters are able to obtain estimates with confidence limits of ± 3% by taking a sample of only 1,000 people (Lake 1987). This is because the variance of a sample depends upon the heterogeneity of the sample and its size, and not on the size of the population or area from which it is drawn (Lake 1987; see also Cochran 1977). The same size of sample could be used to obtain monkey estimates for forests of 5,000 sq km, 50,000 sq km, or 100,000 sq km.

With any type of sample a point is reached where an increase in sample size (= effort and expense) is not balanced by a corresponding increase in accuracy or precision. Doubling the size of the sample will double costs but may not make much difference to the width of the confidence limits. The logistical costs of working deep in the forest are high and it is therefore important to know where the trade-off lies between sample size and precision. For *C. nictitans* in northeastern Gabon the optima appears to be four replicates of each of 15 transects. But *C. nictitans* is the most common and abundant species in the area; less common species which are more patchily distributed may have a greater variance between replicates and between transects, requiring larger samples to achieve the same level of precision.

The data used to illustrate this paper were not collected with this sort of analysis in mind. We took advantage of their availability to test and illustrate the feasibility of this type of census. They serve as a pilot study and are particularly useful in indicating the sort of variation to expect and therefore the optimum sample size. We suggest that the optimum design for a *C. nictitans* census in large areas of uninhabited Gabonese forest may be as follows. The study area should be divided into strata according to hunting pressure. In this study there was only one stratum. For their elephant survey Barnes *et al.* (1997) divided Gabon into two strata, one with high human density and one with low. The gradient of elephant density in relation to roads was less steep in the high human density stratum. Within each stratum there should be 15 transects; the transects should be arranged in three sets; and each set should consist of five transects placed at random distances from the road up to a maximum of 70 km.

The vastness of the equatorial forest means that biologists will be forced to make compromises between the need to sample intensively and the restrictions imposed by limited resources. We suggest that combining estimates of the density gradient with a GIS is probably the most cost-effective means of censusing primates, and other large mammals too, on a large scale in the equatorial forests.

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