A COMPARISION OF TRANSECT METHODS OF ESTIMATING POPULATION DENSITIES OF COSTA RICAN PRIMATES

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ABSTRACT

This study compares population density estimates derived from a variety of transect methods against direct counts for a group of cebus *(Cebus capucinus)* and a group of howling monkeys *(Alouatta palliata)* inhabiting a seasonally dry forest in Costa Rica. Transects stratified by habitat, walked at all hours of the day for a large sample size, covering sufficient area to adequately sample all habitats, and using "mean distance to the animal" to estimate strip width, combined to give the most accurate density estimates. Our study indicated the importance of a large number of trials, which are required before it can be assured that precision becomes stable. Differences in precison and accuracy of various transect methods are discussed in an attempt to provide information on which techniques are best suited for particular situations.

Presently within Costa Rica, as elsewhere, the need to obtain accurate estimates of the primate population densities is critical for the formulation of informed conservation plans for endangered primate species (Vaughan 1983). Scientists, conservationists, and policy makers want population estimates that are as reliable, accurate and comparable as possible. For arboreal primates, repeatedly sampling strip transects is the most common method of estimating population density (eg., Muckherjee and Mukherjee 1972, Struhsaker 1975, Freeze 1976, Green 1978a, b, Cant 1978, Freeze *et al* 1982, Wilson and Johns 1982, Delfer and Pintor 1985). However, there exists a large number of variations in transect methodology. These include variations in the measurement of transect width, the number and placement of transects and in the type and degree of stratification. Thus, there is no ready answer to the question: are there predictably best transect methods for given field situations and primate species? To begin to answer this question, we compared population estimates of two Costa Rica primate species *(Cebus capucinus, Alouatta palliata)* derived from a variety of transect methods, against counts of the same populations conducted as part of intensive studies of these species in Santa Rosa National Park.

The first variation in transect methology examined involves choosing how the width of the transect is determined. Studies following the recommendations of Emlen (1971) and Robinette *et al* (1974), have employed as widths, various distances derived from either the perpendicular distance of the observed animal from the transect line, or the distance the animal is from the observer (Struhsaker 1975, 1981, Cant 1978, Burnham *et al.* 1980, Freese *et al.* 1982, Delfer and Pintor 1985). The use of different methods of calculating transect width can make large differences in the resulting population estimates since area surveyed is calculated as twice the estimated width, multiplied by the total length of the transect.

When censusing primate groups in heterogeneous habitats, varying in use, visibility and accessibility, the adequate sampling of all habitats becomes especially difficult (Struhsaker 1975, Cant 1978, Green 1978a, Crockett 1982, Freese *et al.* 1982). This often leads to the sampling of only selected habitats. The selection of habitats to sample may be done on an intuitive basis, or by stratifying the total sample (Caughley 1977). The accuracy of the population density estimate produced by stratifying the sample is examined here using the transect width which produced the most accurate density estimate.

Precision curves can be used to establish the number of transects that should be sufficient for a transect study, even though the accuracy (ie. how close the derived density estimate is to the true density) of the proposed number of trials in uncertain. It has been suggested that censuses should be made when animals are most active and thus most easily seen (Freese 1976, Green 1978a, Cant 1978, Struhsaker 1975, 1981, Wilson and Johns 1982, Crockett 1982, Delfer and Pintor 1985).This seems intuitively sound, but it requires prior knowledge of the activity patterns of the primate species being investigated.

Methods

Data for this study were collected from January to August 1984 on a group of cebus monkeys *(Cebus capucinus)* and a group of howling monkeys *(Alouatta palliata)* occupying overlapping home ranges in the seasonally dry tropical forest of Santa Rosa National Park, Costa Rica. The cebus monkey group contained 26 animals; 4 adult males, 10 adult females, 4 large immatures, 5 small immatures, and 3 infants. The howling monkey group had 40 members; 8 adult males, 16 adult females, 3 large immatures, 4 small inmatures, and 9 infants. The park consists of a mosaic of distinct habitat types which results from naturally varying environmental conditions and past land use patterns. Habitats used by the study groups included dry deciduous forest, dominated by *Spondias mombin, Luehea candida, Guazuma ulmifolia, Bursera simaruba, Ficus sp., Chlorophora tinctoria;* and semi-evergreen forest, dominated by *Hymenaea courbaril, Quercus oleoides, Mastichodenron capiri, Manilkara zapote* (Bonoff and Janzen 1980, Janzen 1982, personal communications). A large proportion of both of the 'species' home ranges was bordered by abandoned pastures, which are almost entirely *Hyparrhenia rufa* grass. Because of this the groups were semi-isolated from neighboring groups.

As part of intensive behavioural and ecological studies, groups were repeatedly counted by age/sex classes at openings in the forest canopy or at crossing sites. Once stable age/sex counts were obtained it was assumed that the group count was complete. Since individuals were easily recognized in both the cebus and howler groups, no groups other than the study groups were included in the transect calculations.

In July and August of 1983, prior to establishing permanant transects, we determined the approximate extent of each group's home range.Five transects then were established in the area of home range overlap of the groups by cutting small trails along compass bearings and marking the transect line at 10 m intervals. The study area included areas of wet or semi-evergreen forest and areas of drier, secondary forest. The first transect was 900 m long, and started in secondary forest and ran north into the semi-evergreen forest. Two 200 m transects were established parallel to each other in the area of wet forest. The remaining two transects were each 400 m long and were established in a second area of dry forest.

One observer walked along the transect line and recorded all contacts with animals. When a monkey was sighted the observer recorded the date, time, species, height, perpendicular distance to the first animal seen, the distance from the observer to that animal (sighting distance), the location (which 10 m interval), the angle from the transect to the animal seen (sighting angle), the composition of the group and the group's activity. To record the group's composition the observer watched the group for up to 10 minutes, leaving the transect line if necessary. Equal numbers of transects were walked at all times of day. The same transect normally was not walked more than twice a day.

Strip width was calculated in six different ways; mean, maximum and reliable perpendicular distance from the transect to the animal first sighted and the mean, maximum and reliable distance from the observer to the animal. To calculate the two reliable width estimates, a frequency distribution of all estimations of perpendicular distance, and distance to animal, were plotted separately. These plots were inspected and the level at which the curve dropped off was considered to be the reliable strip width (Kelker 1945 in Robinette *et al.* 1974). The accuracy of the population density estimates was considered to be the amount by which the estimate, derived from the transect methods, deviated from the population density, determined by direct count.

To determine the pattern of dispersion of the cebus and howling monkey groups along the transect lines, a coefficient of dispersion was calculated, using the number of sightings per 10 m interval as the unit of measure. The value of the coefficient of dispersion is greater than one when the distribution pattern is clumped, is less than one when the patterns is uniform, and one when the pattern is random (Pielou 1969, Southwood 1966, Sokal and Rohlf 1969, Milton 1980).

To calculate the population density, the number of animals in each group was divided by the size of the group's home range. The method used to measure the home range size can have a large effect on the subsequent population density estimate. To illustrate this, home range was measured in two ways; first a "block" method which considered home range as those areas (200 m by 200 m blocks) that the group was observed in or had to pass through to get from one observation point to another; and secondly a "minimum area" method in which all sightings of the group were connected by straight line, and the area contained inside the lines was considered the size of the home range (Lehner 1979).

Results

Using the "block" method, home range for the cebus monkeys was calculated as 1.79 km^2 while, with the "minimum area" method, the home range was 1.17 km^2. The "block" method produced a home range estimate for howlers of 2.10 km^2 and the "minimum area" method produced an estimate of 1.39 km^2.These two methods of calculating home range result in population density estimates that differ by 7.7 individuals per km^2 for cebus and 9.7 individuals per km^2 for howlers. The two methods used in this study were chosen to give quite extreme differences in the home range estimates; the "minimum area" method almost certainly underestimates the total area used by a group, whereas the "block" method may tend to overestimate the home range size. The two methods result in two quite different "true" densities and thus in two different sets of "accuracy" of the different widths (Table 1).

TRANSECT WIDTH

Six methods of calculating transect width were used (Table 1). For both howling and cebus monkeys the difference between methods resulted in population density estimates that differed by as much as 17.38 and 15.2 individuals per km^2. When the "block" method was used to determine the size of the home range, the "mean distance to the animal" was most accurate for both species. In comparison, using the "minimum area" method, the "mean perpendicular distance" was most accurate for both species. Since for primates, transect methods are normally used to estimate the density in sections of forest, not in carefully delineated areas, the most suitable way of determining home range size would seem to be use the "block" method. For the following analyses, population density was calculated using the "block" method of determining the size of the monkey group's home range.

The error in estimating distances was calculated by using the trigometric function *Perpendicular distance = observer to animal distance x SIN of the sighting angle*. The mean error in estimating distance was $\pm$ 1.8 m. This high average level of accuracy resulted from the effects of over estimates being balanced by under-estimates. The effect of systematically biasing the distance estimated was simulated in Table 2 both for howling and cebus monkeys. A small systematic bias in the estimation of distance can produce a large difference in the derived population density estimates.

SAMPLE SIZE

Researchers using transect methodology need to know at what point they can stop censusing an area. The larger the sample size the greater the precision of the estimate. However at some sample size the precision will level off and will not increase significantly with the addition of more transects. Figures 1 and 2 illustrate the precision and density estimates for each species as the number of transects conducted increases. For howlers the precision curve levelled off rapidly, whereas for the cebus it did not. These figures also illustrate that the level at which the precision curve levels off is not necessarily a point of high accuracy. It is possible to increase the precision of an inaccurate estimate.

NUMBER OF TRANSECTS ESTABLISHED

Since a number of different transects were established, it was possible to examine the population density that was obtained by each of the transects separately (Table 3). When this was done it was evident that both species were preferentially found on certain transects and not others. The extent of this variation was most evident in the howling monkeys where population density estimates varied between transects from 40.3 individuals per km^2 to 7.6 individuals per km^2.

One method often used to reduce the effort required to estimate population density is to assume that particular habitats are not used by the study species. If information on the habitat preferences of the species is available it may be valid to make this assumption. If not, a preliminary survey can be conducted, and those transects with zero or low counts discarded. This stratification procedure was simulated by considering the first 20 times the transects were sampled as a preliminary survey. When those transects not containing at least 10% of the animals seen on the first 20 samples were excluded, the resulting population density estimates were 14.5 individuals per km^2 for cebus monkeys and 21.3 individuals per km^2 for howling monkeys. These estimates have an error of –0.02% and +12.9% respectively. This also demonstrates the effects of establishing fewer transects.

Another means of stratifying the sample is to weight each habitat type in proportion to its representation within the study area. This should reduce the variability between the samples, thereby increasing precision (Caughley 1977). Since both of the study groups used areas that had strongly contrasting habitat types, this approach seemed appropriate. The area covered by each habitat type was determined for each group and its proportion in the total home range was used to weight the density estimate derived from the transects in those habitats. By stratifying the sample according to habitat for cebus monkeys, the population density estimate was 17.6 individuals per km^2, a 21.1% overestimation and for howlers it was 14,1 individuals per km^2, a 25.8 underestimation.

The suggestion that censuses be conducted when animals are most active, assumes that they will be more observable at those times. However when a quantitative transect method using a measure of distance to the animal is used to determine transect width, differential observability between time periods will be accounted for by differences in the transect width. Thus, if samples are taken during periods when the animals are inactive, the width of the transect strip will be less than when the animals are active and no systematic bias should enter into the sampling. However, to test stratification by time of day, density estimates were calculated for each of four different time periods. There was no consistent trend for density estimates derived from transects sampled in periods of increased activity to be more accurate than those estimates made when animals were inactive (Table 4). Similar results to these were found by Janson and Terborg (in press).

To quantify the dispersion pattern, the coefficient of dispersion was calculated using the number of sightings per 10 m intervals as the unit of measure. For cebus monkeys the coefficient of dispersion was 3.60, while for howling monkeys it was 2.98. Both of these values are significantly greater than 1 ($P<0.001$), indicating that groups of both species exhibited a clumped dispersion pattern along the transects.

As an initial step in a long term project to study the demography, ecology and behaviour of primtes in Santa Rosa National Park, a census by group enumeration was conducted in 1983 and 1984 (Fedigan *et al.* 1985). This census estimated that there were 393 cebus monkeys and 342 howling monkeys inhabiting the 100 km^2 park. Approximately 70% of the park is forested and available to the monkeys, thus the ecological density of howlers was estimated at 4.9 individuals per km^2 and for cebus it was 5.6 individuals per km^2. If these estimates are reasonably accurate, as we believe they are, then the "best" population density estimates obtained from the transects, when extrapolated to the forested area of the park, produce an error of 250% for howling monkeys and 112% for cebus monkeys. These large error values probably indicate that the transect area does not accurately represent the whole park. This study site contains areas of lush vegetation not typical of the park and the monkey groups using the study area are some of the largest found in the park (see Table 1 and 2 in Fedigan *et al.* 1985). This extrapolation of transect density estimates to that of the whole forested part of the park illustrates the importance of sampling all habitats in the area that the density estimate is to be used to represent.

Discussion

The transect methods used in this study produced some accurate estimates of the population density for both of the species. However, the accuracy was achieved by making specific a posteriori modifications to the general transect methodology. Without knowing the true population density it would not have been possible to choose the best modifications, but from the results obtained, some specific suggestions can be made about the choice of method. Suggestions are made in three areas: (1) selection of the method to determine transect width, (2) the sample size required to attain a desirable level of precision and accuracy, and (3) the form of the transect system.

TRANSECT WIDTH

The widely disparate density estimates obtained from different methods of determining transect width illustrates that the calculation of strip width is a critical element influencing the accuracy of the population density estimate (Table 1). In this study all methods of determining transect width which do not use all animal sightings were discarded, since it is always undesirable to discard observations (Eberhardt 1968). Thus, the commonly used qualitative method which sets the transect width as the value in which it is "believed" all animals are seen, was not considered. Of the six methods of determining transect width used, "mean distance to the animal" was most accurate for both cebus and howling monkeys. The "reliable distance to animal" and the "reliable perpendicular distance" were the second and third most accurate methods, respectively.

Robinette et al. (1974) examining simulated and real populations, came to the conclusion that "mean distance to animal" produced less bias than other methods based on sighting distance. Defler and Pintor (1985) found that no one method of estimating transect width was accurate for all of the three species they examined *(Alouatta seniculus, Callicebus, torquatus, Cebus apella)*, yet "mean distance to animal" produced accurate estimates for all species except *Cebus apella* where it produced very inflated estimates. However, Struhsaker (1981), has rejected the use of this measure for red colobus, red tail monkeys and blue monkeys because it produced strong overestimations. Janson and Terborg (in press) report similar large overestimates for New World species.

In this study the use of "reliable perpendicular distance" or "reliable distance to animal" produced consistent population density estimates that approached the "true" population density. Struhsaker (1981) reports an overestimation obtained for the monkey populations he censused using both of these methods, but he states that the "reliable distance" produced estimates which were generally closer to the actual density than any other way of determining transect width. Struhsaker reported that 40% of his sightings of red colobus were directly over the transect, and since a sighting directly over head has no perpendicular distance, the use of the "reliable perpendicular distance" overestimated the population density by underestimating the area censused. Defler and Pintor (1985) similarily advocated the use of the "reliable distance to the animal", even though it produced a very inflated density estimate for *Cebus apella.*

With the use of perpendicular distance estimates, sightings that occur directly over the transect or at a steep angle to it, are likely to produce bias. In addition, when the terrain is rough the ability of the observer to estimate perpendicular distance will be limited. Thus, we suggest that the use of perpendicular distance measurements in the estimation of transect width should be avoided. The use of the "maximum distance to animal" tends to underestimate population density except in species of low density (see *Cebus apella* in Defler and Pintor 1985), and therefore its application also should be limited. In all studies the "reliable distance to the animal" produced reasonably accurate estimates, thus we suggest that this method is most applicable on a variety of different primate species found in different ecological settings.

SAMPLE SIZE

For both species studied here, a large number of trials had to be carried out and a large area censused before an accurate estimate that remained stable could be obtained. A precision curve should always be calculated as the study is being conducted because once the curve levels off it is unlikely that erratic fluctuations in the estimate will occur, also at this point adding more samples will not significantly reduce variability. In the present study,the point at which the precision curve leveled off occurred only after a large sample had been conducted (200-500 trials). The need to obtain a large sample has been found in other studies that attempted to estimate the density of primates. Altmann and Altmann (1970) found an increase in accuracy with sample size and Neville (1976) found that an increase in the density estimate of howlers was obtained with more intensive sampling.

The need for a large sample is related to the fact that the monkeys exhibit a clumped dispersion pattern and the number of sightings per trial was low. Thus, it is desirable to obtain as large a sample size as possible within the logistic constraints of the study. One means of increasing the sample size without increasing the duration of the study is to sample the transects at all times of the day. Any decrease in observability resulting from censuses at times of decreased activity levels will be compensated for by a similar decrease in transect width. If logistical constraints do not permit a large sample size to be collected, instead of using transect methodology, a search pattern should be established to enumerate all groups within a block of forest. The results of such a sampling procedure should be expressed as the number of groups contacted per hour of search time, with the average distance that an observer can see through the forest also being reported.

All animals exhibit habitat preferences. Such preferences among the Santa Rosa primates are indicated in this study by the large variation in density estimates from the different transects. Thus, if little is known about the habitat preferences of the species being censused, transects should be established in such a fashion as to sample all habitat types over a large area. In this study stratifying the sample by habitat resulted in a slight decrease in the accuracy of the estimates of both species. We suggest the use of a stratified sampling regime based upon habitat only when censusing areas with very different types of habitats. Stratifying the sample after an initial survery should not be used when censusing primates. The clumped dispersion pattern shown by many primate species and the large temporal variation in the use of different areas can result in the initial survery not being an adequate representation of the area of study.

Resumen

En Costa Rica, como en otros lugares, la obtención de cálculos aproximados en poblaciones de primates es indispensable para la realización de planes de manejo efectivos.

Una de las técnicas más usadas para llevar a cabo censos en primates, incluye métodos de transectos. A pesar de su importancia, la precisión y exactitud de estos métodos, no han sido estudiados a fondo.

Este estudio compara los resultados de densidad poblacional obtenidos por medio de una variedad de técnicas de transectos, y por el conteo directo de un grupo de monos capuchinos *(Cebus capucinus)* y un grupo de monos congos *(Alouatta palliata)*, estudiados en el bosque seco del Parque Nacional de Santa Rosa, Costa Rica.

Cuando se compararon los resultados, se encontró que la "verdadera" densidad de individuos se obtuvo usando el conteo directo y no con los métodos de transectos. Se exminaron seis métodos que estiman el ancho de los transectos con "promedio de la distancia al animal", dando como resultado la obtención de cálculos de densidad muy consistentes y precisos. Un gran número de repeticiones (200 a 500) se requirieron por cada uno de los transectos, antes de que la curva de precisión se empezara a estabilizar. Sin embargo, en este estudio los cálculos de población no siempre fueron muy axactos, aún después de alcanzar un alto grado de precisión.

Un modo de aumentar el tamaño de la muestra sin aumentar el período establecido para realizar el estudio, es haciendo muestreos durante todo el día. En este estudio, se encontró que cuando hubo disminución en la actividad animal, se compensó con una disminución en el ancho del transecto. Al estratificar la muestra de transectos por habitat, se tendió a disminuir la exactitud mientras que al estratificar por transecto, se aumentó la axactitud.

Finalmente, sugerimos que si las limitaciones logísticas no permiten el uso de suficientes senderos es probable que la metodología de transectos no sea la más apropiada, y deberá hacer un intento por enumerar todos los grupos dentro de una misma porción de bosque. Los resultados de tal muestreo podrían ser expresados como el número de grupos encontrados por cada hora de búsqueda, además de reportar el promedio de visibilidad en el bosque.

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Table 1

ESTIMATING THE POPULATION DENSITY OF THE STUDY GROUPS USING DIFFERENT TECHNIQUES OF CALCULATING TRANSECT WIDTH

Method	Estimate	% Error using Block home range	% Error with Minimum area home range
CEBUS			
Distance to animal			
Mean	11.9	–18.4	–46.8
Maximun	6.0	–58.4	–72.8
Reliable	8.1	–44.6	–63.8
Perpendicular distance			
Mean	21.3	+44.6	–4.4
Maximum	6.9	–52.5	–68.9
Reliable	8.1	–44.6	–63.8
HOWLER			
Distance to animal			
Mean	17.2	–9.9	–59.7
Maximum	9.5	–50.3	–67.1
Reliable	15.8	–17.2	–45.2
Perpendicular distance			
Mean	26.8	+40.9	–6.7
Maximum	11.8	–37.9	–58.9
Reliable	13.5	–29.1	–53.1

Table 2

THE CONSEQUENCES OF SYSTEMATICALLY OVER AND UNDER ESTIMATING DISTANCES ON THE POPULATION DENSITY ESTIMATE OF CEBUS AND HOWLING MONKEYS

% Off Actual Distance	Population Estimate	% Error
CEBUS		
+5%	11.26	–22.5
+10%	10.75	–26.0
+20%	9.85	–32.2
+50%	7.88	–45.8
–5%	12.45	–14.3
–10%	13.14	–9.6
–20%	14.78	+1.7
–50%	23.65	+62.8
HOWLER		
+5%	16.35	–16.1
+10%	15.60	–20.0
+20%	14.30	–26.4
+50%	11.45	–41.3
–5%	18.07	–7.3
–10%	19.08	–2.1
–20%	21.46	+10.1
–50%	34.34	+76.1

Table 3

DESCRIPTION OF THE TRANSECTS USED TO CENSUS EACH POPULATION OF MONKEY

Transect	Lenght (m)	Nº. of Trails	Total Number Counted	Density Estimate (km)	S.D.	% Error
Cebus						
1	900	161	105	17.73	2.23	+90.2
2	200	180	28	19.03	1.01	+104.2
3	200	169	45	32.57	0.82	+1249.5
4	400	162	50	18.88	0.50	+102.6
5	400	160	0	——	——	——
Howler						
1	900	161	130	11.21	3.02	–64.1
2	200	180	80	27.78	1.89	+1230.3
3	200	169	50	18.83	1.16	+119.9
4	400	162	27	5.21	2.13	–38.1
5	400	160	20	3.90	1.11	–53.6

Table 4

SUMMARY OF THE EFFECTS OF VARIOUS MODIFICATIONS OF THE TRANSECT METHODOLOGY ON THE ACCURACY OF THE DENSITY ESTIMATES FOR TWO SPECIES OF PRIMATES FOUND IN SANTA ROSA NATIONAL PARK, COSTA RICA

	Cebus	Howlers
Actual Population Density (km)	14.53	19.05
"Best" Transect Width	Mean distance to animal	Mean distance to animal
% Error	–18.4	–9.9
Stratification by Habitat	–	+
Stratification by time of day		
<10:00	–	+
10:00 to <13:00	–	+
13:00 to <16:00	+	–
>16:00	+	–
Nº. of Trials Producing the Most Accurate Estimate	169	748
Precision curve levels off at	450	150

\+ = More Accurate Estimate
– = Less accurate Estimate

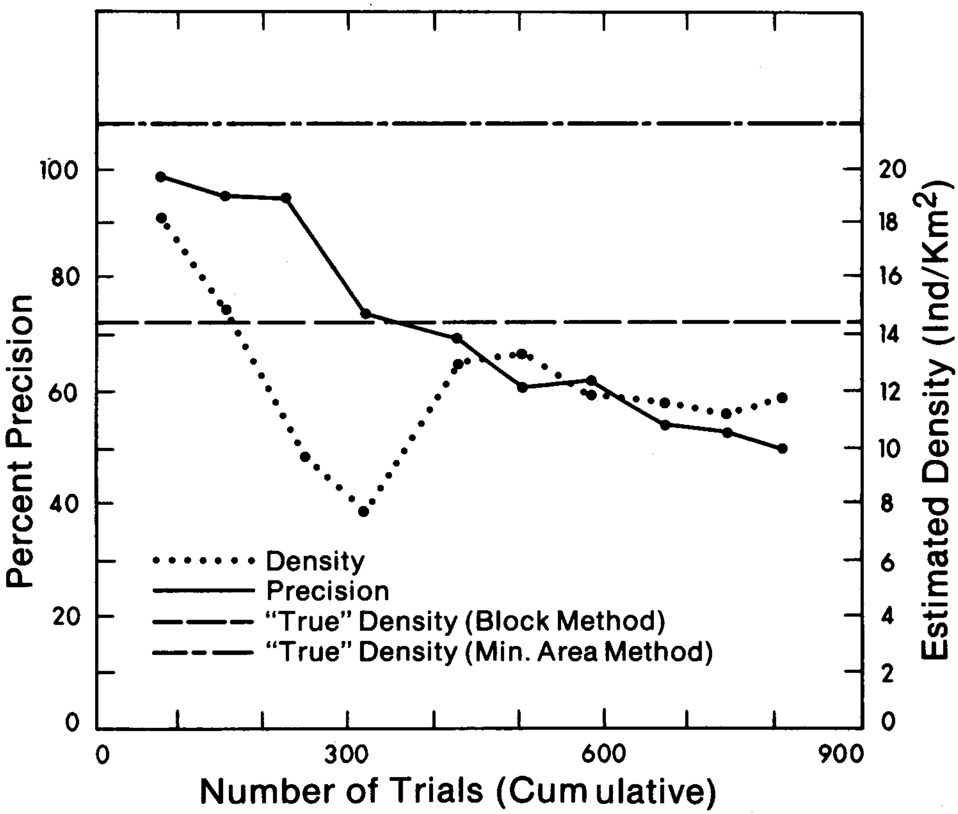

Figure 1.

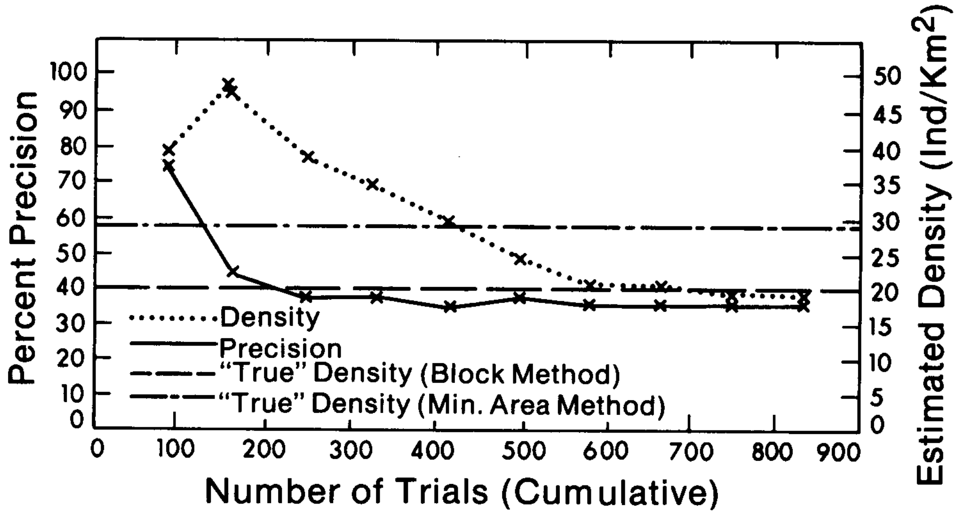

Figure 2.