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A GEOGRAPHIC INFORMATION SYSTEM METHOD FOR ESTIMATING HOME RANGE SIZE

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Abstract: We developed a new technique to quantify home ranges by using coordinate-based data that were collected at small time intervals and entered into a Geographic Information System (GIS). We used this technique (digitized polygons [DP]) and 4 other established methods to estimate home range sizes of groups of black howler monkeys (*Alouatta pigra*). We calculated the size of the area used by the study groups during the study period. The DP method used all available data points, excluded lacunae within home ranges, and accounted for spread of the group. The DP estimates of home range size were compared with 4 widely used methods: minimum convex polygon (MCP), grid-cell (GC), 95% harmonic mean (HM), and 95% adaptive kernel (AK). Sizes of home ranges ranged from 1 to 62 ha. Results of all procedures were strongly correlated ($P < 0.001$), although each gave very different estimates of home range sizes. The DP estimates were smaller than AK ($P < 0.039$) and MCP ($P < 0.002$) estimates and consistently (although not significantly) larger than GC methods ($P = 0.99$). There was no statistically significant or consistent difference between DP and HM estimates. Digitized polygons required the investigator to select path width and size of lacunae to exclude, but these decisions can be based upon biological information. This method may be the most appropriate technique to determine home range size with autocorrelated location data that can be converted to day-range paths.

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Key words: *Alouatta pigra,* Belize, black howler monkey, digitized polygon, GIS, home range, method, primate.

All techniques used to estimate size or use patterns of an animal's home range require subjective decisions on the part of the investigator, and all have statistical limitations (Kenward 1987, Harris et al. 1990, White and Garrott 1990). Most home range estimators were developed to analyze data points collected once or a few times a day, often from live-trapping or radiotelemetry studies. However, many studies investigate habituated individuals or groups of animals. Data collected in these studies are often multiple sequential location points collected over a long time period, and are usually highly autocorrelated. Probabilistic estimators that assume independence of points cannot readily be applied to these data (Dixon and Chapman 1980, Swihart and Slade 1985; Worton 1987, 1989). Increasing the time interval between data points to achieve statistical independence can result in underestimation of an animal's range and loss of information, such as distance moved in a 24-hr period (day-range length), which is crucial to understanding the biology of the animal (Reynolds and Laundre 1990).

Nonstatistical techniques such as MCP or GC counts are widely used by primatologists as home range estimators (e.g., Isbell 1983, Fedigan et al. 1988, Isbell et al. 1990, Olupot et al. 1994, De la Torre et al. 1995, Zhang 1995, Stoner 1996). However, like all methods (including the method presented here), nonstatistical techniques are sensitive to sample size (Goldingay and Kavanagh 1993). In addition, they may give only crude size estimates or require multiple subjective decisions such as grid size, placement, and linkage methods (Voight and Tinline 1980).

Home range data are usually collected as a series of point locations or coordinates with no area associated with a point. However, if the unit under investigation is a group of animals rather than an individual, each location will have an area associated with it that corresponds to group spread. None of the commonly used techniques accounts for the spread of a group.

We present a method for estimating the size of a home range as calculated with the GIS software IDRISI (Eastman 1995). Home range is

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defined as the area the study animals were known to use during the study period. Our goal in using a GIS to analyze ranging data was to create a home range estimator that would use all available data points, exclude areas not used by the animals, account for area used by the whole group during the time period of the study, and be ecologically and behaviorally relevant. We applied this method and 4 commonly used home range estimators to 10 sets of location data collected on groups of black howler monkeys between March 1994 and May 1995. These data were collected as part of a study of translocated black howler monkeys in Belize, Central America (Koontz et al. 1994, Silver 1997, Ostro 1998), and were used to investigate the spatial ecology of translocated monkeys (Ostro 1998, Ostro et al. 1999). We discuss the differences between the DP and other methods used to calculate home range estimates, and the ecological implications of those differences.

METHODS

We collected location data on 8 groups of black howler monkeys in 3 areas. Six groups were studied for 3 months prior to translocation at 2 sites in the Community Baboon Sanctuary (CBS) in northern Belize (T1, T2, T3, T4, C1, C2). Each group was followed for 8 days during this time. In May 1994, Groups T1, T2, T3, and T4 were translocated to the Cockscomb Basin Wildlife Sanctuary (CBWS) in southern Belize. Following the translocation, we continued to study Groups T1 and T2 in CBWS (T1a, T2a), and Groups C1 and C2 in CBS for 1 year. At this time, we also began to follow 2 groups that had been translocated to CBWS in previous years (E1, E2). In the year following translocation, we followed each group of monkeys (T1a, T2a, E1, E2, C1, C2) 4 times a month. A data collection period lasted from the time we first contacted the monkeys to that time the following day.

We created a trail system in CBS by cutting and marking trails every 20 m with position tags. The distance between tags was measured to the nearest meter, and degree readings were taken by sight compass. We calculated the Universal Transverse Mercator (UTM) coordinates of each tag. In CBWS, a trail system marked with position tags every 50 m already existed, and UTM coordinates had previously been determined for each tag in CBWS (Koontz et al. 1994). We checked accuracy via differentially corrected GPS readings and by measuring distances to alternative tags in the area.

During data collection, we recorded the location of the estimated center of the monkey group every 15 min relative to a permanent tag, and we later calculated position coordinates. If monkeys moved away from known positions, we placed and measured new tags along their travel path. Day-range path was recorded as the sequence of coordinates taken every 15 min during a data collection period and was calculated as the sum of distances between each set of coordinates. Group spread was estimated at least once per hour as the diameter of a circle that would encompass all group members.

Data Analysis

We analyzed 10 sets of data points with each of the following procedures: (1) MCP, (2) 20- × 20-m GC counts, (3) 95% HM estimates (Dixon and Chapman 1980), (4) 95% AK estimates (Worton 1987, 1989), and (5) DP (see below).

For the GC method, we used day-range paths of monkeys to calculate number of cells entered rather than use an arbitrary linkage method to join cells with nonadjacent locations. We calculated 95% HM and 95% AK estimates via a subset of independent data points. The subset was created by sequentially removing data points until the ratio of t^2/r^2 (Schoener 1980) for each dataset was >0.95 and <1.05, where t = the distance between points, and r = the distance from each point to the geometric mean of all points. Minimum convex polygons, 95% HM, and 95% AK estimates were calculated via the program CALHOME (Kie et al. 1996). The default option for grid-cell size was used, and the program estimated an optimal smoothing parameter. Home range estimates using DP and GC analyses were calculated with IDRISI (Eastman 1995).

Digitized Polygons

We created DP estimators by mapping day-range paths of the groups (Fig. 1A), and we then created a 20-m-wide buffer around each path. We superimposed an MCP on the resulting range map (Fig. 1B) and calculated the size of all lacunae (contiguous areas within the MCP not entered by the monkeys). The lacunae that were avoided by the groups due to topographic features or abrupt vegetation changes were all ≥1% of the MCP. Lacunae greater than this

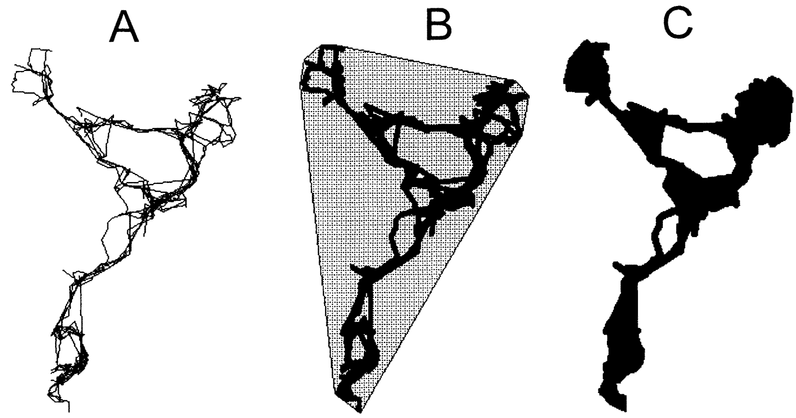

Fig. 1. Creation of digitized polygon (Geographic Information System) estimator for Group E2. Figure 1A shows all day-range paths of Group E2. In Figure 1B, all day-range paths have been widened to 20 m, and a minimum convex polygon placed over the resulting polygon. Figure 1C shows the digitized polygon after lacunae of >1% of the minimum convex polygon have been incorporated into the polygon.

size were excluded from the area calculations of the DP, while lacunae <1% were included as part of the DP (Fig. 1C).

We chose 20 m as the line width (and a cell size of 20 × 20 m for GC analyses) because of the accuracy of the location points (10 m in any direction) and the mean spread of the groups (11.4 m, range = 2–153). We used mean spread rather than the median or mode because there was no significant ($P < 0.01$) skewness in the spread data, and the standard errors of the mean were low (<1.5 in all cases).

To examine the sensitivity of this method to variation in line width and size of lacunae to be excluded, we created DPs for the data from 4 randomly selected groups (C1, T1a, T3, T2a), using 10-, 20-, 30-, 40-, 50-, 75-, and 100-m line widths. The relation between line width and polygon size was examined for each of the 4 sets of polygons via a linear regression. We also calculated the number of lacunae within the different polygons. Because these data were not normally distributed, we used Spearman's rank correlation to investigate the relation between line width and number of lacunae. Because the DP method is also likely sensitive to sample size, we calculated size of the DP by using cumulative datasets from 4 groups. For this analysis, we used groups that had been studied for ≥1 year and had lived in their ranges for >1 year (C1, C2, E1, E2). Each dataset contained 4 day-range paths (each path consisted of approx 48 points). We sequentially added datasets to determine whether the cumulative size estimate and number of lacunae of the polygon approached an asymptote.

Comparisons of Methods

Differences in size estimates among procedures were compared via a repeated-measures analysis of variance (ANOVA). The data were blocked by group, and the different methods constituted the repeated-measures treatment (Statsoft 1995). We used Tukey's HSD test to make post hoc comparisons among methods (Statsoft 1995). The strength of association between different estimators was tested with Pearson's product-moment correlation. However, because size estimates would be expected to vary with sample size, only group ranges studied for >1 year were included in the analysis.

To examine some of the ecological implications of using the different methods, we compared the percent home range overlap between Groups C1 and C2, and we used different estimators to test for differences in home range size before and after translocation for Groups T1 and T2. Only C1 and C2 lived in adjacent home ranges with no intervening groups, so our overlap analysis was confined to these 2 groups. We tested and compared the significance of translocation effects on home range size via a paired t-test. We standardized the number of locations on which estimators were based by using a 3-month subset of data from Groups T1a and T2a in CBWS, which corresponded to the same time period these groups were followed in CBS. The test was repeated for all estimators.

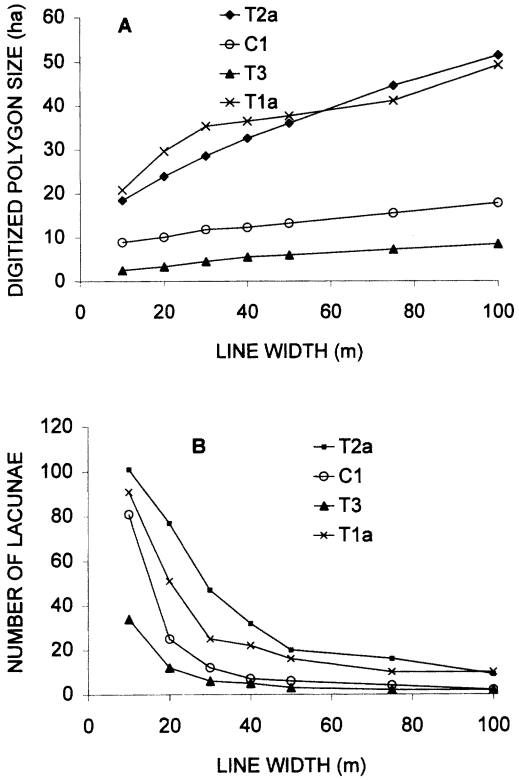

Fig. 2. Effect of line width on (A) digitized polygon size estimates; and (B) number of lacunae for Groups T1a, C1, T3, and T2a.

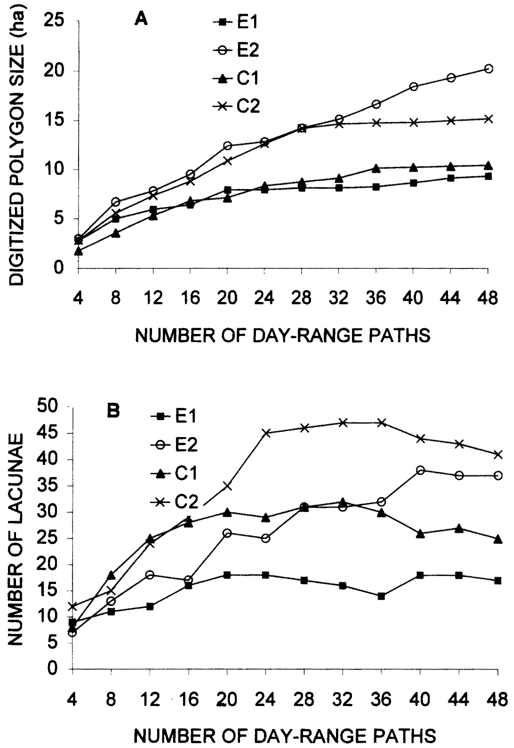

Fig. 3. Effect of sample size on (A) digitized polygon size estimates; and (B) number of lacunae for Groups C1, C2, E1, and E2.

RESULTS

We collected 384 location points (8 day-range paths) for each group studied prior to translocation: 2,300–2,700 points (48 day-range paths) for each group studied from May 1994 to May 1995. The data were highly autocorrelated (mean $t^2/r^2 = 0.22$, range = 0.002–1.1). Group size averaged 5.6 ± 1.0 ($\bar{x}$ ± SE) individuals.

Parameters of the Digitized Polygon

The area of the DPs increased with line width for all polygon sets (T2: $F_{1,5} = 387.79$, $r^2 = 0.99$, $P < 0.001$; C1: $F_{1,5} = 518.71$, $r^2 = 0.99$, $P < 0.001$; T3: $F_{1,5} = 125.13$, $r^2 = 0.96$, $P < 0.001$; T1: $F_{1,5} = 37.09$, $r^2 = 0.88$, $P < 0.002$). The average increase was 0.2 ha (range = 0.07–0.36) for every increase of 1 m in line width, which was a mean increase of 1.3% with a 20-m DP (Fig. 2). In each case, the number of lacunae decreased with increasing line width ($r > 0.99$, $P < 0.001$; Fig. 2). At each line width, the majority of lacunae were <1% of the MCP used for their assessment. Lacunae usually summed to <13% of the area of the DPs, with the exception of the lacunae in a 10-m DP, which summed to 27%.

The DP size for 3 of the 4 groups sampled approached an asymptote after 6–9 months of data were entered (Fig. 3). The number of lacunae in the polygons of these groups peaked and then began to decline as the polygon size approached the asymptote. The cumulative size estimates of the fourth group (E2) continued to increase even after a full year of data collection.

Comparison of Methods

Estimates of home range size were positively correlated for all methods ($r^2 \geq 0.86$, $P < 0.001$). As home range size increased, however, variation in size of the different estimates also increased ($F_{1,8} = 95.53$, $r^2 = 0.92$, $P < 0.001$). There were differences in the estimates of home range size among the methods ($F_{4,36} = 6.93$, $P < 0.001$). Post hoc comparisons did not show significant differences between DP and HM or GC methods, although GC estimates were consistently smaller (by an average of 8%) than DP estimates (Table 1). The AK (60%) and

Table 1. Descriptive statistics and home range sizes (ha) measured by 5 methods for groups of black howler monkeys in Belize, 1994–95. Digitized polygon (DP), grid-cell (GC), 95% harmonic mean (HM), 95% adaptive kernel (AK), and minimum convex polygon (MCP).

Group	DP	GC	HM	AK	MCP	$\bar{x}$	SE	CV
T1	2.0	2.0	3.1	2.3	4.3	2.7	0.44	0.36
T2	3.3	3.2	3.9	5.5	5.4	4.3	0.50	0.26
T3	3.1	2.8	1.4	3.5	5.2	3.2	0.61	0.43
T4	3.5	3.4	3.0	4.4	6.2	4.1	0.57	0.31
E1	9.3	8.6	13.4	14.7	20.2	13.2	2.09	0.35
E2	20.2	16.8	37.1	54.0	62.4	38.1	9.00	0.53
T1a	21.0	17.8	38.0	42.5	45.3	32.9	5.66	0.38
T2a	24.3	20.2	51.1	49.5	60.0	41.1	7.87	0.43
C1	10.4	9.8	10.2	9.9	14.1	10.9	0.81	0.17
C2	15.8	15.1	21.2	24.7	25.2	20.4	2.14	0.23

MCP (101%) estimates were larger than DP estimates ($P = 0.039$ and $P = 0.002$, respectively; Table 1).

The DP estimated smaller percentages of overlap between groups than the other methods. Differences between the GC and DP were negligible and due only to variation in range estimates (Table 2). Only the DP method detected a significant difference between the home range sizes of T1 and T2 in CBS and their ranges in CBWS (Table 3).

DISCUSSION

Digitized Polygons

Digitized polygons are similar to the shape that would be obtained by a planimeter (recommended by Macdonald et al. 1980). The important difference is that the outline of the polygon is produced by a repeatable method and requires no subjective decisions by the investigator regarding the order of points to join together. The DP does not attempt to impose a predetermined shape upon the home ranges and is independent of external influences such as grids. Because DP is not based on statistical methods, independence of data points is irrelevant, and the day-range paths on which the method is based become more accurate with diminishing time between collection of data points.

The strength of the method lies in accurately measuring the area used by the study animals during the study period. As with other methods, increases in sample size lead to increases in area estimates. However, an increase in the area estimate can only be caused by the study animals using new parts of their home range. The DP method does not include any areas in the polygon based upon mathematical assumptions or arbitrary joining rules. Periodic assessments of polygon size allow the investigator to determine whether enough data have been collected for the purposes of the study, and how much new area the animal is using. When the size estimate ceases to increase and the number of lacunae ceases to decrease, the investigator can be reasonably confident of the home range estimate. For example, the cumulative size estimates of Groups E1, C1, and C2 (Fig. 3A) indicate that

Table 2. Degree of overlap between home ranges of Groups C1 and C2, with home ranges calculated by different estimators. Digitized polygon (DP), grid-cell (GC), 95% harmonic mean (HM), 95% adaptive kernel (AK), and minimum convex polygon (MCP).

Method	Overlap (ha)	C1[a]	% C1 overlap	C2[a]	% C2 overlap
DP	1.3	10.4	12.5	15.8	8.2
GC	1.3	9.8	13.3	15.1	8.6
HM	2.6	10.2	25.2	21.2	12.1
AK	3.0	9.9	30.0	24.7	12.0
MCP	4.2	14.1	29.8	25.2	16.7

[a] Home range size (ha).

Table 3. Results of paired *t*-tests on the home range sizes of Groups T1 and T2 in the Community Baboon Sanctuary (CBS) and the Cockscomb Basin Wildlife Sanctuary (CBWS) as calculated with 5 different estimators. Digitized polygon (DP), grid-cell (GC), 95% harmonic mean (HM), 95% adaptive kernel (AK), and minimum convex polygon (MCP).

Method	Site	$\bar{x}$	SD	t	df	P
DP	CBS	2.7	0.92			
DP	CBWS	7.9	0.71	−35.00	1	0.018
GC	CBS	2.6	0.85			
GC	CBWS	7.7	1.56	−10.28	1	0.062
HM	CBS	3.5	0.57			
HM	CBWS	25.4	15.13	−2.13	1	0.28
AK	CBS	3.9	2.26			
AK	CBWS	36.7	13.01	−4.32	1	0.14
MCP	CBS	4.9	0.78			
MCP	CBWS	34.6	13.79	−3.24	1	0.191

enough data were collected to determine the yearly home range of these groups, unlike E2 whose home range size was still increasing after a year of data collection.

Both width of the day-range path and size of lacunae to exclude are elements of subjectivity in the DP method. Digitized polygons are very sensitive to variation in path width, which should be based upon biological information collected by the investigator during the study. While we used mean group spread to determine path width, this parameter could be increased to include the area visually surveyed by the study animals, as suggested by Struhsaker (1975).

If researchers rely on coordinates rather than presence–absence within a predefined grid, the path widths and lacunae of DPs can be adjusted to the size and spread of the group, even if it changes over time. Group size and spread were small in this study, but large groups of animals can occupy a considerable area, and even species with small group sizes can have large group spreads (e.g., chimpanzees [*Pan troglodytes*], Ghiglieri 1984; patas monkeys [*Erythrocebus patas*], Chism and Rowell 1988). Digitized polygons can describe the ranging pattern of any group at an appropriate scale.

The decision about the size of lacunae to exclude will always be arbitrary but can be based upon the knowledge and expertise of the investigator. Upon examination of the raw DPs (Fig. 1B), we were able to determine which lacunae were avoided by the groups, and we generally could identify factors that accounted for their nonuse. We were then able to identify exclusion criteria for lacunae. In our case, lacunae $\leq 1\%$ of the MCP were small enough to be biologically insignificant to the groups and added a relatively small area to the polygon.

Comparison of Methods

The strong correlation among the techniques suggests any of these methods could be used to determine the relative size of home ranges. However, the correlation is mainly due to the large range of home range sizes analyzed, and differences among estimates are not always consistent in their magnitude. By all estimates, the home ranges of T1 and T2 increased by more than 250% following their translocation to CBWS. However, only the DP estimator detected significant differences between area used at the 2 sites. This result is likely due to the low variation in DP estimates at CBWS compared with that of other estimators.

Probabilistic methods appear to be less useful than the DP method for determining home range size with these data. To satisfy the assumption of statistical independence, 90% of the data points were eliminated from consideration, and there was a large degree of both relative and absolute variation in size estimates. Both AK and HM methods generated disconnected polygons and incorporated large areas not used by the monkeys, which led to larger home range estimates than those given by the DP method. One of the strengths of these methods is they can be used to determine core areas and patterns of usage frequencies. By overlaying the day-range paths on a daily or monthly basis, these can be calculated via the DP method.

If the grid cell is the same width as the DP buffer and day-range paths are used for both analyses, the difference in the estimates given by the 2 methods is not significant. However, the lack of a difference between the 2 methods is an artifact of the grid size used in this study. Grid size is rarely based upon biological information such as group spread, and day-range paths are almost never used in grid analyses. Grid size is usually chosen in advance of the study and may be dictated by external factors such as trails or marker locations. Estimates vary with the size and placement of the grid, which cannot be changed after data collection. This variation may be negligible with an appropriately small cell size but increases with increasing grid size (Kool and Croft 1992).

Ecological Implications

Ecological measures such as population density and carrying capacity are often based upon home range size. Percent overlap between home ranges may be used to determine the spacing systems and territoriality of species (Sekulic 1982, Cheney 1987, Lott 1991). Here, home range estimates varied by as much as 300% (Table 1), which suggests methods may not give equally appropriate estimates for the determination of home range size with the type of data used in this study. Methods that include areas within a home range based upon mathematical rules rather than biological information are likely to ignore subtle topographic or social boundaries between home ranges and overestimate home range overlap. Overlooking these boundaries may lead to the mischaracterization of a species' spacing system. Given our definition of home range size, if day-range path data are available, the DP method may give the most accurate estimate.

An advantage of the DP method is that DPs are developed with a GIS, and the analytical techniques of GIS can be used to examine influences on the home ranges of the study organisms. The DP method can pinpoint areas avoided by study organisms and allow additional types of analyses such as the influence of biotic and abiotic features on the movements of the study groups (Ostro 1998). Using GIS, we could determine that, in CBWS, Groups T1a, T2a, E1, and E2 selected habitat close to rivers and streams (Ostro 1998). If behavioral data are collected with accompanying coordinates, the influence of both geographic and intergroup interactions on activity and behavioral patterns can be investigated.

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