Estimating the detection probability of the geometric tortoise

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Received 24 November 1998; accepted 16 June 1999

The geometric tortoise *Psammobates geometricus,* found in the Western Cape, is one of the world's rarest tortoises. The cryptic colouration and sedentary behaviour of the geometric tortoise causes problems when conducting counts using standard capture-recapture methods. The primary purpose of this study was to determine the detection probability of a geometric tortoise in the field on a purely experimental basis. Plaster of Paris tortoise models were placed in predetermined transects in the natural habitat. Observers surveyed these transects for the tortoise models. Three group and two individual experiments were conducted. These experiments suggest that a large percentage of geometric tortoises are not found during a census. In individual experiments no observer detected more than 50% of the models, but in some cases this percentage was slightly higher in group experiments. The effect of the size of the tortoise, density of the habitat, level of experience and searching ability of the observers are discussed. Estimates of the various detection probabilities are derived and suggestions made for conducting tortoise counts.

Keywords: census, detection probability, field technique, *Psammobates geometricus*

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Introduction

South Africa has the highest terrestrial tortoise species richness in the world. No fewer than 13 (31%) of the world's 42 species (Iverson 1992; Broadley 1993; Branch, Benn & Lombard, 1995) occur here, while generic diversity rates even higher with five (46%) of the 11 currently recognised tortoise genera represented. The conservation of tortoises in South Africa is mainly the responsibility of provincial conservation authorities. All South African tortoise species occur in at least two statutory conservation areas, with some (e.g. *Geochelone pardalis)* recorded in 49 nature reserves and/or national parks (Branch, Benn & Lombard, 1995). Of the three tortoise species listed in the South African Red Data Book (Branch 1988), the geometric tortoise *Psammobates geometricus* of the Western Cape Province is at present the most threatened and is listed in the endangered category. Internationally, it is listed as vulnerable (Groombridge 1993).

Threatened by habitat destruction and fragmentation, too frequent fires, alien vegetation encroachment, and a probable increase in predation pressure, geometric tortoises currently survive in at least 31 habitat fragments which include four provincial and three private nature reserves (Baard 1993a). Cape Nature Conservation, the provincial conservation authority of the Western Cape Province, regards the conservation of the geometric tortoise as a high priority, and a conservation strategy (Baard 1993b) for this species provides guidelines for the management and monitoring of these remnant populations. Monitoring of the populations is regarded as an important early warning system to monitor trends, and to provide managers of these areas with decision support regarding population status.

Population counts are usually carried out annually or biennially by teams of observers walking abreast, with each person recording any live tortoise or shell seen in an area of approximately a 2 to 3 m strip to the left and right. In order to establish a population estimate, three surveys are carried out within a time limit (usually one week), the results of which are subsequently used in a Bailey's triple catch analysis of the data (Caughley 1977). In this way trends can be established for the different populations.

In cases where the monitoring of endangered species is involved, it is important to obtain population estimates which are as accurate as possible. The problems mitigating against reliable estimates are more pronounced in the case of geometric tortoises. The cryptic colouration and sedentary behaviour of these tortoises render them extremely difficult to detect in their habitat (Baard 1990).

Methods for the estimation of population properties such as size can be divided into two categories, i.e. direct counts of population units such as the procedures used in quadrant, strip, line-transect and line-intercept sampling, and methods based on indirect counts such as capture-recapture methods (Seber 1982; Sen 1983). Regardless of the procedure being used, non-detection will lead to undercounting bias. Therefore, when estimating population size, the issue of individuals not counted during a census must be addressed.

Baard (1992) described a case study where the geometric tortoise population size of the Elandsberg Private Nature Reserve, Hermon (approximately 1 000 ha of geometric tortoise habitat) was estimated using the method described above, where a team of observers systematically surveyed a study plot. Three methods, namely a so-called 'density analysis' (simple, non-statistical analysis of the real data), Bailey's triple catch and the Jolly-Seber method (cf. Caughley 1977) for capture-recapture were used to analyse the results, with only the first two yielding realistic results. The first method estimated the population density at approximately 2.7 (S.D. = 0.7) tortoises per hectare (between 2 000 and 3 400 tortoises for the study area), while the second method compared well with a density of 2.4 (S.D. = 0.3) tortoises per hectare (between 2 100 and 2 700 tortoises for the study area). The Jolly-Seber method estimated the population density at a much higher value of 25.5 tortoises per hectare. The large standard deviation of 22.0 associated with this estimate leads to uninformative population estimates of between 3 500 and 47 500 tortoises for the study area. Baard (1992) ascribes this aberrant result to the relatively small number of recaptures.

Berry (1984) described the use of similar population surveys to estimate population sizes of desert tortoises, *Gopherus agassizii.* Strip transects of 1.5 miles x 10 yards wide, each arranged in an equilateral triangle of 0.5 mile per side were walked to study the distribution and relative densities of tortoises. Two-mile transects or quadrates were also used, while transects of 10 m wide and 3 - 7 km long were used in another study (Berry 1984). Berry based her strip transect technique on the assumption that the frequency of tortoise sign (i.e. live and dead tortoises, burrows, scats, tracks, etc.) observed within a transect is related to the tortoise population density in the same area. These transects were not randomly located and were placed 3 - 6 miles apart. The issue of undercounting bias remains since the standard strip transect assumption – all objects are observed with a probability of 1 to a distance w (Burnham, Anderson & Laake, 1980) – does not take non-detection into account.

These (Berry's) counts were usually conducted by experienced observers and lead to the belief that only experienced observers can be used for surveying populations. In an attempt to test this hypothesis, Freilich & LaRue (1998) conducted experiments at Ridgecrest, California by placing styrofoam tortoise models inside study plots which did not contain any tortoise sign. These plots contained juvenile, immature and adult models, placed in realistic locations, typically under shrubs. Since desert tortoises are burrowers, some models were placed in burrows. In addition to the models, plots were seeded with a number of real tortoise scats and burrows. Observers were divided into experienced and inexperienced groups and were not told the number of models placed in each plot prior to the survey. They were asked to survey the plots for tortoise sign and record their findings. The results indicated that both inexperienced and experienced observers found a high percentage of adult models, but significantly fewer immature and juvenile models. The large percentages of adults found, can be questioned since some observers could not distinguish between adult and immature models. There was no significant difference between the different levels of experience with respect to the number of reported models and the authors conclude that, irrespective of the level of expertise, observers were not very successful in finding tortoise sign inside the study plots. They remarked that neither inexperienced nor experienced observers could find more than a third of the juvenile tortoises or a fifth of the scats placed in the study plots. Freilich & LaRue (1998) finally recommended that factors such as searching ability, patience, tenacity and concentration which differ widely among observers, rather than previous experience, should be considered carefully, when selecting observers for tortoise survey work.

Western Cape nature conservationists are concerned about the low number of juveniles found in recent tortoise censuses (Baard 1990). The primary aim of this study, therefore, was to estimate the detection probability of both adult and immature tortoises under field conditions and on a purely experimental basis. Furthermore, conditions prevailing during geometric tortoise population counts were simulated by group experiments, while individual observer performance was also investigated. The study methodology is based broadly on the Freilich & LaRue (1998) experiment described above.

Methods

Study site

The experiments were conducted in the J.N. Briers-Louw Nature Reserve near Klapmuts (33°45'S;18°46'E; altitude 120 m a.s.l.). This reserve contains approximately 30 ha of 'renosterveld', a habitat type closely associated with the occurrence of geometric tortoises (Baard 1995a). The habitat in the reserve comprises plant communities which may be classified as open and/or dense (Figure 1). To classify these habitat elements the line intercept method of Floyd & Anderson (1987) was adjusted to estimate the percentage canopy cover and the average vegetation height (in cm). Percentage canopy cover for open and dense habitat was 38% and 60% respectively, while average vegetation height for open and dense habitat was determined as 12 cm and 22 cm respectively.

Models

Forty Plaster of Paris (gypsum) tortoise models (12 females, 8 males and 20 juveniles) were constructed. The female: male:juvenile ratio (3:2:5) was based on the pooled estimates from previous geometric tortoise counts in different habitats (EHWB). Models were moulded from real geometric tortoise shells to closely resemble tortoises in shape and size, and were hand-painted in the characteristic colours of the species (Figure 2). The average carapace length for female, male and juvenile models was 139.2 mm (S.D. = 2.5), 109.2 mm (S.D. = 2.2) and 66.1 mm (S.D. = 1.4), respectively. In this species, females are significantly larger than males (Baard 1995b). To avoid observers finding models because of their reflecting sunlight, diluted brown paint was used to give the models a dusty appearance. These precautions made it almost impossible to distinguish the models from geometric tortoise shells, therefore the detection probability estimates for geometric tortoise models are directly applicable to live geometric tortoises.

Observers

As in the Ridgecrest experiment (Freilich & LaRue 1998), two groups of observers took part in the study: an inexperienced group (Group I) and an experienced group (Group II).

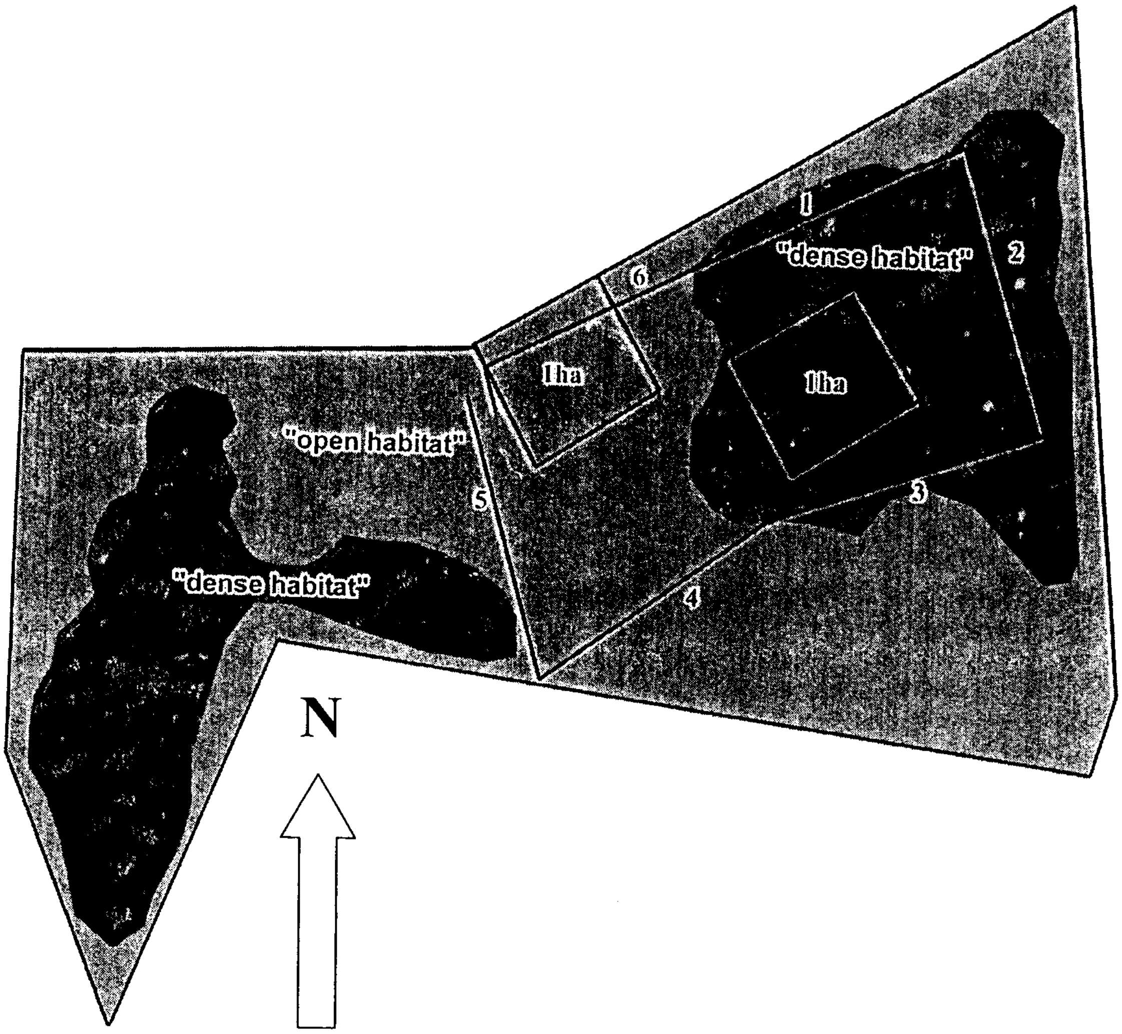

Figure 1 Diagrammatic presentation of the J.N. Briers-Louw Nature Reserve and the placement of the study plots for the group experiments, as well as the transect for the individual experiments.

With the exception of one person, who had very little experience in this regard, and two with bird-watching experience, Group I observers had never taken part in any surveys of this nature. Group II comprised nature conservation officers who had frequently participated in tortoise field surveys since 1977. All but one observer in Group I were women, 16 to 70 years in age (average age 48.9). The experienced Group II consisted of men only with ages ranging between 35 and 60 years (average age 48.7). Both these groups took part in the group experiments, but only experienced observers were used in the individual experiments. The visual ability of all the experienced observers was tested by means of the Keystone Visual Survey-Tests using a visual survey telebinocular (Keystone View Co. 1961), but with no noticeable relationship between the observers' visual acuity, stereopsis, and near and far vision on the one hand, and their actually measured success in finding tortoises on the other hand, this variable was not utilised in the final analysis of the results.

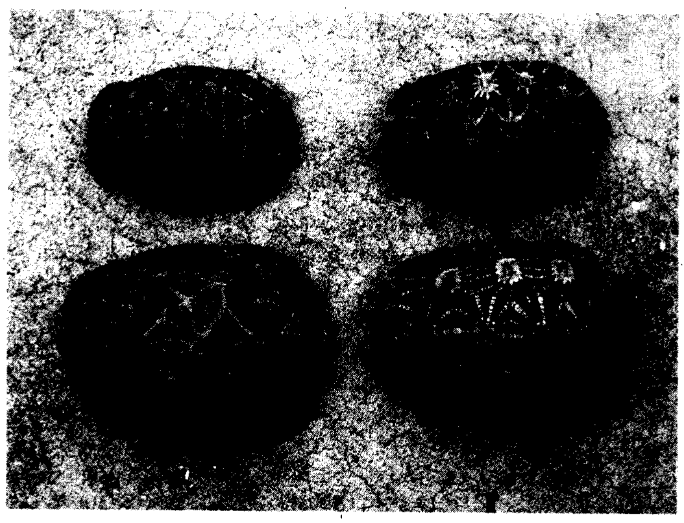

Figure 2 Comparison of a male (top left) and female (bottom left) model to a real geometric tortoise male (top right) and female (bottom right).

Experimental design

To estimate the detection probability of a tortoise, three group and two individual experiments were conducted. In a group experiment, a team of observers searched for tortoise models in a method similar to population surveys conducted in practice (Baard 1992). In addition to these group experiments, the individual experiments determined the performance of each observer separately.

Group experiments:Study plots, placement of models and search scheme.

A known number of models (randomly numbered by computer from 1 to 50, to ensure no indication of the actual number of models in the study plots) were placed in two study plots (open and dense), subdivided into 5 m x 5 m quadrants (plot size during the first group experiment was 100 m x 100 m, but was subsequently reduced to 80 m x 80 m). At a secondary level, individual models were randomly assigned to one of two habitat types, namely open or dense, while at a tertiary level, individual models were randomly assigned to a particular quadrant within the study plot by computer (Figure 3). Within a quadrant, a geometric tortoise expert placed the model in what was considered a realistic location based on typical geometric tortoise behaviour. Distinctive features of the quadrant were recorded to facilitate the recovery of models.

During a group experiment a team of six observers searched the study plot both in an East-West and North-South direction, starting in any of the two directions. The observers were spaced approximately 5 m apart and strips of approximately 30 m were searched at a time. The first strip was searched for example in an easterly, the second in a westerly, and the third strip again in an easterly direction, completing the first full sweep of the study plot. This process was then repeated for the other directions. A supervisor recorded the identities of all models found, the time when a model (or live tortoise) was found, the time it took to complete a strip, as well as ensuring that models were replaced exactly the way they were found. Although they were shown the models beforehand to familiarise them with what they were looking for, the observers were not told in advance the number of models placed in a study plot.

The group experiments were repeated three times (G1, G2 and G3) during the period May to August 1996. This provided some measure of variability in performance. Experiment GI was conducted with Group I starting their survey in the open habitat, while Group II started theirs in the dense habitat. A total of 20 models were placed inside each of the 1 ha study plots (6 females, 4 males, and 10 juveniles). The density of 20 models per hectare is much higher than the estimated 2.4 to 2.7 tortoises per hectare (Baard 1992), but these

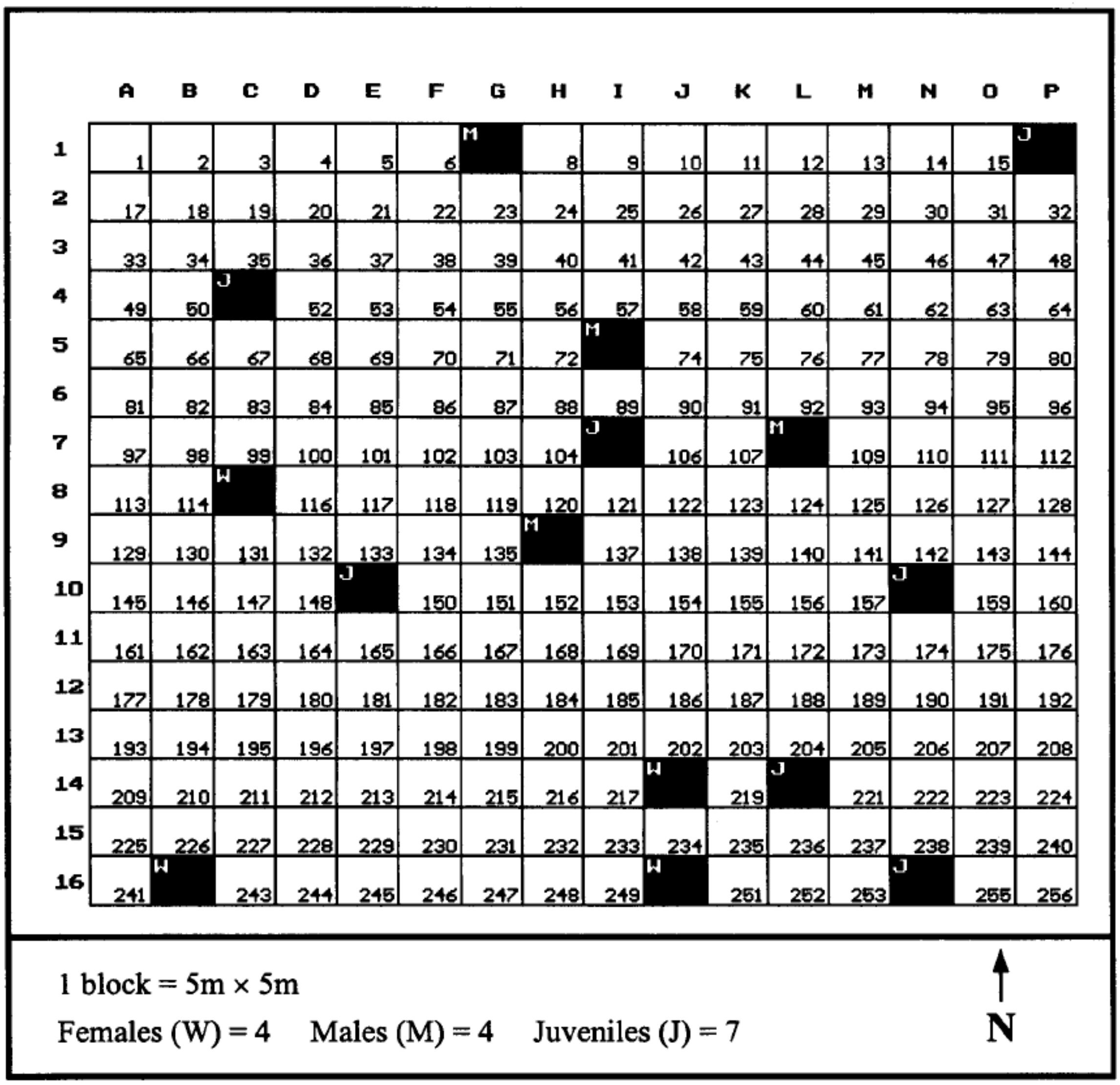

Figure 3 Example of the group experiment study plot layout and random placement of models (filled-in squares).

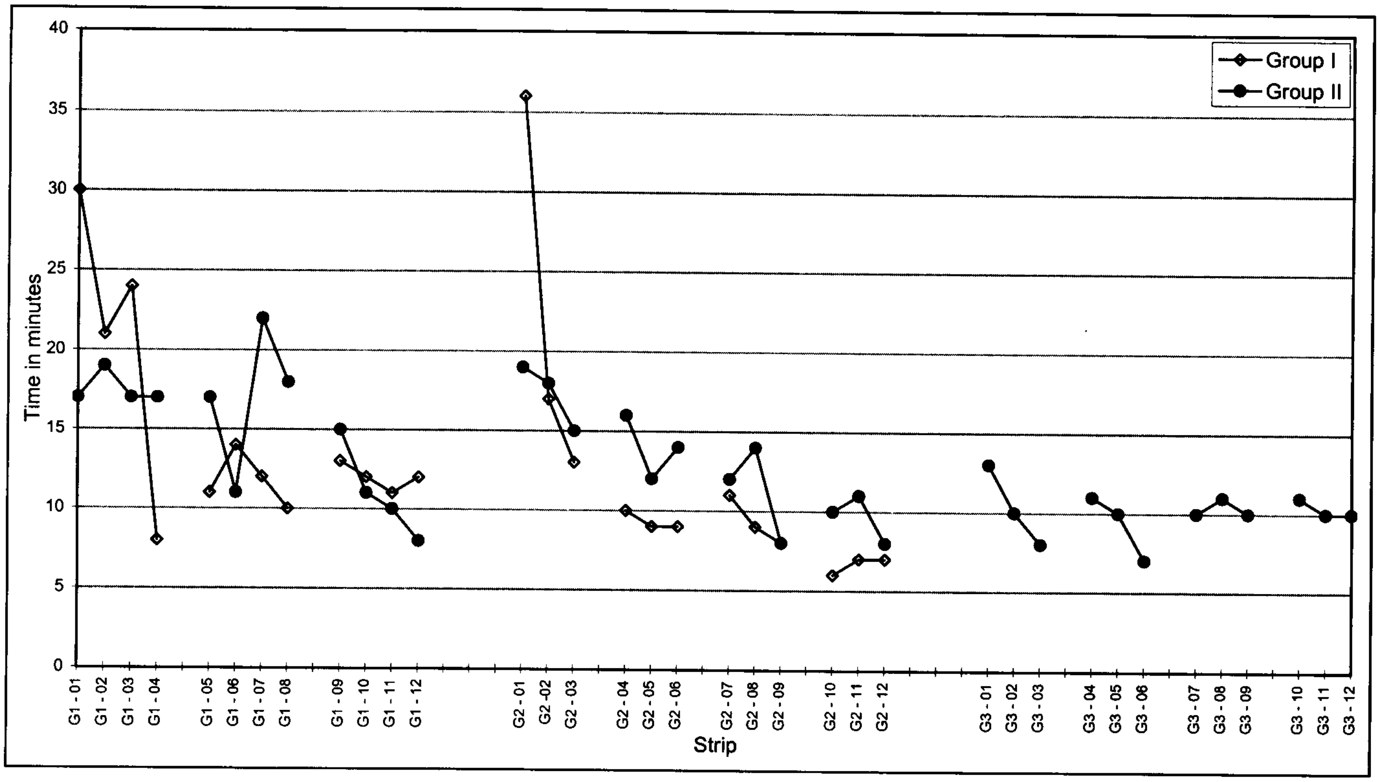

Figure 4 Time to complete individual strips of study plots in group experiments.

density estimates are probably underestimates and using a higher density also allows for finer distinctions to be made in the experimental results. Both groups surveyed their study plots twice and were required to switch study plots during the second phase. The experiments took much longer than anticipated and time allowed only one sweep of the study plots during the second phase. However, it was of interest to note that, as the end of the day approached, the observers appeared rushed and probably did not conduct the second phase survey as thoroughly as the first (Figure 4). The experiment was conducted under favourable sunny conditions.

During experiment G2 some observers in the experienced group (Group II) were replaced with other experienced observers, but to keep Group I inexperienced, a new group of inexperienced observers was used. Practical considerations necessitated the reduction of the study plot size to 80 m x 80 m and 15 models (4 females, 4 males and 7 juveniles) were placed in each plot. Although model density was higher than that of the previous experiment (23/ha vs 20/ha), the models were still sparsely distributed (Figure 3) and the authors were confident that it would not invalidate the results. Both teams of observers once again surveyed each study plot twice in weather conditions virtually the same as the first experiment.

Experiment G3 was conducted in exactly the same way as experiment G2, but with only the experienced Group II. To control for a possible order effect, the open habitat study plot was surveyed first. Similar weather conditions to that of the first and second experiments were experienced.

Individual experiments: Study plot, placement of models and search scheme.

For the individual experiments a line transect of 1 200 m x 5 m was used. It consisted of six strips of 200 m each - three in dense and three in open habitat, and was divided longitudinally into 240 quadrants measuring 2.5 m x 5 m (Figure 5). Brightly coloured markers indicated the boundaries of the line transect. Placement of the models was done in exactly the same manner as with the group experiments, i.e. randomly numbered models were assigned to one of two habitat types and then randomly assigned to a particular quadrant within the transect.

Six experienced observers were used for the individual experiments. All these observers also took part in at least one group experiment. They were assigned random numbers from 1 to 6 without replacement to determine the strip of the transect (cf. Figure 1) where each would start the survey. The survey was done in a clockwise manner. Every observer was accompanied by a supervisor who, in addition to the duties of a supervisor in the group experiments, ensured that observers were spaced in a manner to avoid others noticing where models were found.

Two individual experiments, I1 and I2, were conducted during September 1996. All 40 models were placed in the transect, half of them (6:4:10) in the open habitat and the other half (6:4:10) in the dense habitat.

The first experiment was conducted under sunny conditions, with an occasional light south-easterly wind. The second experiment was conducted to attain an indication of the variability in the searching ability of the individual observers. One observer was replaced by another experienced observer who took part in group experiment G3. All the observers taking part in experiments G2 and G3 took part in at least one of the individual experiments. The second experiment was conducted in cool, partly cloudy conditions with a north-westerly wind at times.

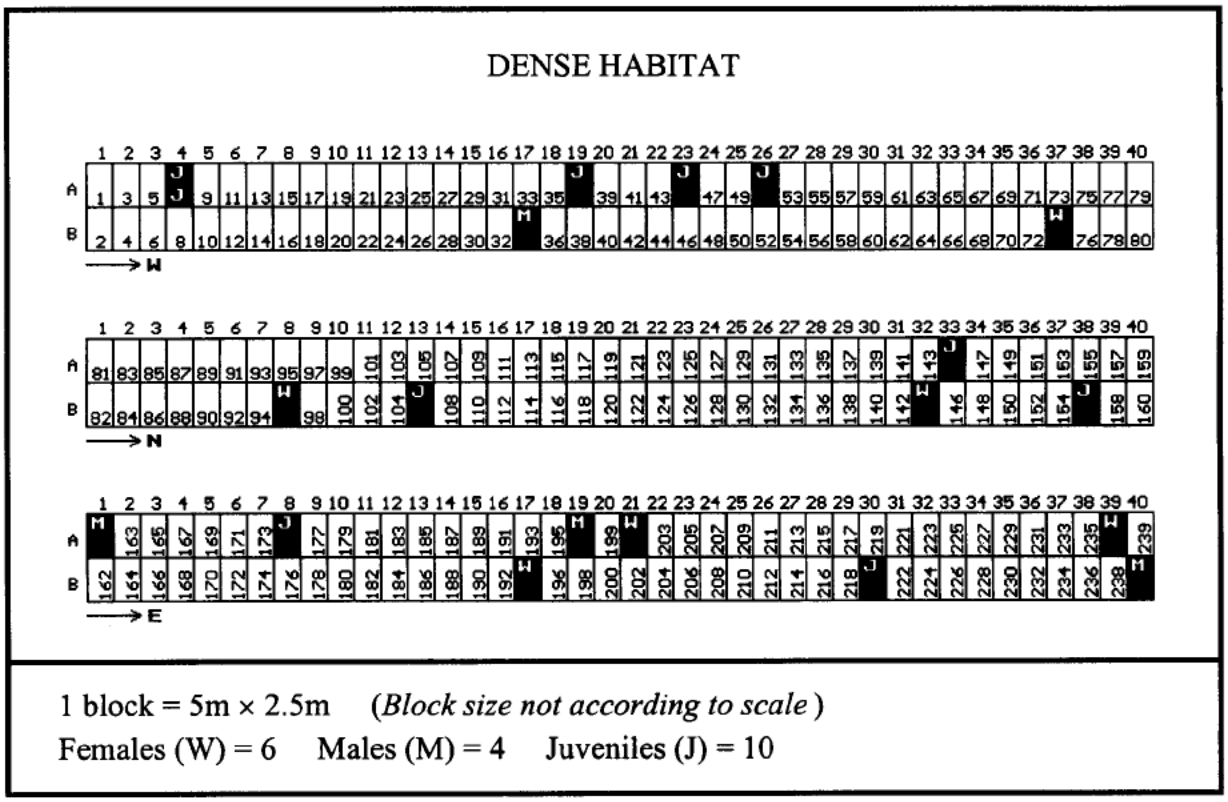

Figure 5 Example of the individual experiment transect layout and random placement of models (filled-in squares).

Results

Group Experiments

Figure 4 summarises the time spent to survey the study plots. The markers on the horizontal axis indicate the different strips of the study plots. Instead of using ordinary bar charts for these discrete data points, the points were connected to ease visual comparison of the two groups. This technique is also used in other similar graphical representations. It is evident that both groups started out relatively slowly on their initial strips, but tended to proceed faster as time passed. This human factor is more noticeable with the inexperienced observers who started out very slowly while the experienced observers maintained a much more consistent rate.

The number and percentage of models detected in the three experiments are presented in Table 1.

It is clear from Table 1 that:

- Except for female models in the open habitat, the experienced observers performed appreciably better than the inexperienced group.
- The percentages of models found varied between the different model sizes, with more of the larger models being found.
- The inexperienced observers performed much better in the open habitat than in the dense habitat (30% vs 5% and 40% vs 27%). Habitat density did not seem to have the same effect on the experienced observers since the number of models found in open and dense habitat never differed by more than one.
- There is a fair amount of variation between the three experiments e.g. the total for experienced observers in open habitat differed by as much as 32%.

Since transects are searched twice when a population estimate of live tortoises is made, the proportion of *different* models found in both runs in an experiment (where possible) is used to estimate the detection probability of a tortoise. In other words, if a model was observed in both runs, it is counted only once. In spite of the large variation in the proportions of models found, as reported in Table 1, there are similar trends in the results of the different experiments. Hence the various detection probabilities are estimated by averaging the results of the different group experiments. These estimated probabilities are presented in Figure 6. Since time constraints influenced the results of experiment G1, only the first run of experiment G1 and both runs of experiment

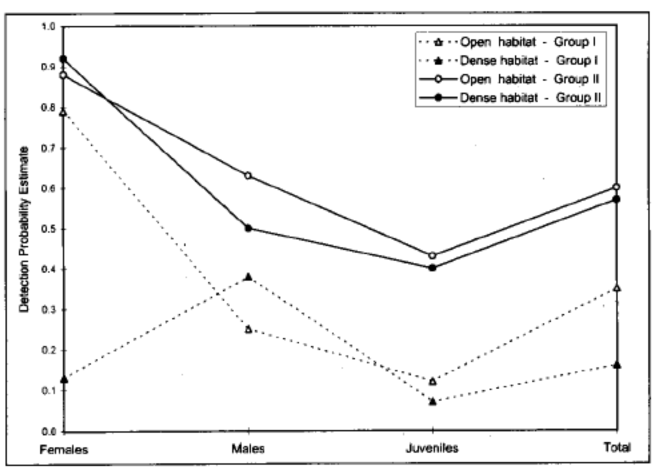

Figure 6 Detection probability estimates for geometric tortoise models under field conditions following group experiments.

Table 1 Results from group experiments to determine the detection probability of geometric tortoises under field conditions

	GROUP I (Inexperienced)						GROUP II (Experienced)					
	OPEN HABITAT			DENSE HABITAT			OPEN HABITAT			DENSE HABITAT		
	Run 1	Run 2	Total	Run 1	Run 2	Total	Run 1	Run 2	Total	Run 1	Run 2	Total
EXPERIMENT G1												
Females	5 83%	3 50%	5 83%	0 0%		0 0%	5 83%		5 83%	4 67%	5 83%	6 100%
Males	0 0%	0 0%	0 0%	1 25%		1 25%	0 0%		0 0%	1 25%	0 0%	1 25%
Juveniles	0 0%	1 10%	1 10%	0 0%		0 0%	2 20%		2 20%	1 10%	2 20%	2 20%
Total	5 25%	4 20%	6 30%	1 5%		1 5%	7 35%		7 35%	6 30%	7 35%	9 45%
EXPERIMENT G2												
Females	3 75%	3 75%	3 75%	1 25%	1 25%	1 25%	3 75%	2 50%	3 75%	3 75%	3 75%	3 75%
Males	1 25%	2 50%	2 50%	1 25%	1 25%	2 50%	1 25%	2 50%	3 75%	0 0%	2 50%	2 50%
Juveniles	0 0%	1 14%	1 14%	1 14%	0 0%	1 14%	1 14%	1 14%	2 29%	1 14%	2 29%	3 43%
Total	4 27%	6 40%	6 40%	3 20%	2 13%	4 27%	5 33%	5 33%	8 53%	4 27%	7 47%	8 53%
EXPERIMENT G3												
Females							3 75%	3 75%	4 100%	4 100%	4 100%	4 100%
Males							2 50%	1 25%	2 50%	2 50%	2 50%	3 75%
Juveniles							2 29%	3 43%	4 57%	2 29%	3 43%	4 57%
Total							7 47%	7 47%	10 67%	8 53%	9 60%	11 73%

G2 were taken into account for the inexperienced observers. In the case of the experienced Group II the estimated probabilities were based on the results from experiments G2 and G3.

Considering only the inexperienced Group I, Figure 6 shows that this group was most successful in finding females in the open habitat with a detection probability estimate of 0.79. The estimated detection probability of juveniles is very small for this group – in the dense habitat this estimate (0.07) is even smaller than in the open habitat (0.12). The larger estimated probability for males in the dense habitat (0.38) than for the open habitat (0.25) is due to a single male model that was found in the dense habitat in experiment Gl, compared to no male models in the open habitat. In view of the differences in the number of models observed in experiments G1 to G3, one additional model observed should rather be ascribed to random variation than to better performance.

There is some evidence that the experienced observers, unlike the inexperienced observers, did not find significantly fewer models in the dense habitat than in the open habitat. Table 1 reveals that several of the dense habitat proportions are in fact higher than or equal to the corresponding open habitat proportions. Averaging the proportions of Table 1 results in the estimated probabilities of Figure 6 being only marginally different for the two habitat types, especially for female (open habitat: 0.88, dense habitat: 0.92) and juvenile (open habitat: 0.43, dense habitat: 0.40) models. These marginal differences, indicating that habitat density does not influence the performance of experienced observers, were unexpected.

When comparing the two groups of observers, the experienced observers performed better in finding all three kinds of models in both habitat types. The inexperienced observers consistently found fewer models than the other group. The difference between the two groups was smaller in the case of female models in the open habitat than in all other cases. Apart from the estimated probabilities in the case of Group I in the dense habitat, the other estimates show a similar trend, but at different levels – the larger the model, the larger the estimated detection probability.

Individual experiments

The number and percentage of models detected in the two individual experiments are represented in Table 2.

Perusal of Table 2 reveals the following:

- There was considerable variation among observers, with the percentage of models found ranging between 15% and 50% (mean 33% and standard deviation 10.6%).
- Similar to the group experiments, the size of the models influenced the percentage found, with more of the larger models (females) being found.
- More models were found in the open than the dense habitat.
- Individual observer performance varied from day to day, for example Observer 2 found 20 models in the first, but only 10 in the second experiment.

The estimates of the detection probabilities for geometric tortoises, derived from the individual experiments, were based upon the binomial distribution. The number of times a model is detected can be assumed to be distributed binomially with parameters n, the number of times a model is passed in an experiment, and π, the (unknown) probability of observing the model. Since six observers independently passed each model, the number of times a model was detected is assumed to be distributed binomially with $n = 6$ and π. The probability π is estimated by $\hat{\pi} = m/6$ where m is the observed number of times a model was detected. An estimate of π was obtained for each model in an experiment. These estimates can be con-

Table 2 Results from individual experiments to determine the detection probability of geometric tortoises under field conditions

		Observer 1		Observer 2		Observer 3		Observer 4		Observer 5		Observer 6		Observer 7	
		Num	%	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%
EXPERIMENT I1															
Dense habitat	Females	1	16.7	5	83.3	3	50.0	1	16.7	1	16.7	3	50.0		
	Males	2	50.0	2	50.0	0	0.0	2	50.0	0	0.0	0	0.0		
	Juveniles	4	40.0	2	20.0	1	10.0	1	10.0	2	20.0	2	20.0		
	Total	7	35.0	9	45.0	4	20.0	4	20.0	3	15.0	5	25.0		
Open habitat	Females	4	66.7	6	100.0	5	83.3	4	66.7	2	33.3	4	66.7		
	Males	3	75.0	2	50.0	2	50.0	3	75.0	1	25.0	2	50.0		
	Juveniles	5	50.0	3	30.0	1	10.0	2	20.0	0	0.0	1	10.0		
	Total	12	60.0	11	55.0	8	40.0	9	45.0	3	15.0	7	35.0		
TOTAL	Females	5	41.7	11	91.7	8	66.7	5	41.7	3	25.0	7	58.3		
	Males	5	62.5	4	50.0	2	25.0	5	62.5	1	12.5	2	25.0		
	Juveniles	9	45.0	5	25.0	2	10.0	3	15.0	2	10.0	3	15.0		
	Total	19	47.5	20	50.0	12	30.0	13	32.5	6	15.0	12	30.0		
EXPERIMENT I2															
Dense habitat	Females	1	16.7	2	33.3	2	33.3	2	33.3	0	0.0			1	16.7
	Males	1	25.0	1	25.0	0	0.0	1	25.0	1	25.0			1	25.0
	Juveniles	2	20.0	1	10.0	0	0.0	0	0.0	1	10.0			1	10.0
	Total	4	20.0	4	20.0	2	10.0	3	15.0	2	10.0			3	15.0
Open habitat	Females	6	100.0	4	66.7	6	100.0	5	83.3	2	33.3			6	100.0
	Males	3	75.0	1	25.0	0	0.0	2	50.0	2	50.0			2	50.0
	Juveniles	5	50.0	1	10.0	4	40.0	5	50.0	2	20.0			2	20.0
	Total	14	70.0	6	30.0	10	50.0	12	60.0	6	30.0			10	50.0
TOTAL	Females	7	58.3	6	50.0	8	66.7	7	58.3	2	16.7			7	58.3
	Males	4	50.0	2	25.0	0	0.0	3	37.5	3	37.5			3	37.5
	Juveniles	7	35.0	2	10.0	4	20.0	5	25.0	3	15.0			3	15.0
	Total	18	45.0	10	25.0	12	30.0	15	37.5	8	20.0			13	32.5

sidered as observed samples from the unknown distribution of the underlying random variable. The latter observed samples were obtained for female, male and juvenile models separately as well as for the total number of models found. The averages of these samples provide estimates of the detection probability of respectively females, males and juveniles, as well as for geometric tortoises in general, irrespective of size. As with the group experiments, there is some variation between the two individual experiments, although the same observers took part in both experiments I1 and I2 (with the exception of one observer who seemed to compare well with the one he replaced). However, final estimates were calculated by combining the experiments since the overall probability over the two experiments can be modelled as a mixture distribution. This mixture distribution was constructed by allocating equal weights to the separate distributions of the two individual experiments. These estimates are displayed in Figure 7.

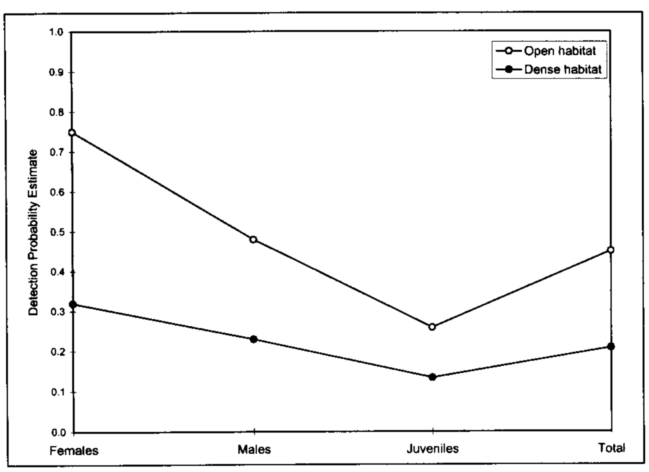

Figure 7 Detection probability estimates for geometric tortoise models under field conditions following individual experiments.

Figure 7 shows the same trends as in the case of the group experiments. The largest proportions found were those of female models followed by those of the males and only small proportions of juveniles. Models are seen more easily in the open habitat than in the dense habitat. The effect of the habitat type seems to be greater when the estimated probability of finding the model is larger since there is a much larger difference between the proportion of females found in the open and dense habitat than between the proportions for the juveniles.

Conclusion and recommendations

The primary aim of this study was to investigate undercounting bias in the case of the geometric tortoise. Figures 6 and 7 summarise the estimated detection probabilities found in the group and individual experiments.

The group experiments reported in Figure 6 agree with geometric tortoise surveys in practice. The probability estimates for dense habitat (0.57) and open habitat (0.60) can therefore be applied in a correction factor for undercounting bias. Moreover, these estimates can be broken down into separate estimates for females (dense habitat: 0.92, open habitat: 0.88), males (dense habitat: 0.50, open habitat: 0.63) and juveniles (dense habitat: 0.40, open habitat: 0.43).

At an individual level Figure 7 shows an interaction effect between habitat denseness and model size. The estimated probabilities for finding tortoises in dense habitat vary between approximately 0.32 for females, 0.23 for males and 0.13 for juveniles while in open habitat it varies between 0.75 for females, 0.48 for males and 0.26 for juveniles. This finding leads to the conclusion that when conducting a count in open habitat one would not only expect an individual observer to find more animals, but proportionally more of the larger animals.

When the above estimated probabilities based upon the group experiments and the individual experiments are compared, the latter estimates are lower. The difference between the estimates for the two habitat types is larger for the individual experiments than for the group experiments. The results of the individual experiments agree more closely to what was expected in that considerably fewer models are found in the dense than in the open habitat. This is especially the case with the larger female models.

The large variation in searching ability of observers can be seen from Table 2, where the total number of models found by a single observer ranged between 6 and 20 for experiment I1 and between 8 and 18 for experiment I2. The performance of a single observer also varied from day to day, for example Observer 2 found 20 models in experiment I1, but only 10 in experiment I2.

It is recommended that various observers be used in a survey since not only did observers differ in their ability to detect tortoises, but different observers see *different* tortoises. This accumulative factor has interesting implications for tortoise surveys in that it implies that the more observers are used during surveys, the more *different* (and effectively, a higher total) tortoises can be expected to be observed. The effect of the accumulative factor is illustrated by representing the performance of Observers 2, 4 and 5 in experiment I1 diagrammatically in Figure 8. Of the 40 models placed in the individual experiment study plot, a total of 28 models was detected by these three observers. Only one model was seen by all three observers while 60% (10 + 5 + 3) of all models found was seen by only one observer. Observer 2, who detected the largest number of models, saw 20 of the 28 models (72%) and 10 of these were not detected by the other two observers. Observer 5 found fewest models, detecting only six of the 28 models, but three (50%) of these were not found by the other two observers. This contributed to a 12% increase (from 25 to 28) in the total number of models found. Therefore, a recommendation for managers seems to be that a transect must be surveyed in such a way that more than one observer search the *same* section.

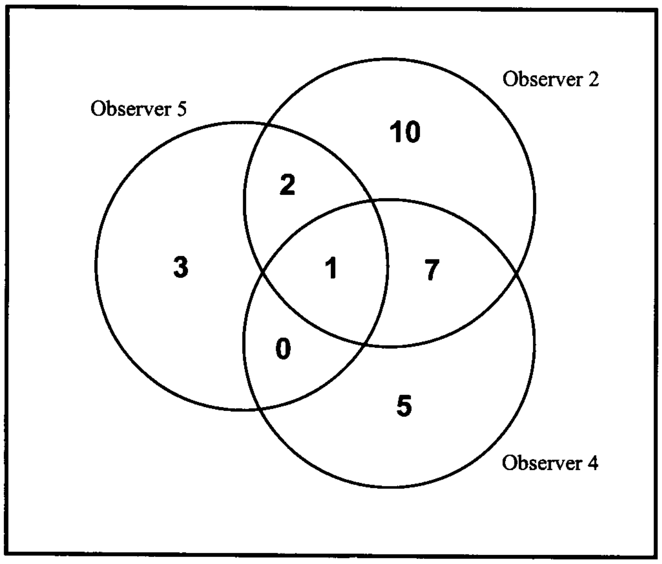

Figure 8 Diagrammatic representation: Example of individual observer performance.

In conclusion this study provides detection probability estimates for the geometric tortoise. These estimates can be used by managers of geometric tortoise populations to quantify the degree of undercounting bias occurring in tortoise counts. Applying the open habitat detection estimate (0.60) to the Baard (1992) study of the Elandsberg Private Nature Reserve, the density estimates for tortoises per hectare should be increased from 2.7 to 4.5 or from 2.4 to 4. If, however, the dense habitat detection estimate (0.57) is applied, the corrected density estimates would be 4.7 or 4.2 respectively. It must be clearly understood that these detection probability estimates were obtained under specific experimental conditions and therefore could not be unconditionally employed for other tortoise taxa.

Practical considerations for managers of tortoise habitat in general would be to make use of experienced observers, conduct counts in both kinds of habitats and have observers trained to focus on finding the smaller tortoises. In view of the accumulative factor it would also be beneficial to have more than one group of observers following one another to increase the likelihood of finding tortoises while at the same time creating a healthy competitive situation.

Acknowledgements

The financial assistance of the Centre for Science Development, (HSRC, South Africa) towards this research is hereby acknowledged. The authors gratefully acknowledge the invaluable assistance of Atherton de Villiers throughout this study and wish to thank all observers who participated in the experiments. The authors are thankful to a referee for suggestions which led to considerable improvement of the text in various places.

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