Accuracy, bias and precision of helicopter-based counts of black rhinoceros in Pilanesberg National Park, South Africa

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Received 3 January 2001. Accepted 28 August 2002

Accuracy, bias and precision of helicopter-based counts for black rhinoceros in Pilanesberg National Park were established using accurate population estimates derived from intensive monitoring. Over the 19-year period studied there were changes in sampling methods, and techniques employed. Accuracy and precision increased similarly as the number of observers increased. Total area counts were more accurate than sampled counts. The most accurate and precise estimates were produced using total area parallel transect counts with three observers. Confidence limits using one observer were wide, and widest for sampled counts with one observer. Sampled counts were more repeatable than total area block counts. Total area counts using blocks produced positively biased estimates for two successive years. This was attributed to management functions, the counting operation, lack of standardization of methods, observer error and environmental factors. The use of multiple teams of observers, multiple scribes/navigators, and inexperienced observers over the period of a count are not recommended. To achieve repeatable counts the technique should be applied in a consistent manner. A logistic regression model predicted the proportion of population counted as a function of the number of observers and seasonal rainfall.

Key words: aerial census, game count, observers, population size estimates.

INTRODUCTION

Aerial counts of large mammals are inaccurate and underestimate animal density or population size (Caughley 1974, 1977; Graham & Bell 1968; Melton 1978a; Bothma et al. 1990; Caughley & Sinclair 1994; Peel & Bothma 1995; van Hensbergen *et al.* 1996). Accuracy of counts decreases with increasing transect width, cruising speed and altitude (Caughley 1974), and consequently population estimates are negatively biased (Pollock & Kendall 1987; Samuel *et al.* 1987). Such 'errors of measurement' occur whenever it is impossible to directly count all individuals on a transect or in a population (Goddard 1967; Caughley 1974; Samuel & Pollock 1981; Pollock & Kendall 1987; Samuel *et al.* 1987; Caughley & Sinclair 1994). A component of 'error of measurement' is visibility bias or sightability bias and is determined by a number of factors associated with the animal (background, lighting, animal colour, size, movement, behaviour, dispersion and group size), observers (Jolly & Graham 1969; Graham & Bell 1969; Caughley 1974; Samuel & Pollock 1981; Samuel *et al.* 1987; Watson *et al.* 1969), environmental conditions (Pollock & Kendall 1987), vegetation cover (Samuel *et al.* 1987), methodological factors (strip width, speed of travel, type of aircraft (Goddard 1967; Caughley 1974; Hitchins 1990; Peel & Bothma 1995; van Hensbergen *et al.* 1996), survey procedures (Melton 1978b) and number of observers (van Hensbergen *et al.* 1996). Helicopter counts are more accurate than fixed-wing counts (Goddard 1967; Watson *et al.* 1969; Hitchins 1990), with more animals being detected as the number of observers increases (van Hensbergen *et al.* 1996). In addition to 'errors of measurement' two other sources of variation are recognized: temporal variation in actual population size and sampling variation defined as variation associated with the population estimation procedure (Link & Nichols 1994).

Caughley & Sinclair (1994) defined accuracy as a measure of bias error and if a set of estimates has little scatter then the estimates are precise or repeatable. Precision refers to the size of the deviations from the mean obtained by applying the sampling procedure repeatedly (Cochran 1963) and is purely a statistical concept; it reflects the degree of sample error (Collinson 1982; Caughley & Sinclair 1994). Counting bias can vary due to a number of factors (*e.g.* sampling error, observer error, instrument error, animal behaviour or vegetation conditions violating a count procedure's underlying assumptions) and changes in these factors over time (or space) may be the main cause of inconsistencies in the magnitude and direction of bias in count population estimates (Collinson 1982). Reilly (2000), using replicated helicopter-based counts in various savanna conservation areas concluded that precision results were largely site and species specific. The species evaluated were zebra, waterbuck, blue wildebeest, impala, kudu, giraffe and warthog. Melton's (1978b) examined helicopter-based counts in Umfolozi Game Reserve as indices of trend and attributed variation in undercounting bias to either methodological (*e.g.* flying time) or environmental factors (*e.g.* weather).

Caughley (1974) lists three approaches used by researches to produce useful count estimates. The first approach is an increase in precision by standardization of survey methods, efficient sampling, stratification and methods of analysis (Caughley & Sinclair 1994). While the second approach argues that the major problem is not so much that the estimates are imprecise as that they are inaccurate; this approach concentrates on detecting how far the mean is displaced from the true mean population size. Measures of repeatability, accuracy and bias are important to this approach. A third approach recognizes that counts are biased and treats aerial estimates as relative rather than absolute measures of abundance. Methods are rigorously standardized to hold bias constant and the calculation of confidence limits allows changes in population size to be detected for certain species (see Sinclair 1972).

The accuracy and bias of aerial counting black rhinoceros populations has been established by Goddard (1967), Melton (1978a) and Hitchins (1990) with aerial counts of black rhino classified as 'unreliable' (Melton 1978a; Hitchins 1990). Melton (1978a) compared a ground count with a helicopter count at two ground-coverage rates. He concluded that near 100% black rhino sightings could be achieved with a helicopter count at slow ground coverage rate and that there were no short-term movement problems. However, neither the helicopter (at each ground coverage rate) nor the ground counts were replicated. Hitchins (1990) found that helicopter counts were more accurate than fixed-wing counts and to produce accurate population size estimates a proportion of individually identified black rhinos in a population are required. The only estimates of precision for black rhino counts are from Tsavo, Kenya where Goddard (1969) used a stratified random sampling design (with a number of density classes) with counts conducted using fixed-wing aircraft. These counts were corrected using ground counts and population size estimates with confidence limits were produced.

In this paper various helicopter-based counting methods used in Pilanesberg National Park (PNP) over a 19-year period were evaluated for accuracy, bias and precision. The annual black rhinoceros population estimates were derived from an intensive monitoring programme.

STUDY AREA

Pilanesberg National Park is circular with a 25-km diameter and is approximately 50 000 ha in size. It features a series of isolated, concentric hills and valleys composed of a unique suite of alkaline volcanic rocks. The moist savanna vegetation (mean annual rainfall 630 mm) is classified as Sour Bushveld (Acocks 1975) and consists of a mosaic of patches of macrophyllous trees (notably *Combretum* species), microphyllous bush (*Acacia mellifera* and *A. tortilis*) and extensive pediment grasslands. This mosaic supports diverse populations of large herbivores and predators.

METHODS

Intensive black rhino monitoring programme

Nineteen black rhinos were introduced into PNP between 1981 and 1983. Each animal was ear notched and its sex and age recorded and post-release monitoring enabled individual identity kits to be developed (Anderson 1983). In 1989 a further five black rhinos were introduced, and following their release intensive monitoring of the black rhino population was undertaken. Monitoring required the maintenance of individual identity (ID) cards and these included: number, name, sex and age, introduction details, illustrations of ear notches and photographs of horn size and shape, tail characteristics and body scars (see Hitchins (1990)). Sighting locations from ground or air observations were recorded. Since 1991, an annual ear-notching programme has been undertaken. Notched and unnotched animals were recorded during the annual helicopter counts between 1992 and 1997. Using all this information it was possible

Table 1. Details of helicopter-based counts conducted in Pilanesberg National Park over a period of 19 years.

Year	Sampling method	No. observers	Helicopter type	Date	Count duration (day)	Ferry time (h)	Total helicopter time (h)
1982	Total area blocks	1	Hughes 300c	21–27.09	7	5.2	35.4
1983	Total area blocks	1	Hughes 300c	20–28.09	8	6.9	34.7
1984	Total area blocks	1	Hughes 300c	21.09–04.10	11	11.1	38.9
1985	Total area blocks	2	Bell 47	10–21.09	13	7.8	53.7
1986	Total area blocks	2	Bell 47	12–21.09	10	12.1	47.9
1987	Total area blocks	2	Bell 47	10–21.09	9	17.4	49.2
1988	Total area blocks	2	Bell 47	18.08–01.09	13	16.0	63.9
1989	Total area blocks	2	Bell 47	14–31.08	15	17.7	58.5
1990	Total area blocks	2	Bell 47	14–27.08	14	15.6	57.5
1991	Total area blocks	2	Bell 47	14.08–01.09	20	10.7	66.5
1992	Sampled blocks	2	Bell 47	26.08–01.09	7	7.3	27.0
1993	Sampled blocks	2	Bell 47	22–28.08	7	7.2	26.8
1994	Total area blocks	2	Bell 47	15–25.08	13	–	45.9
1995	Sampled blocks	3	Hughes 500 D	17.09–03.10	8	7.2	35.6
1996	Total area blocks	3	Bell 206	28.08–08.09	12	10.9	40.2
1997	Total area blocks	3	Hughes 500 D	14–23.08	8	8.3	46.0
1998	Total area transects	3	Bell 206	17–21.08	5	5.2	24.5
1999	Total area transects	3	Bell 206	02–06.08	5	3.5	23.5
2000	Total area transects	3	Bell 206	31.07–04.08	5	3.2	22.8

to produce accurate annual population size estimates since introduction (Adcock, pers. comm.).

Annual helicopter-based counts

An annual helicopter-based large herbivore count was conducted in PNP over a period of 19 years (Table 1). Over this time there were changes in counting strategies and methods used. Sampling methods used were: (1) total area counts using blocks, (2) sampled counts using blocks and (3) total area parallel transect counts.

Count blocks

According to topography PNP was delineated in 1982 into count blocks which were refined in 1983 to 29 blocks. In 1985 there were changes in the delineation of five blocks (some blocks were split, whilst others were combined) that resulted in 26 blocks. These blocks were used from 1985–87 and were called 'Changed Blocks'. From 1988 to 1992 the original delineation of 29 blocks was used and called 'Original Blocks'. Following the lion introduction in 1993 the Manyane Complex and Extensive Educational Zone (EEZ) were fenced resulting in block K being reduced in size with the remaining portion forming the EEZ. These blocks were used for counts from 1993 to 1997.

Total area counts using blocks

Total area counts were conducted using: (a) one observer ($n = 3$); (b) two observers ($n = 8$); and (c) three observers ($n = 2$) (Table 1). If repeat counts of blocks were undertaken then the mean from such counts was used.

Sampled counts using blocks

Using this strategy, count blocks were selected according to animal densities in the various terrain type, and flying time was then allocated to different terrain classes. This resulted in a proportion of the blocks counted per year. All high animal density areas (i.e. valley blocks) and a proportion of the mixed terrain blocks and hill blocks were counted each year (Adcock, pers. comm.). This count was adopted to reduce the cost of the census. Population estimates for most species (including black rhinos, excepting buffalo and springbok) were calculated using correction factors based on animal distributions from total area counts from the previous 3–4 years. Two teams of observers were used for sampled counts and observers changed both between and within counts. Sampled counts were conducted with: two ($n = 2$), and three observers ($n = 1$) (Table 1).

Total area parallel transect counts

Parallel (east-west orientated) 400-m-wide transects were flown. Data were recorded onto a notebook computer in the helicopter which was linked to a geographic positioning system (GPS).

Total area transect counts were conducted using three observers ($n = 3$) (Table 1).

Observer matrix

To examine the consistency with which observers were used between counts, and the total number of observers used per year, each observer was allocated a unique alphanumeric code. Using these codes a matrix of the observers used over the period of each count was compiled (Appendix 1).

Data analysis

Accuracy and bias

Accuracy for each count was measured and mean accuracy (expressed as a percentage of population) for each counting strategy (by number of observers) was calculated. Bias was expressed as 'per cent relative bias' which was calculated for each year's count and defined as

$$PRB = \frac{E(N) - N}{N} \times 100 \qquad (1)$$

where $E(N)$ is the estimated population N. N is the actual population (White *et al.* 1982)

Precision

Precision is estimated using variance or standard deviation (S.D.), standard error (S.E.), coefficient of variation (CV) and 95% confidence limits (CL) (Norton-Griffith 1978; Collinson 1982; Reilly 2000). The CV is a scaled measure of dispersion allowing comparison to other sample dispersion (Reilly 2000). The S.E. was estimated using a formula provided in Sokal & Rolf (1981) for a population with finite variance. These statistics were used to indicate how robust the various sampling methods were.

Sampling replication procedure for sampled counts

Some counting strategies had few samples (*e.g.* sampled counts: $n = 2$ with two observers) and therefore a sampling replication procedure was used to increase sample size for sampled counts with two observers and to create sampled counts with one observer. Sampled counts with one observer were created using total area counts conducted between 1982 and 1984. To increase sample size with two observers to nine samples, seven total area counts (1985–87, 1989–91, 1994) and two sampled counts with two observers (1992–93) were used. The 1988 total area block count data could not be used (see Appendix 2 for reasons). The count blocks used were those from the two sampled counts, but with the proviso that the same blocks needed to have been counted over the seven year total area count period (see Counting blocks). This resulted in changes to the sampled count black rhino totals for 1992 and 1993. One sampled count was conducted using three observers and two total area block counts using three observers were biased and so sample size for these two strategies could not be increased. All sampled counts sampled 50% of the surface area of PNP with no correction factors applied.

Randomization with replacement

A total aerial count is an attempt to completely enumerate the population. Each survey produces a point size estimate, which is some fraction of the population (Reilly 2000). Such estimates can be considered independent samples from the population of all possible surveys for that area. For each count a different estimate of variance will be obtained for each possible combination of 2, 3, 4, or more observations. Hence for small sample sizes, as in some of the cases analysed, the assumption of equity cannot be met and a process of randomization with replacement (or bootstrapping) was required to produce estimates of standard deviations and standard errors. To undertake the randomization with replacement, 4000 samples were generated with replacement using the actual observations (2,3, or 9 values). From each of these sample groups the variance was estimated and the mean of these variances was considered as the estimate of population variance (Reilly 2000). The bootstrapped S.D. for each counting strategy and number of observers was calculated and from this the S.E., 95% CL, and CV were calculated.

Model to predict the percentage of population counted

Logistic regression (McCullagh & Nedler 1989) is appropriate in two specific cases: (1) binary responses (0 or 1) or (2) proportion data (*e.g.* grouped binary responses in the form of count totals). Proportion data gives rise to binomial errors, so a logistic transformation was used to model probabilities directly as a linear function of the exploratory variables, particularly fitted probabilities outside the range of 0 to 1. The general logistic equation for estimating the percentage of a

Table 2. Statistical analysis of helicopter-based counts for black rhinoceros in Pilanesberg National Park.

Sampling method and number of observers	*n*	Mean	Population S.D.	Bootstrapped S.D.	S.E.	CV	Upper 95% CL	Lower 95% CL	Maximum	Minimum
Total area blocks 1	3	55.2	10.76	10.82	6.25	19.6	75.1	35.3	63.6	40.0
Total area blocks 2	8	61.9	13.78	13.73	4.85	22.2	73.1	50.7	90.0	40.0
Total area blocks 3	2	108.7	3.25		2.30	3.00	118.5	98.8	111.9	105.4
Sampled blocks 1	3	46.4	14.57	14.69	8.48	31.6	73.4	19.4	63.6	28.0
Sampled blocks 2	9	53.5	9.74	7.75	2.58	14.5	59.3	47.7	66.7	39.4
Sampled blocks 3	1	78.0								
Total area transects 3	3	71.1	4.33	3.06	1.77	4.3	76.8	65.5	76.6	66.0
All counts	29	62.6	18.94		3.52	31.3	69.8	55.4	111.9	28.0

population counted is:

$$p = \exp(logit) / (1+\exp(logit)) \quad (2)$$

where p is the proportion/percentage of population counted, logit is defined as the transformation $\ln(p/(1-p))$, and p is estimated as a linear function of the form

$$a + bx \quad (3)$$

where x is the explanatory variable affecting the percentage of population counted, *i.e.*

$$p = \exp(a + bx)/(1+\exp(a + bx)) \quad (4)$$

where p is the proportion/percentage of population counted, and a and b are estimated when fitting the regression model.

A logistic regression was used to determine the influence of a number of factors on the percentage of the black rhino population counted. Over-dispersion of the model was corrected using the Williams procedure (Williams 1982). Factors analysed were: (1) number of observers (Observers), (2) flying time (Hours), (3) number of days (Days), (4) beginning Julian day of count (BegJDay), (5) year (Year), (6) seasonal rainfall (Seasonal) and interactions between these factors. Seasonal rainfall was used to index vegetation cover and thereby visibility. A model to predict the percentage of population counted was first developed using all factors and then non-significant factors were excluded.

All sampled counts and two total area counts with three observers (1996 and 1997) were eliminated from the data set used for fitting the logistic regression model. Flying time was poorly recorded for the 1994 count. Using data for total area counts of two observers a linear regression was fitted between helicopter time (h) and flying time (h):

$$y = -5.6001 + 0.8682x \quad (5)$$

($n = 7$; d.f. = 5; $r = 0.929$ ($P < 0.001$); $r^2 = 0.8643$)

where y = Flying time (h) and x = helicopter time (h)

The model is valid for flying time predictions between helicopter time of 38.9 and 66.5 h.

This equation was used to predict flying time (h) for 1994 from the recorded helicopter hours.

RESULTS AND DISCUSSION

Mean accuracy for all counting strategies was 62.6 ± 18.94% (n = 29), with a CV of 30.3% (Table 2). This confirms results in many previous studies (see Caughley 1974) that aerial counts underestimate population size. Table 3 presents a summary of counting results for black rhino. Counts for PNP compare well with helicopter counts of black rhino in Hluhluwe-Umfolozi Park (HUP) (Melton 1978a; Hitchins 1990) and match those at faster ground speeds (Melton 1978a; Hitchins 1990) and random flights searching for black rhinos (Hitchins 1990) (Table 3).

Accuracy and bias

As the number of observers increased the accuracy of the count increased (Table 2; Fig. 1). Total area counts using blocks with three observers were inaccurate and overestimated population size (108.7%, n = 2) (Table 2; Fig. 1). Comparing counting strategies, the most accurate counts were conducted using total area parallel transect counts with three observers (71.1%, n = 3) followed by total area counts with two observers (61.9%, n = 8). Total area counts were more accurate than sampled counts (Table 2). There was a change in the counting bias from underestimating (pre-1996) to overestimating population size for both 1996 and 1997 (Fig. 2). Possible reasons for this are discussed below.

Table 3. Summary of published research results for aerial counts of black rhinos compared with ground counts.

Aircraft	Replicates and methodology	Results counted	Study area	Reference
Fixed-wing & helicopter	17 fixed wing, and one helicopter count, using a total area count	29% of population counted (helicopter 38%) (range 4.5–50%)	Olduvai Gorge, Tanzania	Goddard 1967
Fixed-wing	Stratified random sampling design using five density classes: very high, high, medium, low and very low density classes. Estimates corrected using ground counts.	Very high, high, and medium density areas ±25% (at 95% CL), low stratum ±83% (at 90% CL), and very low ±50% (at 50% CL).	Tsavo West and Tsavo East, Kenya	Goddard 1969
Helicopter	Ground counts conducted over 12-day period. Helicopter count at two ground coverage rates: 33.7 ha/min, and 19.3 ha/min. Neither the helicopter counts nor the ground counts were replicated.	66 and 100% of population counted at each ground coverage rate respectively	Umfolozi Game Reserve	Melton 1978a
Fixed-wing & helicopter	Extensive ground surveys used to establish the population size. Systematic parallel counts, 12 replicates for each type of aircraft	12.2% of population counted using fixed-wing and 44.8% using helicopter.	Hluhluwe/Umfolozi park	Hitchins 1990
Helicopter	Extensive ground surveys used to establish the population size using random flights in search of black rhinos.	65% of population counted (range: 28–140%)	Hluhluwe/Umfolozi park	Hitchins 1990

Precision

Total area counts using blocks with three observers recorded the lowest CV; however these counts were inaccurate (Table 2). The CV of total area counts using parallel transects with three observers was low (CV = 6.1%) and hence its precision (and repeatability) was high (Table 2). There was no clear pattern in CVs between total area, sampled counts and number of observers (Fig. 1). A general relationship was that precision and hence repeatability of counts increased as the number of observers increased (Table 2; Fig. 1). Ninety five per cent confidence limit's (CL) with one observer were high. The CV and 95% CL's were widest for sampled counts using one observer (Fig. 1). However, these relationships were possibly confounded by sample size.

There was a general relationship between the S.E. of the mean, mean percentage of population counted and the number of observers (Fig. 3). As the number of observers increased the percentage of population counted increased and the S.E. of the mean was reduced. However, total area block counts using 1, 2, or 3 observers provided exceptions. Total area block counts using one or two observers recorded a high S.E. in relation to the mean of the population counted compared with sampled counts with two observers. Total area counts using three observers recorded a far higher mean than expected (Fig. 3). Sampled counts with two observers were more repeatable than total area block counts using two or three observers. This suggests that total area block counts were not applied in a methodologically or statistically consistent way. Again, these results might be masked by sample size. Possible sources of error for these counts are discussed below.

Sources of counting bias

The change in counting bias in 1996 and 1997 could be due to a number of sources. To analyse possible sources of counting bias, sources were divided into four classes: (1) management of counting operations, (2) methods, (3) observer error and (4) environmental conditions.

(1) *Management of the counting operation*

A number of problems were noted in the management of counting operations (with respect to the management functions of planning, leading, organizing and controlling) in a number of years. In 1996 the count was conducted over an extended period of 12 days caused by the pilot's prior com-

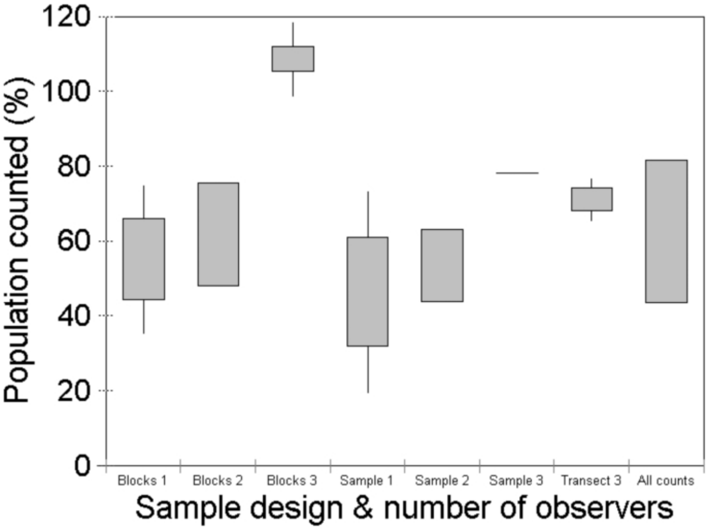

Fig. 1. Bar and whisker plot of mean percentage of population counted and estimated population standard deviation (S.D.) (bar), and the 95% confidence limits (line) for various counting strategies and number of observers. The boot-strapped estimated S.D. was used.

mitments (outside PNP) during the count and unsuitable counting conditions due to weather conditions. This led to counts not being conducted in two morning and three afternoon sessions. In 1997 the servicing of the helicopter and weather conditions caused interruptions to the count (Appendix 3). Control was poor as there was little evidence that management learnt from previous mistakes.

(2) *Methods*

There was a lack of standardization of the same counting methods between and within years, and this applied to the 1996 and 1997 counts (Appendix 2; Appendix 3). These are expanded with reference to the: (1) helicopter, (2) time of year, (3) time of day, (4) counting block sequence, (5) consistency of the observers, and (6) scribe/navigators used.

Helicopter. The size of helicopter changed between counts using the same counting strategy and this increased the number of observers used. For example, sampled counts in 1992 and 1993

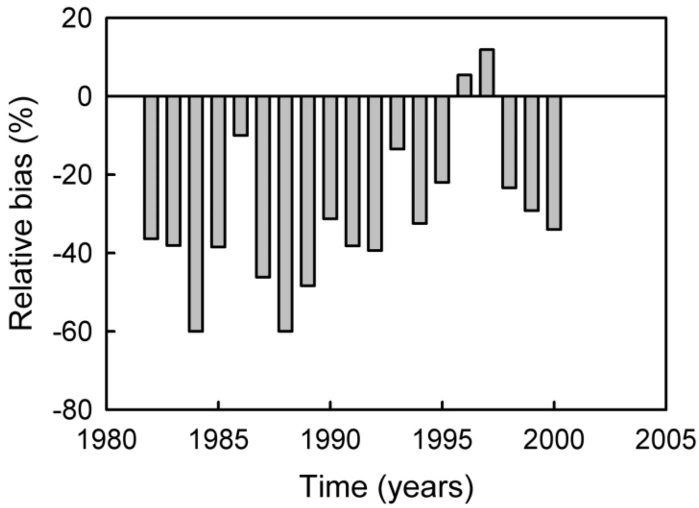

Fig. 2. Percentage relative bias for helicopter-based black rhino counts conducted in Pilanesberg National Park, compared with population size estimates derived from an intensive monitoring programme.

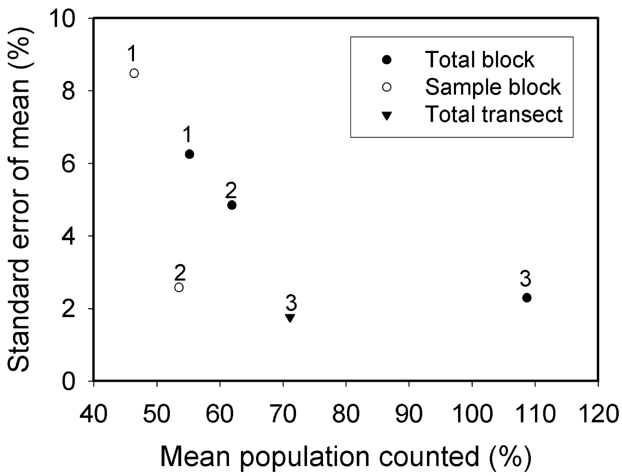

Fig. 3. Relationships between the standard error (S.E.) of the mean and the mean of the population counted for various counting strategies and numbers of observers used.

were conducted using a helicopter carrying 2 observers and in 1995 with a helicopter with three observers. The change in the number of observers invalidated correction factors (using previous counts) applied to sample blocks for 1995 to produce population estimates. In 1994 two helicopters (with two observers) were used to conduct a total area count using blocks, while in 1996 one helicopter with three observers was used. There were changes in the type of helicopter used between counts (*e.g.* a Bell 206 Jet Ranger was used in 1996, while in 1997 a Hughes 500 was used) (Table 1). There may be differences in visibility between these types of aircraft.

Analysing count flying time shows variation for total area counts of blocks with two observers or three observers compared with other counting strategies. Flying time in 1997 increased by 8.4 hrs compared with 1996 (Fig. 4). A relationship between flying time and the progressive area counted for 1996 and 1997 shows that over the count period flying time in 1997 was higher than in 1996 (Fig. 5). Possible reasons for this were that the pilot in 1997 had no previous counting experience in PNP or elsewhere and therefore the increase in flying time could be due to differences in strip width and/or speed and variation in flying height compared to previous counts. In addition flying time increased at some point during the count which was attributed to: (1) photographing elephant, buffalo and sable herds, (2) identification of black rhino, (3) increased search effort and

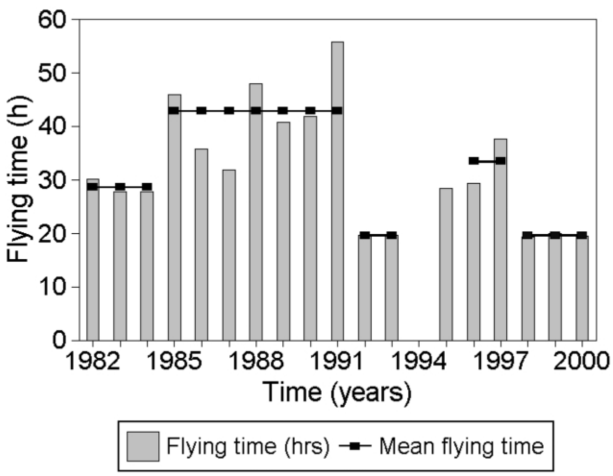

Fig. 4. Total flying time (h) per year, with the mean flying time (h) for each counting strategy.

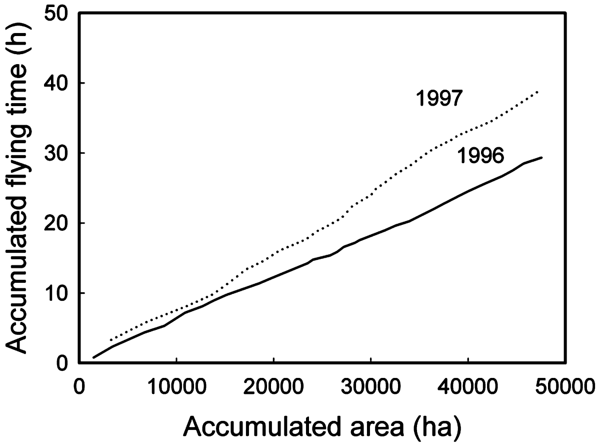

Fig. 5. Relationships between accumulated area (ha) counted per block and accumulated flying time (h) for total area counts in 1996 and 1997.

(4) changes in scribe/navigators (Fig. 5). This indicates a lack of systematic counting procedures within blocks and these factors could have contributed to biased counts.

Time of year. There was variation in the time of year counts were conducted (Table 1).

Time of day. In the development of a counting technique it was recommended that some blocks be counted in afternoon (p.m.) rather than morning (a.m.) sessions. This was due to the terrain (*i.e.* slope and aspect) and hence better visibility in afternoon sessions. Appendix 3 shows that there were differences in the time of day some blocks were counted. In addition to the variation between morning and afternoon sessions there were differences in the sequence of blocks counted within morning sessions. These differences in the time of day would have resulted in different lighting and visibility conditions, and contributed to counting bias.

Counting block sequence. Ferry time increased in 1997 compared with 1996 (Table 1) due to differences in the counting block sequences used (see Appendix 3).

Consistency of observers used. To maintain consistency (as far as possible) a small team of observers should be used over the period of a count. There was some consistency in observers used between counts in 1982–84, 1986–87, and 1990–91, but with poor consistency between 1993–97 with multiple teams of observers used.

Scribe/navigators. Multiple scribe/navigators were used in 1996 and 1997 (Appendix 2) some of which were not trained. This could have led to inconsistencies in the strip width used, delineation of block borders and with decisions as to whether an animal was inside or outside a block.

(3) *Observer error*

Visibility. Variation in seasonal rainfall (as an index of visibility) was a factor in determining undercounting bias; however the 1996 and 1997 count data were excluded from this analysis. Seasonal rainfall for 1995/96 was above average (813.5 mm), and for 1996/97 was classified as abundant rainfall (914.1 mm). Increased seasonal rainfall results in a negative (rather than positive) bias.

Experience of observers. From 1993–97 inexperienced observers and some under training were used (Appendix 1). Studies have shown that experienced observers can see up to 60% more than inexperienced observers (Watson *et al.* 1969), and it should therefore follow that the use of inexperienced observers should result in a greater undercounting bias. However, in a sense each observer has a unique perception bias (both *within* and *between* counts) (Seber 1992), and also the changing animal sightability may not be due to observer error alone (Caughley & Sinclair 1994).

Fatigue. Extended hours of counting can lead to fatigue, which would be exacerbated with the use of inexperienced observers. However, it would be expected that this should lead to observers missing, and therefore undercounting rather than overcounting.

(4) *Environmental factors*

Spatial and temporal weather conditions. During the 1996 count rain was recorded, and this

Table 4. Logistic regression results ($n = 13$) for equation to predict the percentage of the black rhino population counted using total area helicopter counts.

Variables	*P*-value	Coefficient (S.E.)
REGRESSION (proportion deviance explained = 0.40553; $P = 0.01939$; $n = 13$)		
Constant		0.447 (0.561)
No. of observers	0.00517	0.765 (0.282)
Seasonal	0.04076	–0.00239 (0.00118)

coupled with the time of year the count was conducted (thermal spring), and especially a flush on recently burnt veld could lead to animal movement (Appendix 2). However, the degree to which these factors might influence black rhino movement is not known. Weather conditions could have contributed to the overcounting bias in 1996 because of days lost due to strong winds, or counts conducted under unsuitable weather conditions (see Appendix 2).

Model to predict the percentage of population counted

Flying time, number of days, beginning Julian day of count and year did not play a significant role in explaining population counted. The final model developed to predict the percentage of population counted from equation (3) was an interaction model between number of observer and seasonal rainfall. The model was:

$$logit = 0.447 + 0.765 \times Observers - 0.00239 \times Seasonal \quad (6)$$

where *Observers* = number of observers and *Seasonal* = total seasonal rainfall (July to June) recorded prior to count (Table 4).

The implication of this model is that the most important factors determining the percentage of population counted were the number of observers and seasonal rainfall. As the number of observers increased the percentage of the population counted increased (Fig. 6a) and this agrees with research conducted by van Hensbergen *et al.* (1996). There was a negative relationship between the proportion of population counted and seasonal rainfall (Fig. 6b). When total seasonal rainfall was greater than the mean the proportion of population counted was low (Fig. 6b). A similar pattern was found by Samuel *et al.* (1987) for increasing visibility for elk in north-central Idaho, U.S.A. with decreasing vegetation cover.

Besides the number of observers, other count methodological factors tested were not significant. Samuel *et al.* (1987) used a logistic regression to predict elk sightability and showed that helicopter search rate (min/km^2) had no significant relationship to sightability. In addition to the factors analysed, there might be others (*e.g.* the behaviour of black rhinos in response to a helicopter) which might affect the population counted.

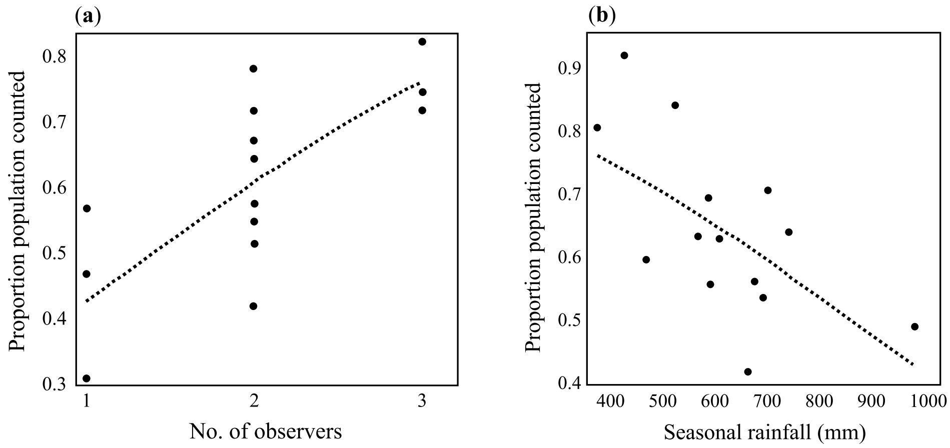

Fig. 6. Logistic regression with the fitted and observed relationship between the proportion of population counted and (**a**) the number of observers, and (**b**) seasonal rainfall.

CONCLUSIONS

Helicopter-based counts of black rhino are inaccurate and produce biased population size estimates. Counting strategy, method and observers had a large influence on the accuracy and precision (and hence repeatability) of black rhino counts. In addition, managerial functions of planning, organizing, leading and controlling counting operations played an important role in determining results.

For managerial purposes both accurate and precise black rhino population size estimates are required. To achieve this the present study shows how important it is that the counting methods are applied in a repeatable and consistent manner both within and between years. To reduce counting bias it is recommended that a small team of observers be used for the duration of the count and that the scribe/navigator remains constant throughout the whole count period. If aerial counts are to be used to establish accurate and precise population size (or density) estimates for black rhino, then it is recommended that total area parallel transect counts (which produced the best accuracy and precision) be used. The biased black rhino counts in 1996 and 1997 could also apply to other species counted in these years, and consequently the interpretation of population trends using such data are strongly cautioned against.

ACKNOWLEDGEMENTS

I thank Keryn Adcock for black rhino data, Vere van Heerden for helicopter hours and other count information, Oonsie Biggs for the logistic regression, Brian Reilly for assistance with data analysis, Ray Schaller for assistance with figures, and Andrew Hudak, Hanne Lindemann, Kate Parr, Brian Reilly and Greg Stuart-Hill for comments on the manuscript.

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Appendix 1. Observer matrix indicating observers used for helicopter-based counts conducted in Pilanesberg National Park.

Observer	Year																		
	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
A	■	■	■	■															
B				■	■	■													
C					■	■													
D					■	■		■											
E							■	■	■	■	■								
F							■												
G									■	■	■								
H											■	■	■						
I											■	■	■	■		■	■	■	■
J												■	■	■	■	■	■	■	■
K												■	■	■	■	■	■	■	■
L												■	■	■					
M												■	■	■	■	■	■		
N													■						
O													■	■	■	■			
P													■		■				
Q															■	■			
R															■	■			
S															■				
T															■				
U															■				
V																	■	■	■
W																	■		
X																		■	
Y																			■

Appendix 2. List of possible sources of counting bias for some helicopter counts conducted grouped by counting methodology, observer error, and environmental conditions.

Year	Management functions	Counting method	Observer error	Environmental factors
1985		CHANGED BLOCKS. Block Q counted in two sessions: first portion in afternoon, the remaining portion following morning.		
1986		CHANGED BLOCKS.		
1987		CHANGED BLOCKS. Block H counted in two sessions: first portion in afternoon, the remaining portion following morning.		Windy conditions from fourthth day. Count postponed for 2½ days due to rain and cloud cover. During this period burnt pediments flushed. This could have resulted in animal movement onto these areas (which had been counted), and could have resulted in an overall undercount for many species.
1988		ORIGINAL BLOCKS. Black rhino recorded during block counts, as well as while ferrying between blocks. Using the completed data-sheets it was impossible to distinguish between the two sightings. Count of block BY and E combined as a single count.		Counts cancelled due to windy or cloudy conditions. Some counts conducted under overcast weather conditions.
1989	Helicopter serviced for one day during count.	ORIGINAL BLOCKS.		Count cancelled for four days due to wind.
1990		ORIGINAL BLOCKS.		Count cancelled for two days due to wind.
1991	Mechanical problems with helicopter delayed count.	ORIGINAL BLOCKS. Helicopter hours, and flying time increased compared with previous years. Number of days over which the count was conducted was extended (Table 1).		Some counts conducted in overcast weather. Counts cancelled due to wind. Wildfires on 18/08 and 20/08, resulted in the count cancelled for these days.
1992		ORIGINAL BLOCKS.		One block counted under unsuitable weather conditions.

1993		ORIGINAL BLOCKS. Block K split into two: one section was the EEZ.		
1994	Counting postponed for two days over a weekend.	ORIGINAL BLOCKS. Two helicopters with two teams of observers used resulted in multi-teams of observers being used.	Inexperienced observers under training included.	Four counts postponed and two days (a weekend) not counted due to wind. Some hill blocks were difficult to count due to wind.
1995	Count of one block postponed for a number of days due to capture commitments in another reserve.	ORIGINAL BLOCKS. Multiple teams of observers used. Repeat counts of Z conducted at different times of day (p.m., a.m.), and with different observers, and O at different times of a morning session .	Inexperienced observers under training included.	Rain recorded in the southwestern section of PNP, and this could have resulted in animal movement, and in a biased count for certain species.
1996	Count conducted over an extended period (12 days), partly because of the pilots other commitments during count. A black rhino was notched during the count of a block.	ORIGINAL BLOCKS. Four scribes/navigators used, and multiple teams of observers used.	Inexperienced observers under training included.	Strong winds experienced during count, and days lost due to poor counting conditions. Rainfall recorded during count.
1997	Pilot had no previous counting experience in PNP or elsewhere. Servicing of the helicopter caused a day's interruption to the count.	ORIGINAL BLOCKS. Three scribes/navigators, and multiple teams of observers used. Possible differences in height, speed, and/or strip width used compared to previous counts. Sequence of blocks counted optimized to reduce ferry costs (van Dyk, pers. comm.).	Inexperienced observers under training included.	
1999			One observer was nauseous.	

Appendix 3. Daily records of blocks counted in morning (a.m.) and afternoon (p.m.) counting sessions for helicopter counts conducted in Pilanesberg National Park from 1992–97. Letters represent block codes.

1992	a.m.	p.m.	1993	a.m.	p.m.	1994	a.m.	p.m.
26/08	L	K	22/08	H, E	I	15/08	H, E, G, J	EEZ, I, K
27/08	O		23/08	L	M	16/08	M, L, N, O	P
28/08	E, H	I	24/08	X, BY	Z	17/08	X, BY, AZ, Y, P	Z, CX
29/08	X, BY, V	Z	25/08	B, A	K, EEZ	18/08	F, D	
30/08	B, A, C	M	26/08	C, W	Q	19/08	B, V, S, U	
31/08	W, T	Q	27/08	V, T	R	20/08		
01/09	DW	R	28/08	O		21/08		
						22/08	A	
						23/08	C	Q
						24/08	T	R
						25/08	W	

1995	a.m.	p.m.	1996	a.m.	p.m.	1997	a.m.	p.m.
17/09	E, H	I	28/08		J	14/08	H, E	I
18/09	L	M	29/08	E, H	I	15/08	L, Z	J
19/09	O, BY, X	Z	30/08	F, G	K, EEZ	16/08	T, V, S	R
20/09	A, B, C	K, EEZ	31/08	P, N		17/08	W, U	Q
21/09	W, O	Q	01/09		Q	18/08	C, B, A	K
22/09	V, T, Z	R	02/09	L, O	M	19/08	EEZ	
23/09	D	U	03/09	AZ, Y, CX, BY	Z	20/08	D, BY, X	M
24/09			04/09	X, D		21/08		
25/09			05/09	W, V, C	T	22/08	Y, AZ, CX, O	N
26/09			06/09		R	23/08	G, F	P
27/09			07/09	A, B				
28/09			08/09	U, S				
29/09								
30/09								
01/10								
02/10								
03/10		S						