Aerial Survey of Large Herbivores in Gorongosa National Park, Mozambique: 2004

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A report for

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Summary

During October 2004, large herbivores were surveyed from the air in Gorongosa National Park (NP), central Mozambique. This multispecies census was commissioned by the Gregory C. Carr Foundation. A fixed-wing aircraft was used to conduct a sample survey. The methods are both repeatable and technically robust, and are similar to those used during the 1994 survey of wildlife in Gorongosa NP. These same methods are now regularly used to census wildlife elsewhere in Mozambique.

During 2004, the survey area in Gorongosa NP was divided into five strata and the area surveyed totalled 3689 km^2. With each stratum, the transects were parallel and regularly spaced 3 km apart. Overall sampling intensity was 10.3 %. Overall mean search effort was 1.08 minutes km^{-2}.

Even the largest herbivores are not easily seen during aerial surveys and the numbers of all species were probably underestimated, with the degree of underestimation greater for small or cryptic species than for large species. However, population estimates were determined for all species, because the estimates provide useful indices of abundance (with measures of precision) that can be used to determine spatial distribution, as well as temporal trends in population number. No corrections have been applied to any of the estimates to compensate for any undercounting or missed animals.

The estimated population numbers of the principal large herbivores in Gorongosa NP were: waterbuck 4136 (95% confidence interval (CI) 84 %); reedbuck 1793 (CI 41 %); warthog 2297 (CI 32 %); sable 668 (CI 79 %); kudu 549 (CI 64 %); impala 520 (CI 82 %); and Lichtenstein's hartebeest 69 (CI 206 %).

No zebras, wildebeests, elands, roan antelopes, elephant carcasses, or domestic livestock were seen during the survey, nor at any time when flying over Gorongosa NP. No elephants were seen in the search strips, but a single bull and a cow herd of 20-22 elephants were seen when flying back to camp. Similarly, no buffaloes were seen in the search strips, but a solitary buffalo was seen outside these strips.

The locations of animal groups seen during the survey were entered into a GIS to produce maps showing the spatial distribution of the principal large herbivores in Gorongosa NP.

Hippos were counted during a separate, dedicated survey. During this, the permanent water bodies likely to contain hippos were searched from the air and an attempt made to count all hippos seen. This dedicated survey provided a minimum estimate of hippopotamus number: there were at least 59 or 60 hippos in Gorongosa NP.

There were an estimated 3581 huts (CI 44 %) in the survey area. Most were sited close to the boundaries of the survey area, or in the north-eastern part of this area.

It is recommended that, during future sample surveys, sampling intensity is greater than 10 % over the rift valley portion of the park (a 20 % sample is suggested). The increased sampling intensity should be achieved by reducing the interval between adjacent transects and increasing the number of transects. Increased sampling intensity should increase the precision of the population estimates. For species that are not uniformly distributed across the floor of the rift valley (e.g. waterbuck, reedbuck), precision can be increased further by pre-survey stratification of the rift valley into species-specific high-density and low-density strata.

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Introduction

Aerial surveys of the large herbivores in Gorongosa National Park (NP) have been conducted since the 1960s (Tinley 1977, Cumming, Mackie, Magane & Taylor 1994 and the references therein, Dutton 2002). The declines in the numbers of all species during the period 1979-1994 (Cumming *et al*. 1994) were so large that they greatly exceeded any variations due to the differences in survey methods. Cumming *et al*. (1994) were the first in Gorongosa NP to use the techniques that are well established for aerial surveys of African large herbivores (Norton Griffiths 1978). These same techniques are now regularly used for aerial surveys of wildlife in Mozambique, notably in the Magoe region of Tete Province (Mackie & Chafota 1995, Davies 1999, Mackie 2000, 2001, Dunham 2004) and in Niassa Game Reserve (Gibson 1998, 2000, Craig & Gibson 2002).

The purpose of the current survey was to estimate the numbers of large herbivores in Gorongosa NP at the end of the 2004 dry season, using methods that are both technically robust and repeatable. The methods were similar to those used by Cumming *et al*. (1994) during 1994 and so the results of the 1994 and 2004 surveys are directly comparable.

Survey Area

The study area covered 3689 km^2 within Gorongosa National Park in the Sofala Province of central Mozambique and was divided into five strata (Map 1, Table 1). The South and Central strata were in the rift valley portion of the park, while the other strata were composed of *Brachystegia* woodland on either side of this valley. The South-east and East strata were along the western edge of the Cheringoma Plateau and the West stratum was in the hills to the south-east of Gorongosa Mountain. The East and South-east strata were divided for operational reasons by the line of an old road.

Methods

Survey Design

The procedures used followed those well established for aerial surveys of African large herbivores (Norton Griffiths 1978). To facilitate comparisons, the boundary of the Central stratum was similar to the boundary of stratum 2 of the 1994 survey of Gorongosa NP (Cumming *et al*. 1994), although with minor differences in the south-west due to variation in the boundaries of the 1994 and 2004 survey areas: during 1994, the south-western boundary of the survey area was the road running westwards from Chitengo, while during 2004 it was the Pungwe River.

The area of each stratum was determined using the software CARTALINX (Hagan, Eastman & Auble 1998). Digital files containing the co-ordinates (in degrees latitude and longitude, WGS84 datum) of strata boundaries were converted into bna-format computer files that could be used by the software for designing transect surveys (see below).

Regularly-spaced, parallel transects were positioned across each stratum. Transects were arranged at right angles to the principal environmental feature within a stratum – for example, transects crossed major river systems (see Table 1 for transect orientations). Transects were uniformly spaced 3.0 km apart, to give a sampling intensity of 10 % with the planned combined strip width of 300 m.

The survey was designed using custom software (AIRDESW, version dated 29/05/97) belonging to the World Wide Fund For Nature – Southern Africa Regional Programme Office (WWF SARPO). Given a stratum boundary in the form of a bna computer file, and the transect orientation and spacing, this software generates flight lines (the transects), with the first flight line offset from the end of the stratum by an entered random number. The start and end points for each transect (Appendix 3) were transferred as waypoints to a Global Positioning System (GPS) receiver in the plane prior to flying each stratum.

Flight Procedure

The aircraft used was a Cessna 206. It was fitted with a radar altimeter and Trimble GPS100 GPS receiver. During surveys, the aircraft was flown at approximately 160 km per hour at about 300 feet above ground level. Waypoints denoting the start and end points of transects were entered into the GPS receiver and navigation along the transects was undertaken by the pilot, with reference to the GPS receiver and a course deviation indicator.

The aircraft crew included a pilot (Jon Cadd), a recorder (Kevin Dunham) who sat next to the pilot, and two observers (Dave Falkner and Rodolfo Cumbane) who sat behind the pilot and recorder. Both observers had previous experience of observing during aerial surveys. All four crew members could talk to one another through an intercom system.

All animals seen by the observers within the strips (see section *Strip Width and Calibration* below) were called to the recorder, who wrote down the species, the number of individuals of the group that were within the strip, and the GPS location against the time (to the nearest 30 seconds) after the start of the transect. To simplify recording, location was noted solely as latitude or longitude. The recorder used a stopwatch to record the time (to the nearest second) taken to fly each transect.

During the surveys, the actual height of the plane above ground level (agl) was recorded by the recorder from the radar altimeter every 30 seconds (of time) while flying along the transects. Later the mean height agl for each transect was calculated.

Observations

Although the surveys were designed especially to count wild herbivores, the observers were instructed to count also domestic livestock (cattle, goats, sheep and donkeys). If any animal group in the transect was too large for all the individuals within it to be counted, group size was estimated by the observer. Groups of elephant bulls can be differentiated from elephant cow herds (i.e. herds containing calves), although the latter may include some bulls.

Ground hornbills are large and conspicuous birds and any seen were counted. Huts and poachers' camps were also counted. Poachers' camps can be identified by the presence of meat racks (horizontal branches mounted above the ground), with or without meat, or meat hanging in trees.

The observers were instructed to record any elephant carcasses seen and to classify them as follows:

Carcass category	Definition
1	**Fresh**: intact; white droppings of vultures visible; vegetation trampled; fluid stain visible on ground around carcass (animal likely to have died within the last 3 months).
2	**Recent**: pieces of hide still attached; skeleton still partly articulated; no vulture droppings; no trampled vegetation; no fluid stain evident (less than 1 year old, but generally since the last rainy season, i.e. 3 to 8 months since death).
3	**Old**: bones scattered and bleached (probably died during or before the last rainy season, i.e. more than 8 months old, but generally more than 1 year old and up to several years old).

All strata were surveyed during the period 27-29 October 2004 (Table 1), which is generally the late dry season (although some rain had fallen about two weeks prior to this survey).

Strip Width and Calibration

For the transect survey, two fishing rods were attached with custom brackets to each wing strut, so that the rods pointed backwards and parallel to the ground during level flight. The distance between the rods on each strut was arranged so that, when the aircraft was flying at 300 feet agl, this distance represented a strip about 150 m wide on the ground. Each rod was marked with a small piece of tape to provide the observers with a "decision point" (it was at this point that the observer decided whether an animal was inside the strip). When deciding whether animals were inside or outside the strip, each observer moved his eye so as to align the tape on the outer rod with a small piece of tape on his window, thereby ensuring that all his decisions were made at the same viewing angle.

The strip widths were calibrated by flying the aircraft at right angles across an airstrip that had two sets of large-sized numbers (from 0 to 35) arranged at 10-meter intervals along the side of the airstrip. The numbers were arranged as 35 34 33….2 1 0 1 2…..33 34 35, with 0 near the centre of the airstrip. Each observer noted the largest and smallest number within his strip and the recorder noted the aircraft's height above ground level, as recorded by the radar altimeter. After a special calibration flight prior to the survey, additional calibration data were collected on the following days, just prior to landing after completion of the survey flights.

The combined strip widths (in meters) were adjusted to 300 feet above ground level:

$$\text{Combined strip width at 300 feet} = \frac{\text{Actual combined strip width} \times 300}{\text{Actual flying height}}$$

The combined strip widths, after adjustment to 300 feet above ground level, were then averaged to give the nominal (calibrated) combined strip width at 300 feet. This was 303.0 m (Appendix 1).

Data Analysis

Population estimates and confidence intervals for individual strata were calculated with custom software (AIRSURVW, version dated 22/05/97) belonging to the World Wide Fund For Nature – Southern Africa Regional Programme Office. This software uses Jolly's (1969) method 2 for unequal-sized sample units. Given the mean combined strip width when the plane was flying at 300 feet and the mean flying height for each transect, the software determines the actual combined strip width for each transect. The actual combined strip width is the product of the nominal strip width at 300 ft and the mean height for the transect, divided by 300. The area of each transect is calculated as the product of the actual combined strip width and the transect length. Transect lengths were provided by the survey design software (Appendix 3).

Transects near the boundary of a stratum were sometimes broken into two or more sections, with land outside the stratum between the sections. For the purposes of analysis, data for all sections of the same transect were combined and entered into the program as one transect. Calculation of the variance of a population estimate required the calculation of N, which is the total number of transects that could have been used in the survey of a stratum. The value of N for a stratum was found by dividing the baseline length by the mean actual strip width for that stratum.

Thus, for each stratum, N was calculated as:

$$N = \frac{\text{Baseline length} \times 1000 \times 300}{\text{Nominal strip width} \times \text{Average flying height}}$$

where:

Baseline length = length (in km) of a straight line aligned at right angles to the orientation of the transects, and running from one end of the stratum to the far end;

Nominal strip width = calibrated combined strip width (in m) when flying at 300 feet agl; and

Average flying height = Mean of the mean flying heights (in feet) for all transects in the stratum.

The value of Student's *t* used to calculate the confidence interval of a population estimate was t_{n-1} for $P = 0.05$ (Rohlf & Sokal 1981), where n = number of transects in stratum.

Calculation of population estimates for entire survey area

A population estimate for the entire study area was calculated as the sum of the estimates for the individual strata within the study area. The confidence interval for such a population estimate was calculated as:

$$t_v \times \text{square root of (Sum of Variances for individual strata)}$$

where:

v = the degrees of freedom estimated by Satterthwaite's rule (Snedecor & Cochran 1980, Gasaway *et al*. 1986).

v was an integer, calculated using the formula:

$$v = \frac{(\text{Sum of Variances for individual strata})^2}{\text{Sum of [(Variance for individual stratum)}^2 \text{ / (n-1)]}}$$

with the outcome of this formula rounded down to the nearest integer. t_v was calculated using the EXCEL function TINV(0.05, *v*).

Search Effort

Search effort (in minutes per square kilometre) for a stratum was defined as the total time spent flying all transects within that stratum, divided by the total area of those same transects. The greater the search effort, the greater the probability that the observers saw all the animals that were within the strips.

Even the largest herbivores are not easily seen from the air and the numbers of all species were probably underestimated, with the degree of underestimation greater for small or cryptic species than for large species. However, population estimates are given for all species, because the estimates provide useful indices of abundance (with measures of precision) that can be used to determine spatial distribution, as well as temporal trends in population number. No corrections have been applied to any of the estimates to compensate for any undercounting or missed animals.

Spatial Distribution of Wildlife

For each sighting of animals (and huts) in the search strips, the location, stratum, transect number, observer, species and number of individuals were entered in an IDRISI Geographic Information System database (Eastman 2003). This was used to prepare maps of the distribution of the different species in Gorongosa NP. The maps are intended to show spatial variations in density across the survey area and are not intended to be accurate representations of all the wildlife present.

Hippopotamus Survey

During the daytime, hippos are usually found in or close to perennial water bodies. A ‘total count’, undertaken by flying along rivers or lake shorelines and counting all hippos seen, may provide a more accurate estimate of hippo number than does a sample survey.

The rivers where hippos were likely to be found in Gorongosa NP were indicated by the former park administrator (R. Zolho, pers. comm. to T. Lynam) and these rivers are highlighted on Map 14. The same Cessna 206 aircraft that was used for the sample survey was used for the hippo survey, with the pilot (J. Cadd), a recorder (K. Dunham) who sat next to the pilot and one observer (D. Falkner) who sat behind the pilot. Starting in the west of the search area, the plane was flown generally eastwards towards and around Lake Urema and then southwards, covering all the waterways earmarked for searching. The plane was flown so that the waterway being searched was generally on the left side of the plane so that both the pilot and observer could simultaneously search for and count any groups of hippos seen. The recorder noted the number of hippos in each group and used a handheld Garmin III GPS receiver to record the location of each group as a waypoint.

The hippopotamus survey was conducted on the afternoon of 29 October 2004.

Results

Search Effort

Overall, search effort averaged 1.08 minutes km^{-2} (Table 1).

Animal Numbers and Distribution

The estimated numbers of waterbuck, reedbuck, warthog, sable, kudu, impala, bushbuck, common duiker, oribi, nyala and Lichtenstein's hartebeest in Gorongosa NP are given in Tables 2 to 12. In these tables, confidence intervals (CI) and confidence limits (CL) are 95 % confidence intervals and limits. 'Number seen' is the number seen in the strips during the survey. There may appear to be small errors in the sums given in some tables, but these are simply rounding errors: population estimates, variances and sums were calculated with great precision before being rounded to zero decimal places.

The spatial distribution of these same species is shown in Maps 2 to 12. The location of each dot on these maps indicates the approximate location where a group was seen and the size of each dot indicates the relative size of the group. Note that the map keys may vary between species.

Some of the survey findings are highlighted below.

There were an estimated 4136 waterbucks (CI 84 %) in Gorongosa NP, with most of them concentrated on the rift valley floor, north of and north-northwestwards of Lake Urema (Map 2, Table 2).

There were an estimated 1793 reedbucks (CI 41 %) in the park, with most of them concentrated on the rift valley floor, west and north of Lake Urema (Map 3, Table 3).

There were an estimated 2297 warthogs (CI 32 %) in the park. They were scattered across a large portion of the park, but were uncommon in the northern and eastern parts of the survey area (Map 4, Table 4).

There were an estimated 668 sable antelopes (CI 79 %) in the park, with most of them in the southern portion of the park, both in the rift valley and the hills covered with *Brachystegia* woodland (Map 5, Table 5).

There were an estimated 549 kudus (CI 64 %) in the park, with most sightings to the west of the Urema and Nhandugue Rivers (Map 6, Table 6).

There were an estimated 520 impalas (CI 82 %) in the park, with most sightings near Lake Urema or along rivers to the west of this lake (Map 7, Table 7).

There were an estimated 725 bushbucks (CI 24 %) in the park, with most sightings northwards of Lake Urema (Map 8, Table 8). Sightings of oribi were also more common northwards of this lake, than they were to the south (Map 10).

There were an estimated 299 ground hornbills (CI 56 %) in the park, with most sightings northwards of Lake Urema (Map 15, Table 16).

The dedicated hippopotamus survey revealed that there were at least 59 or 60 hippos in the park, most of them in Lake Urema, or a short way northwards of this lake, or in the Urema River, which is the outflow of this lake (Map 14, Tables 14 and 15).

No zebras, wildebeests, elands, roan antelopes, elephant carcasses, or domestic livestock were seen in Gorongosa NP during the survey, nor at any other time when flying over the park. No elephants were seen in the search strips, but a single bull and a cow herd of 20-22 elephants were seen when flying back to camp after completing the transect survey (Map 16). Similarly, no buffaloes were seen in the search strips, but a solitary buffalo was seen outside the search strips in Central stratum (Map 16). There were single sightings in the search strips of lion, bushpig and jackal (Map 16).

Human Settlement

There were an estimated 3581 huts (CI 44 %) in the survey area (Table 13). Many were sited close to the boundaries of the survey area, but there were also numerous huts in the north-eastern portion of this area (Map 13).

Discussion

Hippopotamus Survey

As expected, the dedicated hippopotamus survey produced an estimate of hippo number that was much greater than the estimate provided by the sample survey (Tables 14 and 15). The dedicated survey revealed that there were at least 59 or 60 hippos in Gorongosa NP. The few hippos seen during the sample survey were all seen in that area of the park which was later covered by the dedicated hippo survey.

For several reasons, the number of hippos seen during the hippo survey is a minimum estimate of the number of hippos in the park.

a) The water in Lake Urema and the pools around it was not clear and so any hippos that were underwater when the plane flew overhead would have been missed.

b) Many of the waterbodies in the search area were covered with aquatic plants and any hippos amongst these plants could have been missed. However, the idea that a herd of animals the size of hippos could regularly spend the daytime in a water body but leave the plants there unaffected seems unlikely. It seems more likely that hippo bulls, which are often solitary, could escape notice in a water body covered with aquatic plants.

c) The area around Lake Urema is essentially a swamp. It is more difficult to search such a feature for hippos than it is to search linear features such as rivers.

The Cessna 206 is a relatively fast small plane. While a plane capable of safely flying slower might be more suitable for a dedicated hippo survey, the Cessna 206 was already in the park for the sample survey. If, in future, a different type of plane was to be used for hippo surveys, consideration must be given to the extra costs involved in positioning this second plane in the park.

Changes in Animal Numbers since 1994

During the past ten years, the estimated numbers of waterbuck, reedbuck, nyala and oribi in the Urema basin of the rift valley of Gorongosa NP (i.e. in Central stratum) have increased, by five-fold for reedbuck, nyala and oribi, but by more than 30-fold for waterbuck (Table 17). The number of sable antelopes also seems to have increased greatly, because while none was seen during the 1994 survey, there are estimated to be >600 now. The number of hippos has also increased, with none seen during 1994 (not even during reconnaissance flights over the park), while there are at least 59 hippos now. In contrast, the buffalo is still rare: none was seen during 1994 and just one was seen during 2004.

The rate of increase in the number of waterbuck in the Urema basin was high, but probably feasible: the increase from an estimated 129 to 4106 over 10 years (Table 17) is equivalent to a finite rate of increase (as defined by Caughley 1977) of 1.41 per year, only slightly greater than the finite rate of increase of 1.37 per year for waterbuck on Crescent Island (in Lake Naivasha, Kenya) over nine years (Elliot 1976, cited by Spinage 1982).

Recommendations for Future Sample Surveys

Timing of survey

The 2004 aerial survey was conducted during the last week of October. Significant rain had fallen approximately two weeks earlier. During the survey, the sky was often overcast in the early morning. Although cool weather produces pleasant flying conditions for the crew, animals are more difficult to see when the sky is cloudy, compared with when it is sunny. Thus, it is preferable to conduct aerial surveys when the weather is sunny.

By the last week of October, *Brachystegia* woodland (the dominant vegetation type in West, East and South-east strata) had flushed and the new leaves reduced the visibility of wildlife for the observers.

- Aerial surveys will provide more accurate estimates of the numbers of large herbivores if the surveys are conducted when: (a) the *Brachystegia* woodland is largely leafless; and (b) the weather is sunny. Late September would probably be the most suitable time to conduct aerial surveys in Gorongosa NP.

Sampling intensity

One way to increase the precision of population estimates for Gorongosa NP (i.e. to reduce the confidence intervals of the estimates) during future surveys would be to increase sampling intensity, particularly in strata where large herbivores are relatively numerous, i.e. the Central stratum (and maybe also the South stratum, which is also on the floor of the rift valley). The combined width of the search strips should remain at approximately 300 m during future surveys (because to increase sampling intensity simply by increasing the strip width would cause a reduction in search effort, which is definitely not recommended).

- The recommended method of increasing sampling intensity for future surveys is to reduce the interval between adjacent transects to 2.0 or 1.5 km, at least in Central stratum and possibly also in South stratum.

During 2004, Central stratum was surveyed using 25 transects at 3.0 km intervals (Appendix 3). Surveying this stratum required about six hours of flying (Appendix 2) and occupied the survey team for one day (Table 1). The following table shows projections of how flying time and the time to survey the stratum will increase if the interval between adjacent transects is reduced as recommended. This table can be used to determine the financial consequences of an increase in sampling intensity in Central stratum.

Interval between transects (km)	Number of transects	Stratum flying time (hours)	Time to survey stratum (days)
3.0	25	*c*. 6	1
2.0	37 or 38	*c*. 9	1.5
1.5	50	*c*. 12	2

One disadvantage of using differing transect intervals in different strata is that the production of spatial distribution maps is more difficult. On the maps in this report, the spatial variation in animal sightings is largely a reflection of the variation in animal density, because sampling intensity was constant across the survey area. But if transect intervals vary between strata, the variation in sighting density reflects the variations in both animal density and sampling intensity. If, during future surveys, the transect interval is reduced only in some strata, map production would be easier if this interval was, say, half the interval in the other strata (e.g. 1.5 km in Central stratum and 3.0 km in the other strata).

Assuming that the boundaries of the West, East and South-east strata are essentially unchanged during future surveys, it is recommended that the transect interval is not greater than the 3.0 km used during 2004, because to increase transect interval in these strata would make the numbers of transects unacceptably small.

General stratification

In theory at least, a second way to increase the precision of the population estimates for Gorongosa NP during future surveys would be revise the stratification. Strata boundaries should be drawn such that the density of animals within each stratum is relatively homogeneous. However, because different species have differing distributions within the survey area, a stratification that is suitable for a survey of one species may not suitable for other species. If a survey is designed primarily for one species, it is possible to stratify the survey area for that species and accept that this stratification will be less than perfect for the other species (although of course this does not stop the survey being used to estimate the numbers of these other species – it is just that the estimates of their numbers will be imprecise). For example, recent surveys of large herbivores in Zimbabwean protected areas have been funded for – and therefore designed for – the express purpose of estimating the numbers of elephants: the production of population estimates for the other large herbivores has been an incidental bonus.

Examination of the sighting summaries for the transects in Central stratum (Appendix 4) suggests that it might be possible to subdivide this stratum. I explored this possibility further by using post-survey stratification of the 2004 sightings (using four strata) to calculate revised confidence limits for the population estimates for Central stratum, as a means of determining the likely effects of the revised stratification on the results of future surveys. For warthog, the variance of the population estimate for Central stratum was unchanged; for two species (kudu and oribi), it increased by 13-15 %; and for five species (waterbuck, impala, reedbuck, bushbuck and sable), it was reduced by 15-49 %. However, because the number of transects in each new stratum was small, the degrees of freedom estimated by Satterthwaite’s rule were also small. Consequently, the reductions in variance for these five species caused decreases in the confidence interval of 2-17 percentage points for only three species. For all other species, the confidence interval increased.

While reducing the transect interval in future surveys, as recommended above, will increase the number of transects, it is likely that there will still be too few transects in each new stratum if the current Central stratum is divided into four new strata.

- At present, there appears to be no advantage in revising the general stratification of the survey area for future surveys. However, with additional data from future surveys, it may be possible to divide Central strata into two new strata, such that the confidence intervals of the population estimates are reduced for most or all species.

Species-specific stratification

Aerial survey execution is easier if strata boundaries are linear geographical features (e.g. roads or rivers) that are readily identifiable from the plane. However, given that GPS receivers are used during the survey, both as an aid to navigation and to record the position of the plane and wildlife sightings, it is possible to use imaginary lines as strata boundaries, and to vary these boundaries between species. (Imaginary lines are lines that are drawn on a map, but which do not coincide with physical features on the ground, e.g. a contour line).

Species-specific stratification during future surveys could be executed as follows:

1. Prior to the survey, the available data from recent surveys are used to produce a spatial distribution map for each species, e.g. for waterbuck, Map 2 in this report.
2. For each species that appears not to have a uniform spatial distribution across Central stratum, a line is drawn on the map to divide Central stratum into two new strata, a high-density one and a low-density one. The location of the line dividing the two new strata may vary between species and so the new, high-density and low-density strata will be species-specific.
3. The survey is executed in a similar manner to that used during 2004 (although with a reduced interval between adjacent transects in Central stratum). In other words, Central stratum remains in use: during survey design and execution, it is treated as a single stratum and it is flown as such.
4. For each species, the boundary between the high-density and low-density strata is digitised and spatial analysis software (e.g. CARTALINX) is used to divide the Central transects into those portions that are in the high-density stratum and those that are in the low-density stratum, and to calculate new transect lengths and strata areas.
5. For each species, spatial analysis software is used to divide the sightings of that species along the Central transects into those sightings that are in the high-density stratum and those that are in the low-density stratum.
6. For each species, the data are analysed as during 2004, but with Central stratum divided into two, species-specific strata.

There are two disadvantages to the implementation of this plan:

1. There will be a significant increase in the time (and therefore cost) involved in designing the survey and analysing the data (over and above the increase due to a reduction in transect interval in some strata).
2. The locations of animal sightings during the survey are recorded only approximately, because there is a delay between the observer seeing a group of animals and the recorder noting the location from the GPS receiver. This delay is the time that the

observer spends counting the animals in the group and calling details of the observation to the recorder, and the time that the recorder takes to write down these details. Thus, when imaginary lines rather than geographic features are used as strata boundaries, there is the possibility that sightings may be recorded as being on the wrong side of such a boundary. However, particularly if surveys are designed with this problem in mind, it is likely that the advantages of species-specific stratification will outweigh any disadvantages.

Using an onboard computer to record survey data would reduce, but not eliminate, the delay between a group of animals being seen by an observer and the recorder noting details of this observation (and there are the additional problems associated with the use of an onboard computer, e.g. possible system crash, and ensuring a reliable power supply).

Frequency of surveys

An additional way of reducing the confidence interval of a population estimate is to combine data from several surveys, preferably conducted in successive years (so long as there is no evidence of a significant change in population number between those surveys). If sample surveys are undertaken annually for, say, three years and each survey produces similar population estimates, not only does the casual observer start to have more trust in the results, but it is possible to combine the results statistically to produce average population estimates with reduced confidence intervals.

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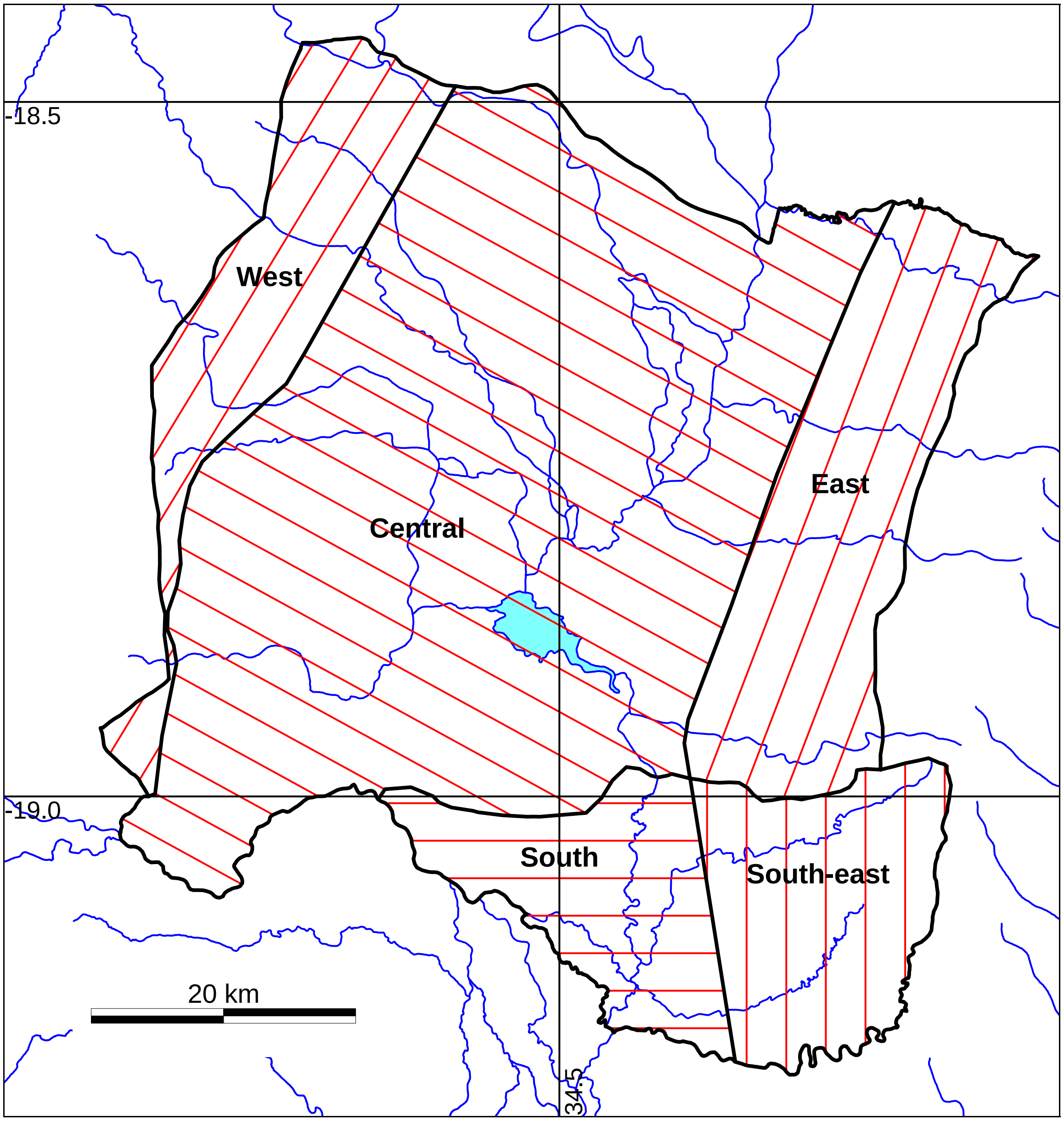
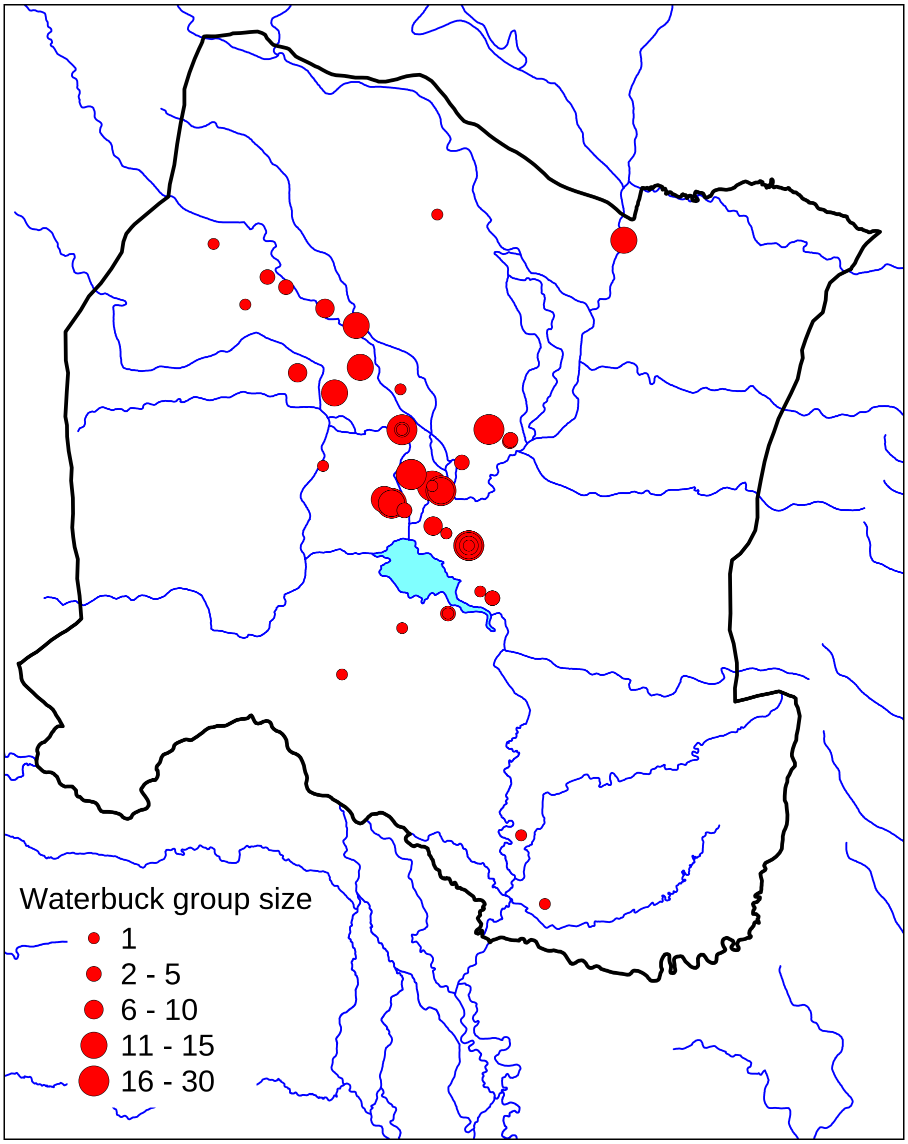
Table 1. Sampling statistics for the 2004 aerial survey of large herbivores in Gorongosa NP

Stratum name	Area (km^2)	Transect spacing (km)	Transect orientation (°)	Number of transects [= n]	Percent of stratum sampled	Time and date sampled	Flying time (hours)			Search effort (minutes km^{-2})
							Transects	Stratum	Total	
West	375.1	3.0	30	7	10.1	am 29 Oct	0.69	1.05	1.50	1.08
Central	2121.8	3.0	120	25	10.4	am, pm 27 Oct	3.75	4.47	5.65	1.02
South	300.3	3.0	90	7	10.0	am 28 Oct	0.58	0.80	2.78	1.15
East	541.6	3.0	20	6	10.4	am 28 Oct	1.06	1.38		1.13
South-east	349.9	3.0	0	7	10.5	pm 28 Oct	0.63	0.87	1.33	1.03
Total	**3688.7 km^2**			**Overall**	**10.3 [a] %**				**Mean**	**1.08**

[a] weighted mean, with stratum area as a proportion of the total area as weight



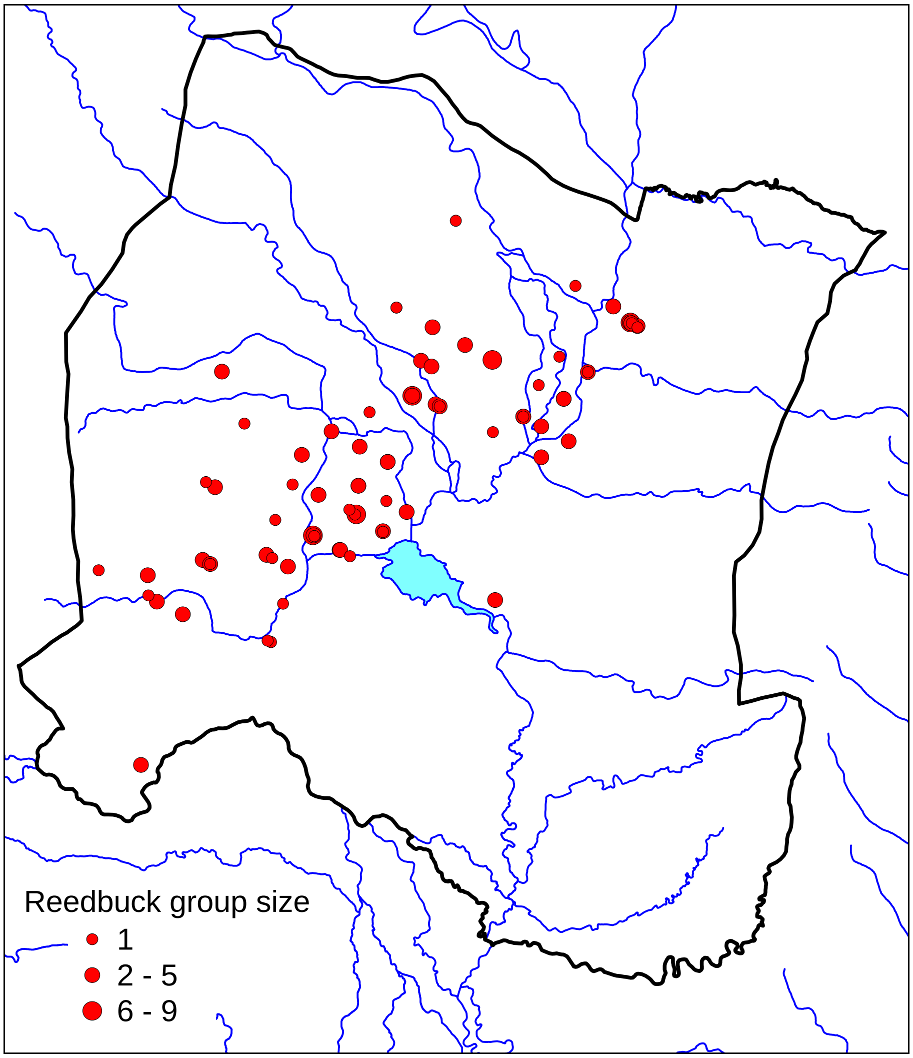
Map 1. The survey area in Gorongosa NP in central Mozambique.
Lake Urema is close to the centre of the survey area. Bold black lines indicate strata boundaries, labels indicate strata names, blue lines indicate rivers and red parallel lines indicate transects.



Map 2. The distribution of waterbuck in Gorongosa NP during October 2004. Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 2. Population estimates and statistics for waterbuck in Gorongosa NP

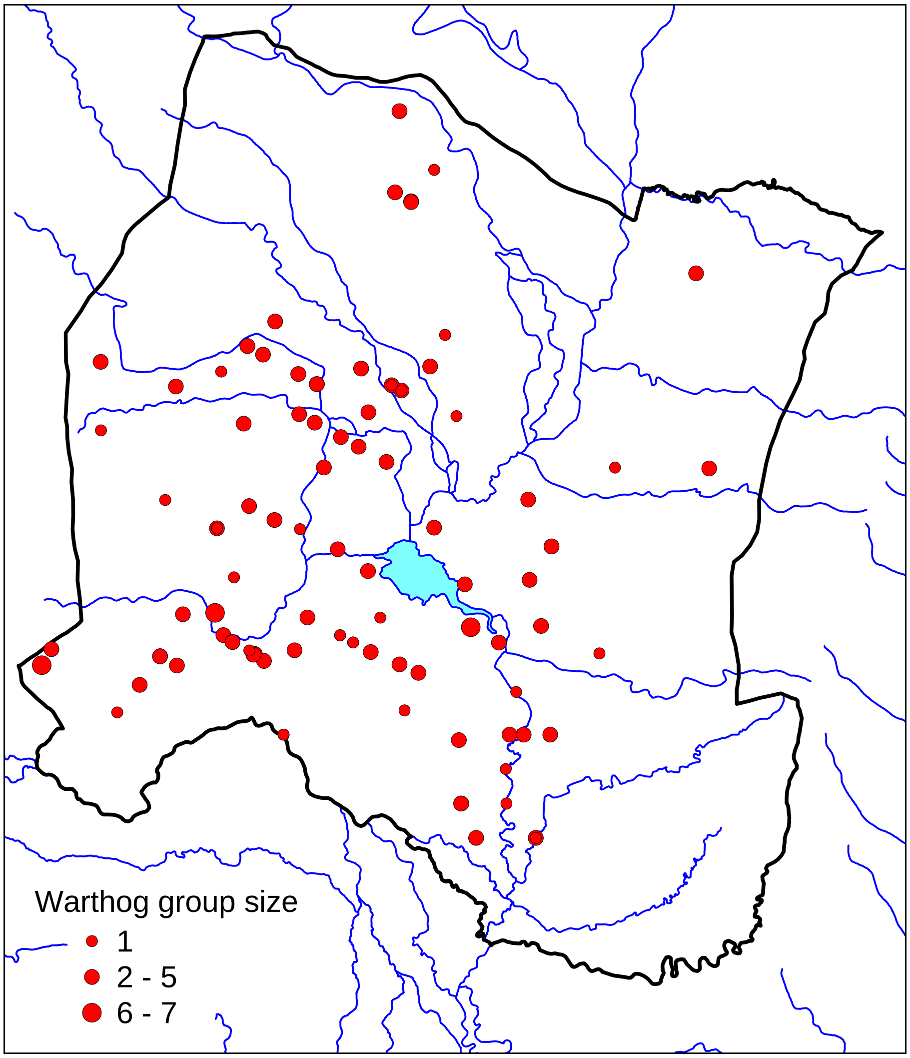
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	10	1	53	180	0	28	0.026
Central	4106	426	2860194	85	615	7597	1.935
South	20	2	213	179	0	56	0.066
East	0	0	0	0	0	0	0
South-east	0	0	0	0	0	0	0
Totals	**4136**	**429**	**2860460**	**84**	**645**	**7627**	**1.121**



Map 3. The distribution of reedbuck in Gorongosa NP during October 2004. Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 3. Population estimates and statistics for reedbuck in Gorongosa NP

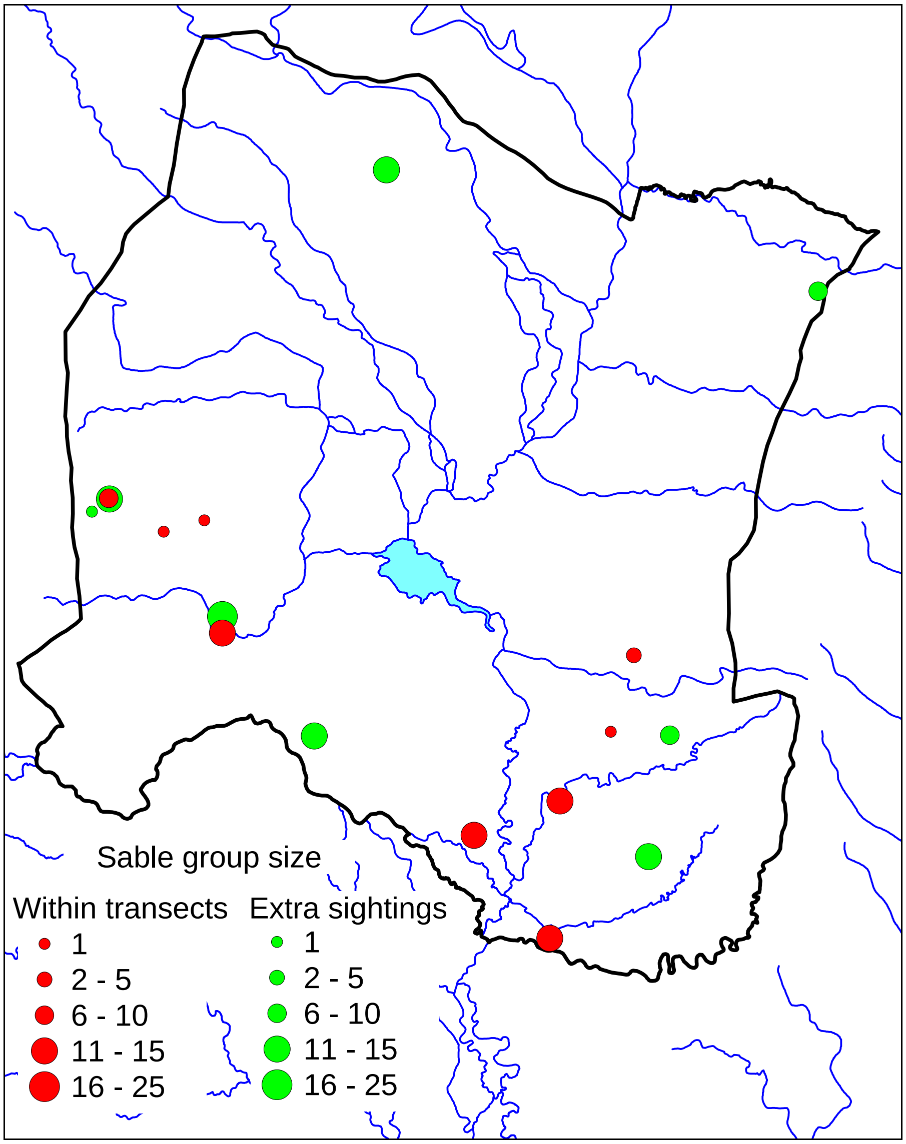
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	0	0	0	0	0	0	0
Central	1793	186	129637	41	1050	2536	0.845
South	0	0	0	0	0	0	0
East	0	0	0	0	0	0	0
South-east	0	0	0	0	0	0	0
Totals	**1793**	**186**	**129637**	**41**	**1050**	**2536**	**0.486**



Map 4. The distribution of warthog in Gorongosa NP during October 2004.
Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 4. Population estimates and statistics for warthog in Gorongosa NP

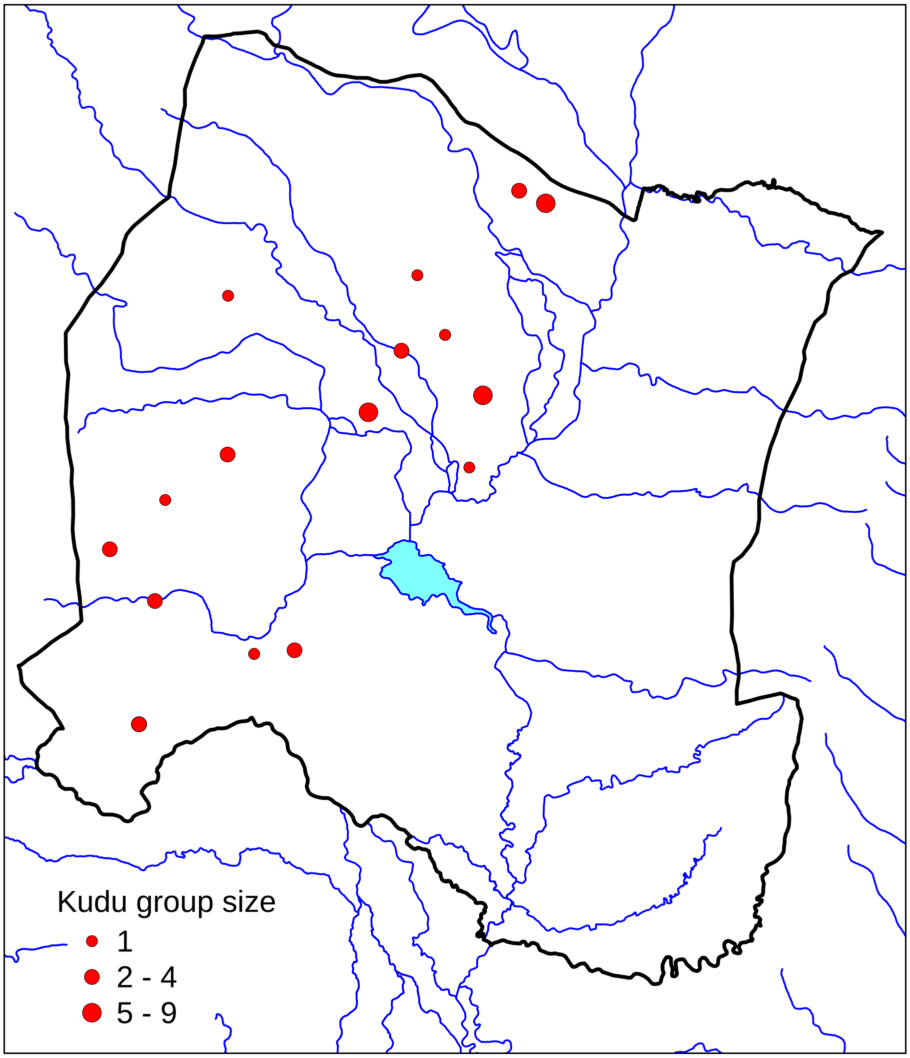
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	109	11	6163	177	0	301	0.289
Central	1851	192	97271	35	1207	2494	0.872
South	309	31	23907	122	0	688	1.030
East	29	3	159	112	0	61	0.053
South-east	0	0	0	0	0	0	0
Totals	**2297**	**237**	**127499**	**32**	**1570**	**3025**	**0.623**



Map 5. The distribution of sable antelope in Gorongosa NP during October 2004. Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 5. Population estimates and statistics for sable in Gorongosa NP

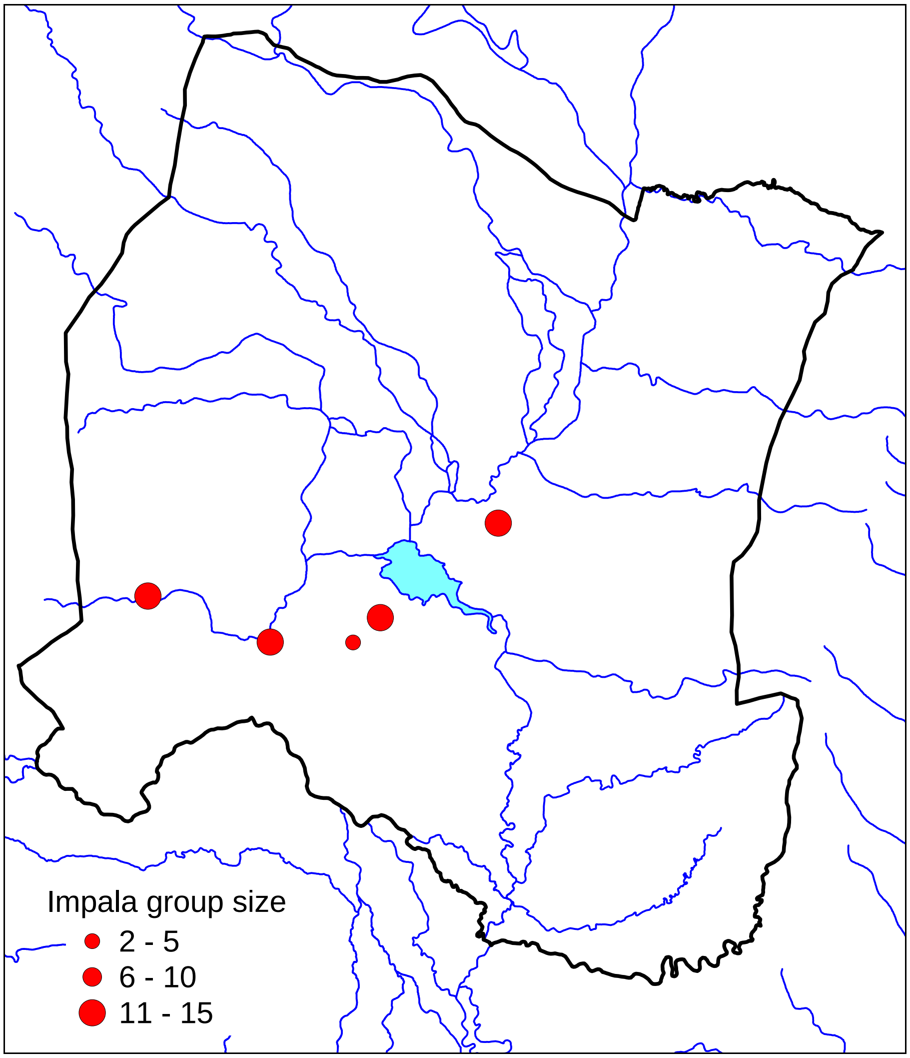
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	0	0	0	0	0	0	0
Central	260	27	26506	129	0	596	0.123
South	369	37	34274	123	0	822	1.229
East	29	3	441	187	0	83	0.053
South-east	10	1	66	210	0	29	0.027
Totals	**668**	**68**	**61288**	**79**	**143**	**1193**	**0.181**



Map 6. The distribution of kudu in Gorongosa NP during October 2004.
Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 6. Population estimates and statistics for kudu in Gorongosa NP

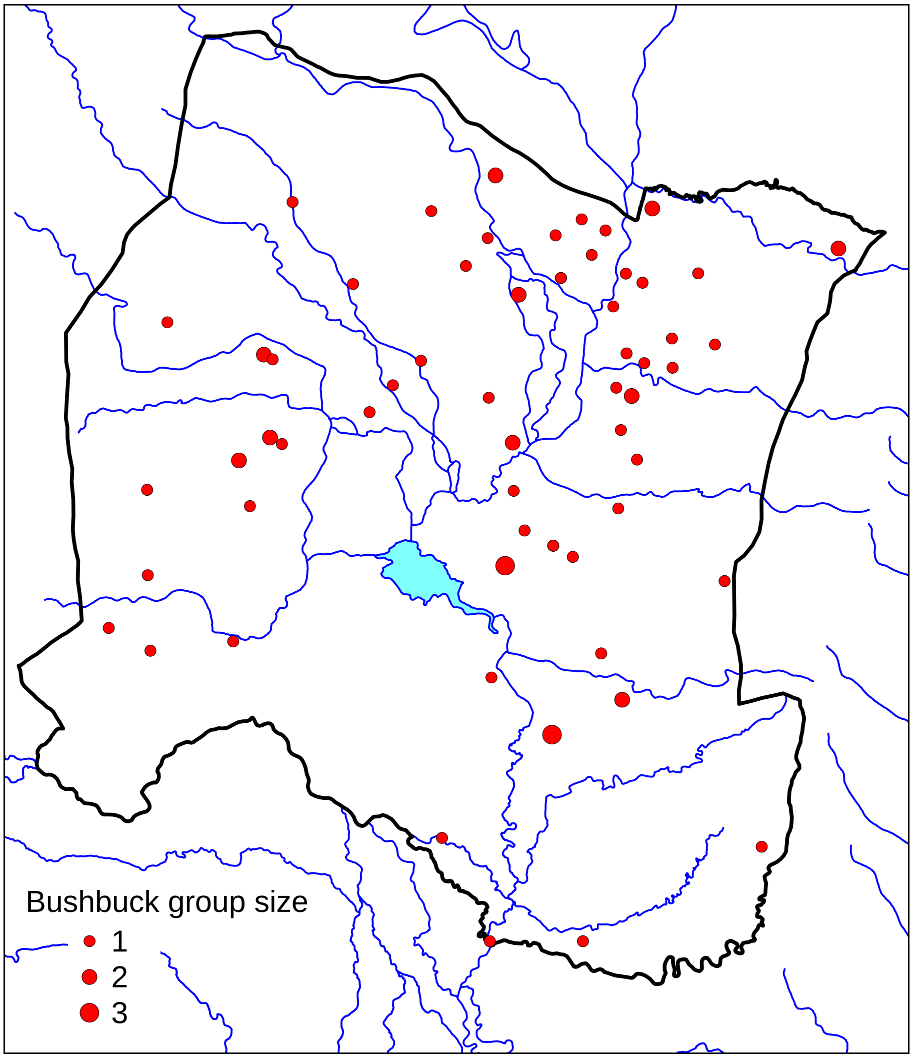
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	0	0	0	0	0	0	0
Central	549	57	29231	64	197	902	0.259
South	0	0	0	0	0	0	0
East	0	0	0	0	0	0	0
South-east	0	0	0	0	0	0	0
Totals	**549**	**57**	**29231**	**64**	**197**	**902**	**0.149**



Map 7. The distribution of impala in Gorongosa NP during October 2004.
Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 7. Population estimates and statistics for impala in Gorongosa NP

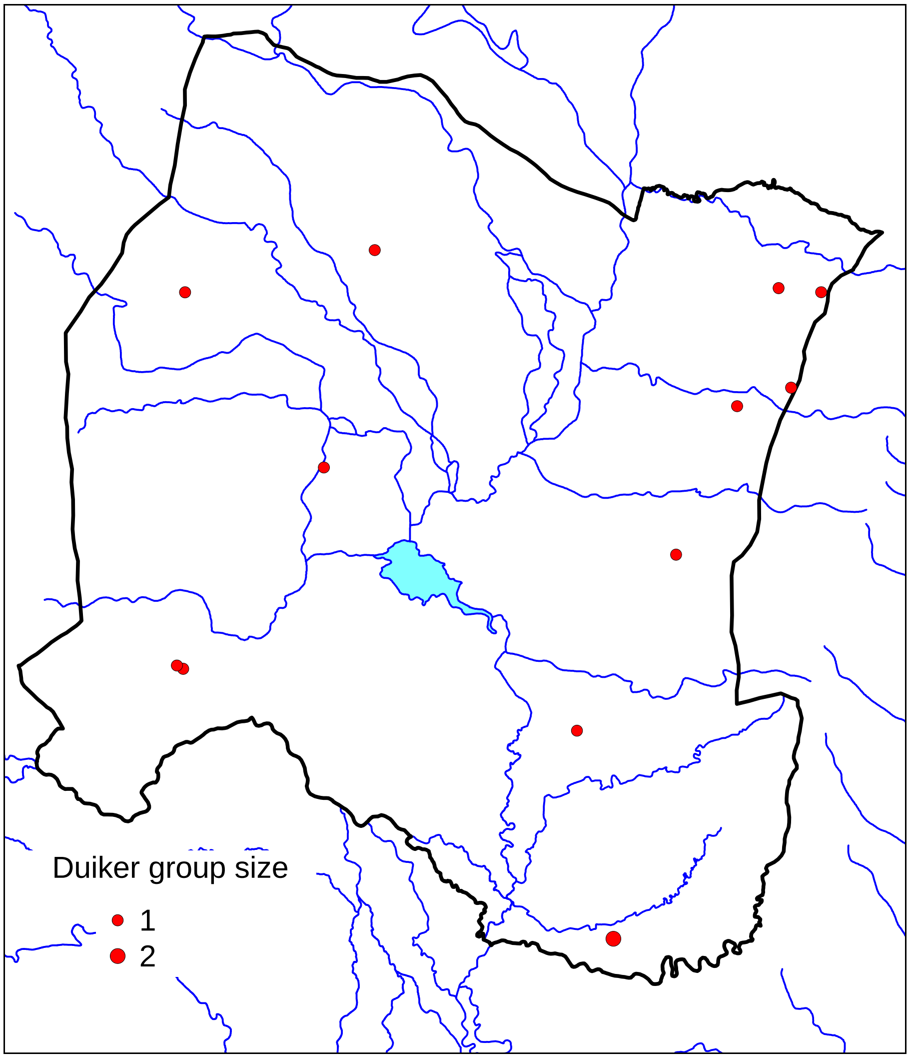
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	0	0	0	0	0	0	0
Central	520	54	43034	82	92	949	0.245
South	0	0	0	0	0	0	0
East	0	0	0	0	0	0	0
South-east	0	0	0	0	0	0	0
Totals	**520**	**54**	**43034**	**82**	**92**	**949**	**0.141**



Map 8. The distribution of bushbuck in Gorongosa NP during October 2004.
Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 8. Population estimates and statistics for bushbuck in Gorongosa NP

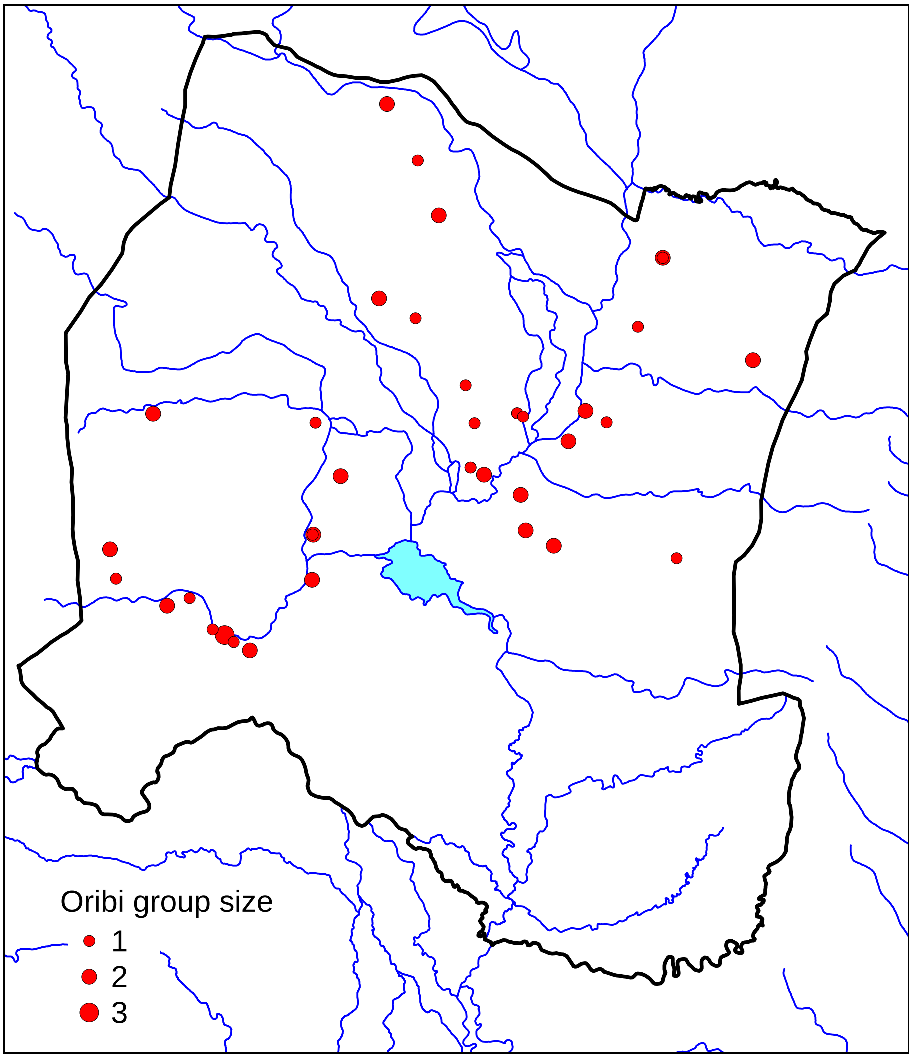
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	10	1	53	180	0	28	0.026
Central	549	57	5594	28	395	704	0.259
South	60	6	1481	157	0	154	0.199
East	96	10	309	47	51	141	0.178
South-east	10	1	72	218	0	30	0.027
Totals	**725**	**75**	**7507**	**24**	**549**	**901**	**0.197**



Map 9. The distribution of common duiker in Gorongosa NP during October 2004. Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 9. Population estimates and statistics for common duiker in Gorongosa NP

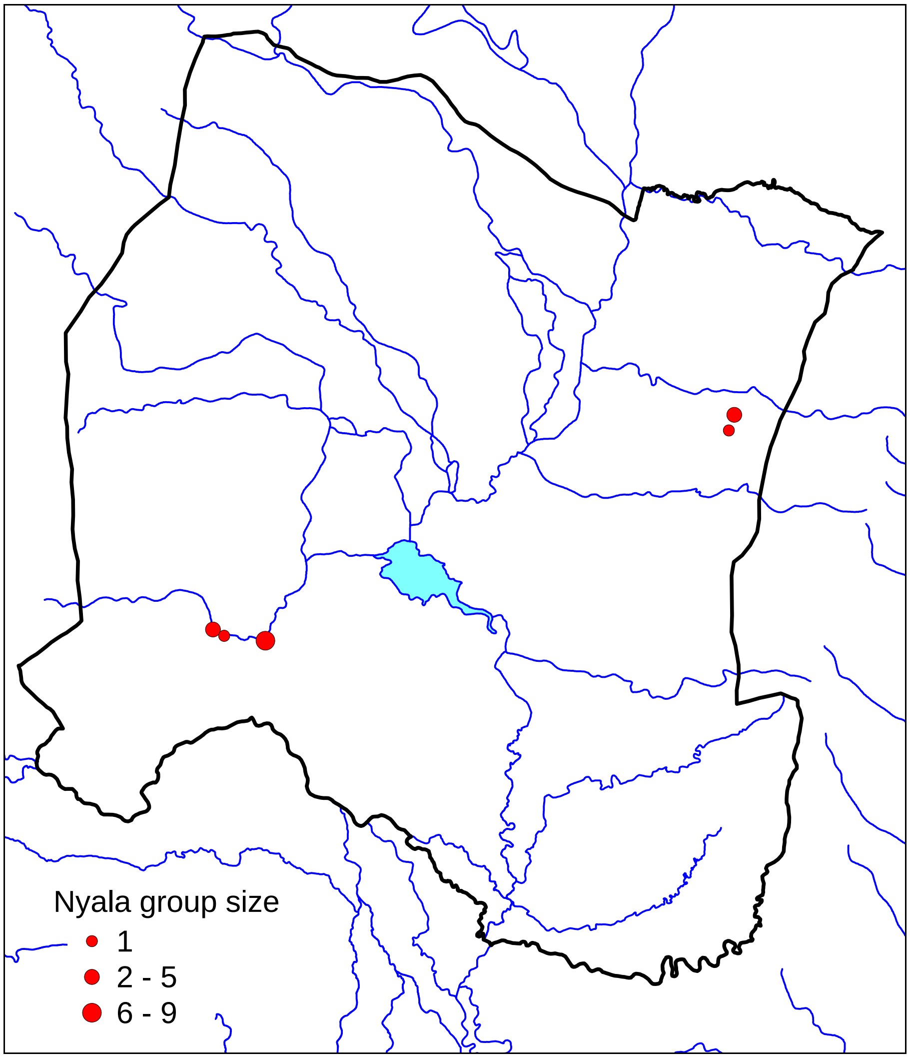
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	10	1	53	180	0	28	0.026
Central	39	4	466	116	0	83	0.018
South	0	0	0	0	0	0	0
East	48	5	399	107	0	99	0.089
South-east	29	3	318	153	0	72	0.081
Totals	**125**	**13**	**1235**	**58**	**53**	**197**	**0.034**



Map 10. The distribution of oribi in Gorongosa NP during October 2004.
Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 10. Population estimates and statistics for oribi in Gorongosa NP

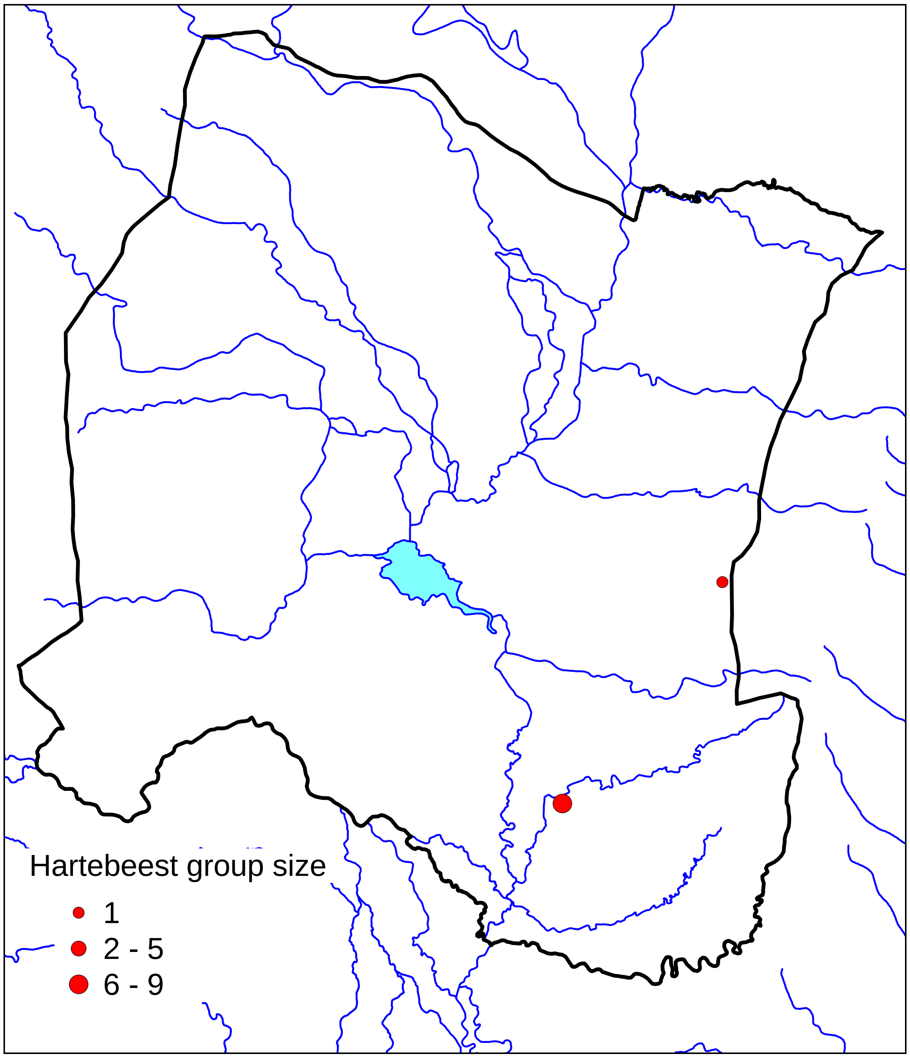
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	0	0	0	0	0	0	0
Central	530	55	11716	42	307	754	0.250
South	0	0	0	0	0	0	0
East	29	3	441	187	0	83	0.053
South-east	0	0	0	0	0	0	0
Totals	**559**	**58**	**12157**	**41**	**332**	**786**	**0.152**



Map 11. The distribution of nyala in Gorongosa NP during October 2004.
Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 11. Population estimates and statistics for nyala in Gorongosa NP

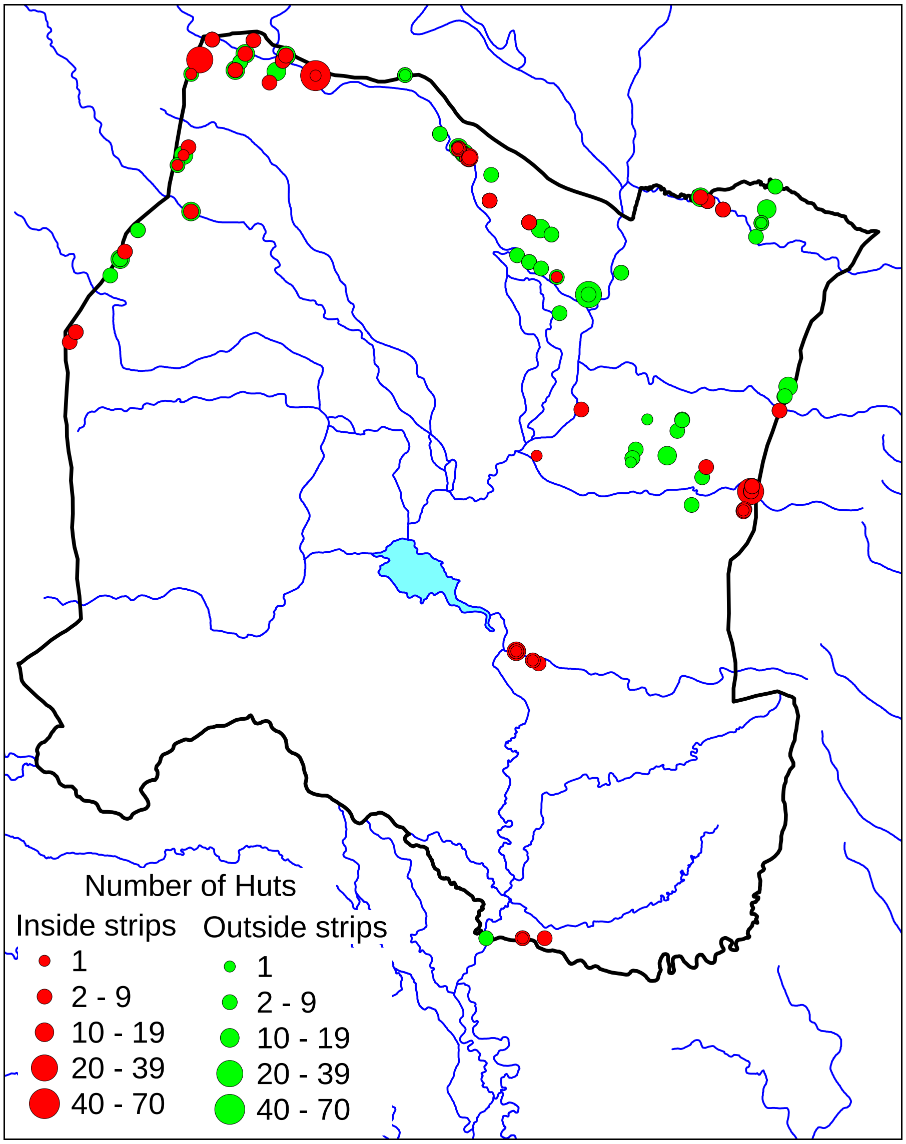
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	0	0	0	0	0	0	0
Central	116	12	7012	149	0	289	0.055
South	0	0	0	0	0	0	0
East	58	6	1766	187	0	166	0.107
South-east	0	0	0	0	0	0	0
Totals	**173**	**18**	**8778**	**111**	**0**	**365**	**0.047**



Map 12. The distribution of Lichtenstein's hartebeest in Gorongosa NP during October 2004. Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 12. Population estimates and statistics for Lichtenstein's hartebeest in Gorongosa NP

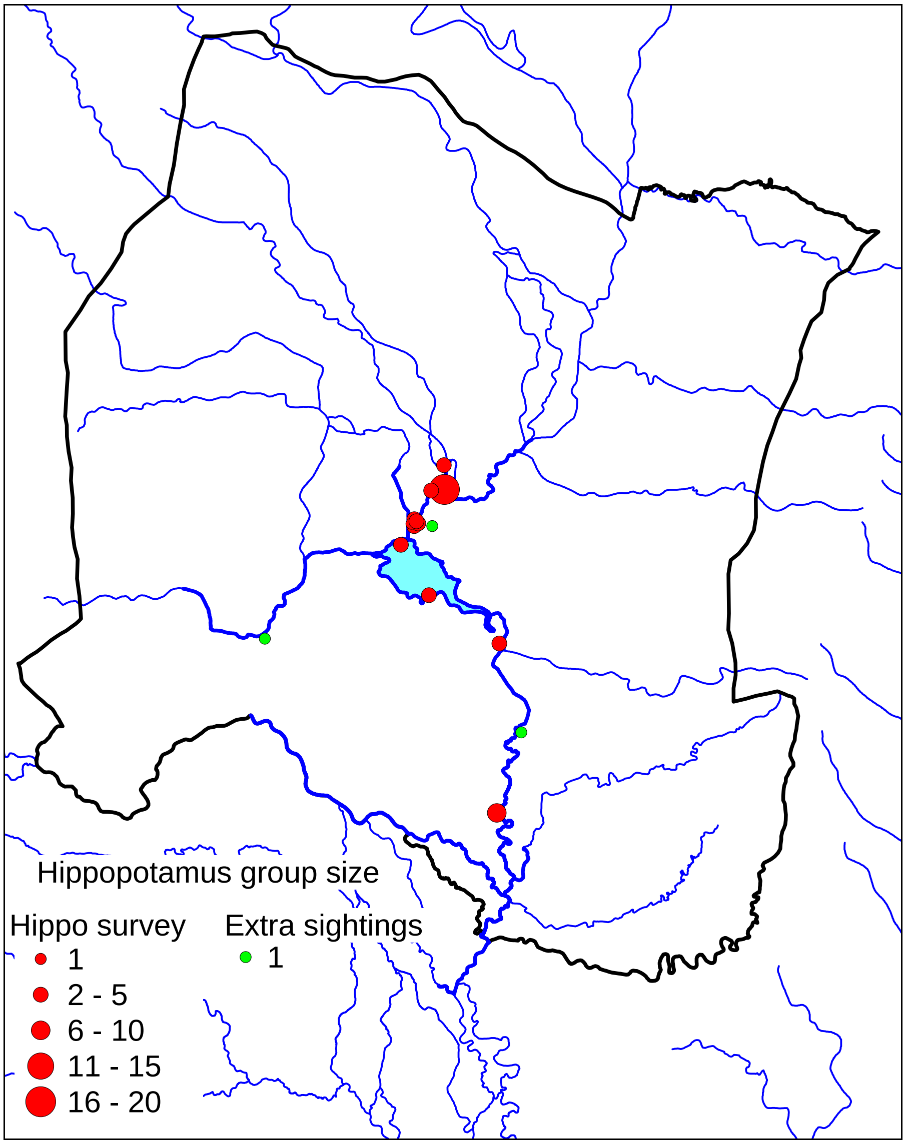
Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	0	0	0	0	0	0	0
Central	0	0	0	0	0	0	0
South	60	6	3373	237	0	202	0.199
East	10	1	51	190	0	28	0.018
South-east	0	0	0	0	0	0	0
Totals	**69**	**7**	**3423**	**206**	**0**	**213**	**0.019**



Map 13. The distribution of huts in the Gorongosa NP survey area during October 2004. Dots show the relative sizes of hut groups recorded during a 10 % sample survey.

Table 13. Estimated numbers and statistics for huts in Gorongosa NP

Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	1737	176	81314	40	1039	2435	4.631
Central	1031	107	234879	97	31	2032	0.486
South	130	13	20899	273	0	483	0.432
East	683	71	235506	183	0	1931	1.261
South-east	0	0	0	0	0	0	0
Totals	**3581**	**367**	**572597**	**44**	**2012**	**5150**	**0.971**



Map 14. The distribution of hippopotamus in Gorongosa NP during October 2004.
Red dots indicate the relative sizes of those groups recorded during the dedicated hippo survey. Green dots indicate hippos seen during the 10 % sample survey (two inside the search strips and one outside).
The bold blue lines indicate the waterways searched during the dedicated hippo survey.

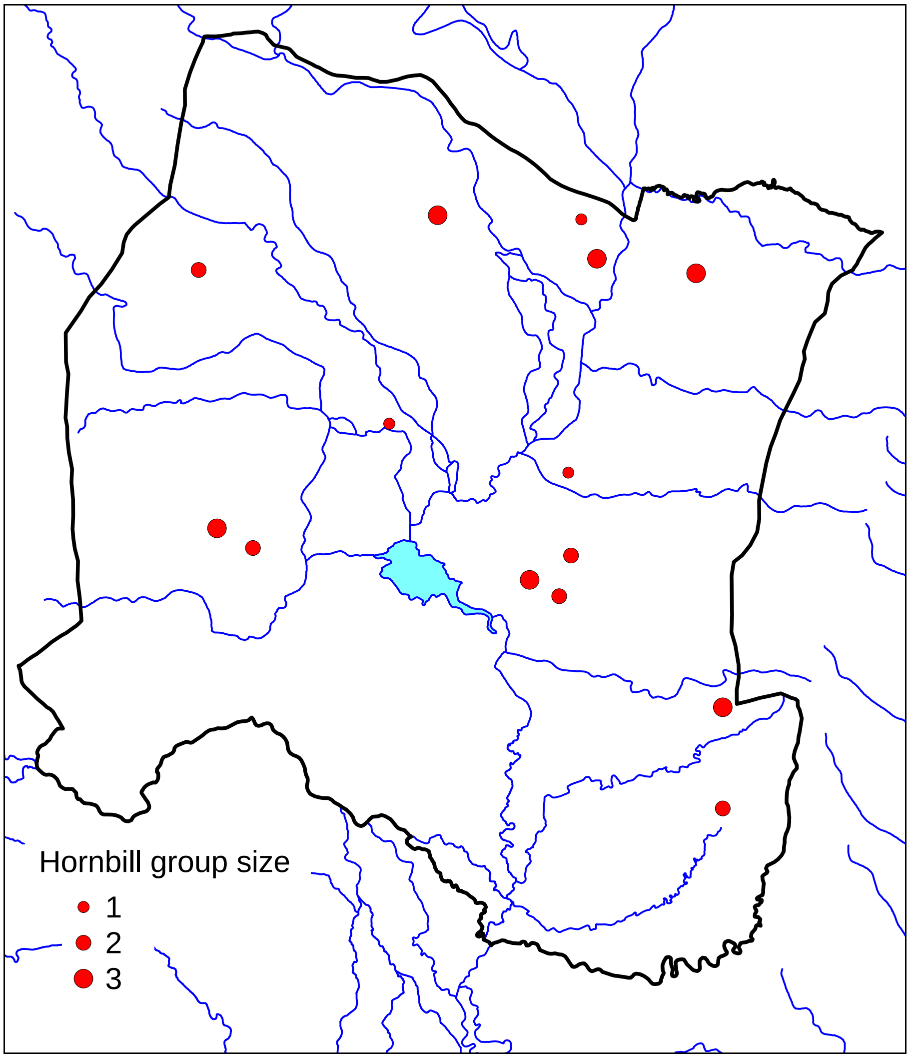
Table 14. Population estimates and statistics for hippopotamus in Gorongosa NP (data from sample survey)

Stratum	Population estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	0	0	0	0	0	0	0
Central	19	2	150	131	0	45	0.009
South	0	0	0	0	0	0	0
East	0	0	0	0	0	0	0
South-east	0	0	0	0	0	0	0
Totals	**19**	**2**	**150**	**131**	**0**	**45**	**0.005**

Table 15. Minimum population estimate for hippopotamus in Gorongosa NP (data from dedicated hippo survey)

Search time totalled 1 hour and 40 minutes

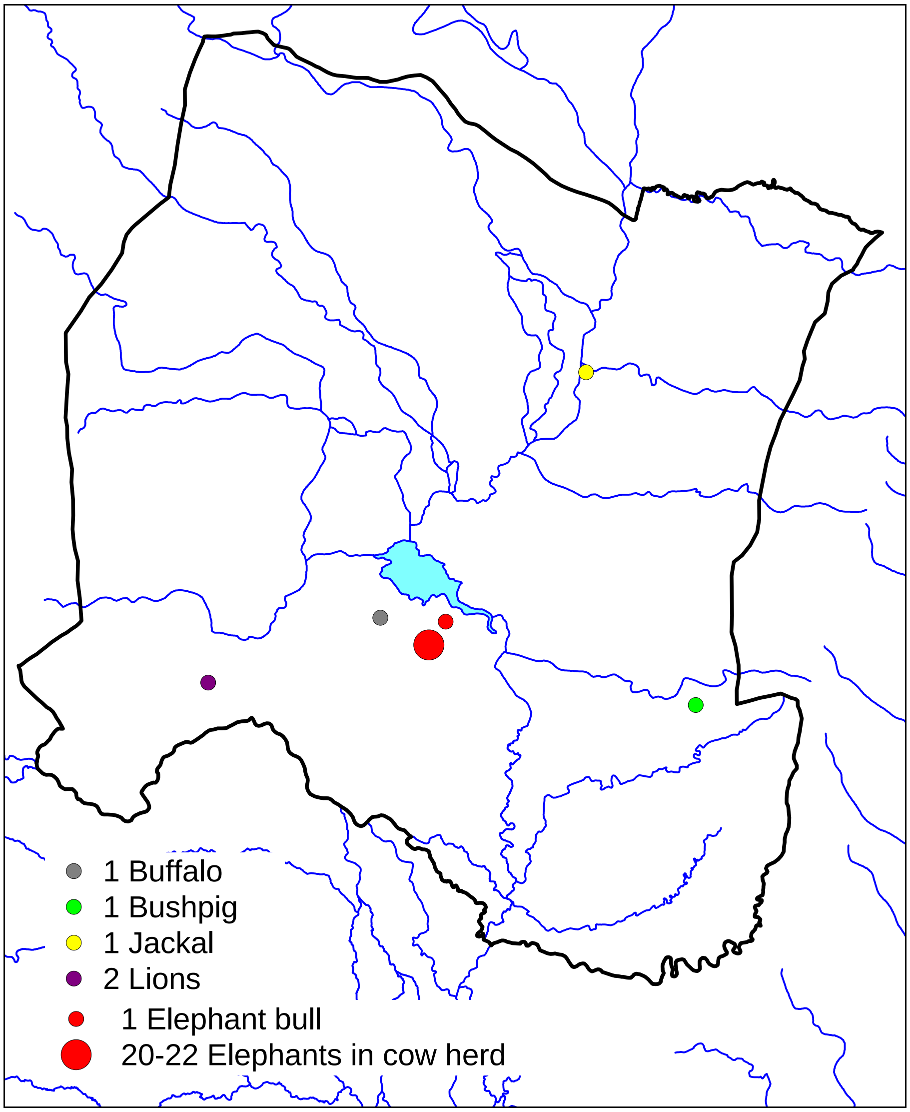
Group number	Location Latitude/Longitude (WGS84 datum)				Number of hippos in group
1	S 18°	51.441’	E 34°	28.198’	2
2	S 18°	50.555’	E 34°	28.822’	5
3	S 18°	50.423’	E 34°	29.013’	3
4	S 18°	50.229’	E 34°	28.834’	4
5	S 18°	50.441’	E 34°	28.699’	5
6	S 18°	47.679’	E 34°	30.229’	1
7	S 18°	48.825’	E 34°	30.252’	2
8	S 18°	48.879’	E 34°	29.628’	17 + 2
9	S 18°	53.817’	E 34°	29.521’	2
10	S 18°	56.093’	E 34°	32.844’	4
11	S 19°	04.089’	E 34°	32.725’	4
12	S 18°	50.333’	E 34°	28.934’	8 or 9
Total seen = minimum number of hippos in survey area =					**59 or 60**



Map 15. The distribution of ground hornbill in Gorongosa NP during October 2004. Dots show the relative sizes of those groups recorded during a 10 % sample survey.

Table 16. Population estimates and statistics for ground hornbill in Gorongosa NP

Stratum	Population Estimate	Number seen	Variance	% CI	Lower CL	Upper CL	Density (km^{-2})
West	20	2	210	180	0	55	0.053
Central	231	24	4776	62	89	374	0.109
South	0	0	0	0	0	0	0
East	0	0	0	0	0	0	0
South-east	48	5	1700	212	0	148	0.136
Totals	**299**	**31**	**6686**	**56**	**132**	**465**	**0.081**



Map 16. The locations of sightings of species seen just once or twice in Gorongosa NP during the October 2004 survey.

The bushpig, jackal (species not specified) and lions were seen in the search strips during the 10 % sample survey. The solitary buffalo was outside these search strips. The elephants were seen after completion of the sample survey, while flying back to camp.

Table 17. Changes in the numbers of large herbivores in the Urema basin in the rift valley of Gorongosa NP between 1994 and 2004

'Number seen' refers only to animals seen in the search strips. Data for 1994 refer to Stratum 2 of Cumming *et al*. (1994) and data for 2004 refer to the Central Stratum of the 2004 survey. The area of Central Stratum was 2 % greater than the area of Stratum 2. In addition, sampling intensity was 4.65 % during 1994, compared to 10.4 % during 2004. Note therefore that even if a population density was unchanged, the 'number seen' would be approximately 2.3 times greater during 2004 than during 1994.

Species	1994				2004			
	Number seen	Estimated population number	Density (km^{-2})	Confidence interval (%)	Number seen	Estimated population number	Density (km^{-2})	Confidence interval (%)
Waterbuck	6	129	0.06	188	426	4106	1.93	85
Reedbuck	16	344	0.17	80	186	1793	0.84	41
Nyala	1	22	0.01	189	12	116	0.06	149
Oribi	1	22	0.01	187	55	530	0.25	42
Sable	0	0	0	-	27	260	0.12	129
Zebra	3	65	0.03	188	0	0	0	-
Hippopotamus	0	0	0	-	2	19 [a]	0.01	131
Buffalo	0	0	0	-	0 [b]	0	0	-

[a] 59-60 hippos were seen during the dedicated hippo survey

[b] 1 buffalo was seen outside the search strips

Appendix 1. Calibration to determine strip width

- Strip width (in meters) for one observer = 10 x (1 + Difference between outer and inner)
- Combined strip width (in meters) at flying height = Left strip width + right strip width
- Combined strip width at 300 feet agl [1] = Combined strip width x 300 / (Flying height)

[1] agl: above ground level

Run no.	Left observer: Dave Falkner			Right observer: Rodolfo Cumbane			Combined strip width (m) at flying height	Flying height agl (ft)	Combined strip width (m) when flying at 300 ft
	Outer marker	Inner marker	Strip width (m)	Outer marker	Inner marker	Strip width (m)			
1	15	3	130	34	15	200	330	300	330
2	19	4	160	21 ?	12	-	-	320	-
3	11	-3	150	26 ?	25 ?	-	-	340	-
4	22	8	150	12 ?	7	-	-	300	-
5	19	5	150	25	12	140	290	300	290
6	21	8	140	19	6	140	280	300	280
7	20	4	170	25	11	150	320	300	320
8	21	9	130	27	10	180	310	260	358
9	13	3	110	33	19	150	260	250	312
10	24	10	150	-	15	-	-	300	-
11	14	3	120	21	14	80	200	250	240
12	23	9	150	25	13	130	280	300	280
13	16	3	140	35	19	170	310	300	310
14	25	9	170	35	14	220	390	280	418
15	19	3	170	-	21	-	-	300	-
16	21	6	160	35	20	160	320	320	300
17	19	7	130	35	14	220	350	-	-
18	19	4	160	34	16	190	350	280	375
19	32	16	170	34	12	230	400	280	429
20	32	19	140	35	8 ?	-	-	300	-
21	23	9	150	26	19	80	230	-	-
22	22	12	110	15	6	100	210	250	252
23	23	10	140	21	12	100	240	250	288
24	27	15	130	16	6	110	240	250	288

Run no.	Left observer: Dave Falkner			Right observer: Rodolfo Cumbane			Combined strip width (m) at flying height	Flying height agl (ft)	Combined strip width (m) when flying at 300 ft
	Outer marker	Inner marker	Strip width (m)	Outer marker	Inner marker	Strip width (m)			
25	25	10	160	-	20	-	-	300	-
26	34	18	170	21	8	140	310	300	310
27	31	16	160	22	8	150	310	280	332
28	32	17	160	21	9	130	290	320	272
29	26	11	160	35	14	220	380	320	356
30	30	16	150	25	8	180	330	300	330
31	26	11	160	30	10	210	370	300	370
32	32	16	170	26	9	180	350	300	350
33	27	11	170	25	14	120	290	310	281
34	33	18	160	21	6	160	320	320	300
35	16	5	120	25	14	120	240	250	288
36	25	16	100	14	0	150	250	250	300
37	22	9	140	22	12	110	250	250	300
38	-	-	-	16	1	160	-	290	-
39	19	6	140	23	9	150	290	300	290
40	25	13	130	16	2	150	280	300	280
41	19	6	140	20	7	140	280	300	280
42	27	16	120	16	0	170	290	300	290
43	17	6 ?	-	22	10	130	-	300	-
44	30	18	130	19	4	160	290	280	311
45	29	15	150	25	6	200	350	300	350
46	32	18	150	16	3	140	290	310	281
47	16	4	130	25 ?	11	-	-	300	-
48	24	12	130	18	3	160	290	300	290
49	15	4	120	23	12	120	240	300	240
50	28	16	130	16	0	170	300	300	300
51	19	8	120	21	8	140	260	300	260
52	27	15	130	12	0	130	260	300	260
53	29	17	130	13	0	140	270	300	270
54	-	-	-	18	7	120	-	250	-
55	26	15	120	10	1	100	220	250	264

Run no.	Left observer: Dave Falkner			Right observer: Rodolfo Cumbane			Combined strip width (m) at flying height	Flying height agl (ft)	Combined strip width (m) when flying at 300 ft
	Outer marker	Inner marker	Strip width (m)	Outer marker	Inner marker	Strip width (m)			
56	17	6	120	23	12	120	240	300	240
57	25	13	130	16	3	140	270	300	270
Mean combined strip width (in meters) when flying at 300 feet agl =									**303**

Appendix 2. Survey flight summary

Date	Time	Flight time (hours:minutes)	Duty
25 October 2004	pm	2:15	Positioning, Harare to Beira
25	pm	0:30	Positioning, Beira to Chitengo
26	pm	0:59	Calibration
27	am	3:53	Stratum Central, transects 1-18
27	pm	1:46	Stratum Central, transects 19-24
28	am	2:47	Strata South and East
28	pm	1:20	Stratum South-east
29	am	1:30	Stratum West
29	am	0:20	Familiarisation flight by GNP administrator
29	pm	1:44	Hippo Survey
30	am	0:34	Positioning, Chitengo to Beira
30 October 2004	am	2:07	Positioning, Beira to Harare
Total		19:45	

Appendix 3. Transect start and end points

Datum WGS84

Stratum : South
Number of transects : 7
Transect Bearing : 90.00 Degrees
Transect Spacing : 3.00 km

Transect # : 1A
Start Lat : S 19 : 0.287 Start Lon : E 34 : 22.478
Finish Lat : S 19 : 0.287 Finish Lon : E 34 : 24.873
Length : 4.19 km

Transect # : 1B
Start Lat : S 19 : 0.287 Start Lon : E 34 : 31.592
Finish Lat : S 19 : 0.287 Finish Lon : E 34 : 35.824
Length : 7.41 km

Transect # : 2
Start Lat : S 19 : 1.907 Start Lon : E 34 : 36.083
Finish Lat : S 19 : 1.907 Finish Lon : E 34 : 23.607
Length : 21.85 km

Transect # : 3
Start Lat : S 19 : 3.527 Start Lon : E 34 : 25.096
Finish Lat : S 19 : 3.527 Finish Lon : E 34 : 36.341
Length : 19.70 km

Transect # : 4
Start Lat : S 19 : 5.147 Start Lon : E 34 : 36.600
Finish Lat : S 19 : 5.147 Finish Lon : E 34 : 28.489
Length : 14.21 km

Transect # : 5
Start Lat : S 19 : 6.767 Start Lon : E 34 : 29.905
Finish Lat : S 19 : 6.767 Finish Lon : E 34 : 36.858
Length : 12.18 km

Transect # : 6
Start Lat : S 19 : 8.387 Start Lon : E 34 : 37.117
Finish Lat : S 19 : 8.387 Finish Lon : E 34 : 32.104
Length : 8.78 km

Transect # : 7A
Start Lat : S 19 : 10.007 Start Lon : E 34 : 32.178
Finish Lat : S 19 : 10.007 Finish Lon : E 34 : 32.739
Length : 0.98 km

Transect # : 7B
Start Lat : S 19 : 10.007 Start Lon : E 34 : 33.062
Finish Lat : S 19 : 10.007 Finish Lon : E 34 : 37.375
Length : 7.56 km

Stratum : South-east
Number of transects : 7
Transect Bearing : 0.00 Degrees
Transect Spacing : 3.00 km

Transect # : 1
Start Lat : S 19 : 3.781 Start Lon : E 34 : 36.382
Finish Lat : S 18 : 59.354 Finish Lon : E 34 : 36.382
Length : 8.20 km

Transect # : 2
Start Lat : S 18 : 59.600 Start Lon : E 34 : 38.095
Finish Lat : S 19 : 11.610 Finish Lon : E 34 : 38.095
Length : 22.24 km

Transect # : 3
Start Lat : S 19 : 11.880 Start Lon : E 34 : 39.808
Finish Lat : S 19 : 0.074 Finish Lon : E 34 : 39.808
Length : 21.86 km

Transect # : 4
Start Lat : S 18 : 59.911 Start Lon : E 34 : 41.520
Finish Lat : S 19 : 11.047 Finish Lon : E 34 : 41.520
Length : 20.62 km

Transect # : 5
Start Lat : S 19 : 10.687 Start Lon : E 34 : 43.233
Finish Lat : S 18 : 58.816 Finish Lon : E 34 : 43.233
Length : 21.98 km

Transect # : 6A
Start Lat : S 18 : 58.563 Start Lon : E 34 : 44.946
Finish Lat : S 19 : 7.901 Finish Lon : E 34 : 44.946
Length : 17.29 km

Transect # : 6B
Start Lat : S 19 : 8.054 Start Lon : E 34 : 44.946
Finish Lat : S 19 : 8.267 Finish Lon : E 34 : 44.946
Length : 0.39 km

Transect # : 6C
Start Lat : S 19 : 8.922 Start Lon : E 34 : 44.946
Finish Lat : S 19 : 9.095 Finish Lon : E 34 : 44.946
Length : 0.32 km

Transect # : 6D
Start Lat : S 19 : 9.132 Start Lon : E 34 : 44.946
Finish Lat : S 19 : 9.257 Finish Lon : E 34 : 44.946
Length : 0.23 km

Transect # : 7A
Start Lat : S 19 : 1.930 Start Lon : E 34 : 46.659
Finish Lat : S 19 : 1.624 Finish Lon : E 34 : 46.659
Length : 0.57 km

Transect # : 7B
Start Lat : S 19 : 0.922 Start Lon : E 34 : 46.659
Finish Lat : S 18 : 58.620 Finish Lon : E 34 : 46.659
Length : 4.26 km

Stratum : West
Number of transects : 7
Transect Bearing : 30.00 Degrees
Transect Spacing : 3.00 km

Transect # : 1
Start Lat : S 18 : 29.625 Start Lon : E 34 : 18.063
Finish Lat : S 18 : 27.443 Finish Lon : E 34 : 19.391
Length : 4.67 km

Transect # : 2A
Start Lat : S 18 : 27.238 Start Lon : E 34 : 21.487
Finish Lat : S 18 : 33.970 Finish Lon : E 34 : 17.391
Length : 14.39 km

Transect # : 2B
Start Lat : S 18 : 35.712 Start Lon : E 34 : 16.331
Finish Lat : S 18 : 42.199 Finish Lon : E 34 : 12.384
Length : 13.87 km

Transect # : 3
Start Lat : S 18 : 45.442 Start Lon : E 34 : 12.382
Finish Lat : S 18 : 28.090 Finish Lon : E 34 : 22.941
Length : 37.11 km

Transect # : 4
Start Lat : S 18 : 28.971 Start Lon : E 34 : 24.376
Finish Lat : S 18 : 48.240 Finish Lon : E 34 : 12.651
Length : 41.20 km

Transect # : 5
Start Lat : S 18 : 51.287 Start Lon : E 34 : 12.768
Finish Lat : S 18 : 49.876 Finish Lon : E 34 : 13.627
Length : 3.02 km

Transect # : 6A
Start Lat : S 18 : 53.578 Start Lon : E 34 : 13.346
Finish Lat : S 18 : 54.057 Finish Lon : E 34 : 13.054
Length : 1.02 km

Transect # : 6B
Start Lat : S 18 : 55.701 Start Lon : E 34 : 12.054
Finish Lat : S 18 : 58.146 Finish Lon : E 34 : 10.566
Length : 5.23 km

Transect # : 7
Start Lat : S 18 : 59.298 Start Lon : E 34 : 11.837
Finish Lat : S 18 : 57.757 Finish Lon : E 34 : 12.775
Length : 3.30 km

Stratum : Central
Number of transects : 25
Transect Bearing : 120.00 Degrees
Transect Spacing : 3.00 km

Transect # : 1
Start Lat : S 19 : 3.782 Start Lon : E 34 : 16.259
Finish Lat : S 19 : 0.956 Finish Lon : E 34 : 11.100
Length : 10.47 km

Transect # : 2
Start Lat : S 18 : 59.867 Start Lon : E 34 : 12.526
Finish Lat : S 19 : 2.164 Finish Lon : E 34 : 16.720
Length : 8.51 km

Transect # : 3
Start Lat : S 19 : 0.790 Start Lon : E 34 : 17.626
Finish Lat : S 18 : 58.109 Finish Lon : E 34 : 12.733
Length : 9.93 km

Transect # : 4
Start Lat : S 18 : 56.394 Start Lon : E 34 : 13.017
Finish Lat : S 18 : 59.988 Finish Lon : E 34 : 19.578
Length : 13.31 km

Transect # : 5
Start Lat : S 18 : 59.692 Start Lon : E 34 : 22.453
Finish Lat : S 18 : 54.709 Finish Lon : E 34 : 13.356
Length : 18.45 km

Transect # : 6
Start Lat : S 18 : 52.675 Start Lon : E 34 : 13.057
Finish Lat : S 19 : 0.835 Finish Lon : E 34 : 27.955
Length : 30.22 km

Transect # : 7
Start Lat : S 19 : 0.709 Start Lon : E 34 : 31.141
Finish Lat : S 18 : 51.006 Finish Lon : E 34 : 13.425
Length : 35.94 km

Transect # : 8
Start Lat : S 18 : 49.222 Start Lon : E 34 : 13.584
Finish Lat : S 18 : 59.427 Finish Lon : E 34 : 32.215
Length : 37.79 km

Transect # : 9
Start Lat : S 18 : 59.038 Start Lon : E 34 : 34.920
Finish Lat : S 18 : 47.476 Finish Lon : E 34 : 13.811
Length : 42.82 km

Transect # : 10
Start Lat : S 18 : 45.912 Start Lon : E 34 : 14.370
Finish Lat : S 18 : 57.452 Finish Lon : E 34 : 35.440
Length : 42.74 km

Transect # : 11
Start Lat : S 18 : 55.825 Start Lon : E 34 : 35.884
Finish Lat : S 18 : 44.648 Finish Lon : E 34 : 15.479
Length : 41.39 km

Transect # : 12
Start Lat : S 18 : 43.466 Start Lon : E 34 : 16.736
Finish Lat : S 18 : 54.275 Finish Lon : E 34 : 36.471
Length : 40.03 km

Transect # : 13
Start Lat : S 18 : 52.726 Start Lon : E 34 : 37.058
Finish Lat : S 18 : 42.308 Finish Lon : E 34 : 18.036
Length : 38.59 km

Transect # : 14
Start Lat : S 18 : 40.929 Start Lon : E 34 : 18.935
Finish Lat : S 18 : 51.170 Finish Lon : E 34 : 37.632
Length : 37.93 km

Transect # : 15
Start Lat : S 18 : 49.600 Start Lon : E 34 : 38.182
Finish Lat : S 18 : 39.502 Finish Lon : E 34 : 19.745
Length : 37.40 km

Transect # : 16
Start Lat : S 18 : 38.074 Start Lon : E 34 : 20.553
Finish Lat : S 18 : 48.031 Finish Lon : E 34 : 38.731
Length : 36.88 km

Transect # : 17
Start Lat : S 18 : 46.461 Start Lon : E 34 : 39.280
Finish Lat : S 18 : 36.646 Finish Lon : E 34 : 21.361
Length : 36.35 km

Transect # : 18
Start Lat : S 18 : 35.218 Start Lon : E 34 : 22.169
Finish Lat : S 18 : 44.924 Finish Lon : E 34 : 39.890
Length : 35.95 km

Transect # : 19
Start Lat : S 18 : 43.400 Start Lon : E 34 : 40.521
Finish Lat : S 18 : 33.790 Finish Lon : E 34 : 22.977
Length : 35.59 km

Transect # : 20
Start Lat : S 18 : 32.362 Start Lon : E 34 : 23.785
Finish Lat : S 18 : 41.875 Finish Lon : E 34 : 41.153
Length : 35.23 km

Transect # : 21
Start Lat : S 18 : 40.350 Start Lon : E 34 : 41.784
Finish Lat : S 18 : 30.934 Finish Lon : E 34 : 24.593
Length : 34.87 km

Transect # : 22
Start Lat : S 18 : 29.506 Start Lon : E 34 : 25.402
Finish Lat : S 18 : 38.825 Finish Lon : E 34 : 42.415
Length : 34.51 km

Transect # : 23A
Start Lat : S 18 : 37.304 Start Lon : E 34 : 43.053
Finish Lat : S 18 : 35.262 Finish Lon : E 34 : 39.326
Length : 7.56 km

Transect # : 23B
Start Lat : S 18 : 30.291 Start Lon : E 34 : 30.250
Finish Lat : S 18 : 29.315 Finish Lon : E 34 : 28.468
Length : 3.62 km

Transect # : 24
Start Lat : S 18 : 34.857 Start Lon : E 34 : 42.001
Finish Lat : S 18 : 35.824 Finish Lon : E 34 : 43.767
Length : 3.58 km

Transect # : 25
Start Lat : S 18 : 34.345 Start Lon : E 34 : 44.482
Finish Lat : S 18 : 34.291 Finish Lon : E 34 : 44.384
Length : 0.20 km

Stratum : East
Number of transects : 6
Transect Bearing : 20.00 Degrees
Transect Spacing : 3.00 km

Transect # : 1
Start Lat : S 18 : 58.837 Start Lon : E 34 : 43.800
Finish Lat : S 18 : 58.615 Finish Lon : E 34 : 43.885
Length : 0.44 km

Transect # : 2A
Start Lat : S 18 : 36.620 Start Lon : E 34 : 50.510
Finish Lat : S 18 : 36.927 Finish Lon : E 34 : 50.392
Length : 0.61 km

Transect # : 2B
Start Lat : S 18 : 54.455 Start Lon : E 34 : 43.664
Finish Lat : S 18 : 59.900 Finish Lon : E 34 : 41.573
Length : 10.73 km

Transect # : 3
Start Lat : S 19 : 0.079 Start Lon : E 34 : 39.687
Finish Lat : S 18 : 35.915 Finish Lon : E 34 : 48.963
Length : 47.62 km

Transect # : 4
Start Lat : S 18 : 35.291 Start Lon : E 34 : 47.384
Finish Lat : S 18 : 59.580 Finish Lon : E 34 : 38.060
Length : 47.86 km

Transect # : 5
Start Lat : S 18 : 59.343 Start Lon : E 34 : 36.332
Finish Lat : S 18 : 34.537 Finish Lon : E 34 : 45.855
Length : 48.88 km

Transect # : 6
Start Lat : S 18 : 39.647 Start Lon : E 34 : 42.075
Finish Lat : S 18 : 51.834 Finish Lon : E 34 : 37.397
Length : 24.02 km

Appendix 4. Transect summaries of sightings

Species codes:

Code	Species
Bbk	Bushbuck
Bpig	Bushpig
Camp	Camp (Poachers' ?)
Cran	Crowned Crane
Croc	Crocodile
Dkr	Common (Grey) Duiker
Ghb	Ground Hornbill
Hbst	Lichtenstein's Hartebeest
Hipo	Hippopotamus
Hut	Hut
Imp	Impala
Jack	Jackal
Kudu	Kudu
Lion	Lion
Nyal	Nyala
Orib	Oribi
Rbk	Reedbuck
Sab	Sable
Wbck	Waterbuck
Whog	Warthog

Other abbreviations

Abbreviation	Meaning
n	number of transects sampled
N	possible number of transects in stratum
t	Student's *t* value, $P = 0.05$
T #	transect number
-	no animals seen in search strips

The following tables list the number of individuals of each species that were seen inside the search strips on each transect.

Date of Survey : 27/10/04
Stratum Name : Central
Stratum Locality : Gorongosa
Base Line Length : 74 km
Stratum Area : 2121.8 km^2
Calibrated Strip Width at 300ft : 303 m
N : 238 n : 25
t : 2.064
Pilot : J Cadd
Observer : D Falkner R Cumbane
Map overlay file : None

Transect summary table :

T #	Sab	Wbck	Imp	Kudu	Hipo	Rbk	Whog	Dkr	Nyal	Orib	Ghb	Hut	Lion	Bbk	Cran	Croc	Jack	Camp
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	10	-	-	1	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	10	2	-	-	-	-	2	2	-	-	-	-
6	15	-	15	3	-	6	22	-	3	10	-	-	-	1	-	-	-	-
7	-	1	12	7	1	4	11	-	9	3	-	-	-	1	-	-	-	-
8	11	-	3	-	-	6	14	-	-	-	-	-	-	-	-	-	-	-
9	1	1	13	1	-	6	7	-	-	2	5	-	-	2	-	-	-	-
10	-	3	-	-	-	21	25	-	-	3	-	31	-	1	-	-	-	-
11	-	8	-	4	-	19	5	-	-	2	-	-	-	2	2	-	-	-
12	-	168	-	-	1	11	15	1	-	2	5	-	-	6	-	-	-	-
13	-	101	11	-	-	14	20	-	-	5	2	-	-	4	-	12	-	-
14	-	53	-	9	-	1	22	-	-	6	1	-	-	5	-	-	-	-
15	-	48	-	1	-	27	15	-	-	1	1	1	-	3	-	-	-	-
16	-	30	-	7	-	16	5	-	-	6	-	-	-	2	-	-	-	-
17	-	-	-	1	-	19	1	-	-	6	-	2	-	2	-	-	-	-
18	-	-	-	1	-	4	-	1	-	-	-	-	-	4	-	-	1	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-
20	-	1	-	-	-	30	9	-	-	3	3	1	-	6	-	-	-	-
21	-	-	-	-	-	-	1	-	-	1	3	15	-	4	-	-	-	1
22	-	12	-	13	-	-	7	-	-	5	4	44	-	5	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	13	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Sighting Totals

	Sab	Wbck	Imp	Kudu	Hipo	Rbk	Whog	Dkr	Nyal	Orib	Ghb	Hut	Lion	Bbk	Cran	Croc	Jack	Camp
	27	426	54	57	2	186	192	4	12	55	24	107	2	57	2	12	1	1

Date of Survey : 28/10/04
Stratum Locality : Gorongosa
Stratum Area : 541.6 km^2
N : 49 n : 6
Pilot : J Cadd
Map overlay file : None

Stratum Name : East
Base Line Length : 15.3 km
Calibrated Strip Width at 300ft : 303 m
t : 2.571
Observer : D Falkner R Cumbane

Transect summary table :

T #	Sab	Bpig	Bbk	Dkr	Nyal	Whog	Hut	Hbst	Orib
1	-	-	-	-	-	-	-	-	-
2	-	1	-	-	-	-	-	-	-
3	-	-	3	2	-	-	69	1	-
4	3	-	2	3	6	2	2	-	3
5	-	-	2	-	-	1	-	-	-
6	-	-	3	-	-	-	-	-	-

Sighting Totals

	Sab	Bpig	Bbk	Dkr	Nyal	Whog	Hut	Hbst	Orib
	3	1	10	5	6	3	71	1	3

Date of Survey : 28/10/04
Stratum Locality : Gorongosa
Stratum Area : 300.3 km^2
N : 76 n : 7
Pilot : J Cadd
Map overlay file : None

Stratum Name : South
Base Line Length : 23.6 km
Calibrated Strip Width at 300ft : 303 m
t : 2.447
Observer : D Falkner R Cumbane

Transect summary table :

T #	Sab	Wbck	Whog	Bbk	Hbst	Hut
1	-	-	14	3	-	-
2	-	-	1	-	-	-
3	13	-	8	-	6	-
4	12	1	8	1	-	-
5	-	-	-	-	-	-
6	-	1	-	-	-	-
7	12	-	-	2	-	13

Sighting Totals

	Sab	Wbck	Whog	Bbk	Hbst	Hut
	37	2	31	6	6	13

Date of Survey : 29/10/04
Stratum Locality : Gorongosa
Stratum Area : 375.1 km^2
N : 64 n : 7
Pilot : J Cadd
Map overlay file : None

Stratum Name : West
Base Line Length : 19.8 km
Calibrated Strip Width at 300ft : 303 m
t : 2.447
Observer : D Falkner R Cumbane

Transect summary table :

T #	Wbck	Hut	Whog	Dkr	Bbk	Ghb
1	-	23	-	-	-	-
2	-	56	-	-	-	-
3	-	34	2	-	-	-
4	1	63	1	1	1	2
5	-	-	-	-	-	-
6	-	-	8	-	-	-
7	-	-	-	-	-	-

Sighting Totals

	Wbck	Hut	Whog	Dkr	Bbk	Ghb
	1	176	11	1	1	2

Date of Survey : 28/10/04
Stratum Locality : Gorongosa
Stratum Area : 349.9 km^2
N : 63 n : 7
Pilot : J Cadd
Map overlay file : None

Stratum Name : South-east
Base Line Length : 19.8 km
Calibrated Strip Width at 300ft : 303 m
t : 2.447
Observer : D Falkner R Cumbane

Transect summary table :

T #	Sab	Dkr	Ghb	Bbk
1	-	1	-	-
2	1	2	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	5	-
6	-	-	-	1
7	-	-	-	-

Sighting Totals

	Sab	Dkr	Ghb	Bbk
	1	3	5	1