Status and distribution of large herbivores in the Marromeu Complex of the Zambezi Delta, Mozambique

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Summary

The Marromeu Complex (11,270 km²) covers the southern half of the Zambezi Delta and the adjacent Cheringoma escarpment, and includes the Marromeu Buffalo Reserve (*Reserva Especial de Marromeu*) and two forest reserves (*Reserva Floresta de Nhampacué* and *R.F. de Inhamitanga*), four hunting concessions (*Coutada Oficial no. 10, 11, 12,* and *14*), large commercial agricultural lands (notably the Sena Estates, the largest sugar plantation in Mozambique), and community lands. In November 2003, the Government of Mozambique ratified the Ramsar Convention and designated the Marromeu Complex as the country's first and only *Wetland of International Importance* because of its vast size and immense value for biodiversity, ecosystem services, and human livelihoods.

During November 2008 and May 2009, a comprehensive survey of large herbivores and selected large bird species of conservation concern was conducted for the Marromeu Complex. The survey was conducted as a cooperative effort between government, private sector, NGO, and academic institutions to advance the sound management of the Marromeu Complex.

Two survey programs were conducted, covering the late dry season 2008 and late wet season 2009. The survey programs included an aerial survey of the open floodplains and ecotone of the Marromeu Complex, aerial reconnaissance of pans and drainage lines of the Cheringoma escarpment, and road survey covering part of the escarpment. The surveys were conducted using a Robinson R-44 helicopter, using methods that are both repeatable and technically robust, and are similar to those used for other wildlife surveys in Mozambique. Survey results were compared to the results of previous aerial surveys conducted over the 40-year period 1968-2007.

An estimated 16,124 individuals of 11 large mammal species were present on the open floodplain in November 2008, with an additional 2,061 individuals of 13 large mammal species observed on the ecotone. At the end of the following wet season, in May 2009, an estimated 15,427 individuals of 12 large mammal species were present on the open floodplain, with 1,411 individuals of 13 large mammal species on the ecotone. On the pans and drainage lines of the Cheringoma escarpment, 3,285 individuals of 16 large mammal species were observed in November 2008, and in May 2009 1,150 individuals of 11 large mammal species were observed with slightly reduced overall coverage. Road surveys shed light on the presence and abundance of smaller and more cryptic species on the escarpment woodlands and forests.

Most species in the Marromeu Complex have undergone steady population growth over the past 10 years. Africa buffalo are the dominant species of the open floodplains of the Marromeu Complex, with an estimated population >10,300 individuals. Most buffalo were concentrated in large herds scattered across the Marromeu Reserve. The population has recovered to about 33% of its pre-war (1979) level, growing at an average annual rate of 12% since 2000. African elephant numbers, approximately 350, are comparable to pre-war levels. Waterbuck are the second most abundant species, with an estimated 4,588 waterbuck present on the floodplain in May 2009. This population remains <10% of the pre-war estimate, but is undergoing steady growth and expansion. Sable antelope are widespread on the seasonally-flooded grasslands along the ecotone and on pans and drainage lines in the miombo woodlands, with an estimate population (>2,000 individuals) comparable to pre-war estimates. Lichtenstein's hartebeest (>500 individuals), reedbuck (>2,500), and warthog (>2,500) are abundant across the floodplain, ecotone, and escarpment pans and drainage lines. Eland, a highly nomadic species, number >200 including a single herd of 152 individuals observed in November 2008.

Two key species in the Marromeu Complex remain vulnerable. Relatively few "Selous" zebra were observed during the surveys, with an estimated population >60. Hippopotamus, a keystone species for

maintaining floodplain grasslands and open waterways in the Marromeu Complex, are recovering slowly and remain in very reduced numbers relative to pre-war estimates (<10%).

Among the bird species targeted in the survey program, an estimated 75 Endangered Grey Crowned Cranes and 250 Vulnerable Wattled Cranes (95 breeding pairs) occur in the Marromeu Complex, both populations of global significance for these declining species.

Substantial human activity was also observed during the surveys, including permanent settlements with agricultural plots, various temporary settlements (typically fishing camps), and other activities including a few abandoned (illegal) meat drying camps and cattle herds. Relatively few wildlife observations were recorded in dense settlements areas in the southwestern portion of the Marromeu Reserve and near Malingapanse, suggesting that increasing human density is reducing the area of suitable habitat for wildlife in the Marromeu Complex.

Other important threats to wildlife populations in the Marromeu Complex include degradation of the hydrological regime due to climate change, dredging, large dams, and flood control dykes, uncontrolled fires, illegal hunting for bushmeat trade, and forest and woodland loss (due to charcoal production, unsustainable logging & fuelwood collection, and land conversion for commercial sugar production and small-holder agriculture.

We recommend conducting regular annual surveys of the Marromeu Complex at the end of the dry season in November, using a collaborative survey team and following the standardized survey methodology described in this report. Consideration should be given to increasing the coverage of Coutada 10 and 14 to better reflect conditions for the entire Marromeu Complex.

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Introduction

The Zambezi Delta is a broad, flat alluvial plain along the coast of central Mozambique. The delta is triangular in shape, covering an area of approximately 1.2 million hectares that stretches 120 km from its inland apex (near the confluence of the Zambezi and Shire Rivers) to the main Zambezi River mouth and 200 km along the Indian Ocean coastline from the Cuacua River outlet near Quelimane south to the Zuni River outlet (Figure 1). The large port city of Beira is located about 200 km to the south. The Delta is bordered to the north by the Morrumbala escarpment that serves as a divide between the Zambezi and Shire River catchments, and to the west by the Cheringoma escarpment that separates the Zambezi and Pungue River catchments.

The Marromeu Complex (11,270 km²) covers the southern half of the Zambezi Delta and the adjacent Cheringoma escarpment (Figure 1). The Marromeu Complex includes the Marromeu Buffalo Reserve (*Reserva Especial de Marromeu*) and two forest reserves (*Reserva Floresta de Nhampacué* and *R.F. de Inhamitanga*), four hunting concessions (*Coutada Oficial no. 10, 11, 12,* and *14*), large commercial agricultural lands (notably the Sena Estates, the largest sugar plantation in Mozambique), and community lands. The Marromeu Complex connects to the Zambezi River through a series of distributary channels via the Salone depression.

In November 2003, the Government of Mozambique ratified the Ramsar Convention and designated the Marromeu Complex as the country's first and only *Wetland of International Importance*. The vast size of the Marromeu Complex and its unique juxtaposition of different landforms, vegetation types, and water bodies gives rise to immense biodiversity value, including:

- Diverse and abundant mammal populations, including one of the densest concentrations of African buffalo *Syncerus caffer* on the continent, the largest herds of African elephant *Loxodonta Africana*, Livingstone eland *Taurotragus oryx livingstonianus*, Lichtenstein's hartebeest *Alcelaphus lichtensteinii*, sable antelope *Hippotragus niger*, and waterbuck *Kobus ellipsiprymnus* in central Mozambique, Endangered wild dog *Lycaon pictus*, and a morphologically-distinct population of a plains zebra sub-species *Equus quagga crawshayi*;
- The largest concentration of waterbirds in Mozambique, including Endangered Grey Crowned Crane *Balearica regulorum*, Vulnerable Wattled Crane *Grus carunculatus*, and one of largest breeding colonies of Great White Pelican *Pelecanus onocrotalus* in southern Africa;
- *Southern Zanzibar-Inhambane Coastal Forest Mosaic*, a critically threatened ecoregion and global biodiversity conservation hotspot that features large tracks of Dry Forest and Moist Evergreen Forest that are not found elsewhere in Mozambique and have unusual species composition and high species richness (including nine forest species on the Mozambique Plant Red Data List);
- The diverse grassland and woodland communities of the Zambezi Delta plain, at the heart of the critically threatened *Zambezian Coastal Flooded Savanna* ecoregion;
- Extensive coastal mangroves that form part of the *East African Mangrove* ecoregion, a critically threatened and global biodiversity conservation hotspot, fronted by pristine coastal dunes and beaches.

The Marromeu Complex also is vital for the national economy of Mozambique and provides sustenance for hundreds of thousands of rural villagers. The extensive coastal mangroves and estuaries nourish the

prawn fishery on the Sofala bank, one of Mozambique's most important sources of export revenue (Turpie *et al.* 1999). The floodplain swamps provide important spawning grounds for riverine and oceanic fishes, and support an important freshwater fishery during years of good flooding. The wet grasslands provide critical dry-season grazing lands for livestock. The rich delta soils support the largest sugar plantation in Mozambique and productive flood-recession agriculture along drainage ways. The savannas and woodlands provide fuelwood, building materials, wild fruits, honey, and medicinal plants to local communities (Beilfuss *et al.* 2002). The complex also offers exclusive ecotourism and trophy hunting opportunities (Dutton *et al.* 2001). Other important ecosystem services provided by the Marromeu Complex include:

- Clean and abundant freshwater, in surface waters and shallow groundwater aquifers, for drinking, cleaning, bathing, and other household uses;
- Papyrus, reeds, palms, thatch grasses, and other resources that can be sustainably harvested from the floodplain;
- Vast wooded areas that provide carbon sequestration to combat global climate change;
- Storm surge and coastal erosion protection; and
- Flood storage and protection.

Sustainable management of the Marromeu Complex depends on accurate information about the ecological and socio-economic resources of this vast and productive ecosystem. This report describes the status and distribution of the main large herbivores and several large bird species of conservation concern in the Marromeu Complex, The report is based on the results of aerial and ground surveys conducted during November 2008 and May 2009, supplemented by field observations from professional hunters, trackers, scouts, and researchers.

The objectives of this report are to:

1. Establish a standardized methodology for the monitoring large herbivore populations in the Marromeu Complex
2. Assess the current status and distribution of large herbivores and several large bird species of conservation concern in the Marromeu Complex based on aerial surveys conducted in November 2008 and May 2009;
3. Evaluate trends in large herbivore populations based on aerial surveys conducted over the past forty years;
4. Describe the implication of these findings for wildlife conservation and management in the Marromeu Complex.

Aerial surveys

Aerial surveys provide an important long-term reference for evaluating changes in wildlife status and distribution on the open floodplains and ecotonal region of the Marromeu Complex. Aerial surveys of the Marromeu Complex were first carried out in December 1968, using a SuperCub aircraft to cover the floodplain as one unit and provide a total census of large herbivores (Tinley 1969). The survey report includes population estimates and distribution maps for African buffalo, eland, African elephant, hippopotamus *Hippopotamus amphibious*, Lichtenstein's hartebeest, sable antelope, waterbuck, and plains zebra. Tello (1978) and Tello & Dutton (1979) conducted three aerial surveys between October 1977 and March 1979, and derived population estimates and distribution maps for the species surveyed in 1968 as well as southern reedbuck *Redunca arundinum,* common warthog *Phacochoerus africanus,* bushbuck *Tragelaphus scriptus*, oribi *Ourebia ourebi,* and southern bushpig *Potamochoerus larvatus.*

These surveys provide an important historical reference for the status, trends, and distribution of wildlife in the Marromeu Complex, which was decimated during and immediately following the Mozambique civil war from 1980-94 (Hatton *et al.* 2001). Infrastructure for management and tourism was destroyed by military action and neglect.

The first opportunity to fully assess the impact of the ongoing civil war on wildlife was in September 1990, when Anderson et al. (1990) undertook a comprehensive aerial survey of wildlife species of the Marromeu Complex using a Cessna 210 aircraft[1]. Both sample and total counts were used. A strip count using flight lines spaced 4 km apart covered the entire open floodplain up to the miombo ecotone, with a 400m observation width, providing a 10% sample estimate for most large herbivores and wattled cranes (statistical analysis based on Norton-Griffiths 1978). When large concentrations of elephant and buffalo were located outside the sampling area, they were photographed and counted (also age and sex) to provide a total count. The total count data was supplemented by a helicopter flight for intensive local sampling of African elephant and African buffalo on the floodplain and hippopotamus in optimal deepwater habitats. An additional 2-hour flight was conducted along the floodplain-miombo ecotone to determine the status of sable antelope and Lichtenstein's hartebeest. The report includes distribution maps for African buffalo and African elephant.

Cumming *et al*. (1994) conducted the first post-war aerial survey of Marromeu wildlife in the 1994 dry season using a Cessna 206 aircraft. Eight transects covered 1,111 km^2, providing a 9.76% sample of the central area of the floodplain (the survey did not extend into the miombo ecotone nor the open floodplain grasslands in the southwest corner of the delta).

Dry season surveys in 2000 and 2001 were conducted for the GERFFA project, using a Bell 206 helicopter. As with previous surveys transects were spaced 4 km apart, but the observation distance was increased to 500m on each side of the helicopter, resulting in a 25% sample for estimating species populations. All groups greater than 10 animals were photographed for subsequent counting. Buffalo and elephant herds were spotted between transects and surveyed to provide a total count for the floodplain (Dutton *et al.* 2002). Raw survey data and suggestions for extrapolating population estimates for other large herbivore species are provided.

From 2004-2007, annual end-of-dry-season aerial surveys were undertaken by the operator of Coutada 11 to provide a total count of buffalo and (intermittently) elephant and waterbuck (Zambezi Delta Safaris *unpublished data)*. The surveys were conducted using a Robinson-44 helicopter.

In addition to these large mammal surveys, a series of waterbird surveys of the Marromeu Complex were conducted from 1995-2001 (Beilfuss and Allan 1995, Bento et al. 2007), repeating the survey design of Anderson et al. (1990). The surveys focused on large waterbirds, especially wattled crane, grey crowned crane, saddlebilled stork *Ephippiorhynchus senegalensis*, and other species of conservation concern, and the hydrological condition of the floodplain during mid-wet season (1995, 1997, 2001) and late dry season (1999, 2000, 2001). Other wildlife observations were also recorded, but no attempt was made to conduct a systematic count of large mammals.

Ground surveys

Ground surveys are better suited than aerial surveys for recording animals that are small, inconspicuous, nocturnal, individual or in small groups, static in response to aircraft, or under dense canopy (Jachmann

[1]Chambal (1988) conducted an aerial survey in November 1988, aimed at recommending safari hunting quotas for buffalo and elephant. The results of the survey are not considered to be reliable

2002). Ground census methods have not been used in a systematic manner to generate wildlife estimates for the Marromeu Complex, mainly due to the limited road network and problems with extrapolating results into reliable estimates for the broader, roadless area (Norton Griffiths 1978). However, road surveys of focal areas have provided important information about numbers and distribution of several wildlife species that are mainly restricted to the Cheringoma escarpment, including nyala *Tragelaphus angasii*, bushbuck *T. scriptus*, greater kudu *T. strepsiceros*, suni *Neotragus moschatus*, and others.

During November 1999, a Land Rover road survey was carried out during the day along all negotiable tracks in the Marromeu Complex, aimed at verifying information about species numbers and distributions provided by safari operators and professional hunters. Since 2004, scouts and professional hunters have conducted annual road surveys of Coutada 11 and 12 by Land Cruiser during the last 10 days of October. Large ungulates observed are counted and marked with GPS.

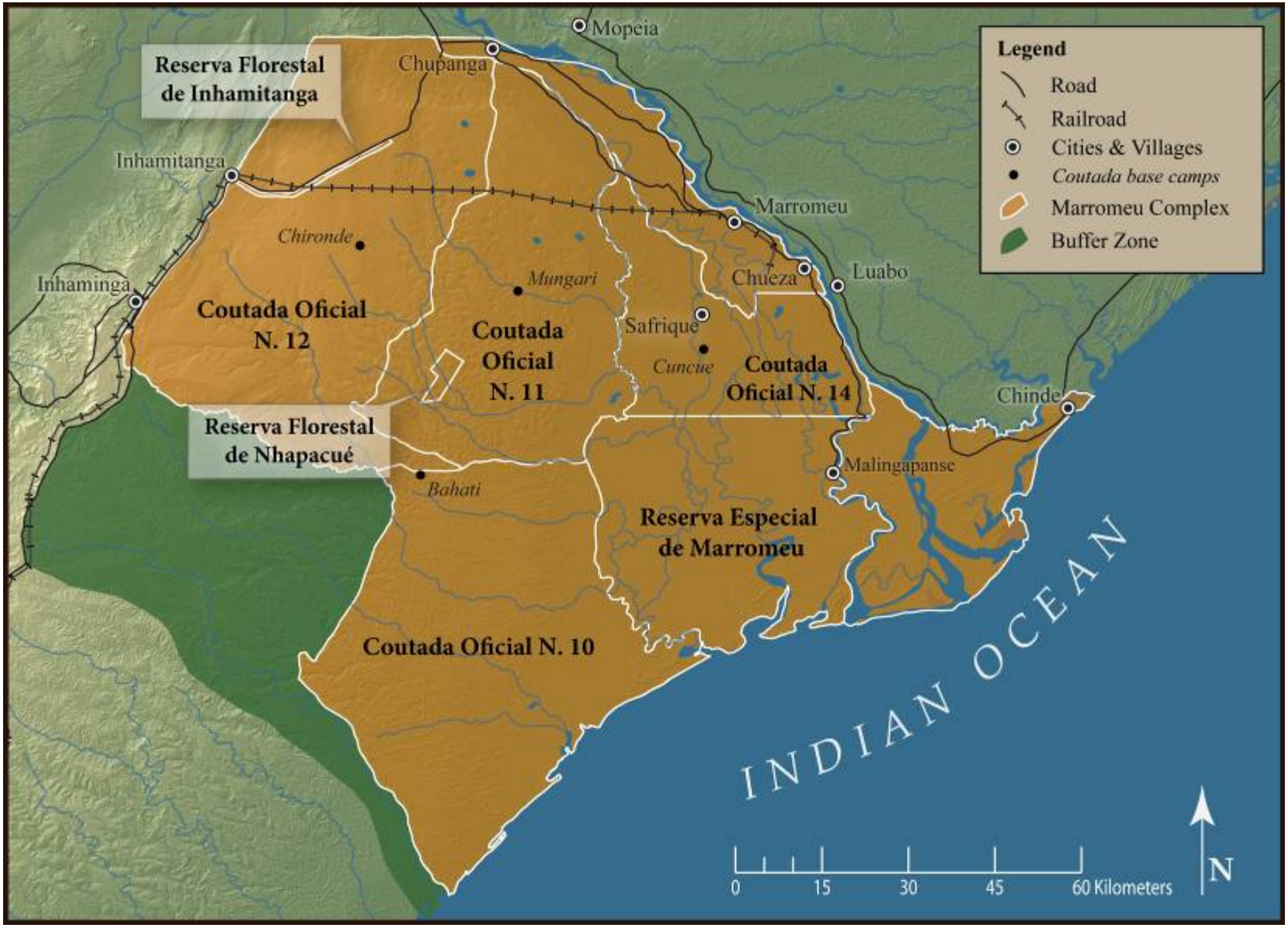

Figure 1. Map of the Marromeu Complex.

Methods

The survey program for the Marromeu Complex was designed to provide sufficient detail for assessing the status and distribution of all large herbivores and selected large bird species of conservation concern in the Marromeu Complex, based on a combination of total counts, statistical sample estimates, pan counts, and field observations, supplemented by interviews with professional hunters, trackers, scouts, and researchers working in the area.

Two survey programs were conducted, the first one covering the late dry season (13-18 November 2008) and the second one following in late wet season (1-4 May 2009). The survey programs included the following activities:

1. An aerial survey of the open floodplains and ecotone of the Marromeu Complex, covering the Marromeu Special Reserve and adjacent parts of Coutadas 10, 11, 12, and 14 (November and May)
2. Aerial reconnaissance of the Cheringoma escarpment of the Marromeu Complex, covering pans and drainage lines of Coutadas 10, 11, 12, and 14 (November and May)
3. A road survey covering part of Coutadas 10 and 11 on the Cheringoma escarpment (November only)

Aerial survey of the floodplain and ecotone

A Robinson-44 helicopter was used for the aerial surveys, fitted with a radar altimeter and Garmin GPSmap 60CSx receiver. The aerial survey team included the pilot (Mark Haldane), left side observer-recorder (Richard Beilfuss), right side observer-recorder (Carlos Bento), and a supplemental observer (Mateus Ribaue). Crew members communicated through an intercom system. The survey team members had significant experience observing and counting during aerial surveys, including previous surveys of the Marromeu Complex.

Observation lines were marked using tape on the windows on each side of the helicopter. The tape was positioned such that when the helicopter was flying at 300 feet agl, this distance represented a strip of about 400 m wide on the ground for a specific observer. The strip widths were calibrated by flying the aircraft at right angles across the airstrip with known distances marked in 100 m intervals.

The first aerial survey covered the Marromeu Complex open floodplain following procedures that are well established for aerial surveys of African large herbivores (Norton Griffiths 1978). Two survey strata were established, one covering the open floodplain and one covering the floodplain-woodland ecotone (Figure 2). The area of each stratum was determined using ArcGIS software, and parallel transects were positioned across each stratum. Transects were arranged at right angles to the principal environmental feature of the Marromeu Complex -- the floodplain-woodland edge or ecotone. The helicopter 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 survey team counted all large mammal species and four bird species—three large waterbird species of concern (grey crowned cranes, wattled cranes, and great white pelicans) and southern ground hornbills *Bucorvis leadbeateri*—that were observed within the transect strips. For each observation, the GPS location and number was marked by the pilot, and the species name and number of individuals were recorded corresponding to the appropriate GPS number. If any animal group within the transect was too large for all the individuals to be counted accurately, group size was estimated by the observer and photographed. Wildlife numbers later were counted accurately on computer screen using MS Paint

software to accurately mark each individual tallied on the airphoto. Observers also recorded and counted human activities, including settlements, domestic livestock (cattle, goats), and any evidence of hunting or fishing within the transect strips.

The floodplain stratum transects were spaced 2 km apart, providing a sampling intensity of 40% for most species and activities observed, based on a fixed observation distance of up to 400m on each side of the helicopter (combined strip width of 800 m). However, a total count was conducted for elephant and buffalo in the floodplain stratum. When buffalo or elephant herds were sited outside the transects, the pilot marked the current GPS location along the transect and then diverged from the transects to enable accurate recording of the species, position, and number for each observation (based on direct count or photographs as appropriate). The pilot then returned to the previous GPS position and resumed the transect survey. Ecotone stratum transects were uniformly spaced 0.8 km apart, to provide a total count for all species in this area (sampling intensity of 100%). Appendix 2 provides the area, transect spacing, number of transects, percent of strata sampled, flying time, and search effort for each strata. The transect start and endpoint coordinates are given in Appendix 3.

The November and May floodplain surveys were designed to provide a total count of all buffalo and elephant herds, and a 40% sampling intensity for other large mammal species and selected waterbirds. Population estimates and confidence intervals for the sampled wildlife species were calculated using Statgraphics Centurion^{TM} software, following the Jolly II (1969) method. Individual transect length and area were calculated using Arc GIS^{TM} software. The value of Student's t used to calculate the confidence interval of a population estimate was t_{n-1} for P=0.05, where n= number of transects in the stratum. The total numbers of buffalo and elephant counted were summed to provide a total population estimate for each species within the floodplain survey area, and additional survey statistics were not calculated.

The ecotone surveys were designed to provide a total count for all large mammal species. Numbers counted from each transect were summed to provide a total population estimate for the ecotone survey area, and additional survey statistics were not calculated.

Species distribution maps were prepared for each species surveyed, combining results from the November and May surveys (including the escarpment surveys described below). The location of each dot on these maps indicates the GPS location where an individual or group was seen and the size of each dot indicates the relative size of the group.

Aerial reconnaissance of Cheringoma escarpment wetlands

Although substantial numbers of many large herbivores occur on the Cheringoma escarpment, none of the previous surveys of the Marromeu Complex has attempted to count or estimate wildlife numbers because of the difficultly in accurately counting individuals through the dense leaf foliage that occurs on the escarpment throughout the year (see, for example, Jachmann 2002). An important objective of the present survey program was to provide a reliable estimate of wildlife numbers and distribution throughout the Marromeu Complex, including the escarpment, while recognizing the inadequacy of traditional transect sampling. These estimates are based on a combination of aerial reconnaissance

The second aerial survey therefore focused on counting large herbivores in areas where and when they were most likely to be concentrated--in wetlands (pans and along drainage slacks) in the dry forest, moist evergreen forest, and miombo woodlands of the Cheringoma escarpment, during the early morning and late afternoon. A total of 160 pans were surveyed during the November and May surveys (Figure 3). For each of the surveyed sites, the GPS location and number was marked by the pilot, and the species name and number of individuals were recorded. In November 2008, a total of 137 pans and

drainage lines were surveyed. In May 2009, 110 pans and drainage lines were surveyed, including 87 pans with repeat coverage from the November 2008 survey and 23 additional pans not previously surveyed.

The observers also recorded the hydrological condition of each of these wetlands (see Table 4 below), using a scale that ranged from dry soils to wet soils with extensive areas of open water. These conditions were used to estimate the hydroperiod for each site, ranging from wetlands with only temporary flooding or saturated soils during the wet season, to permanently flooded wetlands.

The November and May pan surveys were designed to provide data on the distribution and approximate numbers of large mammals associated with pans and waterways on the Cheringoma escarpment. Survey statistics were not calculated.

Ground survey of the Cheringoma escarpment

During November, a third survey was conducted to provide further evidence of wildlife numbers and distribution in the dense forests and woodlands of the Cheringoma escarpment from the ground, as a supplement to the aerial survey and discussions with local scouts and professional hunters. The road survey was 4.5 hours in duration, and covered only a small section of Coutadas 11 and 12. The survey was conducted using a modified Land Cruiser to serve as a game view vehicle, with two rows of elevated seats on the open flatbed. The survey team included the driver (L.J.) and five observers (Richard Beilfuss, Carlos Bento, Tomé Joaquim, José Nhazua, and Mateus Ribaue). The survey route was mapped using continuous GPS tracks. The survey team recorded the species name and number for all mammal and bird species that were observed from either side of the vehicle along the road route. Observation distances varied depending on the density of vegetation, management practices (especially burned vs. unburned), and other factors affecting visibility--a fixed observation distance from the vehicle was not used.

The results of the ground survey, although educational, cannot be used to generate reliable population estimates for any species and therefore are presented separately from the population estimates derived from the aerial surveys described above.

Population estimates

Population estimates for each species are best scientific estimates based on the results of the aerial surveys, supplemented with the results of aerial reconnaissance and road survey of the Cheringoma escarpment, and field records and observations of professional hunters and scouts.

The present aerial survey provides a repeatable methodology for estimating trends over time in large herbivore numbers on the floodplain and along the ecotone. Survey reliability is based on the assumption that large herbivores and large bird species of conservation concern can be accurately counted from the air on the open floodplain and ecotonal areas of the Marromeu Complex, and no corrections have been applied to these data to compensate for any undercounting or missed animals. The total counts on the floodplain (African buffalo and African elephant) and ecotone (all species) provide minimum population estimates for these regions. Measures of precision for the floodplain sample survey are provided for wildlife species that satisfied minimum sample size (Annex 2).

Because none of these species occur exclusively on the floodplain and ecotone, however, these counts are insufficient to provide total population estimates and additional information is required to estimate wildlife numbers and distribution in the woodlands and forests of the Cheringoma escarpment. As

described above, several tools were used to improve the quality of these estimates, including aerial reconnaissance of pans and drainage lines, road surveys in the coutadas, and a review of field records and observations provided by professional hunters and scouts working in the coutadas. Although there is some implicit conflict of interest in engaging concession operators, professional hunters, and scouts in estimating wildlife numbers given their economic interest in the hunting quota allocations, these individuals have considerably more knowledge than anyone else about wildlife status and distribution in the Marromeu Complex and the long-term sustainable management of trophy species in the complex is in the economic interest of all concerned.

Comparison of present counts with historical data

Most of the past surveys of the Marromeu Complex have attempted total counts of large herbivores (Tinley 1969, Tello 1978, Tello and Dutton 1979, Zambezi Delta Safaris *unpublished data*) or a combination of total counts and statistical samples (Anderson *et al.* 1990, Dutton *et al.* 2002). We evaluated the reliability of these previous aerial survey results with respect to species availability, detection accuracy, and counting accuracy (e.g., Elphick 2008) to assess their value for interpreting trends in wildlife status and distribution over time. Species availability (e.g., likelihood of species occurrence within the survey area) was evaluated based on survey timing and local phenology. Detection accuracy (e.g., likelihood that species were correctly observed, identified, and counted) was evaluated based on search effort (survey transect flying time per strip area), number of experienced counters, and sampling intensity (transect coverage as a percentage of study area). Counting accuracy (e.g., likelihood that species were not double-counted or under-counted) was evaluated based on sampling intensity, survey area stratification, and data entry system.

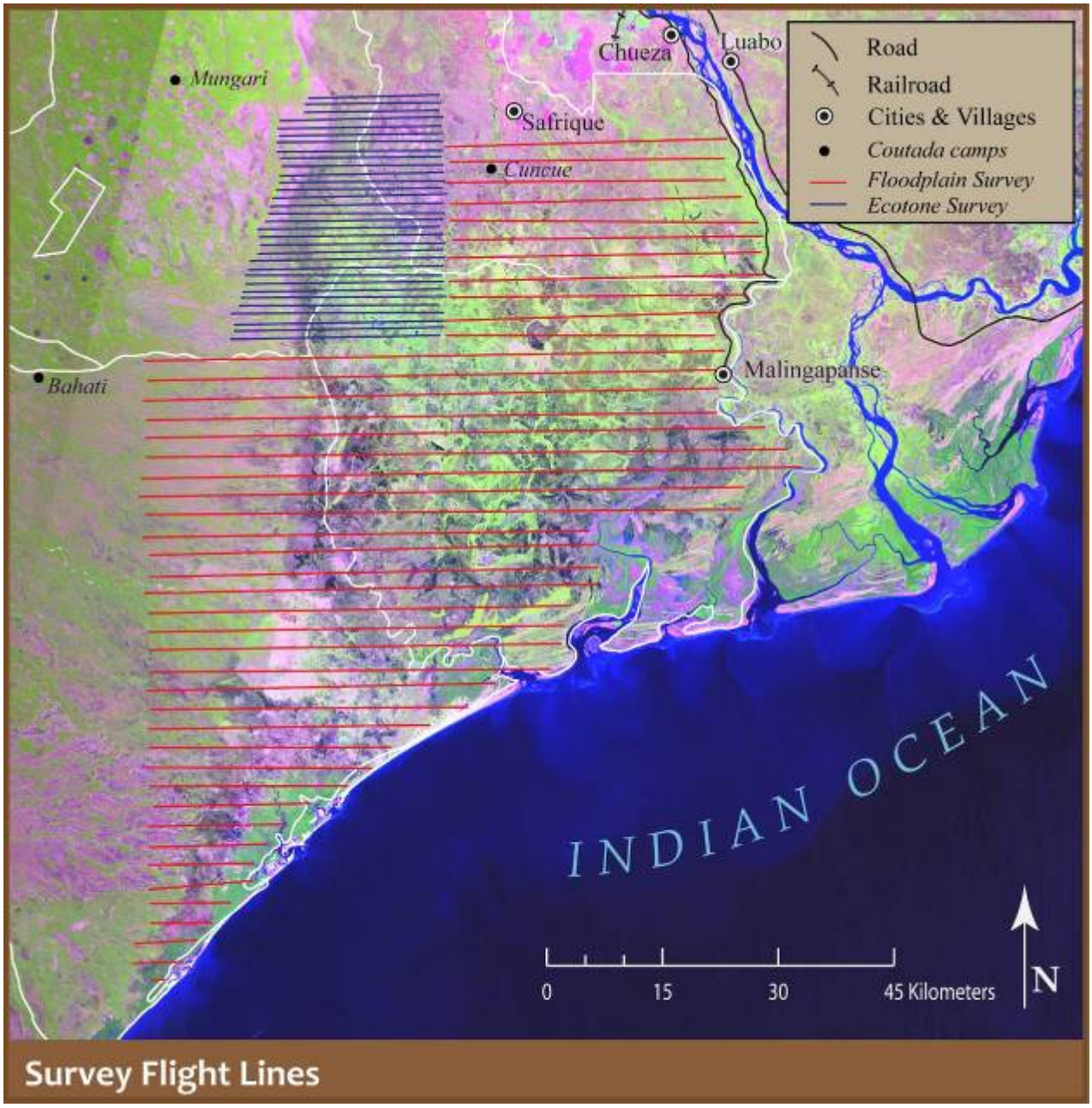

Figure 2. Standardized aerial survey transects, including floodplain strata (2 km spacing, shown in red) and ecotone strata (0.8 km spacing, shown in blue), for estimating large herbivore numbers and distribution in the Marromeu Complex.

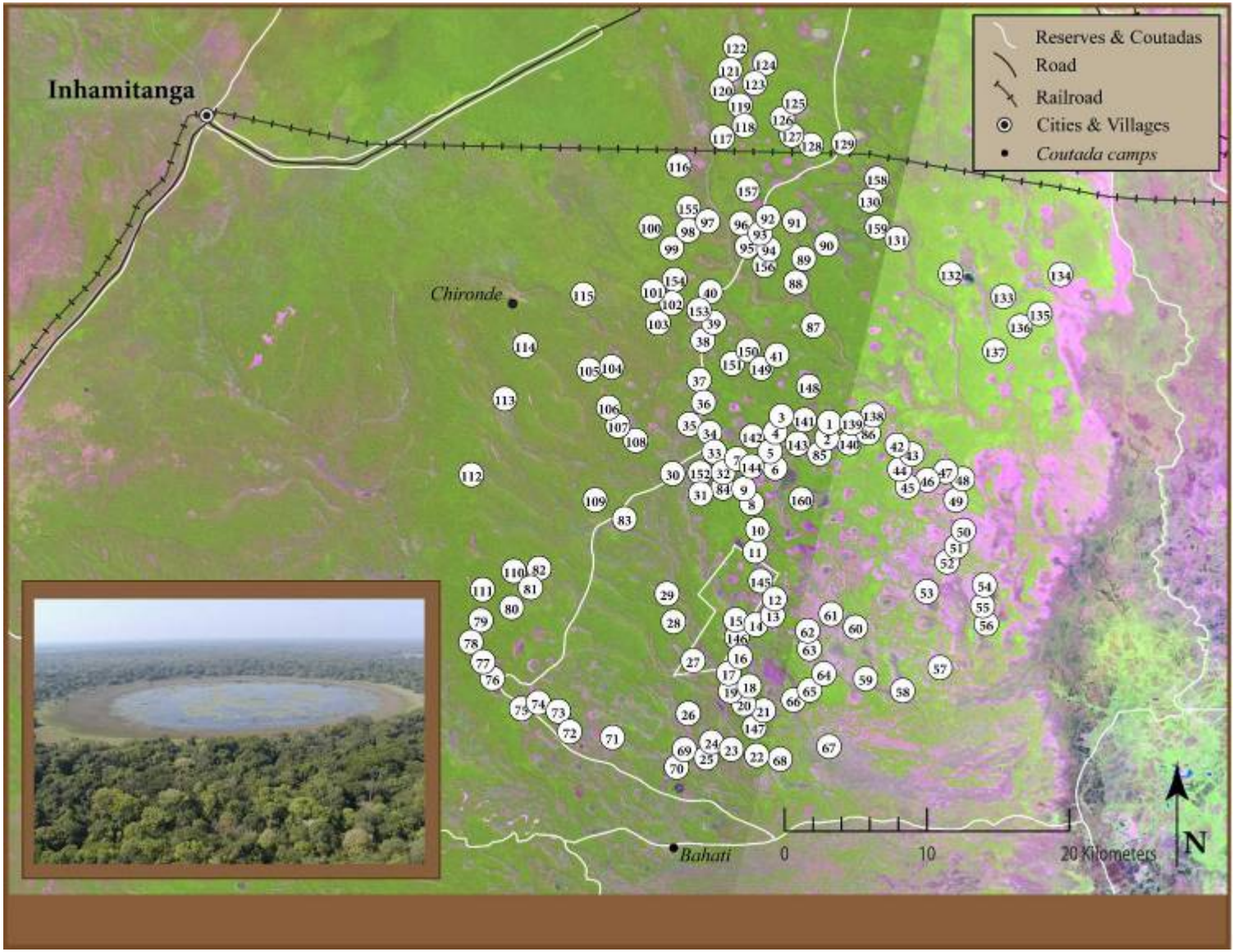

Figure 3. Pans surveyed during aerial reconnaissance surveys aimed at improving the estimate of large herbivore numbers and distribution on the Cheringoma escarpment of the Marromeu Complex.

Results

Wildlife status and distribution

Results from the November 2008 aerial and road survey program and May 2009 aerial survey program, including overall population estimates for each species recorded, are provided in Table 1. An estimated 16,124 individuals of 11 large mammal species were present on the open floodplain in November 2008, with an additional 2,061 individuals of 13 large mammal species observed on the ecotone. At the end of the following wet season, in May 2009, an estimated 15,427 individuals of 12 large mammal species were present on the open floodplain, with 1,411 individuals of 13 large mammal species on the ecotone. On the pans and drainage lines of the Cheringoma escarpment, 3,285 individuals of 16 large mammal species were observed in November 2008 (based on 137 survey sites). In May, we observed fewer individuals (1,150) of a reduced number of large mammal species (11), although overall survey coverage was somewhat reduced (110 survey sites, including 87 from the November survey).

The following estimates of species numbers and distribution should be considered conservative, with undercounting of many species likely, especially those species confined to the escarpment woodlands and forests. As noted in the methods section above, the dense woodland and forest cover over vast areas of the Cheringoma escarpment make it difficult to accurately estimate wildlife numbers for the whole of the Marromeu Complex. Further refinements in survey coverage, especially in Coutada 10, should help improve these estimates over time.

Africa buffalo are the dominant species of the open floodplains of the Marromeu Complex. The estimated population is at least 10,300 individuals. In November, 10,090 buffalo were counted on the floodplain and ecotone surveys. Most buffalo were concentrated in large herds scattered across the Marromeu Reserve (Figure 4). Five herds exceeded 500 individuals, with the largest herd comprising 885 individuals. However, an additional three herds (estimated 800 individuals) were observed in a relatively isolated location on the floodplain during a reconnaissance flight conducted immediately after completion of the transect survey. These herds were not counted in the survey, so that total buffalo population on the floodplain/ecotone in November likely exceeded 11,000. On the escarpment pans, we observed an additional 53 individuals during the aerial surveys, and recorded 5 individuals and evidence (fresh tracks and dung) of 3 additional herds (estimated 120-150 individuals) during road surveys.

The following May 2009, our counts suggested substantially fewer numbers of African buffalo (8,019 individuals, or -25.8% reduction) on the floodplain and ecotone. Comparison of the distribution maps for the two surveys suggests that most of the herds in the Marromeu Reserve are highly sedentary, although average herd size was larger in May, with two herds >1,000 individuals (Figure 5). Large numbers of buffalo living near the ecotone likely move off the floodplain onto Cheringoma escarpment or coastal plains southwest of the Zambezi Delta during the wet season or early dry season. Only two buffalo were observed during surveys of the pans and drainage lines in May, but scouts from Coutada 10 and 12 reported large herds in the miombo woodlands. Coutada operators suggest as many as 1,500 buffalo live permanently or semi-permanently on the escarpment (J. Strasheim, *pers. comm.*)

African elephant numbered 267 individuals during the November total count, and 351 individuals the following May (+23.9%). A herd of 125 individuals was observed in May (Figure 6). Most of the elephant are likely year-round residents of the flooded grasslands of the Marromeu Complex, where they can readily hide in the tall papyrus and acacia-palm thickets[2]. We observed fresh elephant dung and tracks

[2] We observed a large herd of 64 individuals "disappear" into acacia-palm thicket, and were unable to detect them on a subsequent transect pass.

during escarpment road surveys in November. A herd of >200 elephant was observed and photographed in Coutada 11 during October 2008 (J. Strasheim, *pers. com.*)

Waterbuck are the next most abundant species in the Marromeu Complex, with an estimated population of at least 2,500 individuals, likely higher. Waterbuck numbers differed substantially between the two surveys, suggesting strong season movements. In November, we estimated 1855 waterbuck on the floodplain margin, with an additional 96 counted on the ecotone and 11 on Cheringoma pans. The following May, an estimated 4,588 waterbuck were present on the floodplain (densely concentrated near the ecotone of Coutada 10) and 209 on the ecotone (Figure 7).

Sable antelope are widespread on the seasonally-flooded grasslands along the ecotone and on pans and drainage lines in the miombo woodlands. In November 2008, we estimated 1,275 sable on the floodplain, and counted 265 individuals on the ecotone and 828 on escarpment pans and drainage lines (an estimated population of >2,368 individuals) (Figure 8). An additional 52 sable were observed during road surveys. The following May, we estimated 820 sable on the floodplain, and counted 402 individuals on the ecotone and 173 on escarpment wetlands. The 41% reduction in numbers over this period suggests that sable may be widespread in the woodland and forest during the wet season when water resources are abundant.

Lichtenstein's hartebeest occupy similar habitat as sable, commonly occurring along the ecotone and miombo pans and drainage lines. The estimate hartebeest population is at least 500 individuals. Hartebeest numbers differed only slightly between November and May, with an estimated 308 and 212 individuals on the floodplain and ecotone, respectively, during the November survey, and 323 individuals on the floodplain and 217 individuals on the ecotone during the May surveys (Figure 9). Substantially higher numbers were observed on the escarpment pans in November.

A single herd of 152 Livingstone eland was observed on the ecotone during the November survey (Figure 10). Smaller herds of 25 and 41 individuals were observed on the ecotone in May. These herds consist of ~95% cows and calves; suggesting that comparably sized bachelor herds may have been present but undetected during the survey. The estimated population is >200 individuals, but likely approaches 300 or more individuals at times as eland are nomadic and are prone to large-scale movements over their extensive home ranges (Skinner & Chimimba 2006).

Zebra co-occur with waterbuck, sable, and hartebeest on the floodplain margin. Relatively few plains zebra were observed during the surveys. In November, only 44 individuals were counted during the surveys (although a herd of 58 zebra was observed just outside of the survey transects in Coutada 11). In May, we estimated 33 individuals on the floodplain survey and counted 18 on the ecotone (Figure 11). A small herd of 5 was observed at one pan on the escarpment. The estimated population is about 60 individuals.

We estimated 115 hippo during the November floodplain survey; in May, we estimated 243 hippo on the floodplain and counted an additional 9 individuals on the ecotone. We conservatively estimate the hippo population as >100 individuals, but actual numbers likely exceed these estimates, as hippo are largely confined to permanent lakes on the open floodplain and are easily over-looked when they submerge during transect over-flights (Figure 12).

Southern reedbuck and warthog are abundant across the floodplain, ecotone, and escarpment pans and drainage lines, especially in Coutada 11, and were frequently encountered during the road surveys. Estimated and observed numbers for both species were substantially lower during the May survey (Figures 13 and 14), suggesting wider dispersion during the wet season. Populations for both species likely exceed 2,500 individuals. Bushpig were also observed in good numbers, and are frequently active during the day despite predominately nocturnal activity elsewhere (Figure 15).

Oribi were observed on escarpment pans and along the floodplain margin during the November surveys (Figure 16), and were frequently observed during road counts. The species likely numbers in the 100s.

Small numbers of impala, a species that was not recorded historically in the Zambezi Delta, were observed during the aerial and ground surveys (Figure 17). Additional herds are regularly reported in the drier woodlands on the escarpment, including a group of 15-20 along the Mupa River in Coutada 10 (J. Strasheim, *pers. com.*) and a bachelor herd of >20 individuals in Coutada 11 (M. Haldane, *pers. obs.*)

Species principally occurring in the escarpment forest and woodlands, including nyala (Figure 18), bushbuck (Figure 19), red duiker (Figure 20) and suni (not mapped) were observed in small numbers but substantially undercounted due to low detection. For example, 62 suni were counted during the limited road counts in November, but none were observed from aircraft over this area. Rough estimates are given for these species.

Other mammal species observed during the aerial surveys included baboon, samamgo and vervet monkeys, and water mongoose. Baboon troops were recorded during the May 2009 survey, and included an estimated 38 troops on the floodplain, 6 troops on the ecotone, and 4 troops on Cheringoma wetlands. The latter two counts are clearly underestimates, as baboon numbers are rapidly increasing throughout the complex and have been attributed to the decreasing numbers of certain game bird species (J. Strasheim, *pers. com.*).

Among the bird species targeted in the survey program, an estimated 75 Endangered Grey Crowned Cranes occur in the complex. In November, an estimated 40 individuals, all in flocks, occurred on the floodplain in November. The May surveys recorded an estimated 107 individuals, nearly all observed in pairs and small family groups on the floodplain (Figure 21).

An estimated 250 Vulnerable Wattled Cranes (95 breeding pairs) were present on the floodplain in November. In May, we estimated 145 Wattled Cranes, all in pairs, on the floodplain, with no significant flocks (Figure 22). These population estimates are comparable to those reported from previous surveys conducted between 1995 and 2001, although far reduced relative to the estimated 2,500 Wattled Cranes observed in the Marromeu Complex in 1990 (Anderson *et al.* 1990). Bento *et al.* (2007) hypothesized that available habitat in the complex for Wattled Cranes is reduced and presently saturated with breeding pairs due to hydrological degradation.

Estimated southern ground-hornbill numbers on the floodplain/ecotone ranged between 23 in November and 106 in May (Figure 23). Twenty ground-hornbill were observed on pans in November. Actual numbers are likely much higher, as the species is frequently observed throughout the escarpment (J. Strasheim, *pers. com.*)

Great white pelican numbers were also higher in May, with an estimated 283 individuals on the floodplain (Figure 24). No large breeding colonies were observed during the surveys. The population likely numbers in the 100s, but the large colonies reported in the past (e.g., Goodman et al. 1992) were not observed.

Saddlebilled storks were common on the floodplain and escarpment pans, with an estimated population of 270. The species was surveyed only in November 2008 (Figure 25).

Human activity

Substantial human activity was also observed during the surveys, including permanent settlements with agricultural plots, various temporary settlements (typically fishing camps), and other activities including a few abandoned (illegal) meat drying camps and cattle herds. Figure 26 shows the distribution of

human activity across the survey area. Permanent settlements occur in the coutadas all along the floodplain-escarpment ecotone, especially in Coutada 10. Widespread settlements occur in the Marromeu Reserve, especially along the coast and coastal inlets and are radiating into the reserve from Malingapanse. Settlements also are extending into Coutada 14 in associated with the Sena Sugar estates and resettlements at Safrique, into Coutada 12 from Inhaminga and Inhamitanga, and throughout the northern portion of Coutada 11 and 12 (north of the railroad line). Temporary fishing camps occur near Malingapanse and to a lesser extent along escarpment and coastline. Several abandoned poaching camps were observed in the Marromeu Reserve.

Areas with dense human settlements appear to have a strong negative influence on wildlife numbers and distribution in the Marromeu Complex. Relatively few wildlife observations were recorded in the southwestern portion of the Marromeu Reserve and near Malingapanse, suggesting that increasing human density is reducing the area of suitable habitat for wildlife in the Marromeu Complex.

Water availability

Approximately 200 pans and major drainage lines occur on the Cheringoma escarpment. Out of this total, we surveyed 137 sites in November, and evaluated hydrological condition of 98 of the sites. In May, we evaluated hydrological conditions in 110 sites (Table 5), including 50 sites with repeat coverage from the November survey. At the end of the dry season in November 2008, about one-quarter (23.5%) of the wetlands surveyed still contained standing water, and an additional 44.9% maintained high water table conditions with water available to burrowing species. After the 2008-2009 rainy season in May, only 34% of the wetlands surveyed had standing water, including about 10.1% with extensive flooded areas that strongly suggested surface water would persist at the end of the subsequent dry season. Of the wetlands we re-evaluated during the May surveys, 15 (30%) were drier in May than November and 12 (24%) showed not increase in standing water. These data collectively suggested that late dry season water availability in 2009 would be substantially lower than in 2008. However, extensive late wet season rainfall, extending into July, resulted in excellent hydrological conditions by the end of the 2009.

Assessment of previous aerial survey methods and data

Aerial survey methods have differed substantially with respect to survey design, aircraft, and other critical factors, complicating the evaluation of wildlife trends and necessitating the implementation of standardized survey methods for the future (e.g., Elphick 2008).

Wildlife detection accuracy was likely highest for the helicopter surveys (Dutton *et al.* 2002; Zambezi Delta Safaris *unpublished data*) due to their relatively slow flight speed, high visibility, and other factors (Jachmann 2002). The pre-war surveys by Tinley (1969), Tello (1978), and Tello and Dutton (1979) likely also had reasonably high accuracy of detection. The surveys used a small, slow-moving aircraft (Piper PA-18 SuperCub two-seater, 120 kph average airspeed), focused on the open floodplain and ecotone where visibility is highest, and targeted large ungulate groups rather than individuals. Herds were plotted manually on 1:250,000 topographic maps and photographed for later projection and counting. Aerial censusing using Cessna aircraft have lower detection accuracy (higher airspeed and moderate visibility). The post-war Cessna surveys (Anderson *et al.* 1990, Cumming *et al.* 1994) attempted to compensate for reduced detection accuracy by using narrow 200m strips relative to the pre-war surveys, increasing the search effort per transect though significantly reducing the sampling intensity. Species detection within the sample area is expected to be highly dependent on sampling intensity, as

most ungulates in the Marromeu Complex have small populations that are unevenly distributed and often highly clustered.

Counting accuracy on all surveys was enhanced by the use of photographs to count large herds. Double-counting was minimized on the helicopter and SuperCub surveys through the use of real-time GPS and map plotting, respectively, and is expected to be minimal on the Cessna surveys due to low sampling intensity. Misidentification was minimized through the use of highly experienced personnel in all surveys.

All of the previous surveys focused on the open floodplain and adjacent ecotone; none estimated wildlife numbers for the Cheringoma escarpment. The availability (density) of different herbivore species on the floodplain varies throughout the year, as many individuals move seasonally between the open plains and the Cheringoma escarpment, or range outside the Marromeu Complex. Species availability on the open plains is highest for surveys timed to the late dry season (October-November) when many ungulate species are most abundant and conspicuous, according to local scouts and professional hunters. Most of the surveys were conducted during this period (Tinley 1969, Anderson et al. 1990; Dutton et al. 2002; Zambezi Delta Safaris *unpublished data*); or combined late dry season surveys with subsequent wet season surveys (Tello and Dutton 1979). The 1994 survey was conducted during the mid-dry season in June (Cumming *et al.* 1994).

Overall, trends in wildlife numbers and distribution in the Marromeu Complex over the past forty years (reflecting periods of pre-war increase, decimation, and post-war recovery) have been so dramatic that they greatly exceed detection problems and other variations due to differences in survey methods. However, analysis of more subtle wildlife trends in the future requires a standardized monitoring strategy (Reilly & Emslie 1998, Bothma *et al.* 1990) involving repetition of the aerial and ground survey methods used in 2008-2009 to clarify trends for the on-going evaluation of management interventions.

Table 1. Results from the November 2008 and May 2009 aerial survey program. *Floodplain estimate* is the total count of African buffalo and Africa elephant and estimated number of other species recorded on the floodplain transects based on 40% sample coverage (survey statistics are given in Appendix 1). *Ecotone count* is the total count of all species recorded on the ecotone transects. *Cheringoma count* is the total count of all species observed on pans and drainage lines of the Cheringoma escarpment. *Estimated population* numbers for each species is based conservatively on aerial and road survey results and interviews with concession operators, professional hunters, and scouts.

Species	November 2008				May 2009			Estimated population
	Floodplain estimate	Ecotone count	Cheringoma Count	Cheringoma road count	Floodplain estimate	Ecotone count	Cheringoma count	
African buffalo	10,087	3	53	5	8,019	0	2	>10,300
African elephant	267	0	0	0	351	0	0	350
Blue duiker	0	0	0	5	0	0	0	100s
Bushbuck	18	5	16	2	8	8	16	100s
Bushpig	48	15	16	0	58	23	30	100s
Eland	13	163	25	0	3	107	0	>200
Great white pelican	135	57	0	0	283	0	0	100s
Grey crowned crane	40	0	0	0	105	2	0	75
Hippopotamus	115	0	0	0	243	9	0	>100
Impala	0	0	8	11	0	4	0	>20
Kudu	0	0	2	0	0	0	0	100
Lichtenstein's hartebeest	293	212	97	1	307	217	25	>500
Nyala	0	11	44	7	0	7	25	100s
Oribi	18	16	125	21	0	0	23	100s
Plains zebra	0	44	5	0	33	18	0	>60
Red duiker	0	5	37	14	8	1	6	100s
Sable antelope	1,275	265	828	52	817	402	173	>2,000
Saddle-billed stork	232	0	33	4	--	--	--	270
Southern ground- hornbill	23	0	20	0	100	6	0	>50
Southern reedbuck	1,190	633	1154	44	375	135	428	>2,500
Suni	0	0	11	62	0	0	0	1,000s
Warthog	930	536	853	29	580	271	387	>2,500
Waterbuck	1,855	96	11	11	4,525	209	35	>2,500
Wattled crane	250	0	4	2	145	2	4	>250

Table 2. Hydrological condition of wetlands (pans and drainage lines) on the Cheringoma escarpment, based on a rating scale evaluation during aerial surveys.

Rating scale	Observed condition	% wetland surveyed Nov 08	% wetland surveyed May 09	Estimated hydroperiod
1	Dry soils with no evidence of regrowth (typically burned and black)	17.3	3.7	Temporarily flooded or saturated soils during the wet season
2	Dry to mesic soils with patches of recent (green) regrowth	14.3	39.4	Seasonally flooded during the wet season
3	Mesic soils with extensive areas of recent regrowth	44.9	23.9	Year-round high water table (saturated soils) and seasonally flooded during the wet season
4	Mesic to wet soils with some areas of open water (covering <25% of pan)	20.4	23.9	Semi-permanently flooded (open water throughout most years)
5	Wet soils with extensive areas of open water (covering >25% of pan)	3.1	10.1	Permanently flooded

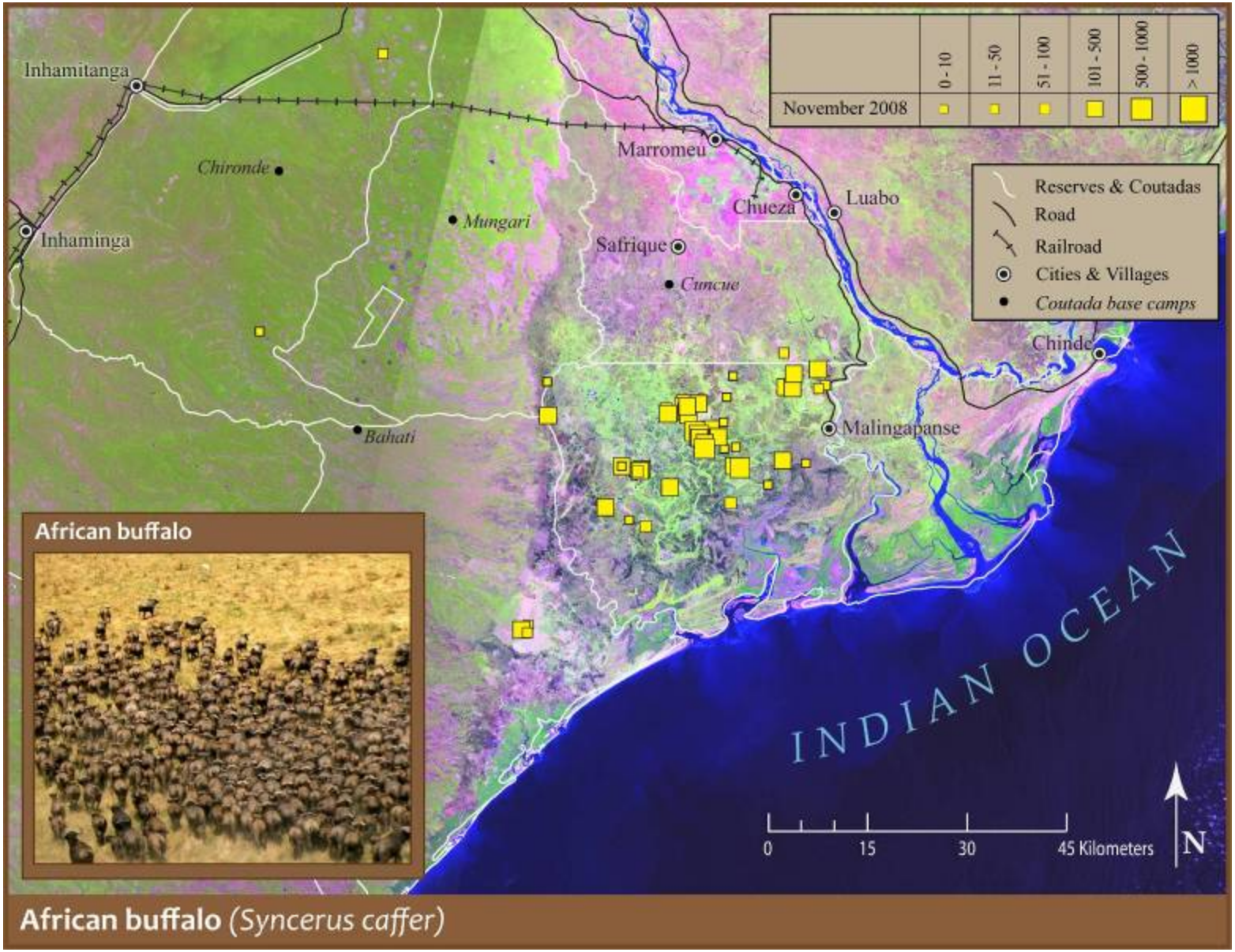

Figure 4. Distribution of African buffalo in the Marromeu Complex, based on November 2008 aerial surveys.

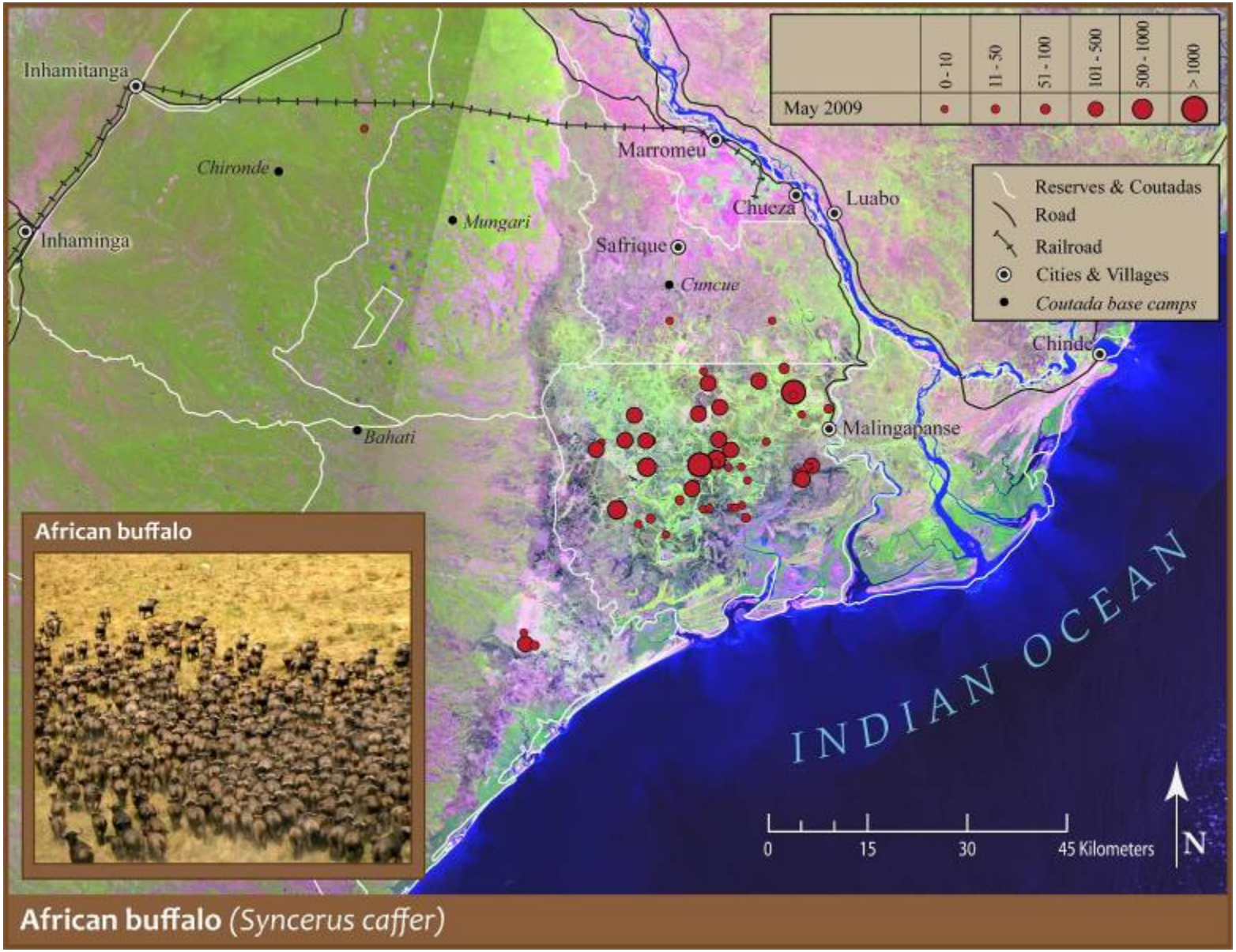

Figure 5. Distribution of African buffalo in the Marromeu Complex, based on May 2009 aerial surveys.

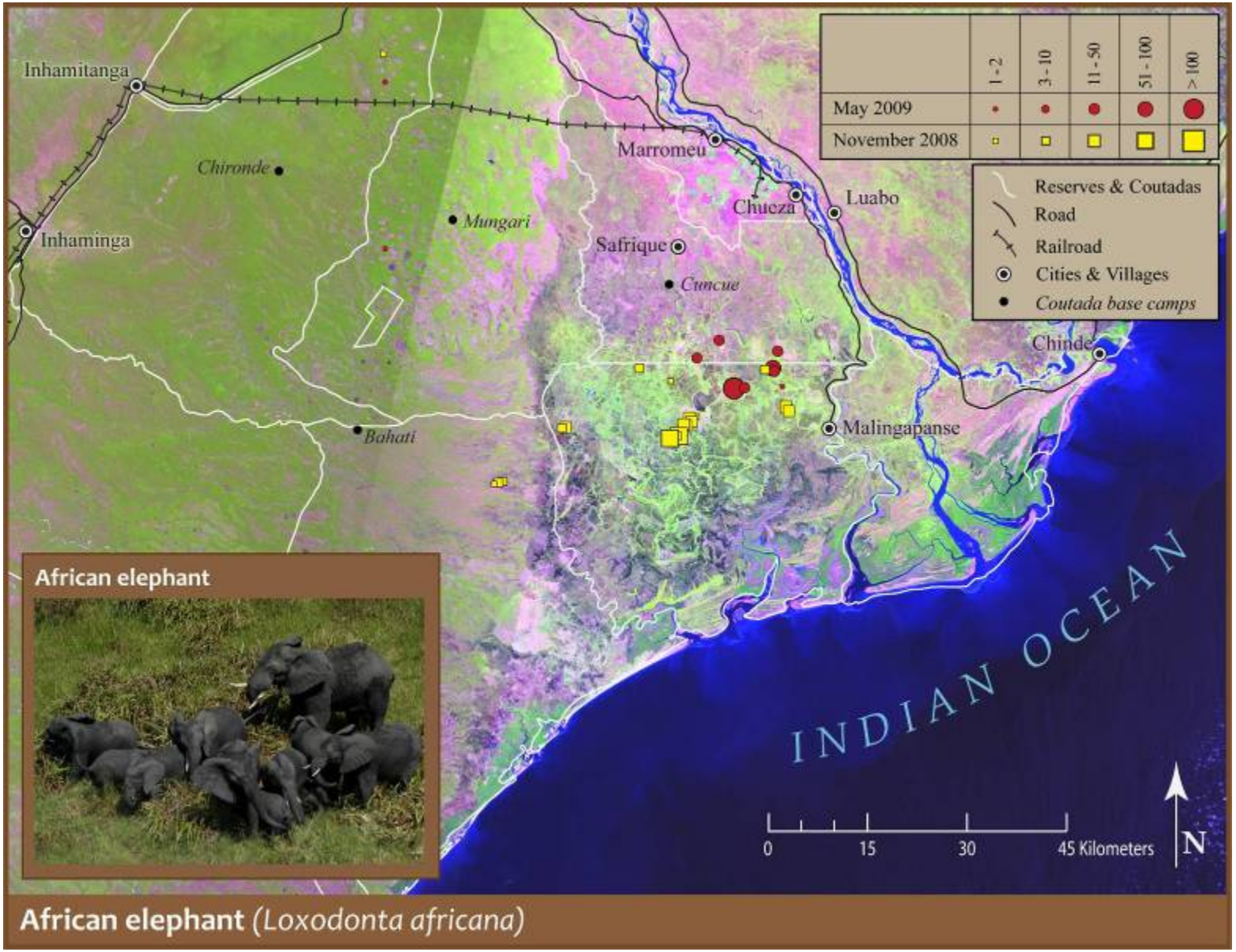

Figure 6. Distribution of African elephant in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

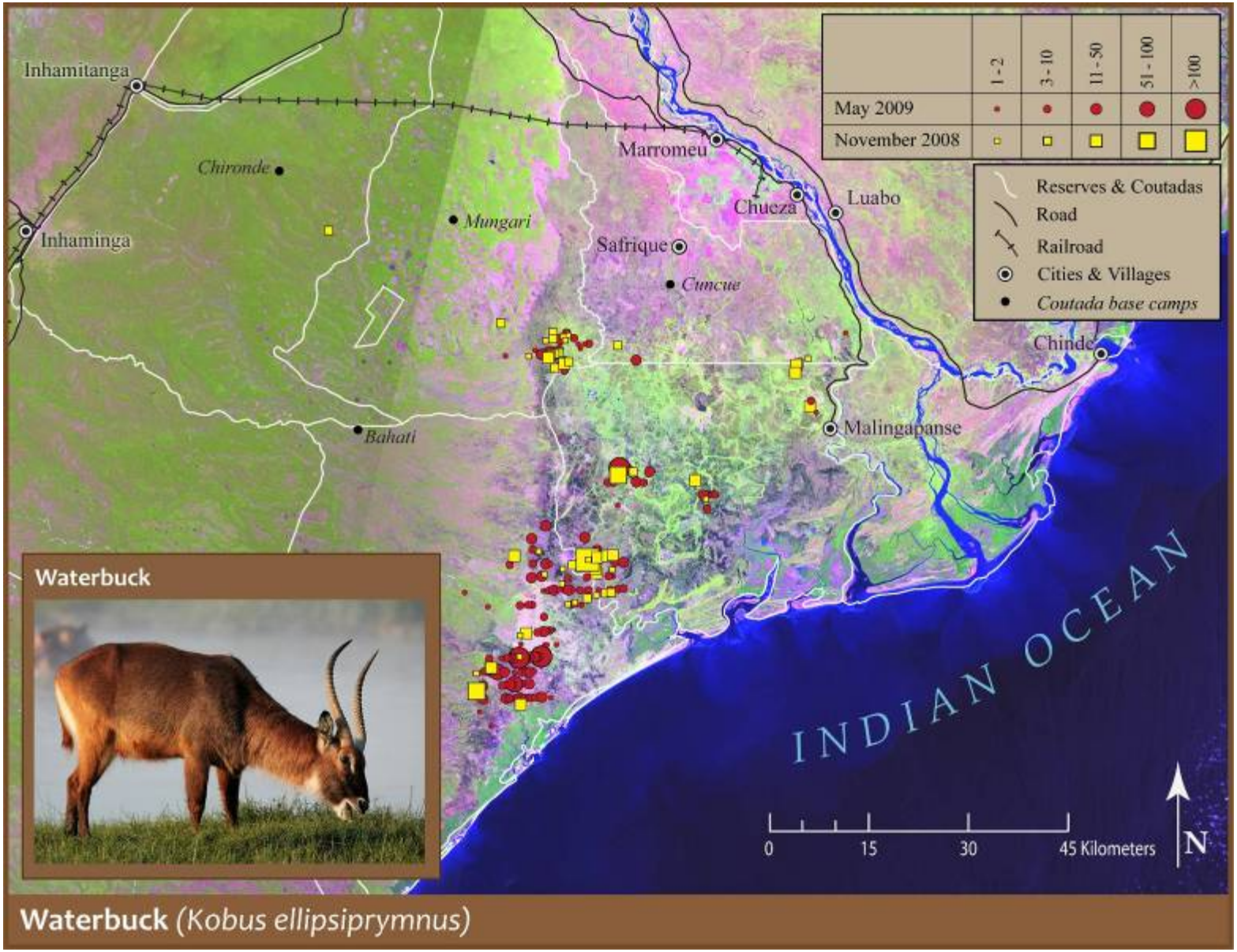

Figure 7. Distribution of waterbuck in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

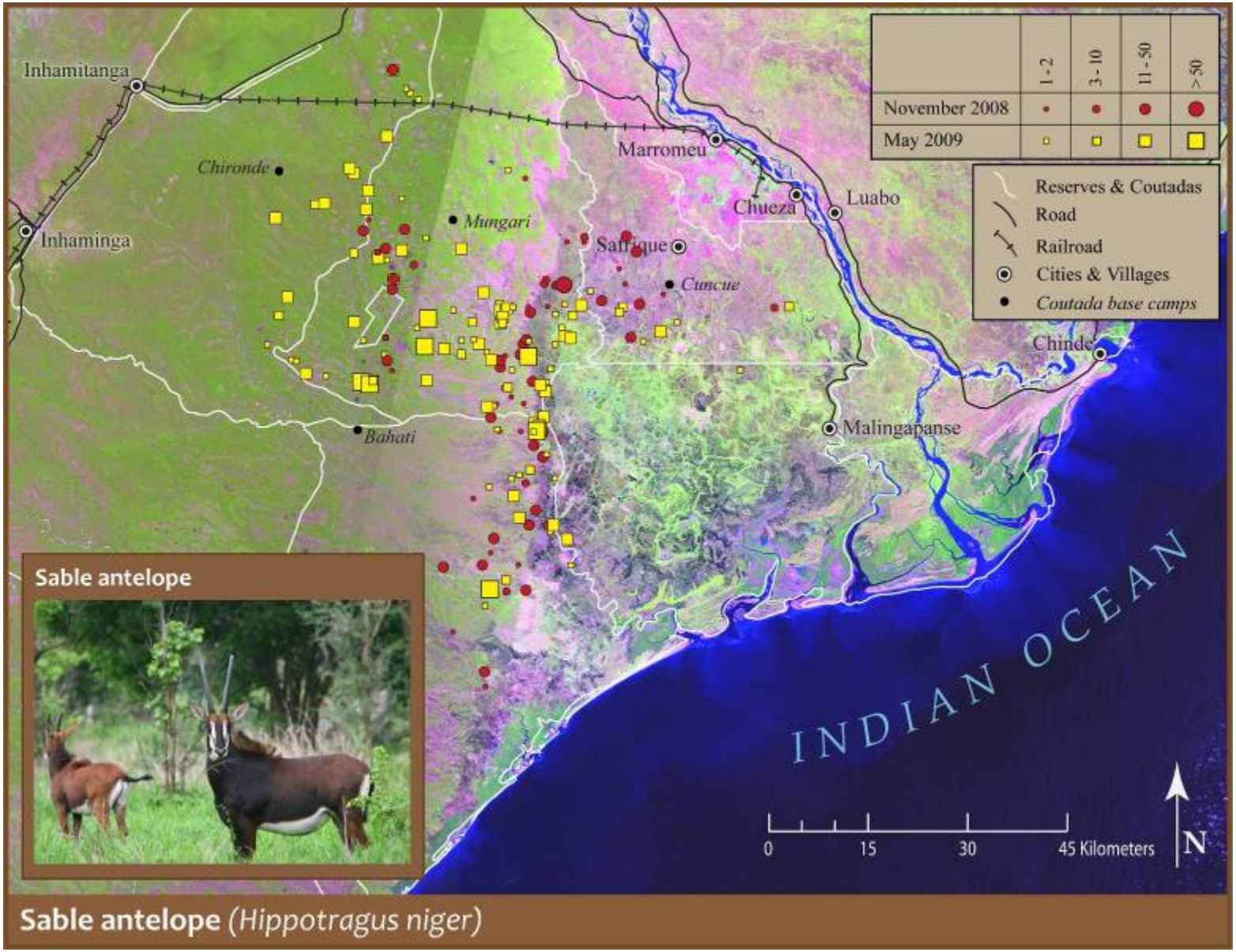

Figure 8. Distribution of sable antelope in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

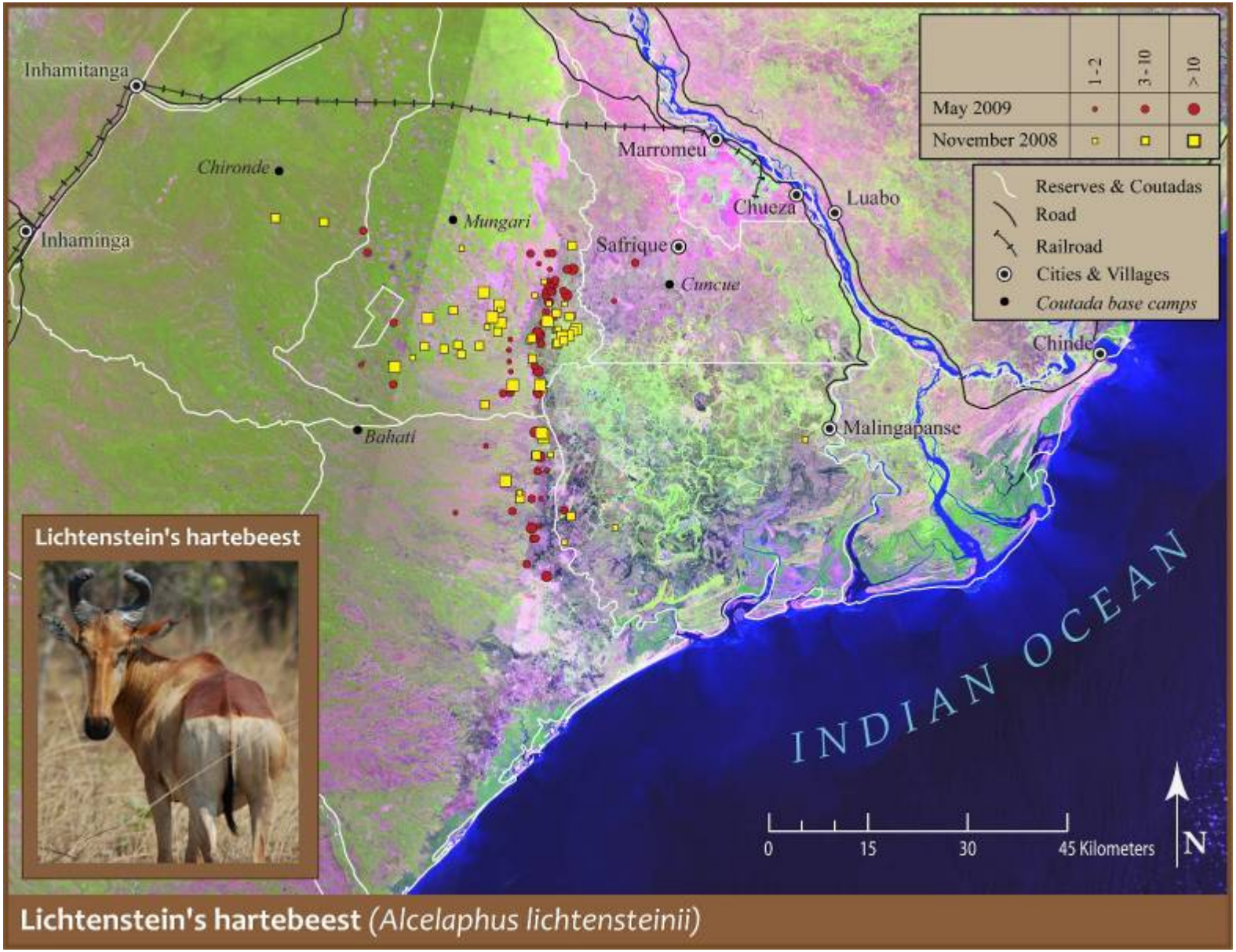

Figure 9. Distribution of Lichtenstein's hartebeest in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

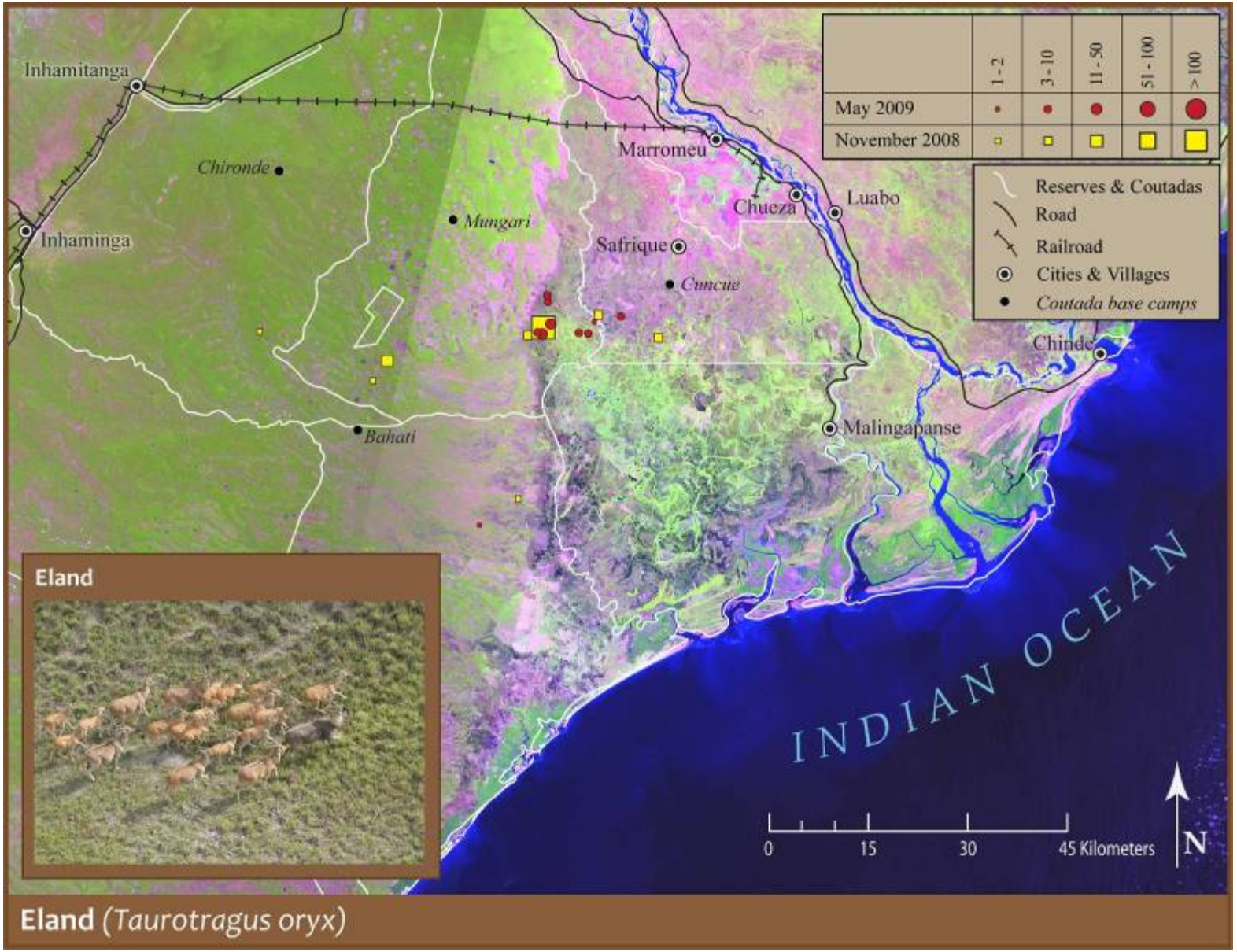

Figure 10. Distribution of eland in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

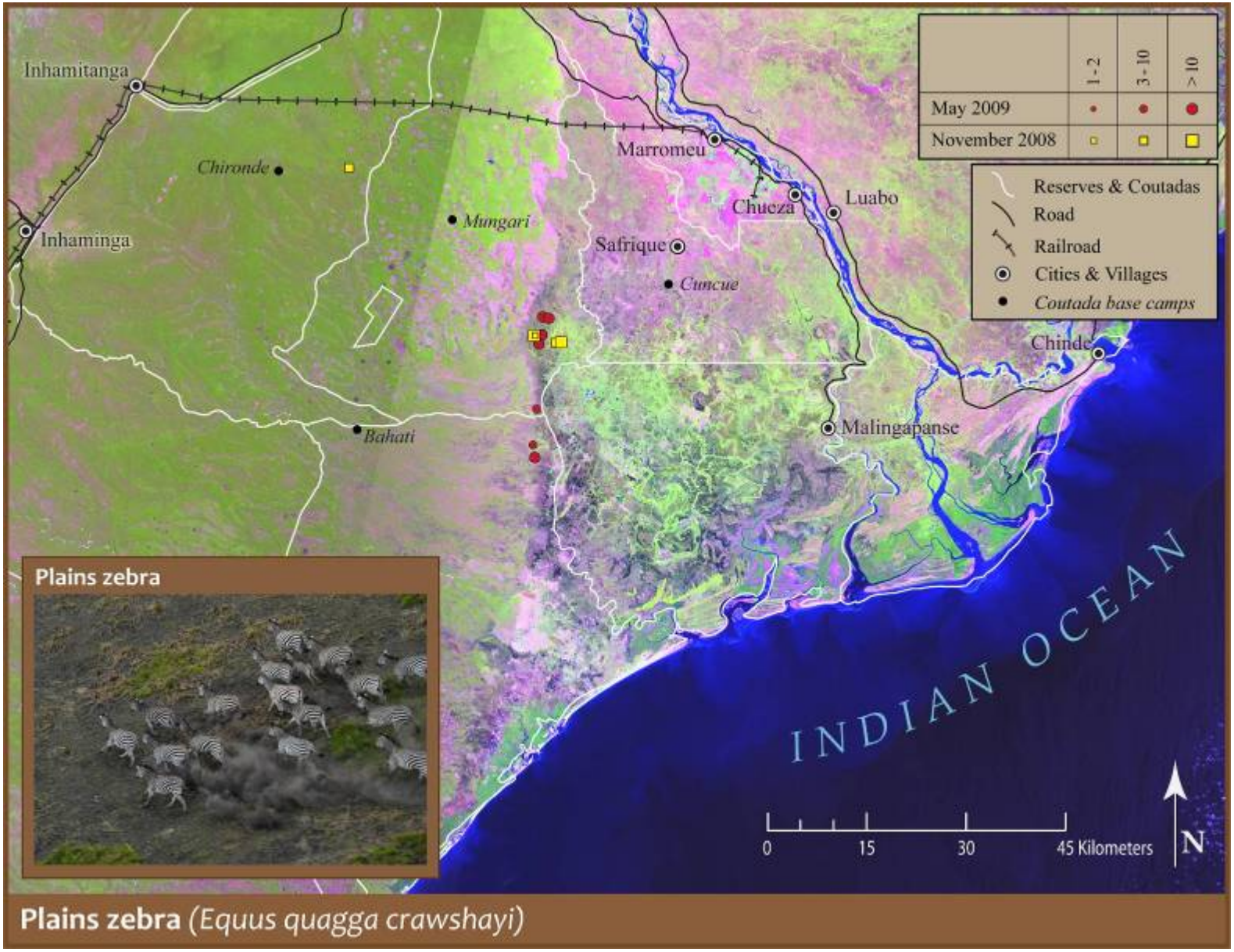

Figure 11. Distribution of plains zebra in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

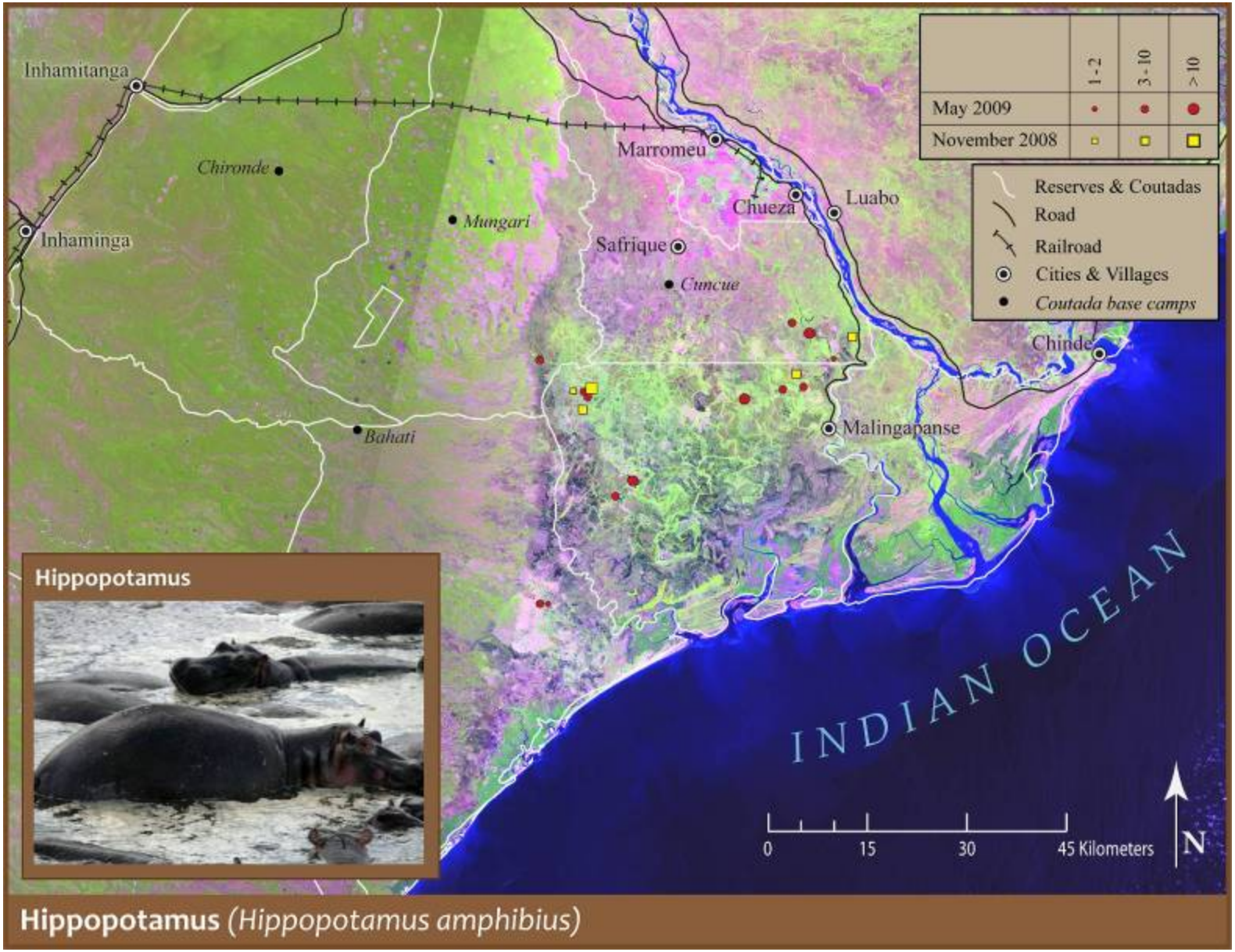

Figure 12. Distribution of hippopotamus in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

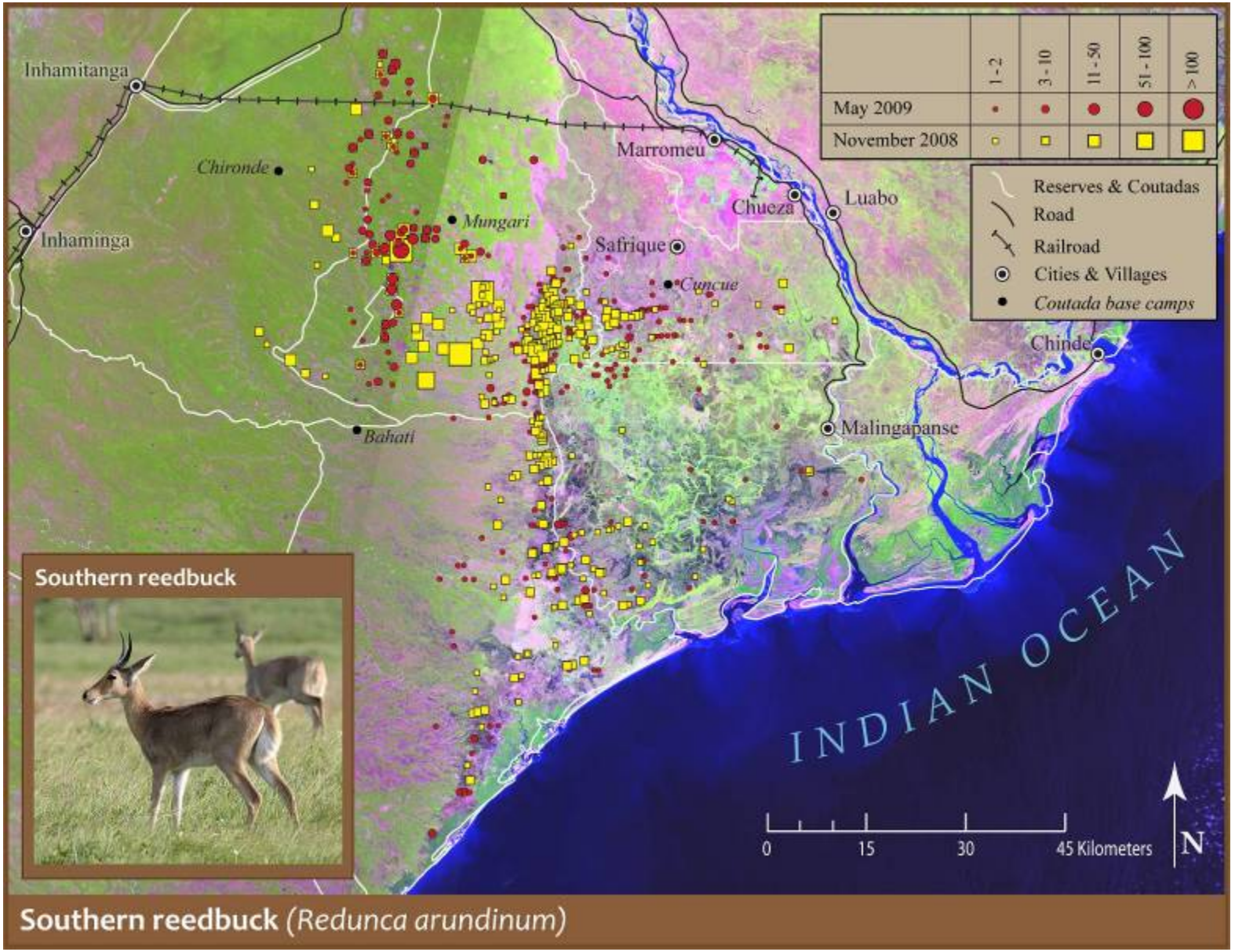

Figure 13. Distribution of reedbuck in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

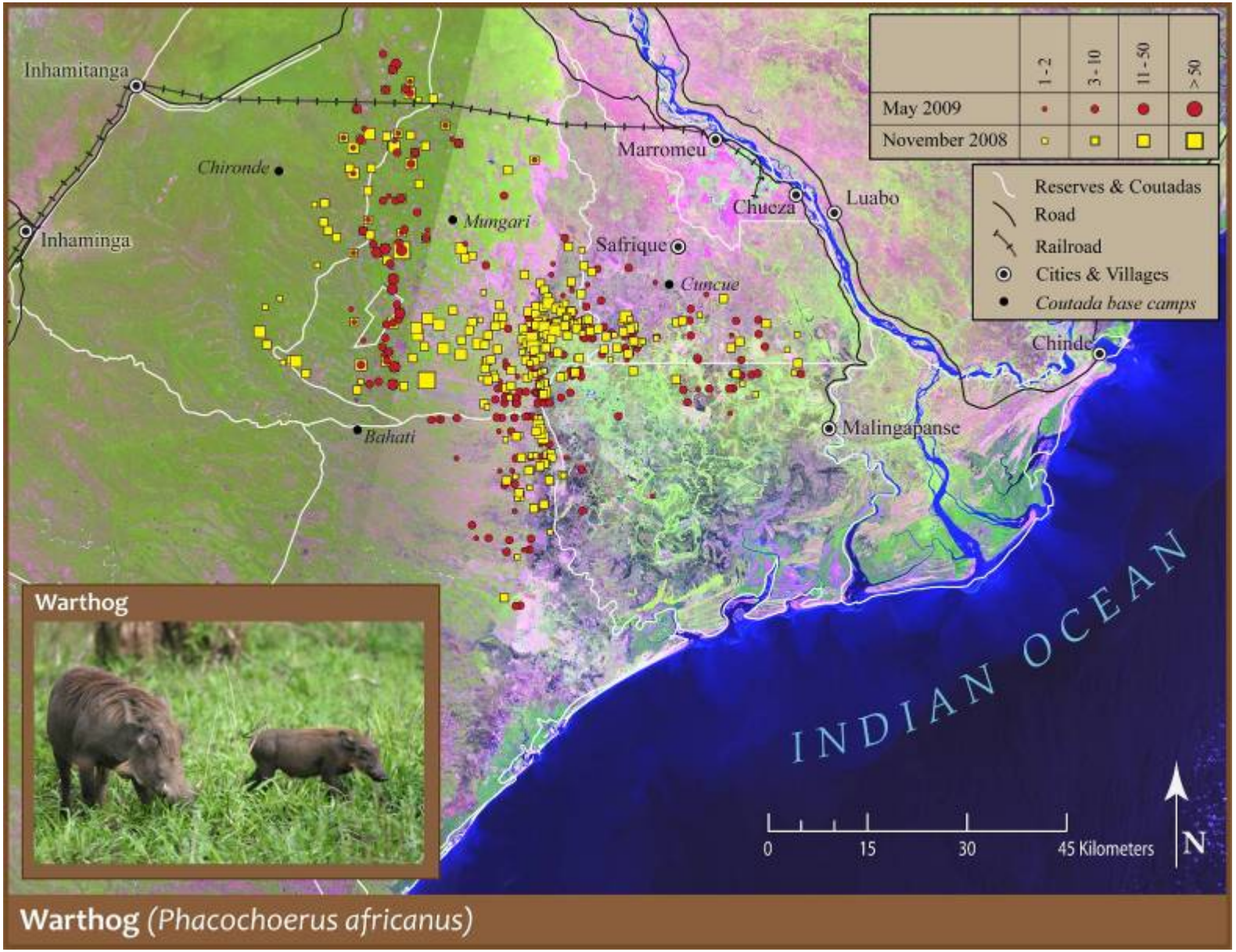

Figure 14. Distribution of warthog in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

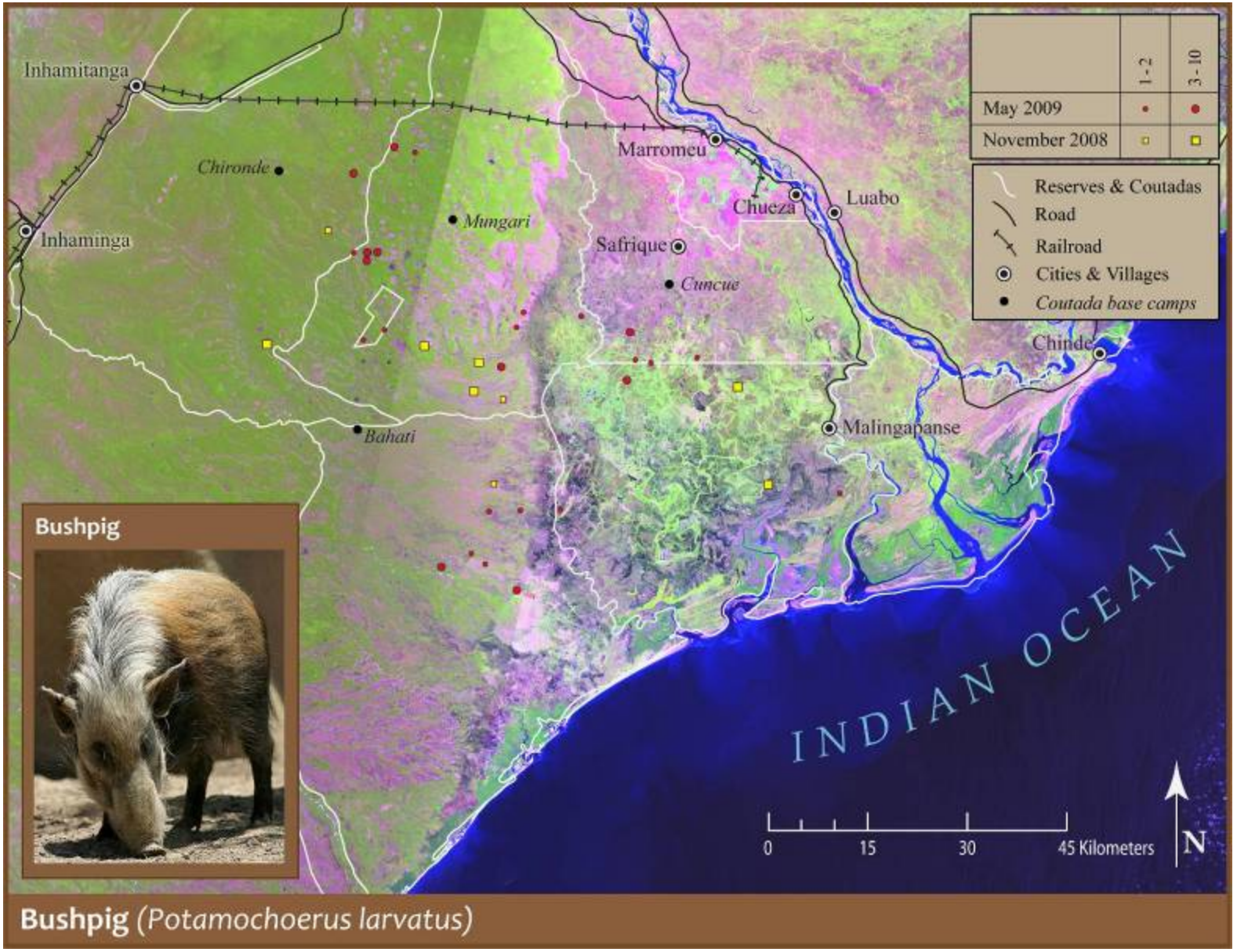

Figure 15. Distribution of bushpig in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

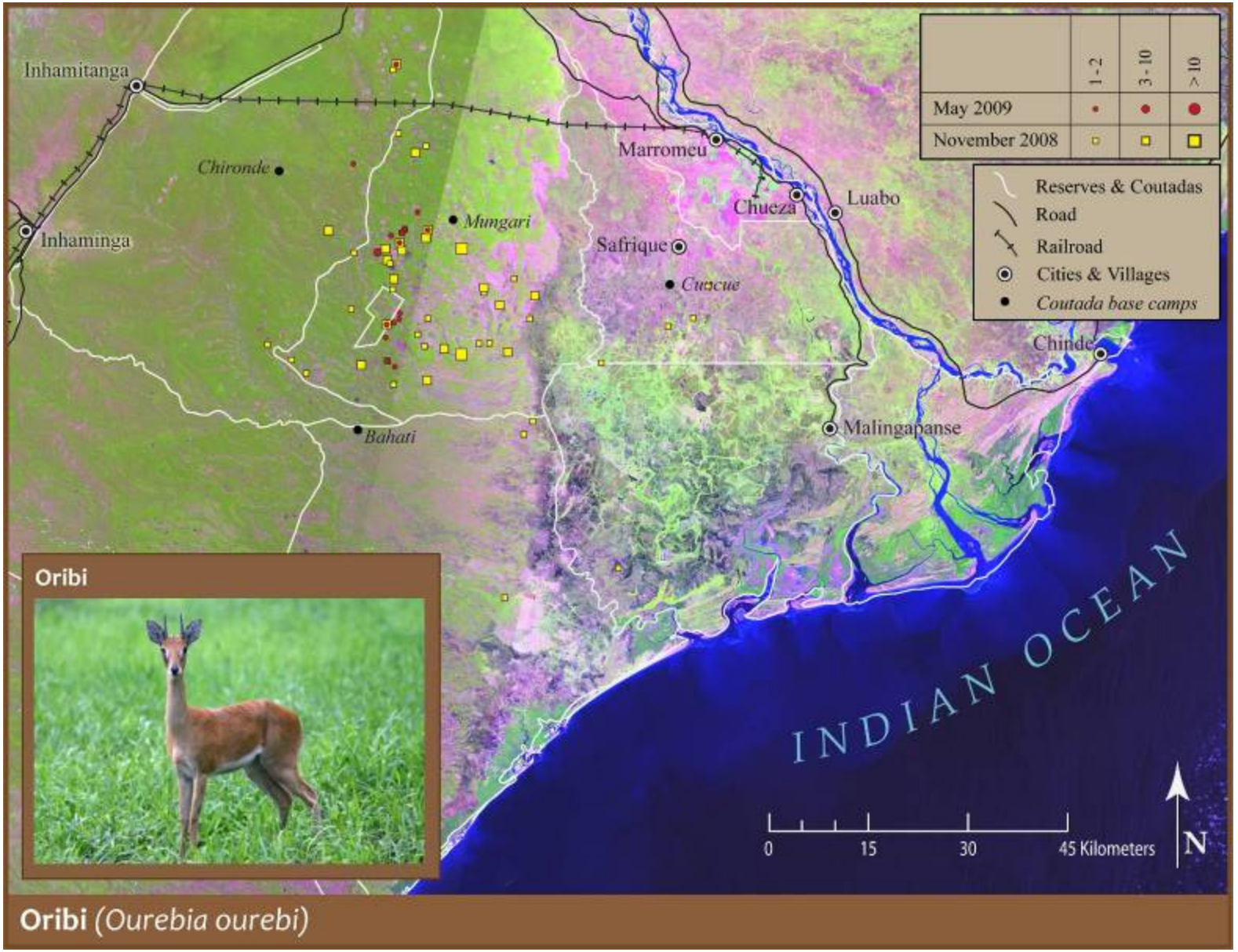

Figure 16. Distribution of oribi in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

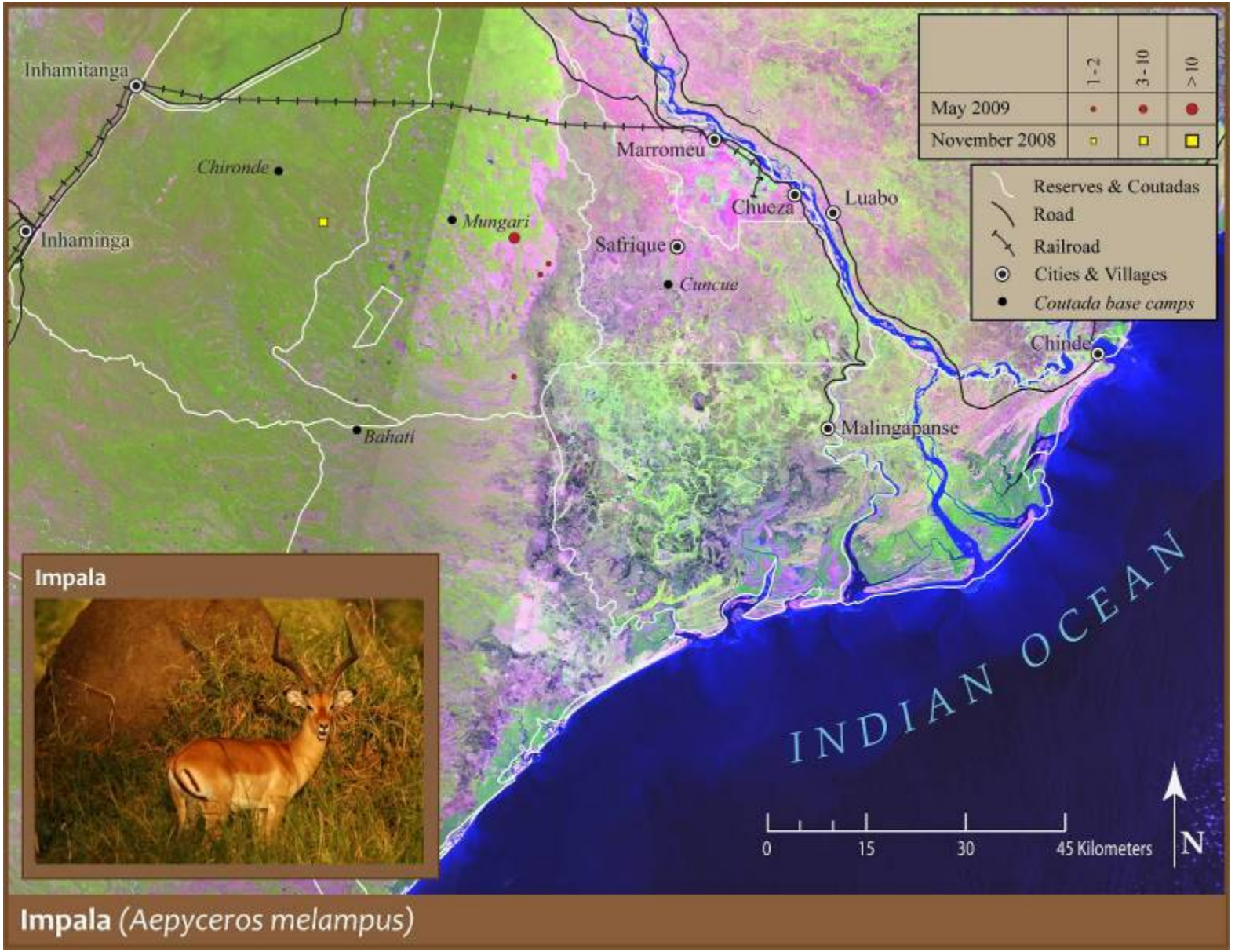

Figure 17. Distribution of impala in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

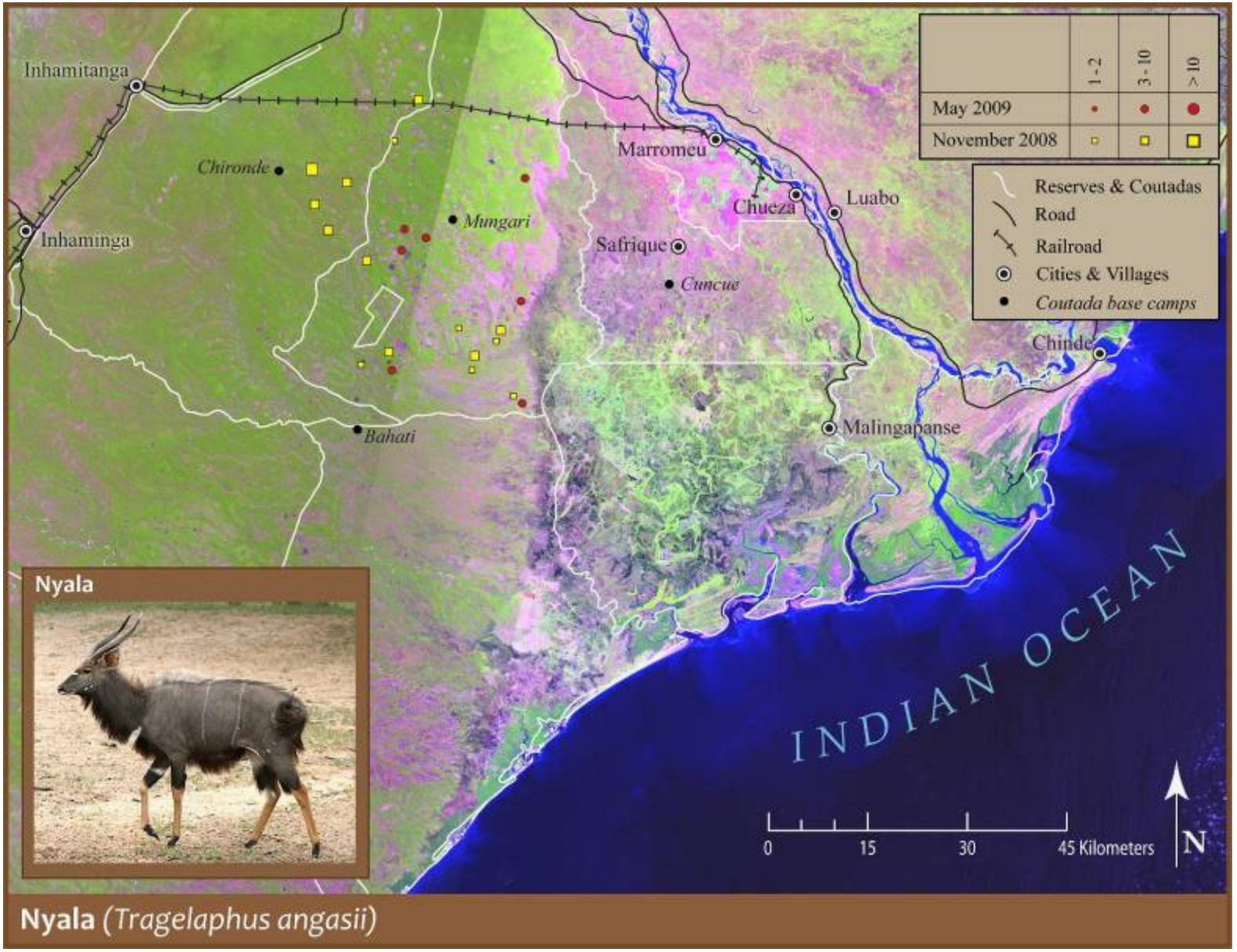

Figure 18. Distribution of nyala in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

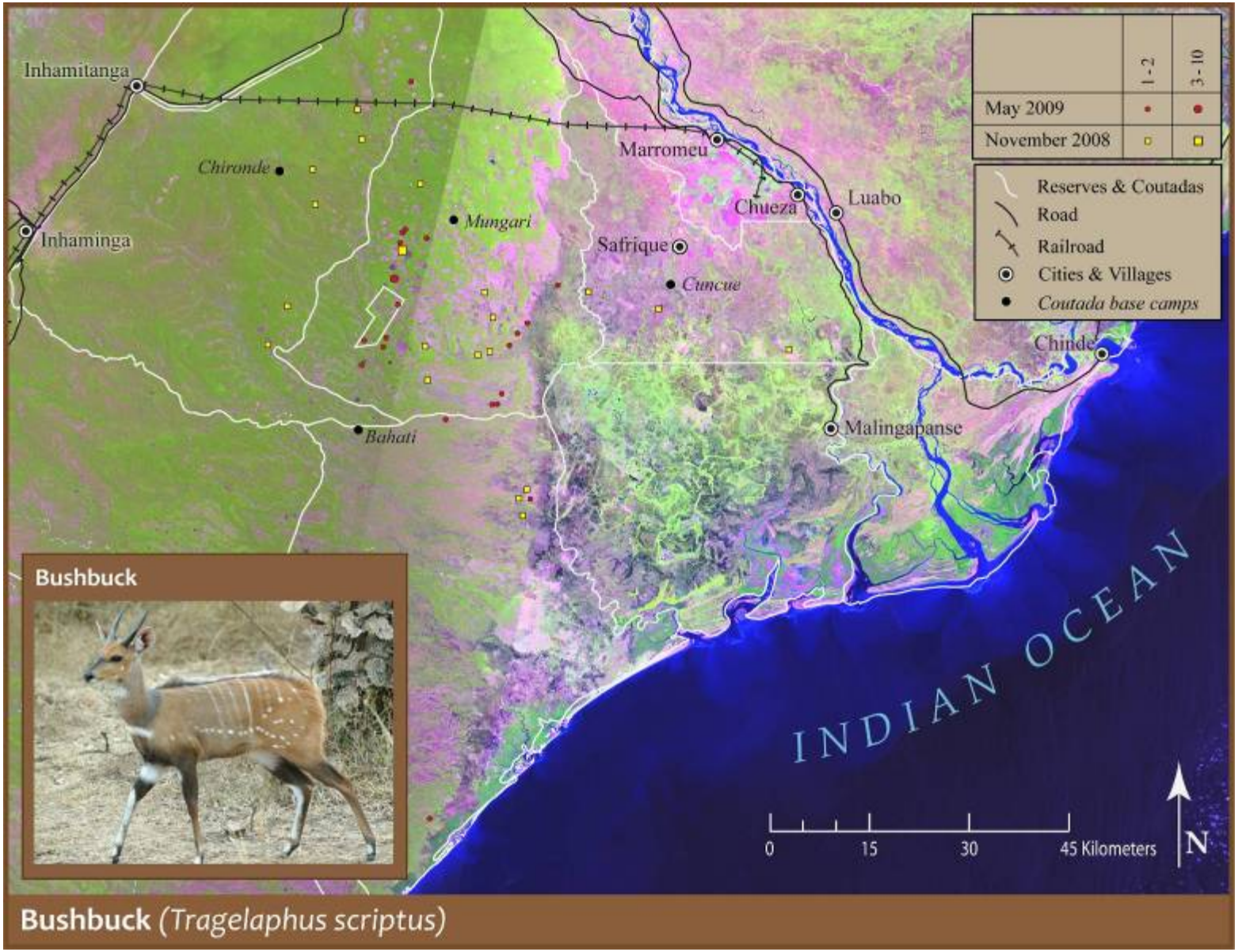

Figure 19. Distribution of bushbuck in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

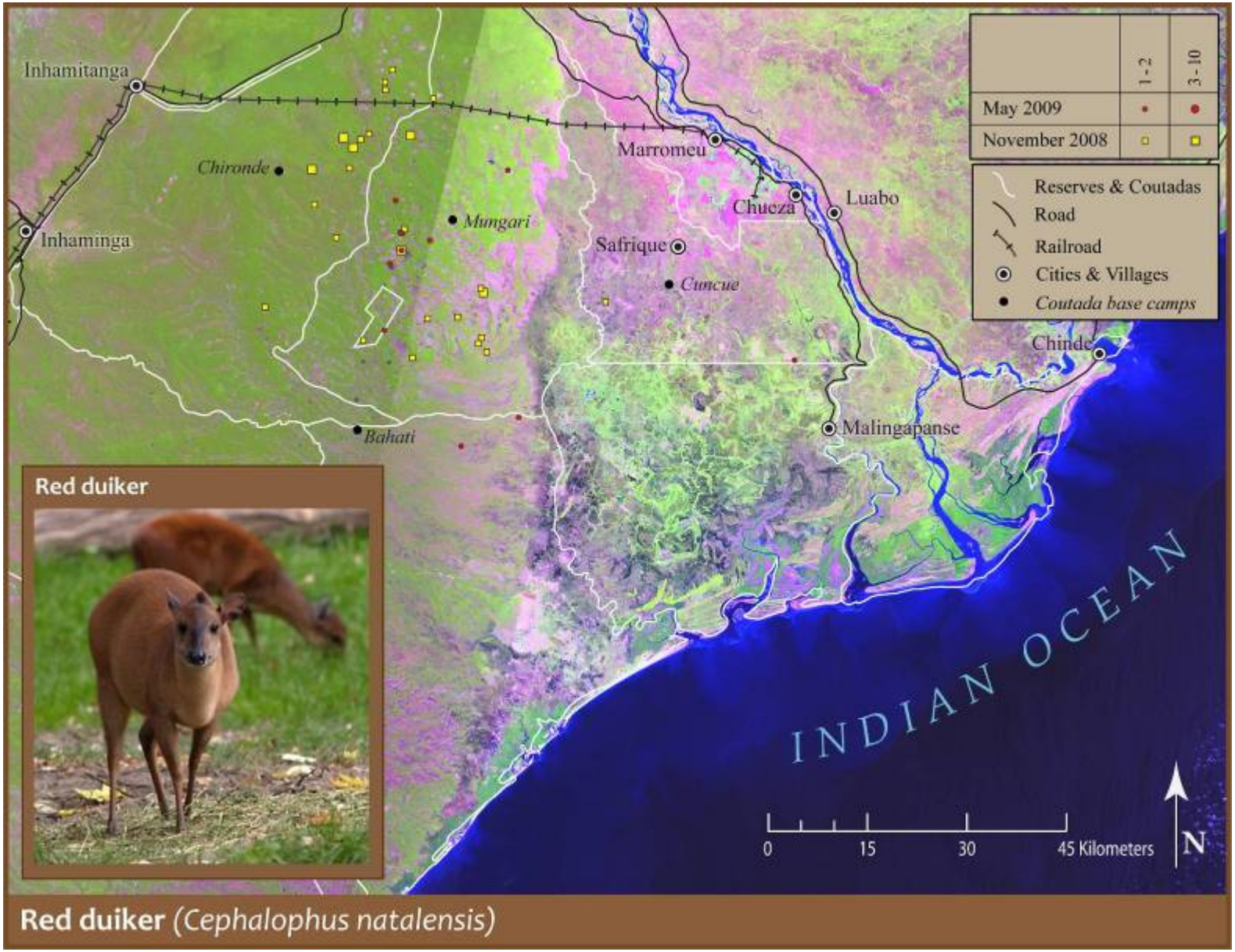

Figure 20. Distribution of red duiker in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

Figure 21. Distribution of grey crowned crane in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

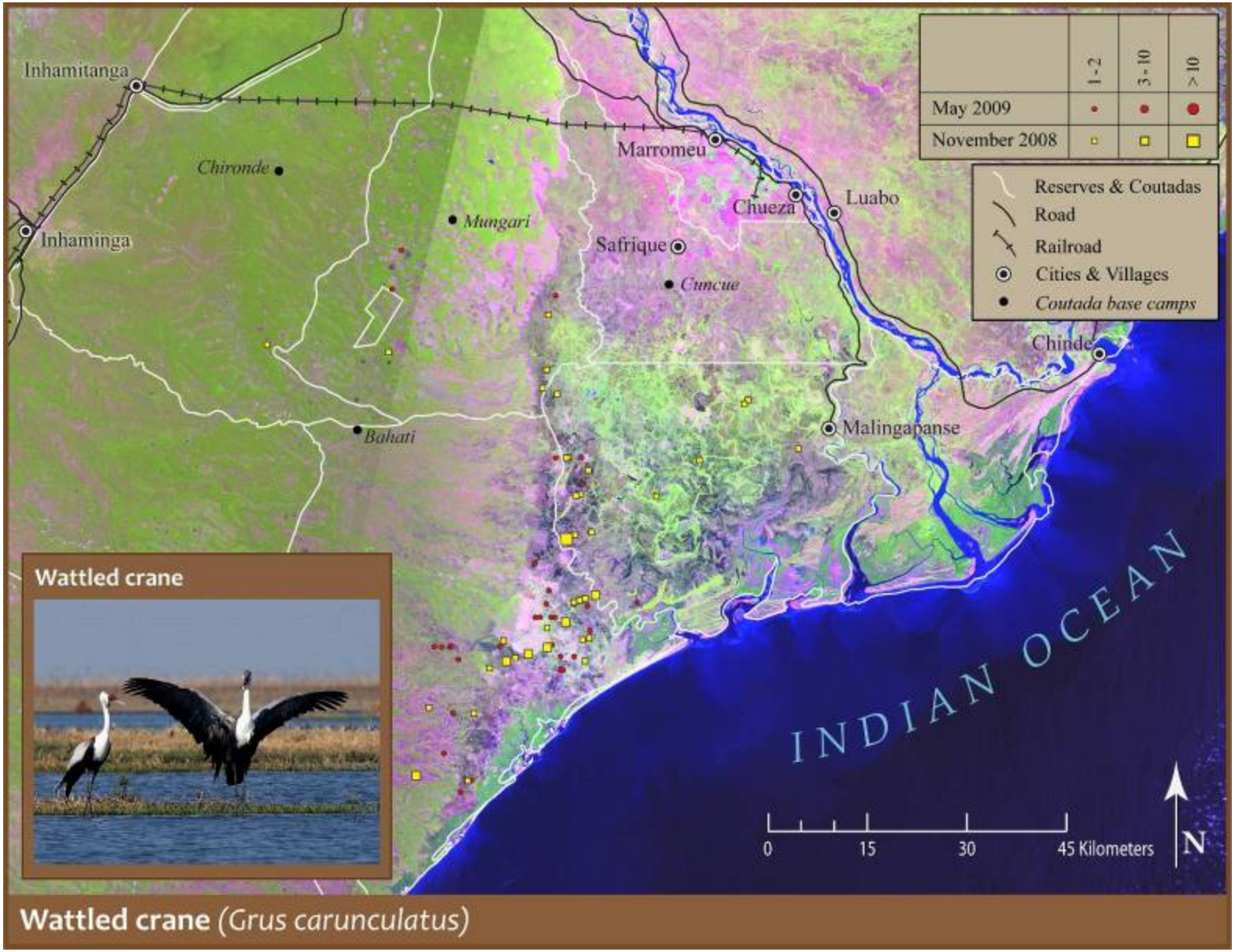

Figure 22. Distribution of wattled crane in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

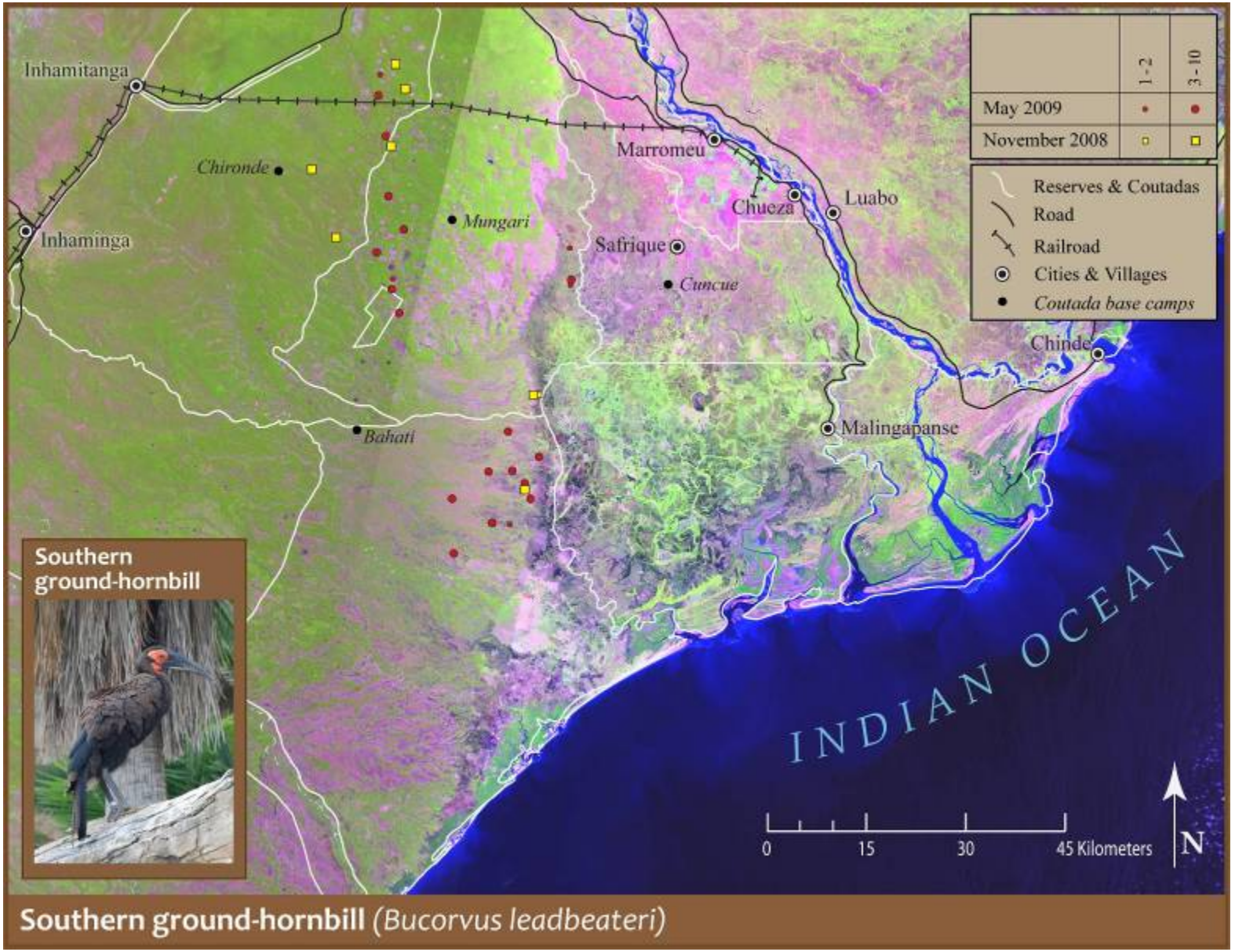

Figure 23. Distribution of southern ground-hornbill in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

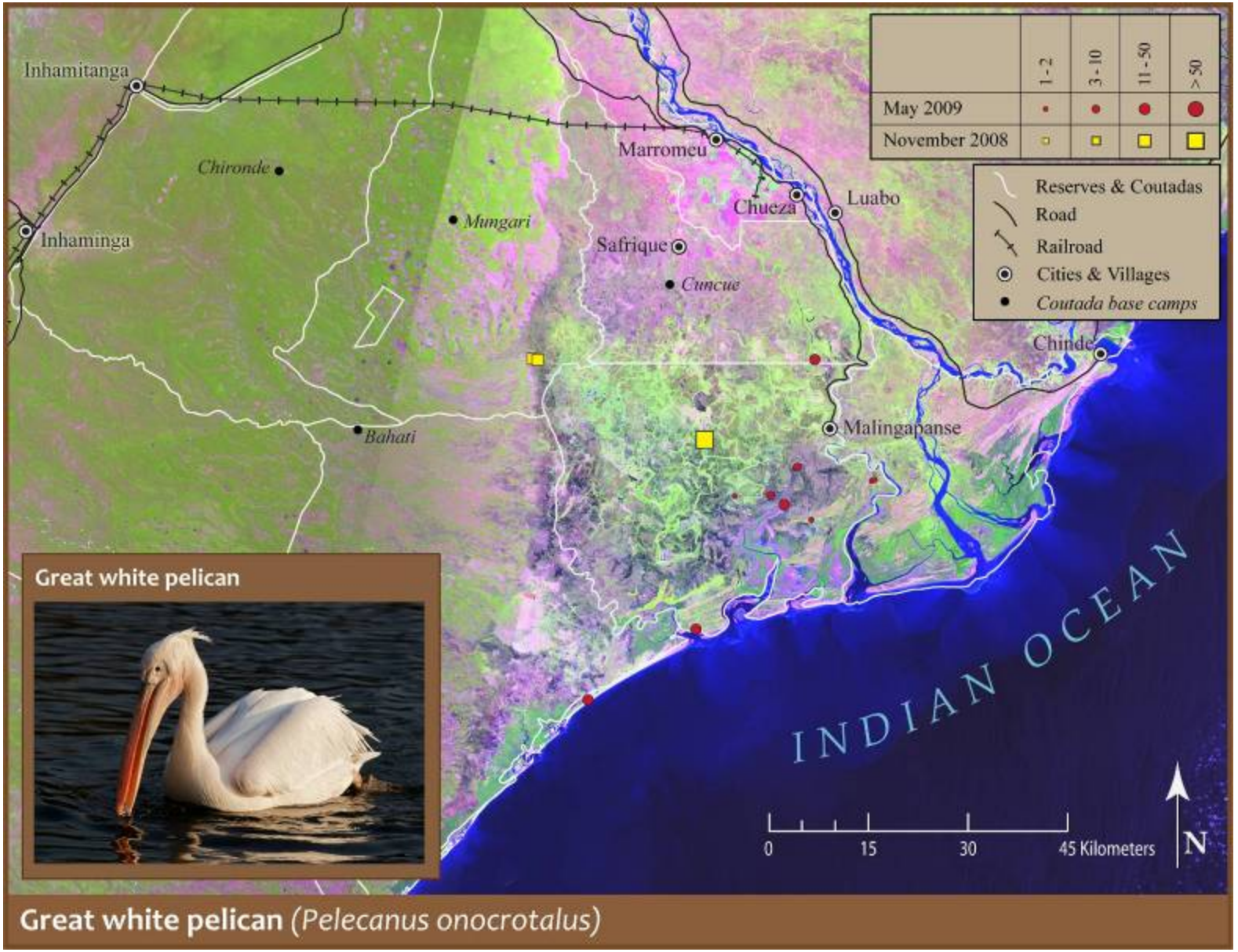

Figure 24. Distribution of great white pelican in the Marromeu Complex, based on November 2008 and May 2009 aerial surveys.

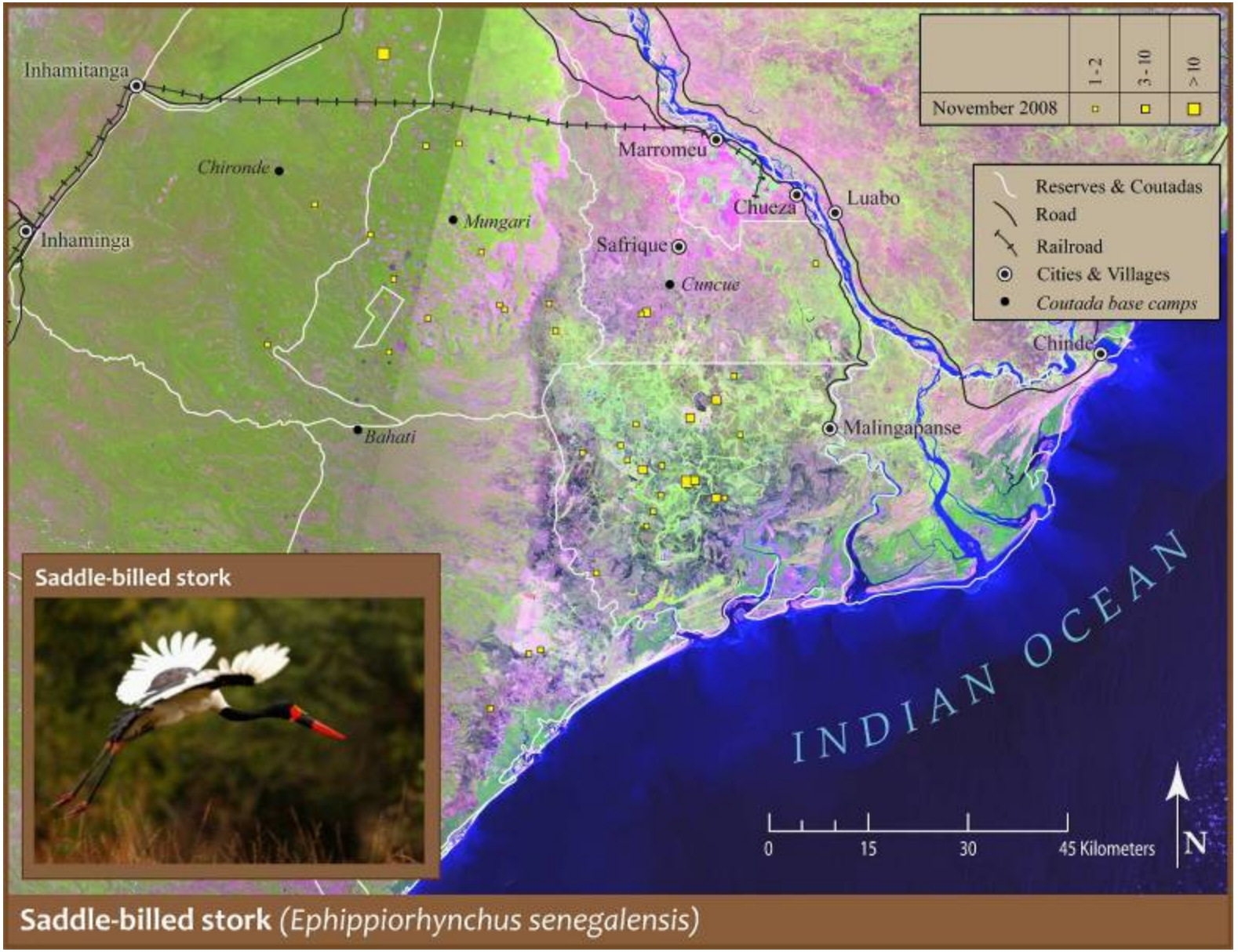

Figure 25. Distribution of saddlebilled storks in the Marromeu Complex, based on November 2008 aerial surveys.

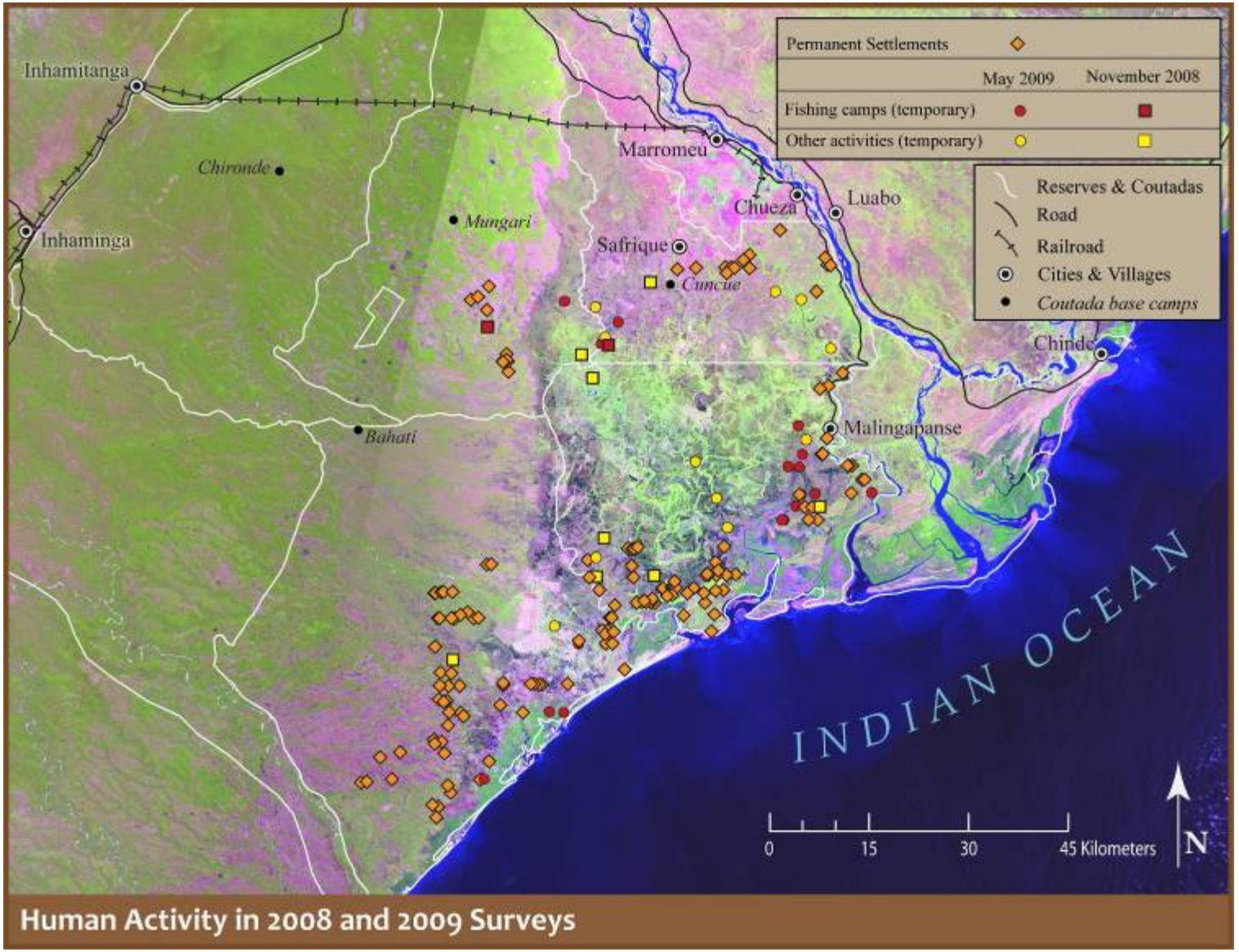

Figure 26. Occurrence of human activity in the surveyed area of the Marromeu Complex, including permanent settlements and fishing camps, and other temporary activities such as cattle herding, based on November 2008 and May 2009 aerial surveys.

Discussion

Trends in wildlife numbers over the past forty years

Table 3 (African buffalo and African elephant) and Table 4 (other species) provide a comparison of estimated wildlife numbers in the Marromeu Complex over time dating back to the first aerial survey conducted in 1968. The pre-war period was characterized by steady increase in numbers for most large ungulates in the Marromeu Complex. Figure 26 shows the distribution of three of the twelve principal ungulates --- African buffalo, waterbuck, and plains zebra—in December 1968. By the late 1970s, total numbers of the principal ungulates of the Marromeu Complex reached an estimated 110,590 individuals, with a density of 23.9 individuals per km^2 on the open floodplain. Total biomass exceeded 39,000 kg (Tello and Dutton 1979). This period was the culmination of the long-term recovery of wildlife numbers in the region after they were decimated for their skins and meat during World War II. Tinley (1975) speculates that the African buffalo numbers in the Marromeu Complex may have exceeded 130,000 in the 1930s.

In 1976, a joint venture between the Government of Mozambique (through the parastatal agency, EMOFAUNA) and the safari company Safrique was established to sustainably harvest wildlife from the Marromeu Complex for the provision of dry meat to the Sena sugar estates and other regional markets. During the period 1976-1979, a total of 12,861 Africa buffalo, 1000 waterbuck, 20 plains zebra, 20 Lichtenstein's hartebeest, 20 reedbuck, and 10 hippopotamus were cropped (Tello and Dutton 1979). These operations ceased after 1979 due to civil warfare in the region.

The prolonged civil war had a profound impact on the status and distribution of wildlife in the Marromeu Complex. The systematic decimation of wildlife is a staggering indictment of the well-organized, large-scale poaching operations that thrive during times of socio-political unrest. Regionally, large mammal decline in central Mozambique exceeded 120,000 individuals between 1980-94 and is comparable in magnitude to the worst reported declines in modern warfare history, including the 1979-87 Ugandan civil war (Anderson *et al.* 1990; Dudley *et al.* 2002; Eltringham & Malpas 1993). Only three species (African buffalo, waterbuck, southern reedbuck) were observed during the first post-war aerial surveys in 1994, almost none from the ground. The Africa buffalo population was reduced by 95% to fewer than 2,400 individuals. Waterbuck, hippopotamus, and plains zebra declined by >98%. The declines in the numbers of all species during the period 1979-1994 were so large that they greatly exceeded any variations due to differences in survey methods.

During the post-war period since 1994, most ungulate species in the Marromeu Complex have steadily recovered through the growth of small remnant populations and immigration from the surrounding landscape. No species were extirpated from the region. Figure 27 provides a snapshot of the recovery of African buffalo, waterbuck, and plains zebra as of October 2000.

The current population of Africa buffalo exceeds 10,300 individuals, with additional numbers of resident buffalo in the miombo woodlands of the Cheringoma escarpment. Large herds are once again grazing down and trampling vast areas of flooded grasslands of the Marromeu Reserve. Over the past decade the population has grown at an average annual rate of about 12%, despite the possible die-off of >1,500 individuals or more during the extensive floods of 2001 (a reconnaissance flight by Dutton and Beilfuss, reported in Dutton et al. 2002, noted extensive mortality of buffalo due to starvation and drowning associated with the rapid, widespread flooding that resulted from emergency water releases from Cahora Bassa Dam). The lower count in 2007 (7,111 buffalo, or 6.9% reduction relative to the previous year) is attributed to poor visibility due to dense smoke on the floodplain (M. Haldane *pers. obs.*) and all of the surveys were undercounts as they did not survey the Cheringoma escarpment.

African elephant numbers have reached approximate pre-war levels, with recent total counts suggesting a population of about 350-400 individuals (Table 4). Hippo have re-established several pods on the floodplain but remain drastically reduced relative to historic levels (<5% of pre-war population) with corresponding minimal influence on the floodplain grazing regime and river geomorphology relative to historic times (e.g., Naiman & Rodgers 1997). This reduction, and corresponding reduction in large predators especially lion, may be enabling other species to thrive in the complex. Numbers of Sable antelope may now exceed historical population levels, and eland, Lichtenstein's hartebeest, and southern reedbuck numbers are also approaching their historic population levels. Waterbuck are also steadily increasing on the floodplain, but remain far below historic numbers which exploded in the decade prior to civil war.

Of highest conservation concern is the unique "Selous" zebra population[3] that occurs in the greater Gorongosa-Marromeu region. A viable population likely persisted after the civil war (estimated population >1,200 individuals), but continued to decline over the next decade. Today the population is slowly expanding again, and nine colts were observed in the population during November 2008, but likely fewer than 100 individuals remain in the Marromeu Complex. The species is nearly extirpated from neighboring Gorongosa National Park. The decline may be attributed to selective hunting pressure for their valuable hides, and zebra propensity for poor reproductive success when their social structure is disrupted (Moehlman 2002). Substantial numbers of zebra also may have drowned during the 2001 floods (J. Strasheim, *pers. com.*)

Implications for wildlife conservation and management in the Marromeu Complex.

The General Management Plan for the Marromeu Complex recognizes two important wildlife assemblages for conservation and management strategies: (1) locally rare and threatened species and (2) wildlife trophy species.

The locally rare and threatened species assemblage includes species that comprise the "Marromeu Complex Red Data List" of species that are regionally or globally threatened and vulnerable to local extirpation from the Marromeu Complex:

- Plains "Selous" Zebra (rare, morphologically-unique population)
- Hippopotamus (rare, <5% of historic population level)
- Impala (rare or uncommon, recently established)
- Sharpe's grysbok *Raphicerus sharpei* (rare, poorly known)
- Wild dog *Lycaon pictus* (Endangered, poorly known)
- Lion *Panthera leo* (Vulnerable)
- Spotted Hyena *Crocuta crocuta* (rare or uncommon, poorly known)
- Cape clawless otter *Aonyx capensis* (regional decline, poorly known)
- Wattled Crane (Vulnerable)
- Grey Crowned Crane (Endangered)
- Southern ground-hornbill (regional decline)

[3] Although the "Selous" zebra has been described as a distinct sub-species in popular press, this status is not conferred by the IUCN/SSC Equid Specialist Group (Moehlman 2002).

The present study confirms that plains zebra remain rare and highly vulnerable in the Marromeu Complex. Impala are rare, though increasing in numbers in drier areas of the complex. Hippopotamus are likewise recovering in numbers, on the open plains, but remain greatly diminished relative to historic numbers. These species should be assigned no quota (or at most an extremely limited and closely monitored quota) for trophy hunting. With proper management and recovery, however, these species could soon become valuable wildlife trophy species in the future and at present they provide important ecotourism values.

The trophy hunting assemblage includes large mammal species of regional conservation concern that have viable, increasing populations in the Marromeu Complex which can be sustainably hunted:

- Blue duiker *Philantomba monticola*
- African Buffalo
- Bushbuck
- Bushpig
- Eland
- African Elephant
- Lichtenstein's hartebeest
- Greater kudu
- Leopard *Panthera pardus*
- Nyala
- Oribi
- Red duiker
- Southern reedbuck
- Sable
- Suni
- Common warthog
- Waterbuck

The present study confirms the suitability of these species for scientifically-based, sustainable hunting quotas. These species are an important source of revenue, and provide income (twenty percent share of revenue) and meat for local communities. Cunliffe *et al.* (2007) provide useful recommendations for assigning hunting quotas based on trophy value for these species. However, several species are subject to intensive hunting pressure for bushmeat, most notably suni, blue duiker, and red duiker, and should remain on watch list for possible inclusion on the ""Marromeu Complex Red Data List" if numbers begin declining. Trophy wildlife species are also an important focal point for ecotourism development if hunted and managed sustainably.

The General Management Plan for the Marromeu Complex identifies fifteen factors that are currently, or could likely, have a significant negative affect on these wildlife assemblages. These threats can be broadly categorized as:

1) Degradation of the quantity (timing, magnitude, duration, frequency) and quality of water resources
    - Increased frequency & severity of drought-induced water scarcity due to climate change
    - Dredging & canalization of the Zambezi River for river transportation
    - Inappropriate flow releases from Zambezi River dams
    - Obstructions to Zambezi River-floodplain water movement caused by dykes for roads, railroads, & sugar estates
    - Dams & water diversions on the Cheringoma escarpment

- Agro-industrial drainage & pollution (eutrophication) from commercial sugar expansion

2) Uncontrolled fires

3) Prospecting, drilling, & mining for oil, natural gas, & other resources

4) Degradation and loss of woodland and forest ecosystems on the escarpment
   - Smallholder shifting agriculture
   - Charcoal production & fuelwood collection
   - Unsustainable logging for export & building materials
   - Eucalyptus & other agro-forestry plantations

5) Unsustainable wildlife hunting
   - Illegal hunting for bushmeat trade & subsistence
   - Unsustainable trophy hunting

In addition to growing regional development interests, ever-increasing human settlements throughout the Marromeu Complex are a significant driver of most of these threats.

Management strategies to ameliorate these threats are described in detail in the management plan, and include:

1) Zoning strategies to prohibit or regulate land use practices that threaten the biodiversity and ecosystem services of the Marromeu Complex and to encourage ecologically-sensitive land use practices
2) Biodiversity conservation strategies aimed at reducing threats to conservation targets in the Marromeu Complex; and
3) Sustainable livelihoods strategies to improve local livelihoods based on the ecosystem service targets provided by the Marromeu Complex;

Recommendations for future wildlife monitoring in the Marromeu Complex

1. Conduct annual surveys of the Marromeu Complex.

Annual surveys will provide an ongoing record of wildlife recovery, the impact of hunting operations, and the effectiveness of management in reducing bushmeat, fires, and other threats to wildlife. More frequent surveys will also build stakeholder trust in wildlife population estimates, as trends are more clearly discerned from year-to-year fluctuations. If funding is not sufficient for annual surveys, surveys should be conducted as frequently as funding permits rather than reducing survey coverage.

2. Conduct surveys at the end of the dry season in November.

Although no single time period is ideal of all wildlife species of conservation interest, most large herbivores reach their maximum concentrations on the floodplain just prior to the rainy season when water resources are widely restricted to the ecotone and floodplain region. The woodland and forests of the Cheringoma escarpment are a challenge to survey at any time of year. In theory, aerial surveys will provide more accurate estimates of the numbers of large herbivores if the surveys are conducted when

the *Brachystegia* woodland is largely leafless. In practice, leaf fall on the Cheringoma is asynchronous and visibility is always poor.

3. Implement the standardized survey methodology, with consideration of increased coverage of Coutada 10 and 14

The annual survey program should repeat the aerial survey strata for the floodplain total count and sample estimate and the ecotone total count, as described in this report and Figure 2. Animals are more difficult to see when the sky is cloudy, so it is preferable to conduct aerial surveys when the weather is sunny. We recommend repeating the aerial reconnaissance of wetlands on the Cheringoma escarpment, based on a standardized number of sites repeated each survey year (refer to text and Figure 3). The pans and drainage lines must be surveyed at the same time of day. We recommend surveying over 2-3 successive days between 4-6 pm.

Given that survey methods have been implemented inconsistently over time, yielding results that are difficult to interpret and compare over time, the value of conducting regular counts and sample estimates using a standardized methodology outweigh the benefits of continually tweaking survey methods. However, consideration should be given to extending the aerial survey transects further to the west to improve coverage of Coutada 10. The relatively open miombo woodland interspersed with grassland on alluvial fan drainage lines in Coutada 10 might offer reasonable wildlife detection rates. These transects should terminate where the open miombo gives way to more dense forest. The ecotone survey transects might also be extended several kilometres to the west into Coutada 11, until these relatively open areas give way to dense forest (best coverage by the pan survey). Surveys also may be extended to the north to improve coverage of Coutada 14.

We also recommend conducting one or more ground surveys in association with each survey. The ground survey coverage should be expanded to include the road networks of Coutada 10 and 14—requiring 2-3 additional days.

4. Use a collaborative survey team

The survey team represented an effective collaboration of key stakeholders for the Marromeu Complex, including representatives of the Government of Mozambique (e.g., Provincial Department of Tourism), academic institutions (e.g., University of Eduardo Mondlane), private sector (e.g., hunting concession operators), and non-government organizations (e.g., World Wide Fund for Nature).

5. Adopt an on-board data recording system

An on-board data recording system should be developed using a GPS navigational system linked to a notebook computer. With each sighting, species name and number are entered into the computer using codes, and their GPS location and flight paths are mapped in real time during the survey. Use of an onboard computer to record survey data also will reduce delays between when a group of animals is observed and when the recorder enters the observation into the database.

Table 3. Total counts of African buffalo and Africa elephant over the period 1968-present, based on total count aerial surveys[1].

Species	Dec 1968	Oct 1977	Oct 1978	Mar 1979	Sep 1990	Jul 1994	Nov 2000	Nov 2001	Nov 2004	Nov 2005	Nov 2006	Nov 2007	Nov 2008	May 2009
African buffalo	16,116	45,000	43,992	30,394	3,696	2,346	3,589	2,425	5,353	6,236	7,640	7,111	10,090	8,019
African elephant	257	331	361	373	326	0	219	421	--	--	388	355	267	351

[1]Exception: 1994 survey results based on a 10% sample survey.

Table 4. Population estimates for the seven ungulate species of the Marromeu Complex over the period 1968-present. Estimates are based on aerial surveys and best scientific judgement.

Species	1968	1977-1979	1990	1994	2000	2001	2008-2009
Method	Total count	Avg. three total counts	10% sample est.	9.76% sample est.	25% sample est.	25% sample est.	40% sample est. & total count
Eland	36	400	0	0	84	160	>200
Hippopotamus	250	3,000	137	0	48	68	>100
Lichtenstein's hartebeest	81	1,400	32	0	504	480	>500
Plains zebra	673	2,500	1,206	0	60	136	>60
Sable antelope	170	2,000	24	0	1,784	1,176	>2,000
Southern reedbuck	--	3,500	260	10	236	952	>2,500
Waterbuck	4,300	47,500	4,480	143	524	672	>2,500

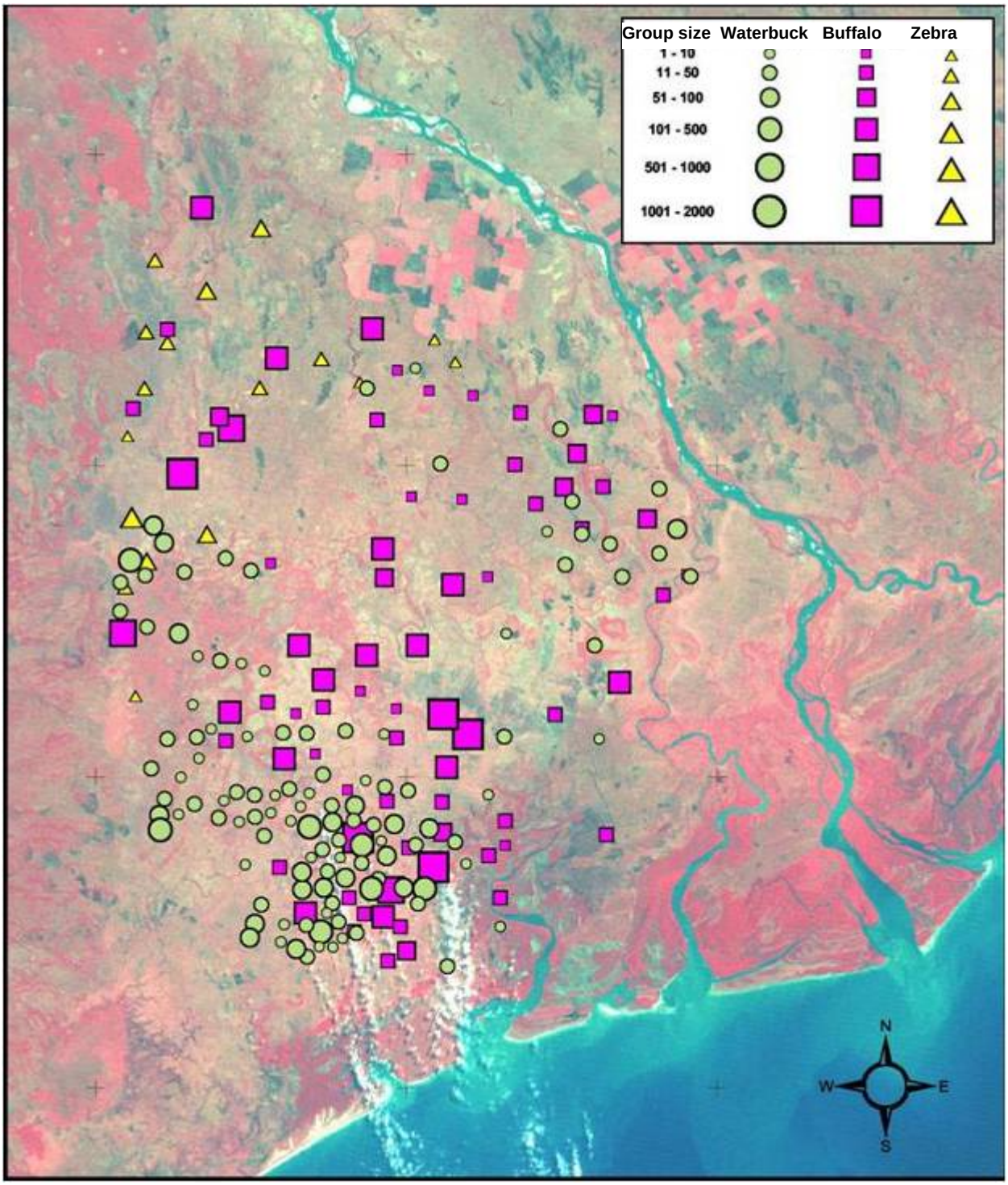

Figure 28. Distribution of African buffalo, waterbuck, and plains zebra in the Marromeu Complex, based on December 1968 aerial survey (Tinley 1969).

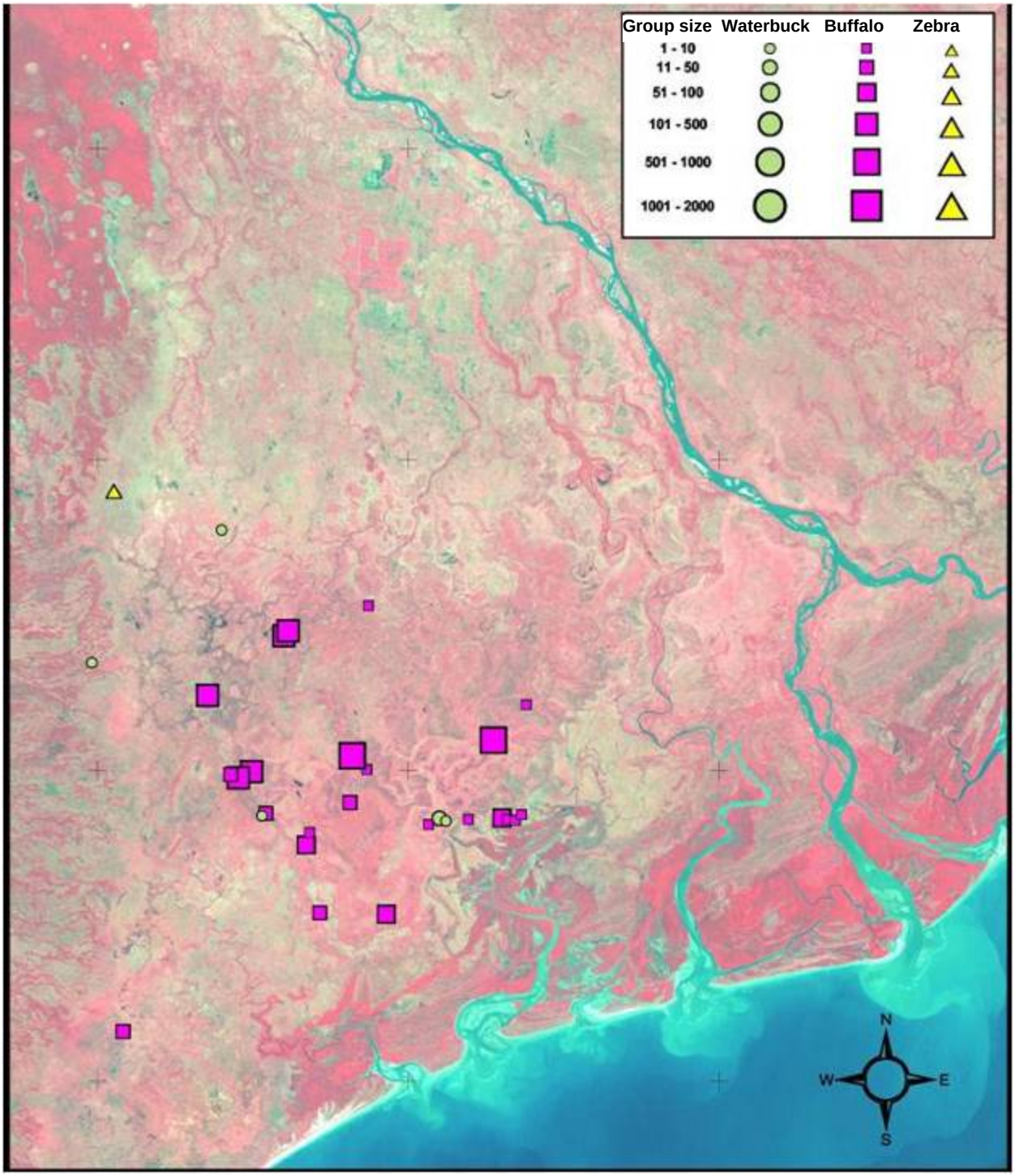

Figure 29. Distribution of waterbuck, African buffalo, and plains zebra in the Marromeu Complex, based on October 2000 aerial surveys (Dutton *et al.* 2002).

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Appendix 1. Actual count, population estimate, and 95% confidence intervals for species recorded on the floodplain strata (40% sample).

November 2008

Species	Actual count	Population estimate	95% confidence interval
Bushbuck	7	18	--
Bushpig	19	48	--
Eland	5	13	--
Great white pelican	54	135	--
Grey crowned crane	16	40	--
Hippopotamus	46	115	--
Lichtenstein's hartebeest	117	308	±375
Oribi	7	18	--
Sable antelope	510	1275	±885
Saddlebilled stork	93	232	±123
Southern reedbuck	476	1190	±571
Warthog	372	930	±670
Waterbuck	742	1855	±1291
Wattled Crane	100	250	±145
Southern ground-hornbill	9	23	--

Note: confidence intervals were not calculated for species with highly clumped distribution, because the assumption of (quasi-) normal distribution could not be satisfied.

May 2009

Species	Actual count	Population estimate	95% confidence interval
Bushbuck	3	8	--
Bushpig	23	58	--
Eland	1	3	--
Great white pelican	113	283	--
Grey crowned crane	42	105	--
Hippopotamus	97	243	--
Lichtenstein's hartebeest	123	307	±237
Plains zebra	13	33	--
Sable antelope	327	817	±560
Southern reedbuck	150	375	±226
Warthog	232	580	±315
Waterbuck	1810	4525	±3022
Wattled Crane	58	145	±83
Southern ground-hornbill	40	100	±78

Note: confidence intervals were not calculated for species with highly clumped distribution, because the assumption of (quasi-) normal distribution could not be satisfied.

Appendix 2. Statistics and coordinates for the standardized survey program.

Aerial survey

Stratum name	Stratum area (km^2)	Transect spacing (km)	Transect orientation (°)	No. transects	% stratum sampled
Floodplain	3220	2.0	90	46	40.0
Ecotone	758	0.8	90	32	100.0

Aerial survey - floodplain stratum transects

No.	Length (km2)	Transect start		Transect end	
1	26	35.8383	-18.4291	36.0842	-18.4253
2	26	36.0845	-18.4433	35.8386	-18.4472
3	28	35.8389	-18.4652	36.1037	-18.4611
4	28	36.1040	-18.4791	35.8392	-18.4833
5	28	35.8395	-18.5013	36.1044	-18.4972
6	30	36.1236	-18.5149	35.8398	-18.5194
7	30	35.8401	-18.5374	36.1239	-18.5330
8	30	36.1243	-18.5510	35.8404	-18.5555
9	32	35.8407	-18.5735	36.1435	-18.5687
10	32	36.1439	-18.5868	35.8410	-18.5916
11	30	35.8413	-18.6097	36.1253	-18.6052
12	26	36.0877	-18.6238	35.8416	-18.6277
13	26	35.8419	-18.6458	36.0881	-18.6419
14	58	36.1073	-18.6596	35.5580	-18.6679
15	56	35.5583	-18.6860	36.0887	-18.6780
16	58	36.1080	-18.6957	35.5586	-18.7040
17	56	35.5588	-18.7221	36.0894	-18.7141
18	64	36.1655	-18.7309	35.5591	-18.7401
19	64	35.5594	-18.7582	36.1658	-18.7489
20	66	36.1851	-18.7666	35.5596	-18.7763
21	62	35.5599	-18.7943	36.1475	-18.7853
22	62	36.1479	-18.8034	35.5602	-18.8124
23	60	35.5605	-18.8304	36.1292	-18.8217
24	60	36.1296	-18.8398	35.5607	-18.8485
25	58	35.5610	-18.8665	36.1110	-18.8582
26	60	36.1302	-18.8759	35.5613	-18.8846
27	58	35.5616	-18.9027	36.1116	-18.8943
28	58	36.1120	-18.9123	35.5618	-18.9207
29	48	35.5621	-18.9388	36.0175	-18.9319

30	42	35.9609	-18.9509	35.5624	-18.9568
31	34	35.5627	-18.9749	35.8853	-18.9701
32	32	35.8666	-18.9885	35.5629	-18.9929
33	28	35.5632	-19.0110	35.8290	-19.0071
34	24	35.7913	-19.0258	35.5635	-19.0291
35	22	35.5638	-19.0471	35.7726	-19.0441
36	20	35.7539	-19.0624	35.5641	-19.0652
37	16	35.5643	-19.0832	35.7163	-19.0811
38	14	35.6976	-19.0994	35.5646	-19.1013
39	12	35.5649	-19.1193	35.6789	-19.1177
40	10	35.6602	-19.1360	35.5652	-19.1374
41	10	35.5654	-19.1555	35.6604	-19.1541
42	8	35.6417	-19.1724	35.5657	-19.1735
43	6	35.5660	-19.1916	35.6230	-19.1908
44	4	35.6043	-19.2091	35.5663	-19.2096
45	4	35.5666	-19.2277	35.6046	-19.2271
46	4	35.5859	-19.2455	35.5671	-19.2638

Aerial survey - Ecotone stratum transects

No.	Length (km2)	Transect start		Transect end	
1	29.60	35.5547	-18.4241	35.8347	-18.4202
2	29.60	35.8348	-18.4274	35.5548	-18.4314
3	29.60	35.5549	-18.4386	35.8349	-18.4346
4	29.60	35.8350	-18.4418	35.5550	-18.4458
5	29.60	35.5551	-18.4530	35.8351	-18.4490
6	29.60	35.8353	-18.4563	35.5552	-18.4602
7	29.60	35.5553	-18.4675	35.8354	-18.4635
8	29.60	35.8355	-18.4707	35.5554	-18.4747
9	29.60	35.5555	-18.4819	35.8356	-18.4779
10	29.60	35.8357	-18.4852	35.5557	-18.4891
11	29.60	35.5558	-18.4964	35.8358	-18.4924
12	29.60	35.8360	-18.4996	35.5559	-18.5036
13	29.60	35.5560	-18.5108	35.8361	-18.5068
14	29.60	35.8362	-18.5140	35.5561	-18.5180
15	29.60	35.5562	-18.5253	35.8363	-18.5213
16	29.60	35.8364	-18.5285	35.5563	-18.5325
17	29.60	35.5564	-18.5397	35.8366	-18.5357
18	29.60	35.8367	-18.5429	35.5565	-18.5469
19	29.60	35.5566	-18.5542	35.8368	-18.5501
20	29.60	35.8369	-18.5574	35.5567	-18.5614
21	29.60	35.5568	-18.5686	35.8370	-18.5646

22	29.60	35.8372	-18.5718	35.5569	-18.5758
23	29.60	35.5571	-18.5830	35.8373	-18.5790
24	29.60	35.8374	-18.5863	35.5572	-18.5903
25	29.60	35.5573	-18.5975	35.8375	-18.5935
26	29.60	35.8376	-18.6007	35.5574	-18.6047
27	29.60	35.5575	-18.6119	35.8378	-18.6079
28	29.60	35.8379	-18.6151	35.5576	-18.6192
29	29.60	35.5577	-18.6264	35.8380	-18.6224
30	29.60	35.8381	-18.6296	35.5578	-18.6336
31	29.60	35.5579	-18.6408	35.8382	-18.6368
32	29.60	35.8384	-18.6440	35.5580	-18.6481

Aerial reconnaissance – pan and drainage line survey

Site	GPS coordinates
1	S18 24.718 E35 33.289
2	S18 25.376 E35 33.132
3	S18 24.673 E35 31.407
4	S18 24.944 E35 31.181
5	S18 25.748 E35 30.986
6	S18 26.378 E35 31.175
7	S18 26.229 E35 29.854
8	S18 27.449 E35 30.220
9	S18 27.162 E35 29.990
10	S18 28.693 E35 30.507
11	S18 29.531 E35 30.413
12	S18 31.460 E35 31.019
13	S18 31.954 E35 30.945
14	S18 32.241 E35 30.512
15	S18 32.384 E35 29.944
16	S18 33.459 E35 29.847
17	S18 34.214 E35 29.612
18	S18 34.636 E35 30.128
19	S18 34.829 E35 29.746
20	S18 35.321 E35 29.985
21	S18 35.821 E35 30.601
22	S18 37.255 E35 30.477
23	S18 37.024 E35 29.315
24	S18 36.955 E35 28.830
25	S18 37.219 E35 28.571
26	S18 35.671 E35 27.882
27	S18 33.674 E35 28.068
28	S18 32.192 E35 27.325
29	S18 31.141 E35 27.077
30	S18 26.586 E35 27.286
31	S18 27.222 E35 28.348
32	S18 26.537 E35 29.206
33	S18 25.893 E35 28.870
34	S18 25.098 E35 28.628
35	S18 24.783 E35 28.057
36	S18 23.892 E35 28.464
37	S18 23.035 E35 28.295
38	S18 21.542 E35 28.435
39	S18 20.866 E35 28.513
40	S18 19.701 E35 28.716
41	S18 22.167 E35 31.173
42	S18 25.576 E35 35.853
43	S18 25.853 E35 36.346
44	S18 26.224 E35 36.021
45	S18 27.019 E35 36.341
46	S18 26.831 E35 36.882
47	S18 26.502 E35 37.623
48	S18 26.790 E35 38.271
49	S18 27.589 E35 38.014
50	S18 28.875 E35 38.239
51	S18 29.286 E35 38.040
52	S18 29.795 E35 37.816
53	S18 31.061 E35 36.908
54	S18 30.807 E35 39.098
55	S18 31.797 E35 39.026
56	S18 32.279 E35 39.165
57	S18 33.935 E35 37.408
58	S18 34.804 E35 35.998
59	S18 34.355 E35 34.597
60	S18 32.402 E35 34.215
61	S18 31.904 E35 33.291
62	S18 32.670 E35 32.402
63	S18 33.217 E35 32.472
64	S18 34.162 E35 33.022
65	S18 34.780 E35 32.479
66	S18 35.093 E35 32.065
67	S18 36.917 E35 33.209
68	S18 37.398 E35 31.357
69	S18 37.030 E35 27.870
70	S18 37.702 E35 27.577
71	S18 36.577 E35 25.015
72	S18 36.360 E35 23.395
73	S18 35.384 E35 22.635
74	S18 35.258 E35 22.209
75	S18 35.488 E35 21.567
76	S18 34.010 E35 20.271
77	S18 33.714 E35 20.117
78	S18 32.967 E35 19.656
79	S18 32.140 E35 20.029
80	S18 31.658 E35 21.196
81	S18 30.908 E35 21.848
82	S18 30.176 E35 21.905
83	S18 28.303 E35 25.471

84	S18 26.996 E35 29.267
85	S18 25.566 E35 32.922
86	S18 24.618 E35 34.384
87	S18 20.993 E35 32.616
88	S18 19.349 E35 31.947
89	S18 18.445 E35 32.259
90	S18 17.905 E35 33.120
91	S18 17.043 E35 31.912
92	S18 16.889 E35 30.895
93	S18 17.489 E35 30.606
94	S18 17.996 E35 30.580
95	S18 17.920 E35 30.393
96	S18 17.110 E35 29.953
97	S18 16.929 E35 28.559
98	S18 17.384 E35 27.876
99	S18 18.048 E35 27.253
100	S18 17.246 E35 26.466
101	S18 19.705 E35 26.946
102	S18 20.137 E35 27.264
103	S18 20.885 E35 26.737
104	S18 22.549 E35 24.918
105	S18 22.656 E35 24.123
106	S18 24.085 E35 24.866
107	S18 24.777 E35 25.221
108	S18 25.336 E35 25.896
109	S18 27.587 E35 24.358
110	S18 30.281 E35 21.282
111	S18 30.981 E35 20.099
112	S18 26.634 E35 19.673
113	S18 23.756 E35 20.937
114	S18 21.744 E35 21.701
115	S18 19.802 E35 23.910
116	S18 14.927 E35 27.521
117	S18 13.805 E35 29.352
118	S18 13.347 E35 29.877
119	S18 12.729 E35 29.836
120	S18 12.117 E35 29.483
121	S18 11.300 E35 29.466
122	S18 10.438 E35 29.681
123	S18 11.733 E35 30.448
124	S18 11.270 E35 30.722
125	S18 12.697 E35 31.864
126	S18 13.286 E35 31.538
127	S18 13.623 E35 31.852
128	S18 14.147 E35 32.544
129	S18 14.066 E35 33.773
130	S18 16.250 E35 34.747
131	S18 17.703 E35 35.784
132	S18 19.033 E35 37.815
133	S18 19.882 E35 39.804
134	S18 19.049 E35 41.972
135	S18 20.538 E35 41.184
136	S18 21.013 E35 40.441
137	S18 21.943 E35 39.488
138	S18 24.368 E35 34.677
139	S18 24.675 E35 34.080
140	S18 25.439 E35 33.983
141	S18 24.555 E35 32.211
142	S18 25.174 E35 30.301
143	S18 25.453 E35 32.150
144	S18 26.311 E35 30.141
145	S18 30.781 E35 30.816
146	S18 32.855 E35 29.784
147	S18 36.127 E35 30.382
148	S18 23.288 E35 32.442
149	S18 22.335 E35 30.705
150	S18 21.979 E35 30.150
151	S18 22.353 E35 29.679
152	S18 26.549 E35 28.395
153	S18 20.656 E35 28.418
154	S18 19.368 E35 27.240
155	S18 16.508 E35 28.137
156	S18 18.437 E35 30.814
157	S18 15.851 E35 30.136
158	S18 15.504 E35 34.943
159	S18 17.344 E35 35.274
160	S18 27.556 E35 32.154