VEGETATION AND CARRYING CAPACITY OF THE 'SANCTUARIO'

Parque Nacional da Gorongosa, Moçambique

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PARQUE NACIONAL DA GORONGOSA, MOÇAMBIQUE

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SUMMARY

An assessment was made of the vegetation, habitat suitability and carrying capacity of the 6,200 ha Sanctuario in the south-western part of the Parque Nacional da Gorongosa (henceforth PNG).

Primarily, this study is aimed at supporting the re-introduction strategy for wildlife as part of the restoration of the PNG. The intention is to determine the 'envelope' of potential within which policy and actual implementation decisions can be made.

A total of 39 localities in the Sanctuario were assessed on the ground in terms of habitat factors, vegetation structure, dominant woody and grass species and suitability for grazers and browsers. An estimate of carrying capacity was made. Information on habitat for a further 81 GPS points were recorded during helicopter flights.

The ground data were used to define habitat units. An ASTER satellite image was used to map their distribution. The aerial data were used to groundtruth this map. It has an accuracy level of 77.8% which is satisfactory for planning and management purposes.

The Sanctuario is made up of the following habitats:

- Miombo (1,821 ha or 29.4% of the Sanctuario);
- *Combretum* veld in miombo (362 ha - 5.8%);
- Grasslands along drainage lines in miombo (317 ha - 5.1%);
- Grasslands of the Rift Valley (401 - 6.5%);
- Sparse to open *Combretum* or palm veld of the Rift Valley (1,221 ha - 19.7%);
- *Combretum – Acacia* veld of the Rift Valley (1,795 ha - 29.0%);
- Riverine & dry forest/thickets of Midlands/Rift Valley (275 ha - 4.4%).

These habitats exhibit marked differences in carrying capacity and suitability. The miombo habitats units and the closed riverine forest/thickets have a much lower suitability and carrying capacity than the Rift Valley habitats. The average carrying capacity for the Sanctuario is conservatively estimated at 6,783 kg km^{-2} or 6.7 ha per Animal Unit. This estimate falls within a range of carrying capacities derived from published equations that relate rainfall and soil fertility to carrying capacity. The habitats are suitable to a wide range of species as is evidenced by the impala, nyala, kudu, warthog, sable, hartebeest, elephant and oribi that were observed.

Carrying capacity should not be seen as a static number. It depends on objectives, environmental conditions and management history. The current estimate must thus be adapted as better knowledge emerges from the management of the Sanctuario.

A number of stocking scenario's can be developed. A diversity of species with a total of more than 2,500 animals could be supported. It is recommended to stock the Sanctuario at below carrying capacity in order to maximise production of animals for release in the greater PNG as part of its restoration. The Sanctuario can absorb all of the species and numbers proposed for re-introduction in 2006 and 2007.

Monitoring the effect of management actions on the status of the resource and on the performance of the animals will be of critical importance to evaluate management effectiveness and to further guide management decisions.

1. BACKGROUND

Wildlife numbers in the Parque Nacional da Gorongosa (henceforth PNG) have declined significantly over the last few decades mostly as a result of illegal hunting. The Carr Foundation in co-operation with the Ministry of Tourism of Moçambique has embarked on an ambitious, long-term restoration project for the PNG.

The restoration programme includes a strategy for active re-introduction and supplementation of wildlife into the PNG. One of the mechanis
ms that is proposed as part of this strategy is the use of a 'sanctuary' (Sanctuario) (Anderson *et al.* 2006). A significant number of animals of different species would be actively re-introduced into the Sanctuario. They would originate from healthy wildlife stocks (probably from Zimbabwe and South Africa) and would need to confirm to certain veterinary and genetic requirements.

The use of a 'sanctuary' is not new and applies often to specific species (for example black rhino re-introduction into North Luangwa (Zambia)). Within Moçambique, a 'sanctuary' has been successfully established and stocked in the new Limpopo National Park to the point where animals are already being released to recolonise the larger Park. A similar approach would be followed in the PNG, whereby animals would breed up in number in the Sanctuario before being released into the larger Park.

It thus becomes critical to establish that the Sanctuario does indeed provide the appropriate habitat for the intended species and that its carrying capacity is sufficient to support the re-introduced numbers and to cater for population expansion.

The objective of this report is to:

- Assess overall carrying capacity for wildlife in the Sanctuario;
- Determine suitability of individual habitats;
- Make recommendations on appropriate stocking levels and species mix; and
- Comment on required management actions.

The above objectives specifically address the need expressed by the Director of the Gorongosa Research Center (e-mail dated 07 February 2006 06:23 PM) and form part of addressing the wider objectives set out in the 'Vision for the Gorongosa Research Centre (Beilfuss 2005, unpublished). This report will be further expanded into a larger assessment of habitat suitability and carrying capacity of the larger PNG as well as the required management and monitoring actions surrounding this issue.

Primarily, this study is aimed at supporting the re-introduction strategy. It is not the aim to be prescriptive in terms of wildlife stocking scenario's. Rather, this report aims to provide the necessary information and to define the 'envelope' within which policy and actual implementation decisions can be made.

2. STUDY AREA

The PNG has been described in detail by Tinley (1977). Only those aspects that are most relevant to the Sanctuario will be described in the current report. One of the major problems with existing information sources is that the descriptions and maps do apply to much larger areas. As a result, the boundaries between very different units (e.g. with regard to geology and soils) may have positional errors of hundreds of meters if not kilometres. Whereas this may not matter too much at the scale of the larger PNG, it is problematic for a relatively small area such as the Sanctuario.

The Sanctuario is situated in the south-western part of the PNG, with its eastern boundary 6 km west of Chitengo (Fig. 1). It covers an area of approximately 6,200 ha. The length of the boundary fence is approximately 30 km.

The elevation is below 200 m above sea level, dropping gradually in a south-easterly direction. The Sanctuario straddles the transition from the Midlands to the Rift Valley physiographic units (see also Fig. 3). The Midlands occur on the western side and consist in the Sanctuario of gently rolling low hills with a relatively high drainage density. Some rock outcrops occur. The Rift Valley has a very even and flat topography that is prone to flooding and water logging. The geology in the western sector consists mostly of gneisses and pegmatite. This area is also characterised by many dolerite dykes. This has an important bearing on the carrying capacity (see section 4.1. and 4.2.). The Rift Valley is mostly underlain by alluvial deposits. The soils reflect the underlying geology and topography. Brown soils derived from gneisses and red soils derived from the dykes occur in the Midlands section. Grey soils (some of which are hydromorphic) occur in the Rift Valley and are derived from detrital fan material and from sands (Fernandes 1968).

Generally, one can note a lack of correspondence between the physiographic, geological and soils units. This is probably an artefact resulting from the mapping of these different components having been done at different scales across large areas.

The mean annual rainfall at Chitengo is given as 840 mm (Tinley 1977). A mean annual value of 1,038 mm applies to the Sanctuario using the grid at 0.5 degree longitude/latitude resolution of the Leemans & Cramer database (Leemans & Cramer 1991). This higher value reflects a grid that straddles the Rift Valley with higher rainfall on the eastern and western rims. The 900 mm isohyet intersects the area of the Sanctuary (Tinley 1977). The figure of 840 mm can therefore be safely used for the Sanctuario as it will provide a conservative estimate for related plant production.

The vegetation of the PNG has been detailed by Tinley (1977) but he did not produce a vegetation map at the scale of the Park. Such a map was produced on the basis of remote sensing data by Cunliffe & Lynam (2005). This map has a number of shortcomings including very limited groundtruthing, a lack of vegetation composition information attached to the units, and a lumping of units with similar spectral characteristics but that have very different value to herbivores (for example low quality grasslands on Gorongosa Mountain and highly palatable grasslands on the Rift Valley floor). No detailed and applicable assessment of the vegetation of the Sanctuario was therefore available prior to this report.

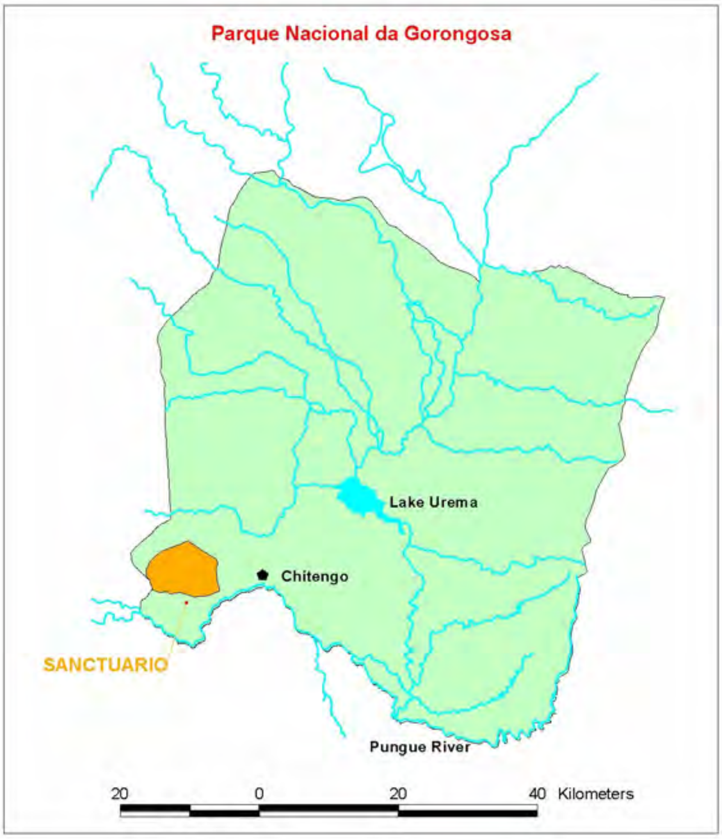

Fig. 1: Locality map of the Parque Nacional da Gorongosa (proclaimed boundaries only) and the Sanctuario. Two Coutada's are situated along the north-western border of the Park.

3. METHODS

3.1. Defining vegetation and habitat units of the Sanctuario

The main concern of this study is the capacity of the Sanctuario to support the re-introduction of a significant number of animals of different species. Vegetation is often used as a surrogate or building block for the definition of habitats. The use of broad habitat units defined by a combination of environmental factors and vegetation would probably represent the most useful input for the drafting of re-introduction and management recommendations. This is because such units have relevance to animal species, their availability of water might differ, they might require specific fire regimes, and they will differ in their sensitivity to utilisation and development.

The sampling and subsequent analysis was aimed at defining, identifying and mapping such units in order to qualify and quantify the resource available to the wildlife. A combination of ground sampling, aerial survey and analysis of remote sensing data was used.

3.2.1. Field assessment (ground work)

A number of localities were subjectively chosen and assessed. Due to poor accessibility, the majority of the samples were selected along the cleared perimeter of the Sanctuario. A total of 39 samples have been surveyed so far inside or on the boundary of the Sanctuario (Fig. 2).

The following information was recorded at each sample that covered an area of approximately 30 m x 30 m:

- GPS position;
- Physiographic unit (Midlands, Rift Valley, …);
- Abiotic factors (landscape position, slope, soil texture, etc.);
- Woody structure (following Edwards 1983);
- Important woody species (at least 3 major ones);
- Important grass species (at least 3 major ones);
- Overall carrying capacity in ha per Large Stock Unit (estimate based on the knowledge and experience of the author);
- General suitability for grazers (on a scale of 1 (marginal) to 5 (excellent)); and
- General suitability for browsers (on a scale of 1 to 5).

3.2.2. Field assessment (aerial survey)

A number of over flights of the Sanctuario were made with a helicopter. During the low-level, low-speed flights, GPS positions were recorded together with information on the structure and where possible the dominant woody species occurring at that spot. A total of 81 points were assessed within the boundaries of the Sanctuario (Fig. 2). On a number of flights a 'real-time' map was displayed on the notebook PC within the ArcView GIS environment. This enables one to follow the flight path across the satellite image and to directly input any vegetation observation. These observations form but a limited sub-sample of a much larger assessment of the PNG.

These 81 aerial points were used to groundtruth the map developed from the analysis of the satellite image and the ground data. The correspondence between the habitat map and the aerial evaluation was assessed as follows. A radius of 25 m (or a circle with a diameter of 50 m) was drawn around each aerial point. This circle captures a 3 x 3 pixel grid. The map occurrence within this circle of the habitat unit of the aerial point was assessed (yes/no). This approach was considered acceptable as there are invariably and unavoidably errors in spatial registration of the satellite image, errors in the GPS readings and in the drift by the helicopter away from the point in the time it takes to input a waypoint. This grid allows for 1 pixel error. This is minimal.

3.3.3. Defining units and mapping

Remote sensing is a useful tool for inventory and evaluation of wildlife habitat because of its multispectral and multitemporal capabilities at different spatial scales (Quattrochi & Pelletier 1991). Processed remotely sensed data may be used as input to a Geographic Information System (GIS) and together with ancillary data may be used for environmental modelling and analysis (Wilkinson 1996). Wildlife habitat maps derived from remote sensing need to be evaluated for accuracy and ecological relevancy before they are used for management purposes. Accuracy assessment relies on independent reference data, not used during the process of classification (Fairbanks & Thompson 1996).

LANDSAT and ASTER satellite images were available. The LANDSAT ETM+ (Enhanced Thematic Mapper Plus) image was dated December 2000 and has a resolution of 30 m x 30 m except for the extra 15-meter resolution panchromatic (=black and white) band. The ASTER scene dated to October 2000 and has a resolution of 15 m x 15 m (thus four times better than LANDSAT).

Both supervised and unsupervised classification can be used. In contrast to a supervised classification in which use is made of pre-defined training sites to assign each pixel to a certain class, the unsupervised classification allocates each pixel to a certain class based on its spectral characteristics only. The drawback to the supervised approach is that it is often difficult to locate and define homogenous training sites for all plant communities of interest. The considerable pixel to pixel variation generally results in many pixels being misclassified (Tueller 1989). Unsupervised classification approaches have worked better in rangelands. However, the drawback of the unsupervised classification is that a measure of subjectivity is unavoidable in the interpretation of the resulting clusters.

The GIS packages ArcView 3.2 (ESRI 1997) and ArcGis 9.1 were mostly used for visualisation and analysis. Some use was made of the raster-based IDRISI package (Eastman 1992) for purposes of manipulation of the remote sensing images.

Whereas vegetation communities can often readily be identified separately in the field and from the collected data, they may not always be mapped individually when using remote sensing images. The best possible discrimination into individual habitat units was sought without unduly compromising accuracy. Therefore the habitat units are spatially explicit (physically delineated on a map) but individual plant communities that make up these habitat units landscapes may however only be spatially implicit (not mapped, but merely described).

3.2. Assessment of habitat suitability and carrying capacity

The estimation method applied in this survey has previously been successfully used in a number of areas to rapidly arrive at an approximate carrying capacity based on the integration of knowledge of a range of similar habitats in southern Africa (Peel & Stalmans 2002, Peel & Stalmans 2004, Stalmans *et al.* 1999, Stalmans & Peel 2003). Note that a high intrinsic habitat suitability score may in practice, where elements of inter-specific competition, predation and veld management geared towards other species come into play, not translate into a high number for that species.

Available information on the carrying capacity in the Gorongosa area is very limited. However, some comparative values of stocking rates exist for other African Protected Areas with similar rainfall. Some good correlations have been established between mean annual rainfall and carrying capacity. Use was made of these general equations to put the PNG into context.

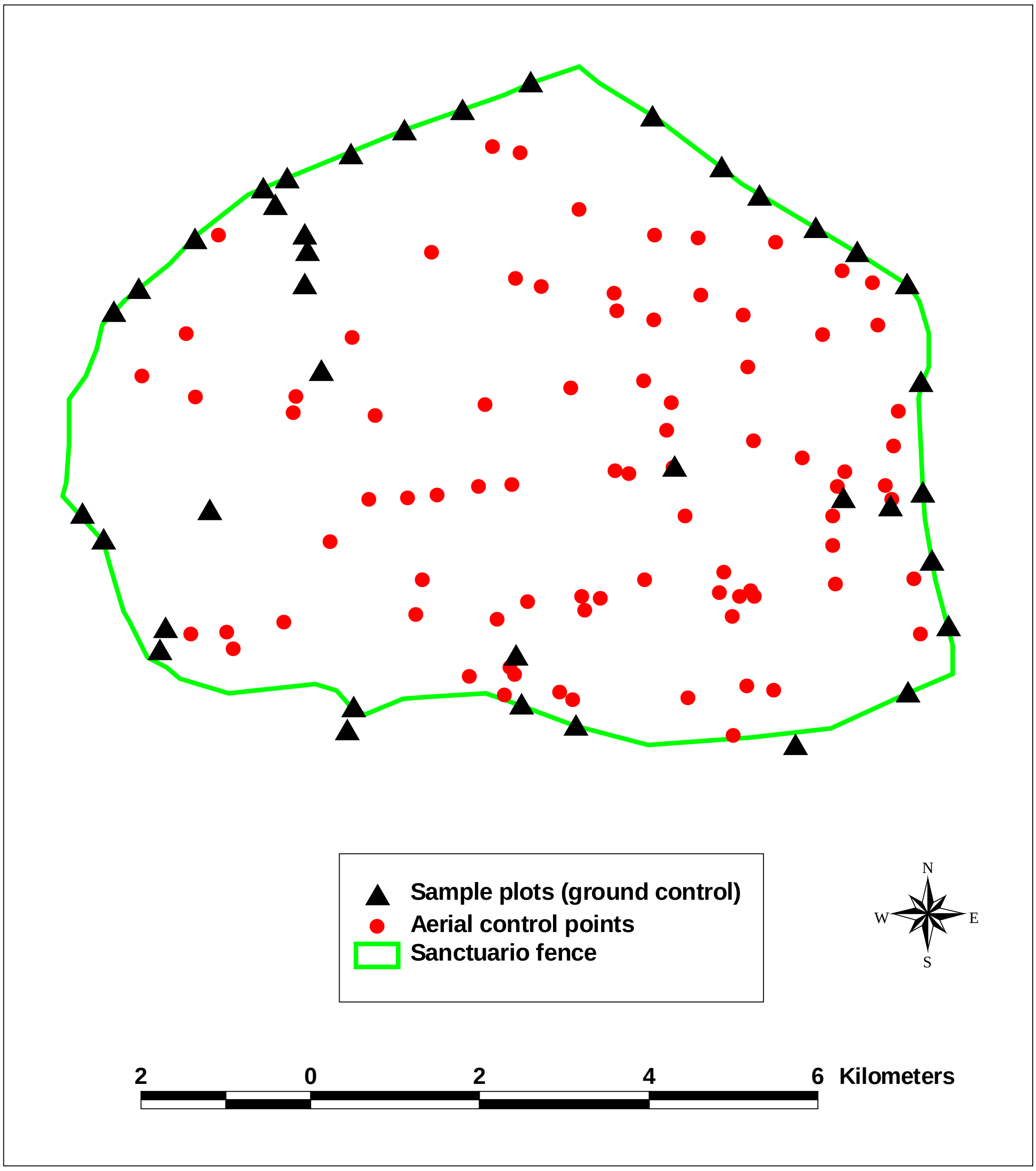

Fig. 2: Position of ground and aerial sample points.

4. RESULTS & DISCUSSION

4.1. Vegetation / habitat units

The ASTER image provided a much better resolution than the LANDSAT at the scale of the Sanctuario. The former was therefore used exclusively for this report. A visual inspection of the raw ASTER image is informative (Fig. 3). The east-west split between respectively Rift Valley and Midlands is very clear through the middle of the Sanctuario. The most prominent feature is the Pungue River. The inundation path from the river in a northerly direction through the eastern portion of the Sanctuary is very conspicuous. Fire scars are clearly visible, mostly to the west of the Sanctuary and south of the Pungue in the settled areas.

The spectral bands of the raw image can be recombined into the so-called NDVI index (Fig. 4). Actively growing vegetation will show higher values for this index through a higher reflectance in the Near Infrared spectrum. The NDVI image clearly shows the very low biomass and dormant nature of the fire scars in the west. The Pungue River bed is devoid of vegetation. The numerous drainage lines in the miombo remain fairly humid as well as the inundation path of the Pungue in the east of the Sanctuario. These areas that are waterlogged for a long period support grasslands as trees literally ‘drown’ and are excluded in this manner.

A number of vegetation units were identified. These vegetation units have been combined in larger habitat units (Fig. 5) because of limitations in discriminating their occurrence on the satellite image. The thicket and forests of the Midlands and Rift Valley have been combined into a single map unit straddling both these physiographic units. A total of 7 units are therefore mapped for the Sanctuario:

- Miombo (1,821 ha or 29.4% of the Sanctuario)
  - Miombo with *Acacia nigrescens*
  - Miombo on rocky ridges
- *Combretum* veld in miombo (362 ha - 5.8%)
- Grasslands along drainage lines in miombo (317 ha - 5.1%)
- Grasslands of the Rift Valley (401 - 6.5%)
- Sparse to open *Combretum* and/or palm veld of the Rift Valley (1,221 ha - 19.7%)
- *Combretum – Acacia* veld of the Rift Valley (1,795 ha - 29.0%)
  - *Acacia* groves
  - *Acacia* in saline grasslands
  - Mixed *Combretum* - *Acacia*
- Riverine & dry forest/thickets of Midlands/Rift Valley (275 ha - 4.4%)
  - Riverine forest and thickets of the miombo
  - Riverine forest/thickets of the Rift valley
  - Dry forest/thickets of the Rift Valley.

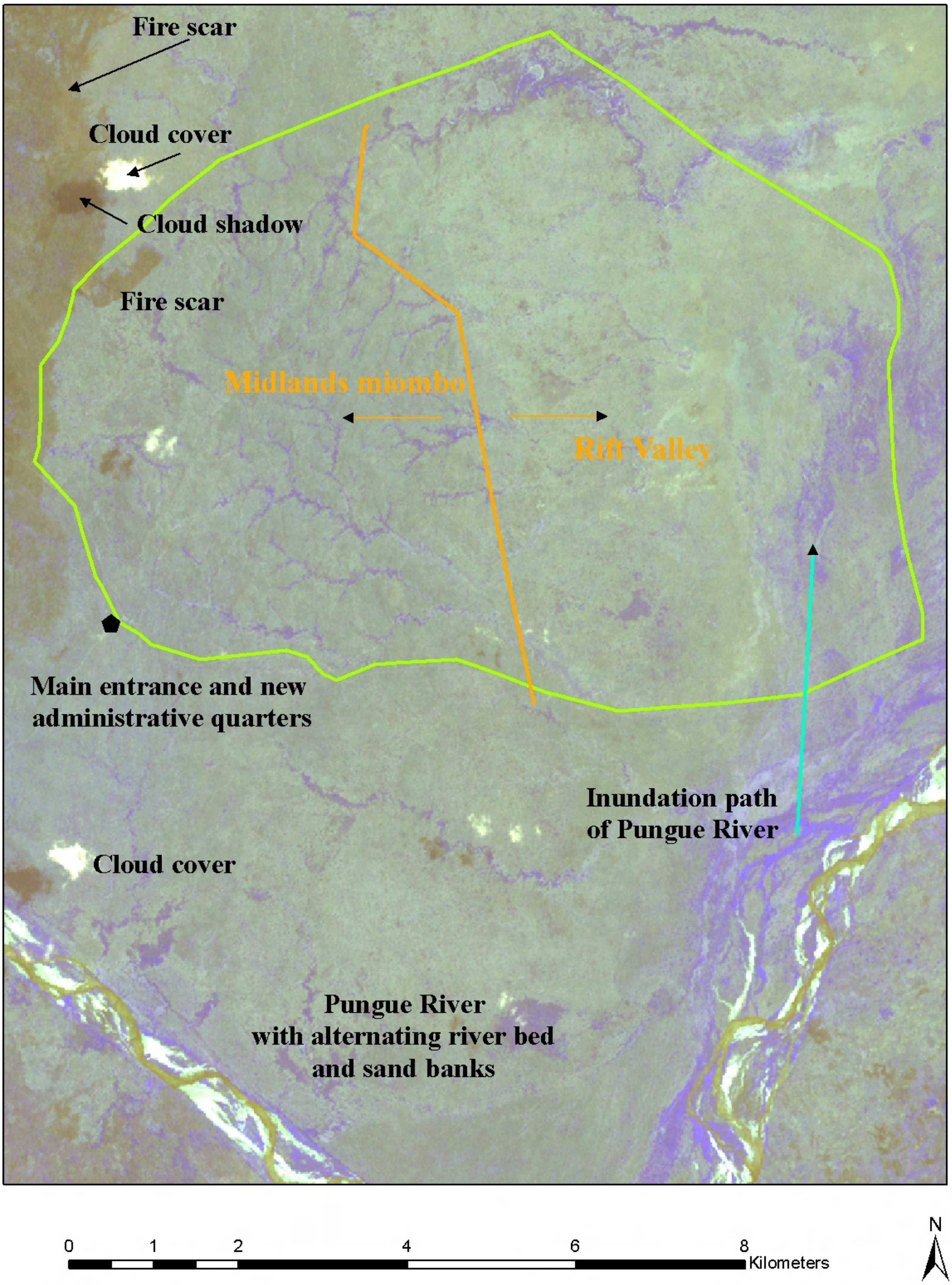

Fig. 3: ASTER satellite image of the Sanctuario and surroundings.

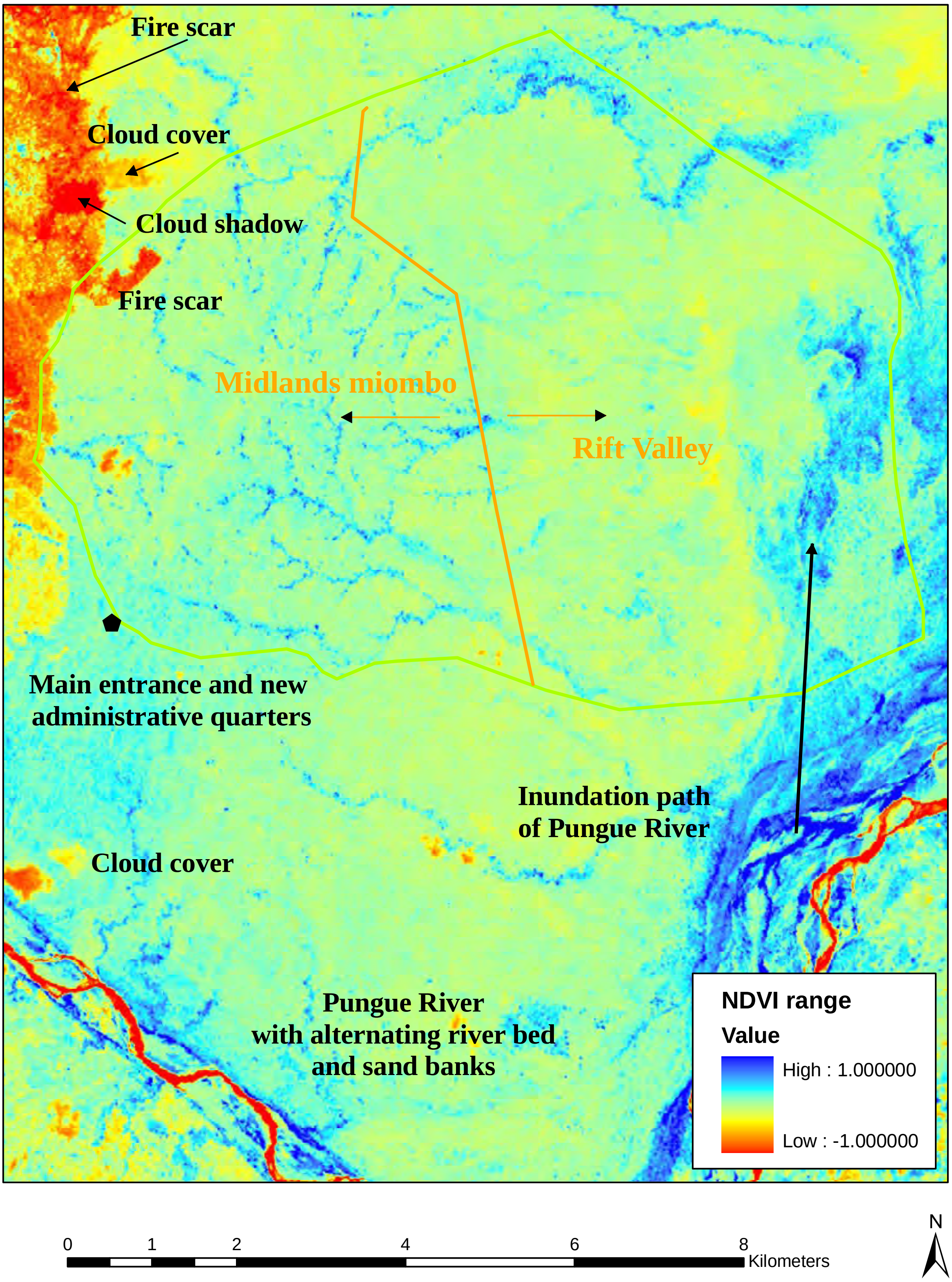

Fig. 4: NDVI index derived from the ASTER satellite image. The more orange-red colours denote water, bare ground or low levels of phytomass. The bluer colours denote actively growing phytomass (for example in and near drainage lines and in inundation zones).

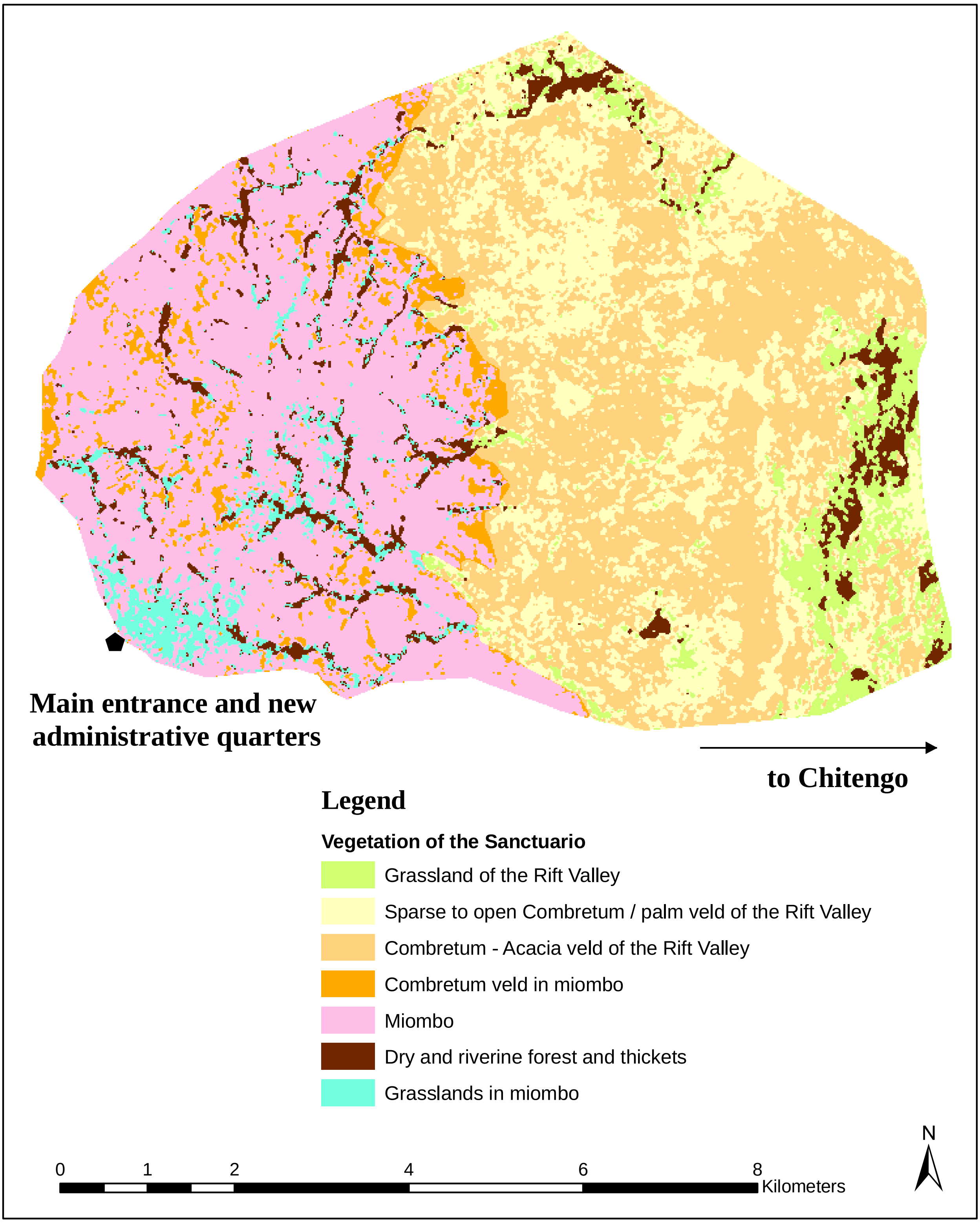

Fig. 5: Habitat units of the Sanctuario

4.4.1. Miombo

The miombo habitat unit harbours three major communities (Fig. 6). The first community is made up by a tall (>10 m), closed canopy of *Brachystegia boehmii / Julbernardia globiflora.* These are typical exponents of true miombo. This community is found at the site of the proposed research centre. Most of the miombo in the Sanctuario consists of *Brachystegia/Julbernardia* with *Acacia nigrescens*. The latter brings in a 'sweet' element (see Glossary in Appendix A) with a resulting higher carrying capacity and habitat suitability for browsers. The numerous termite mounds support an even more palatable vegetation with species such as the tree *Ziziphus mucronata* and the grasses *Cenchrus ciliaris* and *Urochloa mossambicensis*. Lastly, a more species diverse miombo is found on rocky ridges (e.g. Site 126). *Sterculia quiqueloba* and *Pterocarpus angolensis* are prominent. Generally, the miombo in the Sanctuario is not as 'sour' or with as low carrying capacity as that found on poor sandy soils on the wet Cheringoma plateau. The occurrence of numerous dolerite dykes plays a major ameliorating role with regard to a more clayey soil with a higher nutrient status. These communities are equivalent to Tinley's (1977) Miombo Savanna Woodland on the Midlands.

4.4.2. *Combretum* veld in miombo

A more open woodland that is short (<10m) is found within the miombo often closer to the drainage lines and on gravelly soils derived from pegmatite (Fig. 7). Typical woody species are *Combretum fragrans, Diplorhynchus condylocarpon, Crossopteryx febrifuga* and *Terminalia* spp. (*T. stenostachya* and/or *T. mollis*). Characteristic grasses are *Digitaria eriantha, Heteropogon contortus, Andropogon gayanus* and *Themeda triandra*.

4.4.3. Grasslands along drainage lines in miombo

These are narrow strips of very tall grassland in some of the drainage lines (Fig. 8). They are often fringed by tall miombo. Typical components are *Panicum maximum, Setaria incrassata* and *Rottboellia cochinchinensis*. These grasslands are not quite as 'sour' as those on dambos in the wet miombo of the Cheringoma plateau. Nevertheless, they provide a habitat of lesser quality than the grasslands found in the Rift Valley.

Fig. 6: Miombo habitat unit (top – tall *Brachystegia*, middle – rocky ridge with *Sterculia quiqueloba*, bottom – on termitaria with *Acacia nigrescens)*..

Fig. 7: *Combretum* veld in miombo habitat unit.

Fig. 8: Grassland in drainage line in miombo habitat unit.

4.4.4. Grasslands of the Rift Valley

Virtually treeless expanses are formed through extensive and prolonged water logging in the lower parts of the landscape in the eastern part of the Sanctuario (Fig. 9), A very distinct inundation line is visible on the satellite image and from the air where the Pungue overflows it banks in the bend and flows straight north into the Sanctuario. This regular flooding is probably critical in maintaining the open nature of these grasslands as well as in ensuring their high fertility. The grasslands occur on heavy grey clayey soils. They are tall (1.50 m) and are characterised by *Setaria incrassata, Heteropogon contortus, Digitaria eriantha, Echinochloa colona* and *E. pyramidalis*. These correspond to the Floodplain Grasslands of Tinley (1977).

4.4.5. Sparse to open *Combretum* and/or palm veld of the Rift Valley

Where water logging is less pronounced a number of trees can survive. A sparse woodland with typically *Combretum imberbe, Philenoptera violacea* and the palm *Hyphaene petersiana* occurs (Fig. 10). *Acacia nigrescens, Acacia sieberana* and *Acacia xanthophloea* can be found, but not together as they each tolerate different inundation regimes. The grass layer is very similar to that found in the pure grasslands. *Echinochloa* spp. are less important. A number of small, seasonal pans occur in this habitat unit as well as in the previous unit. This is one of the units that was most difficult to map and this map unit encompasses probably some pure grasslands as well as some open *Combretum-Acacia* veld. (Fig 6). This unit is similar to the Marginal Floodplain Woodlands of Tinley (1977).

4.4.6. *Combretum – Acacia* veld of the Rift Valley

This habitat covers the largest section of the eastern part of the Sanctuario. It consists of open to closed, short woodlands (Fig. 11). Dense, almost monospecific groves of *Acacia robusta* can be found. On the other extreme, very sparse *Acacia* woodlands with a saline grassland (with *Sporobolus ioclados* as typical exponent) is found. The majority of this habitat unit however typically consists of a mixed woodland with *Combretum fragrans* and *Acacia robusta,* with as grasses *Panicum maximum, Digitaria eriantha, Heteropogon contortus* and *Urochloa mossambicensis*. This corresponds to the Saline Grasslands and the Mixed Savanna of Tinley (1977).

4.4.7. Riverine and dry forest/thickets of the Midlands and the Rift Valley

The closed forest and thicket communities of the Midlands and the Rift Valley were mapped as a single habitat unit as they generally represent a fairly low carrying capacity environment. Three main communities can be recognised (Fig. 12). In the miombo, riverine forest and thicket occurs along the drainage lines. High (>20 m) trees may emerge from the riverine fringe. Conspicuous species are *Breonadia salicina* and *Ricinodendron rautenii.* Towards the Rift Valley, the tree *Sterculia appendiculata* becomes more prominent. Dry forests and thickets occur as pockets in the Rift Valley. Often, *Piliostigma thonningii* is the most conspicuous species. The forest grass *Oplismenus* typically occurs in the ground layer under closed canopies.

Fig. 9: Grasslands of the Rift Valley habitat unit in the middle ground, immediately surrounded by Sparse Woodlands of the next habitat unit and *Combretum – Acacia* veld beyond the Sparse Woodlands.

Fig. 10: Sparse to open *Combretum* and/or palm veld habitat unit. Note *Setaria incrassata* grass in the foreground.

Fig. 11: *Combretum* – *Acacia* veld of the Rift Valley habitat unit (top – mixed woodland, middle – dense *Acacia robusta* grove, bottom – saline grassland).

Fig. 12: Riverine and dry forest/thickets habitat unit (top – riverine forest in miombo with fallen *Breonadia salicina*, bottom – dry forest in Rift Valley).

4.2. Accuracy assessment

The correspondence between the 81 aerial points and the actual habitat map was 77.8%. Furthermore, 3 points observed to belong to the riverine habitat failed to fall within the correct map unit by only 1 or 2 pixels. It is understandable that riverine units that occur as narrow linear elements in the landscape and on the map are more prone to such an error.

Classification accuracy reported by other researchers mapping land cover (Brondizio *et al.* 1996, Fuller *et al.* 1998, Hodgson *et al.* 1988, Lunetta & Balogh 1999), forest cover (Congalton *et al.* 1993) and grassland cover (Lauver & Whistler 1993, Stalmans *et al.* 2002) ranged from 69 to 94% (Table 2). The accuracy figure of 77.8% achieved in the present study can thus be considered to be very satisfactory for an operational product of this kind.

A subjective personal evaluation by the author suggests that the extent of miombo may have been overestimated as a larger proportion of the western area may be made up by *Combretum* veld. As these two habitats have been ranked as having both a relatively low carrying capacity for wildlife, any error would have little impact on the calculated potential of the Sanctuario. The extent of grassy habitat in the south-western corner is overestimated. This area consists more of miombo.

Table 2: The accuracy of the present study as compared to results from various single-date satellite image studies related to land cover and vegetation classes.

Study	Scale (km^2)	Description (n = number of classes)	Overall accuracy (%)
Brondisio *et al.* (1996)	10^3-10^4	Land cover/land use (n=14)	94
Fuller *et al.* (1998)	10^3-10^4	Land cover/land use (n=14)	86
Congalton *et al.* (1993)	10^4-10^5	Forest cover (n=2)	82
Herr and Queen (1993)	unclear	Vegetation/land cover (n=9)	81
SANCTUARIO (this study)	**10^3-10^4**	**Vegetation structure/cover (n=7)**	**79**
Stalmans *et al.* (2002)	10^2-10^4	Grassland /forest (n=3)	78-80
Lauver & Whistler (1993)	10^3-10^4	Grassland types (n=2)	75
Hodgson *et al.* (1988)	10^3-10^4	Land cover (n=6)	74-88
Ringrose *et al.* 1999	10^3-10^4	Vegetation structure/cover (n=11)	73-78
Lunetta & Balogh (1999)	10^2-10^3	Land cover/land use (n=6)	69
Joria & Hearn (1991)	10^2-10^3	Forest canopy attributes (n=3)	67

The position of the boundary: between the miombo and the Rift Valley habitats is most important in terms of carrying capacity and habitat suitability in the Sanctuario This split is clearly visible on the raw satellite image (Fig. 3) and reflects the transition from the eastern Midlands with pegmatite and gneiss substrates to the Rift Valley with its mostly deep alluvial soils. The overriding concern in the mapping (and in the determination of the relative extent of habitats with low or high carrying capacity) is therefore the accuracy with which the boundary between miombo and non-miombo has been fixed. In this respect the habitat map (Fig. 5) seems to be accurate. During the aerial survey, no miombo was observed to the east of the map boundary. A total of 13 miombo survey points were correctly allocated on the map. The 11 other survey points in the miombo area were defined as non-miombo in the aerial survey and were similarly allocated to non-miombo on the map.

The Cunliffe & Lynam (2005) map was done at a different scale that comprises the whole PNG. A direct comparison is therefore not necessarily. Nevertheless, the concern is that this map, regardless of scale, does not capture the major split between the miombo habitat and the habitats of the Rift Valley (Fig. 13).

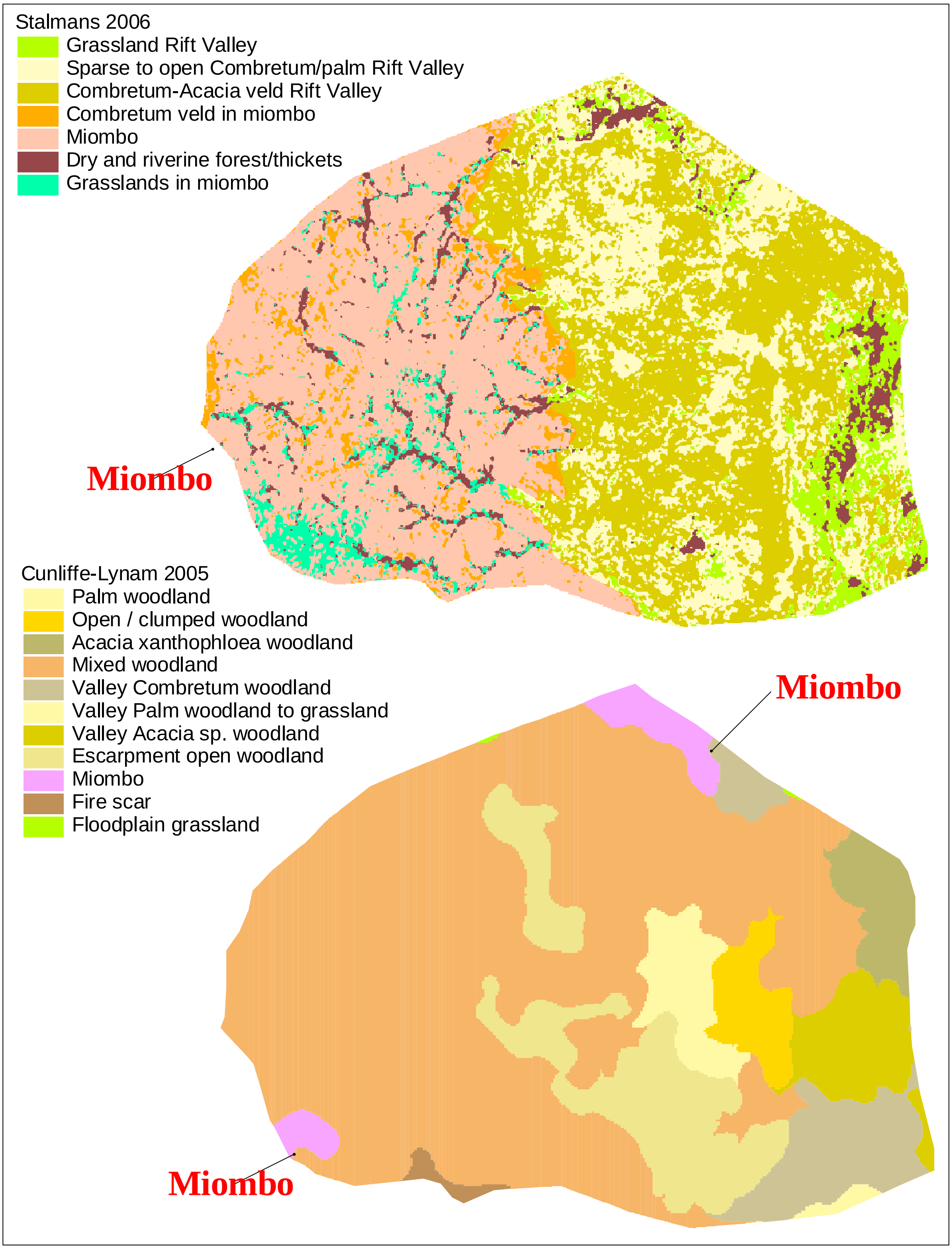

Fig. 13: Comparison for the Sanctuario between the Cunliffe & Lynam (2005) and current map. Note the lack in correspondence in identifying the miombo versus non-miombo split. Note also the supposed occurrence of miombo in the north-eastern corner of the Sanctuario according to Cunliffe & Lynam (2005). This is definitely not the case based on a ground inspection during March 2006.

4.2. Carrying capacity

The concept of 'carrying capacity' is a nebulous one with many definitions, and it is difficult to determine in heterogeneous environments experiencing variable environmental and resource conditions (Peel *et al.* 1998)[1]. It should therefore not be considered as a static figure but must reflect climatic conditions and influence of management practices followed.

Within the context of the PNG, 'ecological carrying capacity' is loosely defined as the population size of a species in an area as determined by the capacity of that area to support the individuals in that population and enable them to reproduce (adapted from Caughley 1979 and Grossman 1984). The assessment of carrying capacity looks at ecological carrying capacity. Management decisions as to stocking rate may however be based on economic carrying capacity that looks at higher production levels (which can be attained by stocking at lower than ecological carrying capacity).

Traditionally, carrying capacity has been expressed as the number of hectares required to support a Animal Unit (ha/AU). This has several shortcomings including the fact that the unit decreases in magnitude as animal numbers increase. The term is also not linearly related to the number of animals on an area of land. The Animal Unit also ignores dietary differences. The use of kg km^{-2} is preferred from a methodological viewpoint. Both units are however being used in this technical document as the former is familiar to most and as it allows easy comparison with other documents and opinions.

The carrying capacity for the different habitats based on the field estimate ranges from very high for the Grasslands of the Rift Valley to medium values for the miombo (Table 3). Using the extent of the habitat units, the total carrying capacity for each unit and for the Sanctuario as a whole can be calculated (Table 4).

Table 3: Carrying capacity for the habitat units of the Sanctuario based on the 2006 field estimate.

	Carrying capacity	
	ha / AU	kg km-2
Miombo with *Acacia nigrescens*	9.2	4,909
Combretum in miombo	8.1	5,556
Grassland in drainage line in miombo	7.0	6,429
Grasslands of the Rift Valley	4.3	10,588
Sparse to open woodlands (*Combretum* / palm)	4.3	10,588
Combretum - *Acacia* veld of the Rift Valley	6.2	7,258
Closed riverine and/or dry forest	14.3	3,158
Average (weighted for habitat size)	6.7	6,783

[1] See Appendix A for a definition of a number of technical terms used throughout the report.

Table 4: Overall carrying capacity for the Sanctuario.

	Carrying capacity		Size of habitat	Carrying capacity	
	ha / AU	kg km-2	ha	AU	kg
Miombo with *Acacia nigrescens*	9.2	4,909	1,821	199	89,395
Combretum in miombo	8.1	5,556	362	45	20,111
Grassland in drainage line in miombo	7.0	6,429	317	45	20,379
Grasslands of the Rift Valley	4.3	10,588	401	94	42,459
Sparse to open woodlands	4.3	10,588	1,221	287	129,282
Combretum - Acacia veld	6.2	7,258	1,795	290	130,282
Closed riverine and/or dry forest	14.3	3,158	275	19	8,684
Total				979	440,592

How does this compare to other estimates based on general equations and how does this compare to other case studies?

Coe *et al.* (1977) established that a high degree of correlation exists in natural systems between the herbivore biomass and annual rainfall. This allows for predicting animal biomass from simple long-term rainfall figures. The model importantly provides a range of stocking densities for a given long-term mean annual rainfall. This allows management to take into account resource conditions at a variety of spatial and temporal scales (although this is not actually provided by Coe *et al.* (1976)). The relationship between rainfall and carrying capacity starts deteriorating above a rainfall of 800 to 900 mm, particularly in nutrient-poor environments. Carrying capacity can actually drop in very wet areas due to excessive leaching of nutrients from the soil and the ensuing production of a low quality sward. This would certainly apply to the miombo on the Cheringoma plateau. Fritz & Duncan (1994) further refined the rainfall-related carrying capacity approach by taking into account the habitat make-up in terms of low, medium and high fertility substrates.

Only limited recommendations on stocking rates and carrying capacity are available for Moçambique and further research is required (Maposse *et al.* 2003). A predictive model for livestock carrying capacity has been developed for Moçambique (Timberlake & Reddy 1986). This document could however not be sourced for the current study. Tinley (1977) mentions carrying capacity estimates by Myre & Antão (1972) of 15 ha per AU for miombo, 6 – 8 ha per AU for *Urochloa* savanna grasslands (similar to *Combretum – Acacia* veld of the present study) and 3 – 4 ha per AU for flooded alluvial grasslands. The 2006 estimates for the Sanctuario fall within these ranges. The Myre & Antão (1972) document could not be accessed for this study.

Comparative figures can be gleaned from animal counts in a number of Parks with similar rainfall regimes and similar underlying soil fertility patterns (East 1984). A stocking rate for the PNG is given by Tinley (1977). It should be noted that the animal biomass for these Parks is mostly derived from fixed wing counts which may significantly underestimate number of medium sized and smaller ungulates. These figures represent actual stocking rates which may indicate potential carrying capacity.

It is however not known whether these areas were at, below or above carrying capacity at the time of the count.

The results from the predictive equations, PNG counts, case studies from Parks further a field and the current study are synthesized in Table 5. The 2006 field estimate for the Sanctuario fits within the overall 'envelope' of carrying capacity derived from other sources. It should also be noted that recent work indicates that the 'true' figure for carrying capacity lies closer to the upper limit of Coe *et al.* (1976) rather than the average figure (Dr M Peel, ARC, pers. comm..). All of the above would indicate that the field estimate can indeed be used as a safe and conservative guideline for initial planning and stocking of the Sanctuario.

Table 5: Estimate of carrying capacity based on predictive models (based on a rainfall of 840 mm) as well as recorded stocking rates from other studies. Estimates are ranked from lowest (top) to highest (bottom).

Information source	Carrying capacity	
	Ha / AU	**kg km^{-2}**
Coe et. al. (1979) lower limit	11.2	4,017
Tinley (1977) - adapted Stalmans 2006	10.0	4,500
Fritz & Duncan (1994) low fertility	9.2	4,916
East 1984 – Serengeti – rainfall 803mm - high fertility	8.7	5,144
Tinley (1977)	8.1	5,531
Coe et. al. (1979) average	7.4	6,089
Stalmans 2006 – Sanctuario field estimate	**6.7**	**6,783**
Fritz & Duncan (1994) medium fertility	5.9	7,677
Coe et. al. (1979) upper limit	5.5	8,160
Fritz & Duncan (1994) Sanctuario fertility	5.5	8,242
East 1984 - Luangwa Valley – rainfall 832 mm - medium fertility	5.3	8,555
Fritz & Duncan (1994) high fertility	5.0	8,920

4.3. Habitat suitability

The habitat suitability of the different habitat units generally ranges from medium to good for grazers (Table 6). The grasslands and sparse woodlands of the Rift Valley are most suited, followed by the *Combretum – Acacia* veld. In contrast, the closed riverine and dry forest and thickets are of low value to grazers. The *Combretum – Acacia* veld offers the best habitat for browsers. The low suitability scores for the grasslands and sparse woodlands do not properly represent the full picture. The quality of the browse in these habitats is actually good to very good. The amount of available browse however is fairly limited.

No formal assessment of suitability for individual herbivore species was made. However, the following range of species was observed inside or in the immediate vicinity of the Sanctuario: impala, Lichtenstein's hartebeest, sable, nyala, kudu, oribi, grey duiker, elephant, hippo and warthog. This would indicate that the habitat is generally suitable for a wide range of species. In line with expectations, most visual observations and spoor was recorded in the eastern part of the Sanctuario in the Rift Valley habitat units.

Current utilization of the resource is limited. Signs of grazing were observed in the *Combretum – Acacia* veld, particularly on saline grasslands. Although the biomass of browsers are low, preferred species can be significantly impacted upon (Fig. 14).

Table 6: Average habitat suitability of the different habitats of the Sanctuario for grazers and browsers (on a scale of 1 (marginal) to 5 (excellent).

	Habitat suitability	
	Grazers	Browsers
Miombo with *Acacia nigrescens*	3.0	2.7
Combretum in miombo	3.2	2.5
Grassland in drainage line in miombo	3.0	1.0
Grasslands of the Rift Valley	4.1	1.0
Sparse to open woodlands (*Combretum* / palm)	4.1	2.0
Combretum – Acacia veld of the Rift Valley	3.7	3.0
Closed riverine and/or dry forest	1.8	2.8
Weighted average (based on habitat size)	**3.5**	**2.5**

Fig. 14: *Boscia salicifolia* (in *Combretum – Ac*acia woodland habitat unit) that has been regularly and extensively browsed.

4.4. Stocking recommendations and management

4.4.1. Decision-making framework

Regardless of the approach followed to determine carrying capacity, the Sanctuario is currently stocked at a very low rate. Any recommendations on re-introductions can largely ignore the impact of the herbivore numbers already present.

It is of critical importance to clearly define the purpose of the Sanctuario: is it a production facility or should it be a tourism attraction ? This issue has been discussed at length and the consensus appears to be that the Sanctuario has to fulfill a production function. In order to achieve high productivity, stocking rates should be kept relatively low. The short-term tourism benefit will be partly sacrificed in order to assist with quickly boosting the overall Park tourism product through releases from the Sanctuario.

As a result of constantly varying environmental conditions, carrying capacity does not remain constant. A decision regarding stocking rates should therefore be similarly flexible to take into account changing environmental conditions. The uncertainty involved in predicting environmental variables (e.g. rainfall) makes related management actions such as the manipulation of animal numbers difficult. A certain risk of under-utilising or over-utilising the resource base is always present.

Different stocking scenario's could be developed within a certain envelope of carrying capacity, depending on objectives. The species mix, particularly in terms of feeding classes, is very important in terms of impact on the grass layer and in terms of inter-specific competition. Numbers are proposed that take into account the overall carrying capacity under different scenario's, relative habitat suitability, individual species limits and required species mix (Table 7). It is important to keep in mind that these should not be seen as rigid prescriptions nor are these the only appropriate numbers. Furthermore, environmental conditions may vary resulting in significant temporal fluctuations in carrying capacity.

The appropriate strategy would seem to be one in which the Sanctuary firstly remains in a productive state with high growth rates for a wide diversity of individual species or secondly, where rare species could be bred for restocking. The two options need not be mutually exclusive.

With regard to the first alternative strategy, high productivity is best realised by keeping the stocking rate below the ecological carrying capacity. This is in terms of classic understanding of stocking rate – animal performance (Jones & Sandland 1974), It is recommended that animal numbers within the Sanctuary be kept below 80% of the field estimate of Table 4. Temporal variability in carrying capacity should always be kept in mind. This recommendation can be adjusted depending on results obtained from the monitoring.

Given that Tinley (1977) reports very high concentrations of animals on the most fertile portions of the landscape at the end of the dry season and given that several of the larger species exhibited poor body condition, it would be prudent to build this into the stocking recommendation. The 80% stocking rate would fall within the carrying capacity offered by the Rift Valley habitat units, the Grassland in miombo and the *Combretum* veld in miombo. It does therefore not even rely on the large component of Miombo with *Acacia nigrescens* habitat to support the animals. However, in practice, despite its lower carrying capacity this latter habitat unit will support a number of kudu. Nyala and impala will also utilize the vegetation on termitaria in the miombo.

It is likely that at these lenient stocking rates, competition for grazing will be reduced thereby allowing sensitive species such as sable to perform well. This would partly fulfill the second alternative strategy. If not immediately, then certainly in the future, the Sanctuary could be used as a production unit for species such as roan.

The practical implication of the proposed management strategy is that within a few years it will become necessary to release surplus animals into the greater PNG (thereby fulfilling the wildlife introduction objectives of the management plan).

4.4.2. Species choice and numbers

Within a certain ‘envelope’ of carrying capacity and suitability, a large number of possible stocking scenario’s can be envisaged. Different scenario’s address different objectives, different availability of species for restocking, species cost etc. Invariably, some species that are expected to do well, will not. Others will perform much better than expected.

Therefore, any scenario should be considered as such. It should not be seen as an immovable prescriptive goal to be pursued at all cost by management. Rather, the scenario’s provide an indication of what could be achieved assuming a certain focus.

The following scenario’s have been developed (Table 7):

- A: focus on the species that are to be introduced (zebra, wildebeest, impala, buffalo). Most of the already occurring species (such as nyala) are kept at low levels. Stocking to 80% of carrying capacity only in order to promote productivity. Surplus animals are released into the larger Park to maintain high levels of production within the Sanctuario;
- B: balance between new species and already occurring species. This allows for some waterbuck, sable antelope and Lichtenstein’s hartebeest. The risk is always in losing focus and in allowing secondary objectives to take precedence over the short-term production objective. Stocking to 80% of carrying capacity only in order to promote productivity;
- C: as in B, but with the addition of a breeding herd of elephant and some white rhino. Stocking to 80% of carrying capacity only in order to promote productivity;
- D: as in B but stocking to 100% of carrying capacity in order to maximize numbers. This would be at the detriment of productivity;
- E: as in C, but stocking to carrying capacity;
- F; based on the proposed introductions (Table 3 - Anderson *et al.* 2006).

The different scenario’s have been set in such a way as to favour the proportion of bulk grazers, rather than impala, warthog and wildebeest that have the potential to overgraze selected sites. Feeding ratio’s of 45%:20%:20%:15% of bulk grazers, concentrate grazers, mixed feeders and browsers respectively as proposed by Collinson & Goodman (1982) has been aimed for (see also Peel *et al.* (1998) for a more detailed discussion of these feeding ratio's). The overall score for 'browser suitability' was only between 2 and 3 (out of a possible 5) compared to a score of more than 3 for grazers. A lower proportion of browsers is therefore preferred (Table 7). Numbers of individual species may also be adjusted temporally to higher levels (e.g. zebra) to take up the 'slack' because other species may not be up to capacity yet (e.g. buffalo).

Once again it should be re-iterated that the above is neither prescriptive nor rigid, but should be adapted to reflect actual climatic and resource conditions. Monitoring of the resource as well as the animal performance therefore forms an integral and vital part of management of the Sanctuario.

Scenario F illustrates that the Sanctuario is well capable of absorbing the proposed introductions for 2006 and 2007 (Table 3 in Anderson *et al.* 2006). The stocking rate of 86% of carrying capacity should be beneficial in ensuring a high productivity of these animals. This would support the aim of wildlife releases over time from the Sanctuario into the greater PNG.

Table 7: Stocking scenario's for the Sanctuario.

A: focus on re-introduced species
B: re-introduced species and allowing growth of already occurring species
C: re-introduced species, naturally occurring, elephant and rhino
D: maximum number of re-introduced species
E: maximum number of re-introduced, already occurring and elephant/rhino
F: based on the proposed introductions for 2006 and 2007 (Table 3 - Anderson *et al.* 2006).

	Number of animals for different scenario's					
	A	**B**	**C**	**D**	**E**	**F**
Bulk grazers						
Buffalo	200	200	200	275	230	250
Zebra	300	250	250	400	350	600
Waterbuck	10	30	30	10	40	
Sable	0	20	20	0	25	
White rhino	0	0	6	0	8	
Concentrate grazers						
Blue wildebeest	600	500	500	700	550	480
Warthog	50	200	200	50	250	
Common reedbuck	50	100	100	100	250	
Lichtenstein's hartebeest	0	20	20	0	30	
Mixed feeders						
Impala	900	800	500	900	750	600
Nyala	150	250	200	50	250	
Elephant	0	0	10	0	10	
Browsers						
Kudu	250	250	250	400	300	100
Total animals	2,510	2,620	2,286	2,885	3,043	2,095
Stocking % of carr. cap.	80	80	80	100	100	86

Included in F scenario – roan 20, tsessebe 25, eland 20, (not shown in above table but included in stocking calculation).

4.4.3. Required management actions

It is not the intention to detail required management actions. These have been described in the re-introduction strategy document (Anderson *et al.* 2006).

It is imperative that there always remains clarity on the objectives for the Sanctuario. All management actions should be geared towards achieving the accepted objectives. It is likely that objectives will change as time goes by (for example - shift from production of common species to that of rare species). This will then require a change in management. This is perfectly acceptable as long as clarity and focus are maintained.

The vegetation of the Sanctuario is not uniformly accessible and of similar value throughout the year. The bottom eastern part gets flooded. The gradual drying out will allow greater access towards the dry season. It will also lengthen the period during which green vegetation is available. This can be further enhanced through the use of fire. The burning of part where there is still sufficient soil moisture will enable a green 'flush' that provides high quality feed at the end of summer and the beginning of winter. 'Early' burns would thus be beneficial. The scale and intensity of fire management may be very different from that of the larger PNG. This would be acceptable given the specific production objectives for the Sanctuario.

Together with this 'succession' that is determined by climatic and soil conditions, there is a 'grazing' succession that greatly influences individual herbivore species. Most of the grass at present is very tall and difficult to access for species such as wildebeest and impala. Most utilization was actually observed on shorter grass (such as the saline areas). One the grass has been cropped fairly short, it is being kept at that (highly acceptable) level through continued utilization. The introduction of large animals such as buffalo will definitely benefit the other species (Perrin & Brereton-Stiles 1999). The value of large bulk grazers must not be underestimated for the functioning of the Gorongosa ecosystem.

So far, predation has not been factored in. Management will have to seriously consider what level of predation will be acceptable if the primary objective of production from the Sanctuary is to be realised. This becomes even more critical where the production of rare species is concerned. Maintaining the integrity of the fence and putting a policy in place to deal with any large predators that may enter the Sanctuario is important. Here again, the approach to predators may be very different to that followed in the larger PNG.

Monitoring the effect of management actions on the status of the resource and on the performance of the animals is of critical importance to evaluate management effectiveness and to further guide management decisions.

5. CONCLUSION

In conclusion, the Sanctuario consists of a diverse mix of habitats with different carrying capacity and habitat suitability. It provides the opportunity to re-introduce a number of species. Significant populations of important species such as buffalo, zebra, wildebeest and impala can be accommodated. This will greatly support the restoration of the PNG.

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APPENDIX A: Glossary of some terms commonly used in the text

Animal Unit – a standardised unit that is used to translate domestic livestock and wild herbivores to a common denominator. The AU used in this report denotes an average cow of 450 kg live weight (= 1 Animal Unit or AU).

Browser – an animal that uses browse which is the proportion of the woody vegetation that is available for consumption by animals.

Carrying capacity – potential of an area to support livestock through grazing and/or browsing and/or fodder production over an extended period of years without deterioration to the overall ecosystem.

Grazer – an animal that utilizes grass.

Habitat – type of environment in which a plant or animal normally lives.

Sour (sour veld) – veld in which the forage plants become unacceptable to the animals and less nutritious upon attaining maturity. There is a sharp drop in protein content in late-summer/autumn. Although a large amount of forage might remain standing throughout the winter (dry season), it is of such low quality that it cannot fulfil the nutritional requirements of most herbivore species.

Sweet (sweet veld) – veld in which the forage plants retain their acceptability and nutritive value after maturity or in which different plants are acceptable at different times so that the veld can be utilized by animals at all times of the year.

Stocking rate – the area of land in the system of management that is allocated to each animal unit in the system (ha/AU or AU/ha).

Veld - indigenous vegetation used as grazing and/or browsing which may be composed of any of a number of plant growth forms and structure. This is equivalent to the concept of ‘range’ used in the USA and to ‘capi’ in Portugese as used in Moçambique.

Adapted from:

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