PARQUE NACIONAL DA GORONGOSA, MOÇAMBIQUE

LONG-TERM PLAN FOR GORONGOSA NATIONAL PARK VEGETATION MONITORING AT MULTIPLE SCALES

Prepared for the Gorongosa Research Center by

Dr. Marc Stalmans
International Conservation Services-South Africa

and

Dr. Richard Beilfuss
Department of Scientific Services, Gorongosa National Park

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SUMMARY

The core principle of biological conservation and sustainable development for Gorongosa National Park is *Adaptive Management*. This is a systematic, iterative approach to management that acknowledges that, from an ecological and socio-economic perspective, one is working with incomplete knowledge of the Gorongosa ecosystem. Because the outcomes of management are not always guaranteed, each management action is carefully monitored to evaluate whether desired outcomes are indeed being achieved.

Monitoring must thus be regarded as one of the most important steps in an adaptive management process.

The monitoring system for Gorongosa will operate at two levels. Indicators that are reliably measured through day-to-day monitoring activities will be assessed by field scouts, tourism staff and other participating staff on Park drives, and by local communities. Indicators that require more technical or long-term scientific monitoring will be assssed by professional research staff and consultants at the Park, including extensive use of remote sensing. This document focuses on the latter level of scientific monitoring and in particular looks at the vegetation component.

A scaled approach is proposed whereby the monitoring at a lower scale is nested in the monitoring applied at a higher scale.

At ground level, 2 to 4 km long transects that cover the major vegetation communities will be spread throughout the Park. Accessibility by vehicle will be taken into account when locating these transects. In each transect different habitat, woody and grass parameters will be assessed in 3 to 6 plots that capture the gradient along the transect.

At the next higher spatial scale, aerial transects will be monitored by means of digital aerial photography and/or videography. These transects will encompass the ground transects as well as covering areas inaccessible on the ground.

Finally, at the highest spatial level, full coverage of the Park will be obtained by means of high-resolution satellite imagery.

The ground transects will be monitored on a annual to biennial cycle, whereas the aerial transects will be sampled on a 3 to 5 year basis and the remote sensing of the full park will take place on a decadal time scale.

The inter-linked system of vegetation transects at three spatial scales surveyed at three different time scales can assist in a meaningful integration and understanding of ecosystem dynamics.

The proposed vegetation monitoring set-up also serves to ‘anchor’ additional monitoring and research in a framework of scaled and spatially-referenced vegetation data that can be used to underpin, support and elucidate additional research questions in a variety of disciplines. These include other vegetation monitoring systems such as the establishment of large (total inventory) census plots, fixed-location photopoints, and vegetation exclosures.

1. BACKGROUND & OBJECTIVE

The core principle of biological conservation and sustainable development for Gorongosa National Park is *Adaptive Management* (Beilfuss 2006). This is a systematic, iterative approach to management that acknowledges that, from an ecological and socio-economic perspective, one is working with incomplete knowledge of the Gorongosa ecosystem. The process starts with clearly defined mission, goals, and measurable objectives, based on agreed-upon target states, and implements management practices based on best current knowledge to achieve the desired outcomes. Because the outcomes of management are not always guaranteed, each management action is carefully monitored to evaluate whether desired outcomes are indeed being achieved.

Monitoring must thus be regarded as one of the most important steps in an adaptive management process.

The monitoring system for Gorongosa will operate at two levels. Indicators that are reliably measured through day-to-day monitoring activities will be assessed by field scouts, tourism staff and other participating staff on park drives, and by local communities. Indicators that require more technical or long-term scientific monitoring will be assessed by professional research staff and consultants at the Park, including extensive use of remote sensing (Beilfuss 2006). This document focuses on the latter level of more scientific monitoring.

The monitoring techniques and procedures applied in Gorongosa must be:

- Related to adaptive management assumptions;
- Based on the latest ecological monitoring theory;
- Cost effective and practically feasible.

The techniques chosen for application must be consistently used over an extended period, including climatic cycle fluctuations, and only amended or disbanded if they are clearly inappropriate or when a vastly superior technique and procedure has been developed.

Vegetation in combination with a range of environmental factors define habitats that have relevance to animal species, whose availability of water might differ, that may require specific fire regimes, and they will differ in their sensitivity to utilisation by animals and to development for tourism purposes.

The challenges faced in the design of a monitoring system for the vegetation of Gorongosa are as follows:

- Extensive system with a wide range of structural vegetation types from pure grasslands to closed woody formations;
- Limited and/or difficult accessibility by vehicles of a large section of the Park;
- Need to be able to document a multiplicity of potential impacts and changes including the following:
    - Those brought about by changes in the hydrological regime (invasion / recession / densification);
    - Changes in fire regime (woody densification);
    - Restoration of the grazing succession;
    - Impact of increasing number of elephant;

    - Influence of resource utilisation by the surrounding human population.

The objectives of this document are to:

- Place the vegetation monitoring in the context of the research and management approach for Gorongosa;
- Outline the conceptual approach followed in designing the monitoring system (with regard to spatial coverage and frequency);
- Recommend a practical lay-out of the monitoring units;
- Describe the techniques to assess specific vegetation parameters.

Although this document focuses on the Park itself, linkages are made with the Greater Gorongosa Ecosystem.

2. SCALED SPATIAL & TEMPORAL APPROACH

As stated earlier, the core principle of biological conservation and sustainable development for Gorongosa National Park is *Adaptive Management*. Gorongosa represents a complex and likely very dynamic ecosystem.

A new conservation theory has emerged globally that relies on the key concepts of patchiness and heterogeneity as crucial elements in the functioning of ecosystems (Pickett & Cadenasso 1995, Christensen 1997). Landscape heterogeneity is perceived at different scales by different organisms (Wiens & Milne 1989). This requires the adoption of a multi-scale perspective on landscape patterns and dynamics. There is a need to dissect landscapes into their constituent patterns and processes and to obtain quantitative information at a detailed level if the structure and functioning of spatially heterogeneous landscape ecosystems are to be understood (Wiens *et al.* 1985). Delcourt & Delcourt (1988) offer an operational paradigm in which nested spatio-temporal domains ranging from micro- to mega-scale are defined. Senft *et al.* (1987) similarly propose an ecological hierarchy encountered by large herbivores while foraging (from small patch or feeding station to plant community, to landscape, and finally to region).

The monitoring system should mirror the multi-scale approach taken to management and research of Gorongosa.

A combination of on-the-ground monitoring with higher spatial levels of aerial videography and remote sensing will be required to overcome the issue of physical accessibility. The higher-scale remote sensing also enables a broader perspective on changes in landscape pattern and processes.

The principle has been described as follows by Stohlgren *et al.* (2000): 'In many national parks, monuments and wildlife reserves, a few long-term monitoring plots are used to infer the status and trends of natural resources in much larger areas. To make defensible inferences about populations, habitats, and landscapes, it is necessary to extrapolate from monitoring plots (local scale) to the larger, unsampled landscape with known levels of accuracy and precision.'

New technology with airborne aerial photography or video that is linked to GPS coordinates enables a much wider coverage that includes inaccessible areas.

The spatial and temporal scales are linked in that larger spatial scales will be assessed at longer time intervals compared to the ground observations (Fig. 1 & 2). The ground transects are nested in the area covered by the aerial transects. In turn, the aerial transects are nested in the full coverage achieved by the remote sensing (Fig. 2). Certain vegetation parameters will link the different spatial scales. Although the same parameter is involved at each scale, the measurement technique will be adapted to the relevant scale. The parameter 'percentage woody cover' is used for illustration purposes in Fig. 1 as the linking element between the three spatial scales.

The inter-linked system of vegetation transects at three spatial scales surveyed at three different time scales can assist in a meaningful integration and understanding of ecosystem dynamics.

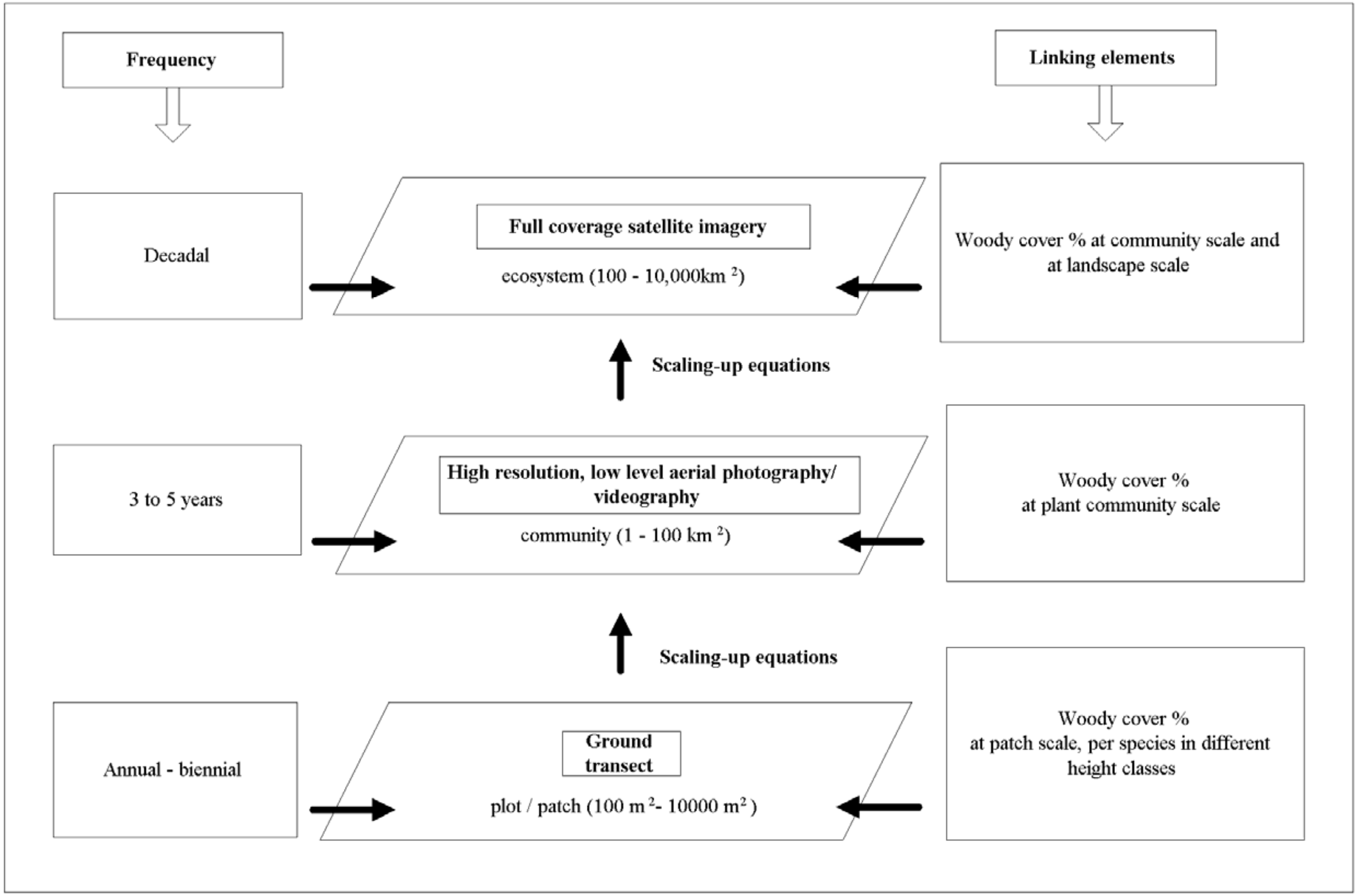

Fig. 1: Scaled approach to the vegetation monitoring system.

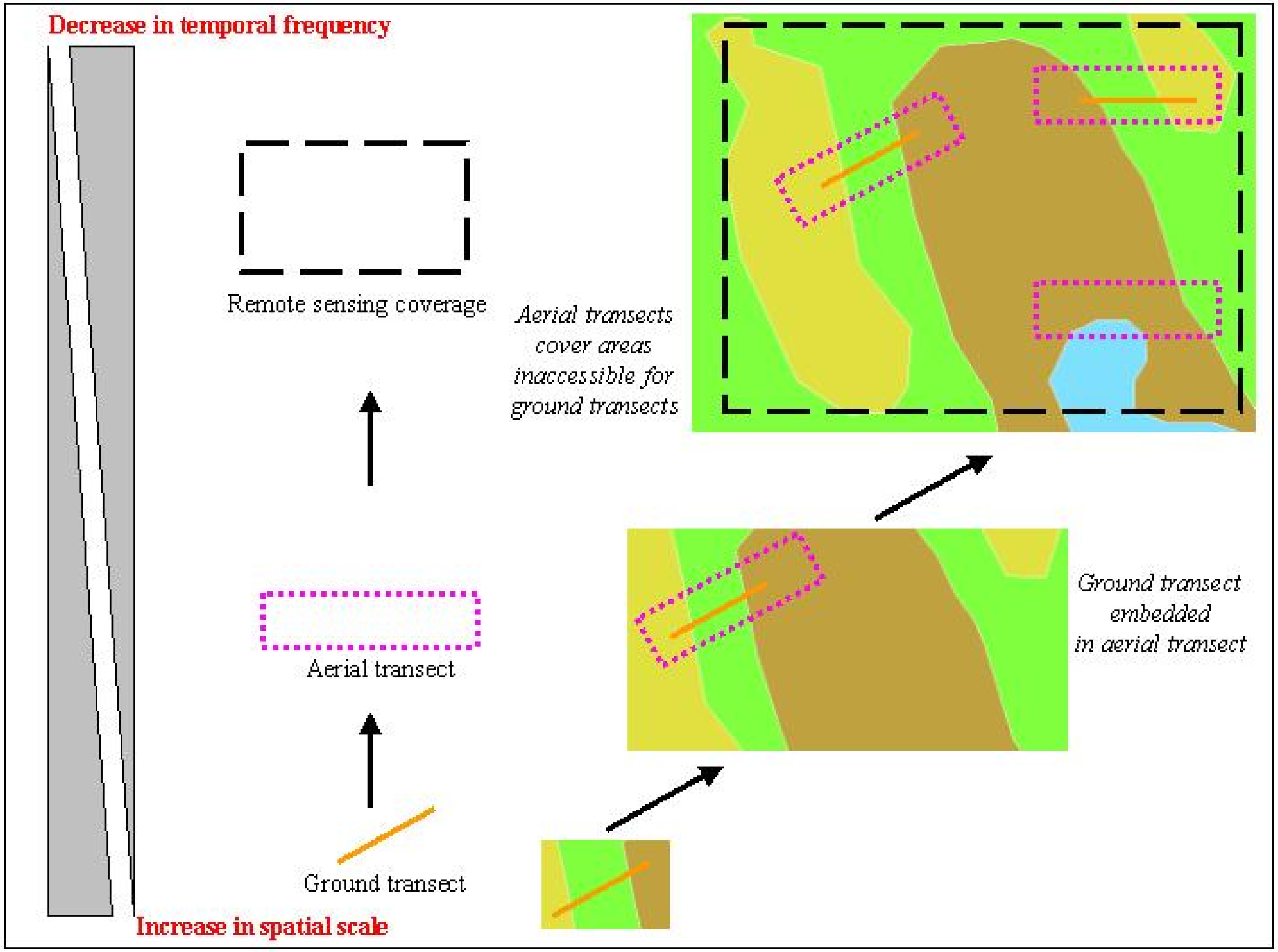

Fig. 2: Nested system of ground, transects, aerial transects and remote sensing coverage.

3. TECHNIQUES

3.1. General

Monitoring indicators have four key characteristics (Margoluis & Salafsky 1998):

- Measurable (can be recorded or analyzed in quantitative or qualitative terms);
- Precise (defined the same way by all people);
- Consistent (not changing over time so that is always measures the same thing);
- Sensitive (changing proportionately in response to actual changes in the condition or item being measured).

At this stage it is not necessarily known what vegetation parameters are most important. This is because the questions that need to be answered are not all known and may only become apparent in the face of changes, for example in response to global change.

It will therefore be necessary to err on the side of caution and to take a wide range of measurements, whilst staying within realistic logistical and practical limits.

3.2. Ground transects

Ground transects will be assessed at an annual or biennial interval. Balancing the need to cover the diversity of the Park and the need to stay within available resources, a deliberate decision was made to limit their number to a maximum of 40 transects. This number may be reviewed in time.

The transects will mostly be established along a catenal gradient (for example from upland woodland into the floodplain). These transects cover the major landscapes of the Park. For practical reasons, they are mostly located closely to roads (Fig. 3).

3.2.1. Location of transects

The following steps are required to identify the location of the ground transects:

- Step 1: Define tentative locations for 40 ground transects using LANDSAT and/or LISS IV satellite imagery;
- Step 2: Determine GPS positions from the satellite image;
- Step 3: Use GPS positions to assess the transects from the helicopter to ensure that the desired plant community coverage is achieved with no major physical obstacles (e.g., river channel that is difficult or dangerous to cross). Where necessary new GPS positions are determined (Appendix A and Fig. 3);
- Step 4: Use GPS positions from the helicopter to conduct ground reconnaissance of the transects. Where necessary the beginning and endpoints are adjusted as well as the general orientation of the transect;

- Step 5: Determine the position of the individual sampling plots in relation to the plant communities that are traversed by the transect and in relation to the steepness of the gradient;

Steps 1 to 3 have now been applied (August 2007). A total of 33 transects have been positioned. This leaves some room for growth towards the envisaged 40 transects.

Four to six fixed plots in each transect span this gradient. The plots are not spaced systematically along the gradient but placed in such a way as to capture the underlying environmental and biological diversity (Fig. 4). This is the so-called 'gradsect' approach whereby samples are deliberately selected to contain the strongest environmental gradients present in an area to optimise the amount of information gained in proportion to the effort and time spent (Austin & Heyligers 1989).

A series of measures will be taken to assess functional aspects of hydrology, the re-establishment of the grazing succession, the impact of increasing numbers of elephant, changes in fire regime, and spread of alien invasive species.

Some of these transects replicate Tinley's transects from the early 1970s, and enable direct assessment of long-term vegetation change at the species level. The new transects however will be covering a longer section of the catenal transition from woodland to floodplain (Fig. 5).

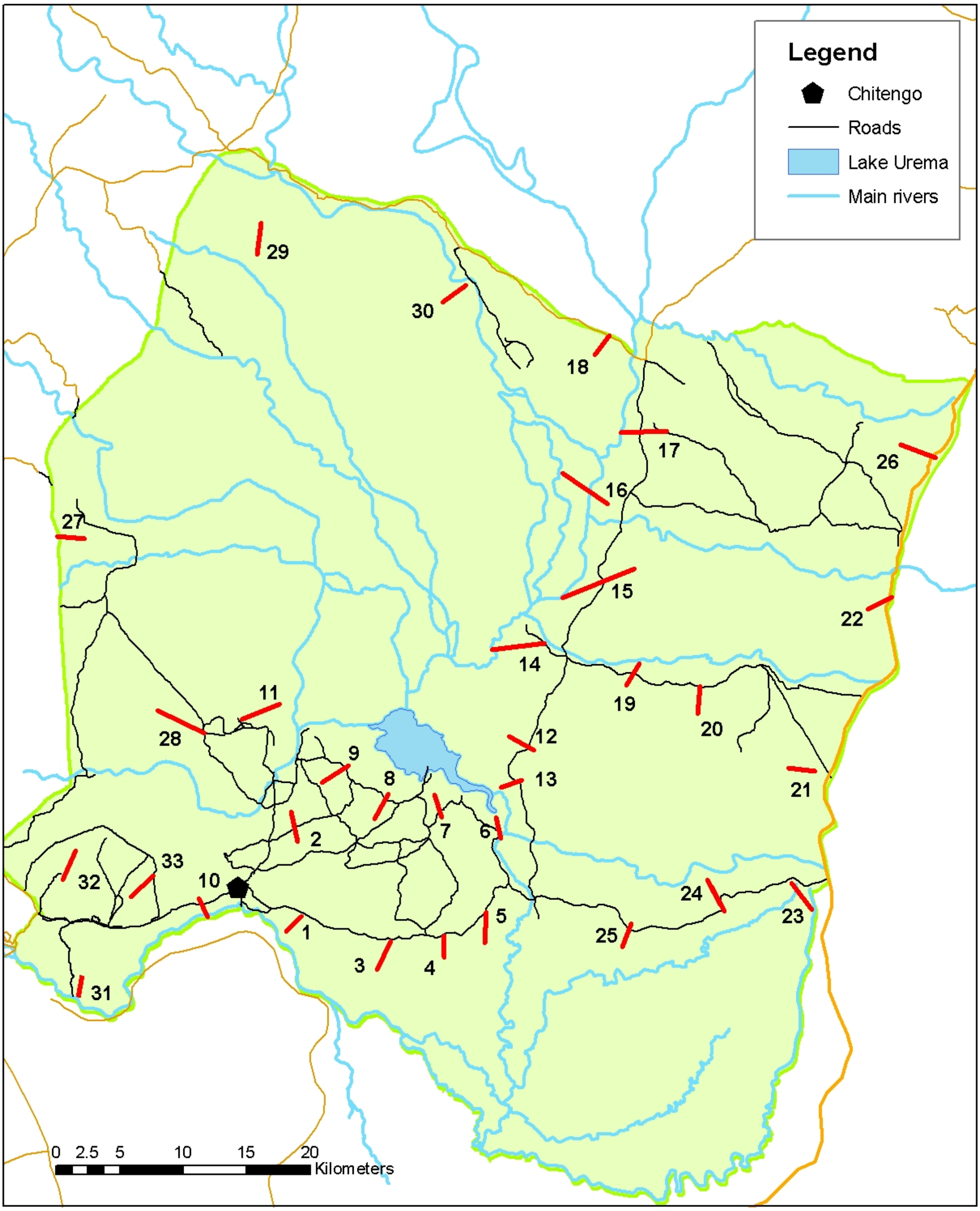

Fig. 3: Location of proposed ground transects.

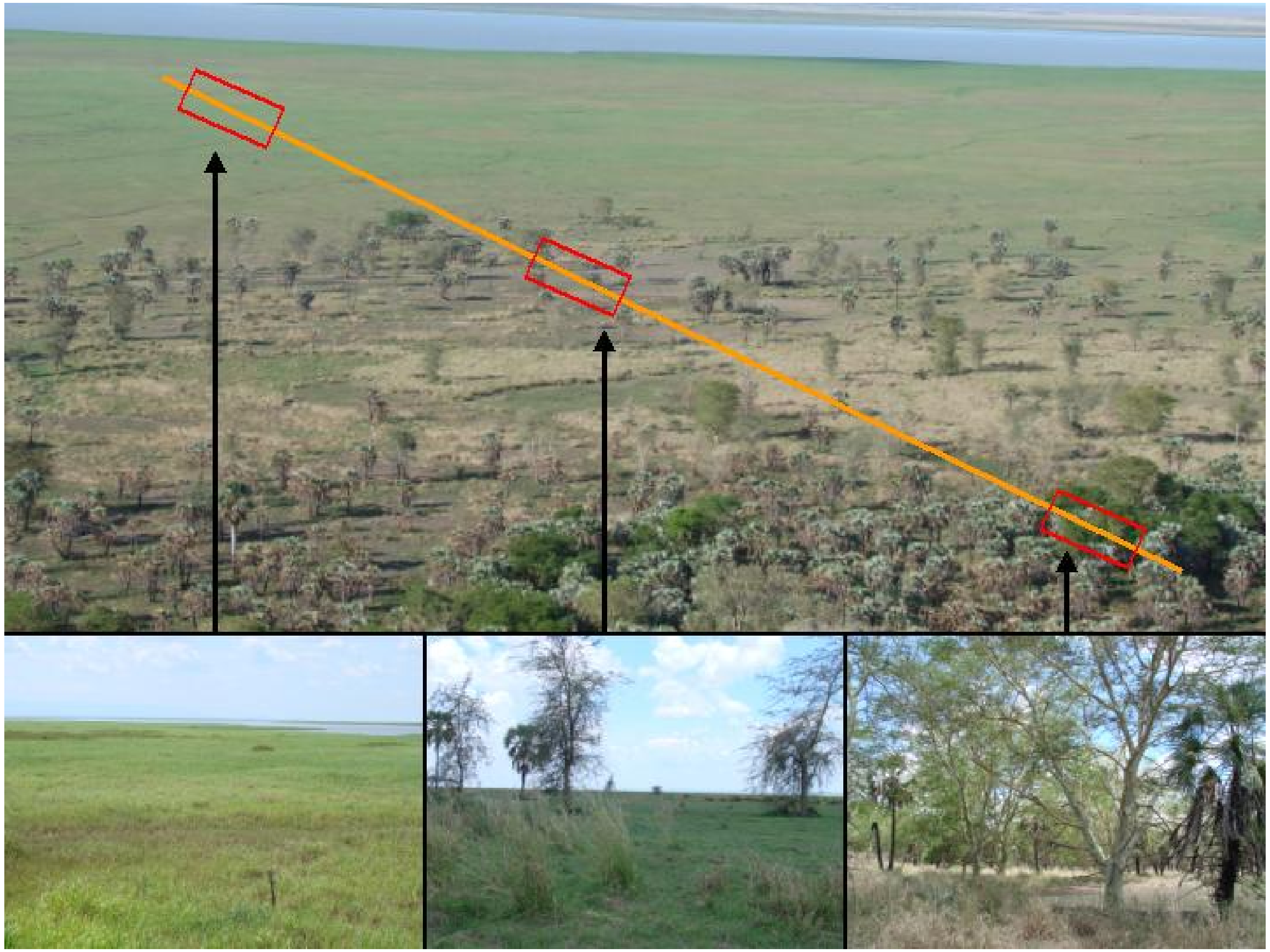

Fig. 4: Change in vegetation communities along a gradient from woodland to flooded grassland as captured by fixed plots along the fixed transect line. The orange line represents transect line and the red boxes represent individual sampling plots.

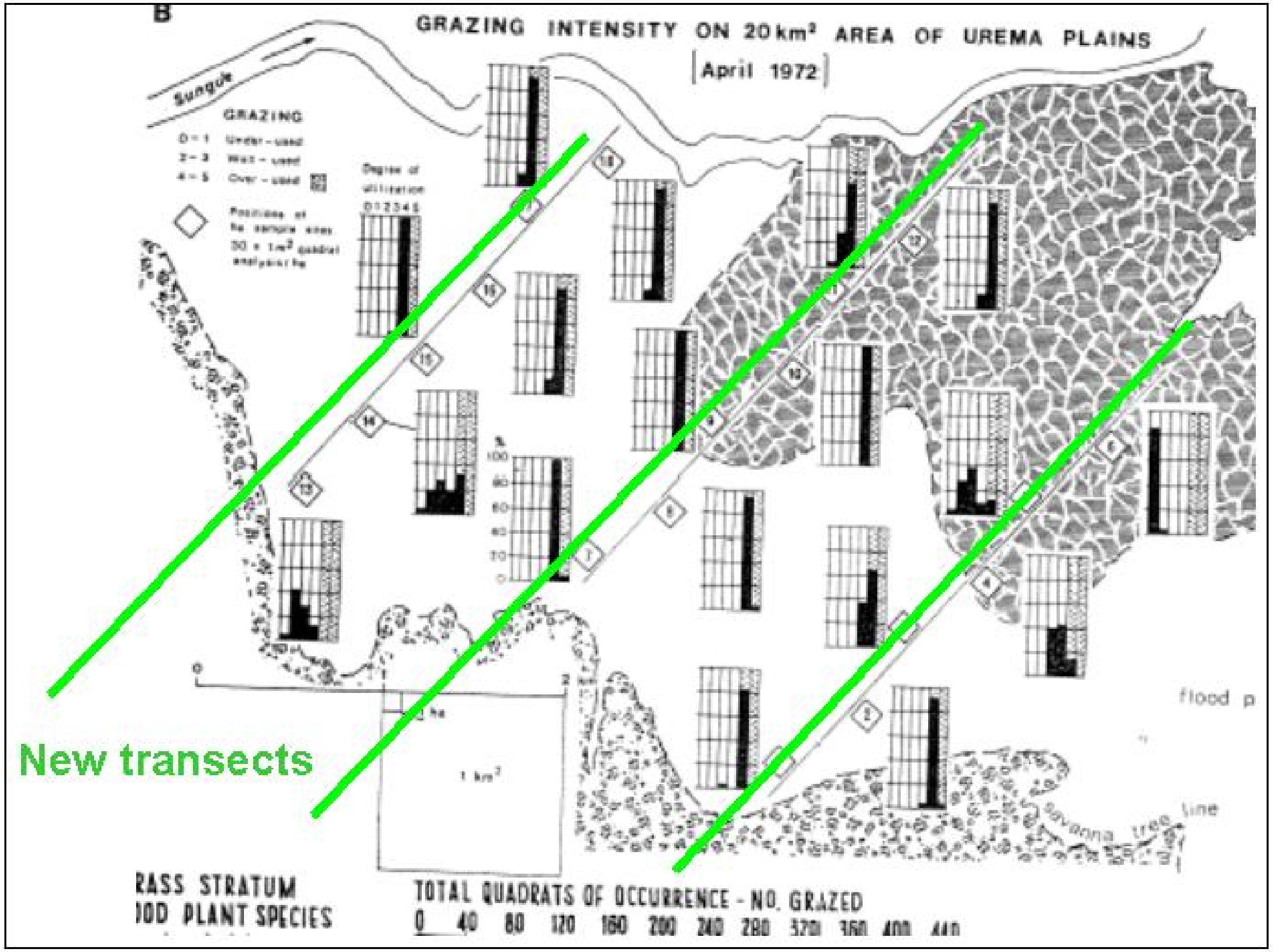

Fig. 5: Tinley (1977) transects south of lake Urema with proposed new transects. Note that new transects will capture a longer gradient into the woodland south of Tinley's transect.

3.2.2. Sampling methodology

The following minimum description is required for each plot in terms of its position:

Date of survey	
Observer name	
Plot number within transect	
Transect number with orientation	
General description of locality (nearest road)	
GPS position (differential GPS on 4 corners of plot)	
Include photograph from central point in each of the 4 cardinal directions	

The following parameters will be measured for each plot:

Structure & composition

Parameter	**Description of measurement**
Woody Layer (see detailed sampling approach further in this document)	
Species composition	Species identification of individual stems (see proposed methodology further in this document)
Cover	Aerial cover as an estimate (by species and overall) – adapted Braun-Blanquet cover scale) or intercept on sampling line(s) in plot. Basal area determined by allocating each stem to a diameter class.
Density	Enumeration of all stems (based on certain criteria – see proposal)
Height structure	Allocation of each stem into a height class.
Grass & field layer	
Phytomass	Disc pasture meter or weighted rank method (depending on practicality of using a disc pasture meter in very tall and tufted grassland)
Species composition	Identification of nearest-rooted individuals to 100 points systematically spread through the plot.
Cover	Transformation of species composition data to cover value.

Utilisation (by animals)

Parameter	**Description of measurement**
Woody Layer	
Browsing intensity	Estimate on a relative scale of 1 to 5
Elephant impact	Estimate on a relative scale for main stem, branches, …
Grass & field layer	
Grazing intensity	Estimate on a relative scale of 1 to 5
Selectivity	Estimate on a relative scale of 1 to 3 in terms of relative uniformity or area selection
Grass height	Estimate of leaf table height in 0.50 m increments or measurement across plot in 0.20 m increments

Landscape Function Analysis

Parameter	Description of measurement
Tuft diameter and/or inter-tuft distance	Average size of tufts and inter-tuft distance (measurement taken at the 100 points used for the grass layer composition assessment – see above).
Obstructions to flow	Estimates using approach described in the manual of Tongway & Hindley (2004).
Surface flows	
Soil capping and cracks (vertisols)	
Litter cover	
Cryptogams	
Slake test	
Presence/absence of *Auswuchs*	Observations of algal and detritus crust on floodplain

Biodiversity surrogates (microhabitats)

Parameter	Description of measurement
Geomorphological habitats	Holes in the ground, rocks ….
Live vegetation as habitat	Trees (bark structure & cavities), Shrub (multi-stemmed), grass tuft structure
Dead vegetation as habitat	Standing logs, prostrate logs (bark structure, cavities …)
Litter as habitat	Litter amount and structure on the ground.

The above list is not exhaustive and will be finalized following field tests. A specific assessment and scoring procedure (actual measurements or estimates and relevant class sizes) must be developed for each parameter.

The following considerations apply to the specific techniques that need to be used, for example to record the density of trees:

- Plotless techniques (for example *Bitterlich* method) would be difficult to implement because of the height of the grass layer that ompromises the visibility of the woody stems;

- A nested approach, with smaller subplots within the plot will enable the efficient enumeration of individual stems in the lower height classes (it becomes very time consuming to record the (generally abundant) smaller individuals. At the same time this greater sampling effort adds little value);

- Techniques applied in the South African Lowveld in the Kruger National Park (South African Parks Board) and in the adjoining private reserves (Range & Forage Institute of the Agricultural Research Council) can be adapted to fit local circumstances.

Therefore, a variable plot size will be adopted with a small sampling area for the smaller specimens (that generally occur at higher densities) with larger sampling areas for large specimens (that are generally scattered). These subplots are somewhat larger than those of the KNP for the lower height classes (40 m^2 and 300 m^2) and similar for the largest height class (600 m^2) (Fig. 6).

These subplots are embedded in a sample plot of 30 m x 30 m that is suitable for phytomass measurement with the disc pasture meter and for the assessment of species composition of the grass layer.

The following illustrates how woody specimens could be recorded in terms of proportional composition and height structure (technique to be field tested and adapted as required):

- Woody layer (subplots per Fig. 6);
    - < 1 m height
        - subplot of 2 m x 20 m = 40 m^2;
        - for all woody specimens:
            - species,
            - single stemmed, 2-stemmed, more than 2 stems (if stems further apart than 2 x average diameter, consider as separate specimen,
            - height class < 0.5 m or 0.5 to 1 m,
            - diameter class (if multi-stemmed – average diameter) <2 cm above root collar, 2 – 5 cm, 5 - 10 cm, 10 – 20 cm, 20 - 50 cm, > 50 cm.
    - 1 – 3 m height
        - subplot of 10 m x 30 m = 300 m^2;
        - for all woody specimens:
            - species,
            - single stemmed, 2-stemmed, more than 2 stems (if stems further apart than 2 x average diameter, consider as separate specimen,
            - height class 1-2 m, 2 to 3 m,
            - diameter class (if multi-stemmed – average diameter) < 2 cm above root collar, 2 – 5 cm, > 5 cm, 5 - 10 cm, 10 – 20 cm, 20 - 50 cm, > 50 cm.
    - > 3 m height
        - subplot of 20 m x 30 m = 600 m^2;
        - for all woody specimens:
            - species,
            - single stemmed, 2-stemmed, more than 2 stems (if stems further apart than 2 x average diameter, consider as separate specimen,
            - height class 2 – 3 m, 3 – 5 m, 5 – 10 m, 10 – 20 m, > 20 m,
            - diameter class (if multi-stemmed – average diameter) < 2 cm above root collar, 2 – 5 cm, > 5 cm, 5 - 10 cm, 10 – 20 cm, 20 - 50 cm, > 50 cm.

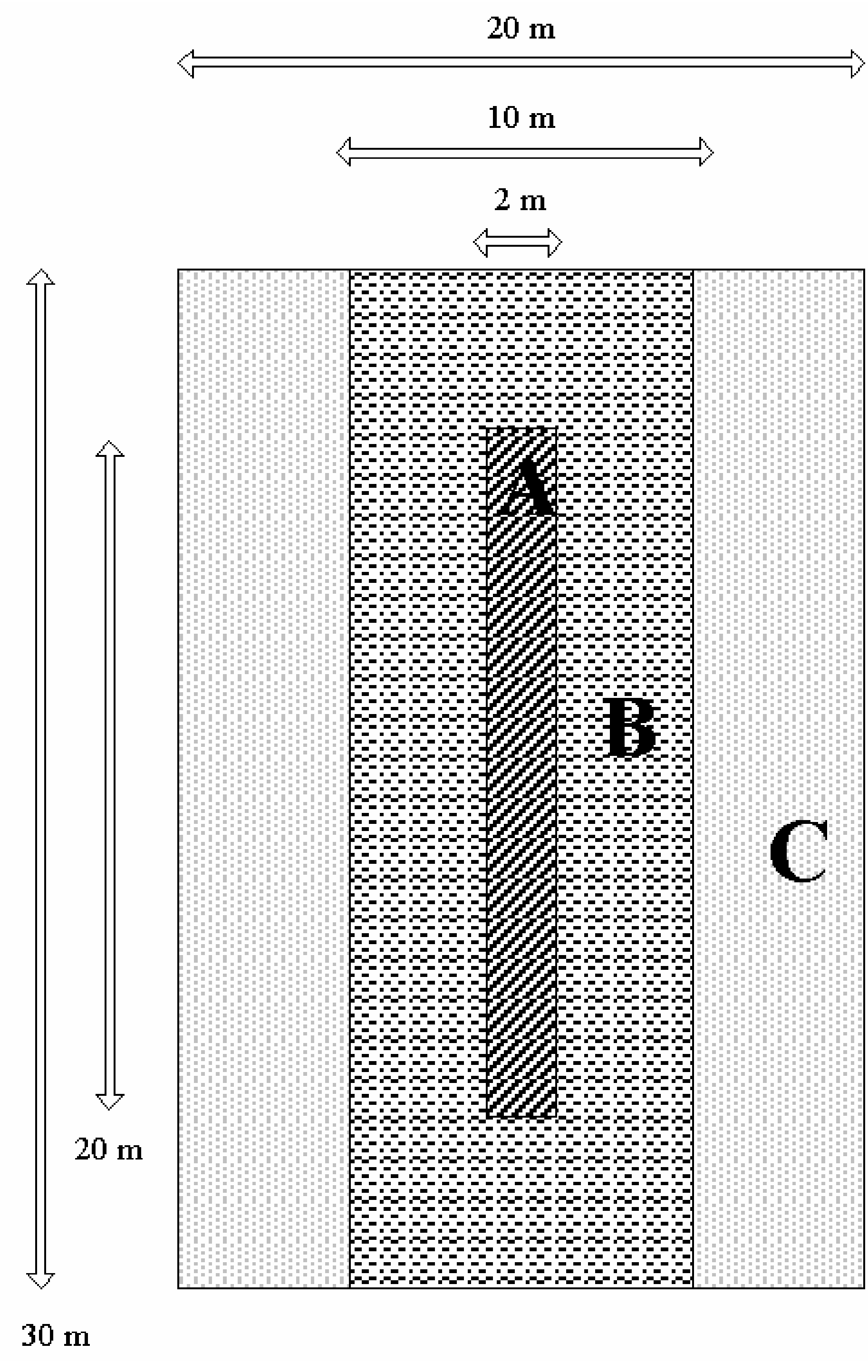

Fig. 6: Schematic layout of monitoring plot for the woody layer (for illustrative purposes only):

A = 2m x 20m sampling area for woody specimens ≤1 m height,
B = 10m x 30m sampling area for woody specimens >1m and ≤3m height,
C = 20m x 30m sampling area for woody specimens >3m height (if less than 10 specimens taller than 3m are recorded in this sample size it may be prudent to extent the width of the sampling area to 30 m thereby resulting in a sample area of 900m^2).

3.2.3. Timing of sampling and logistics

The following is important with regard to timing of the ground surveys:

- Due to flooding, many of the transects will be inaccessible when the grasses are easiest to identify;
- Conversely, when access is easiest towards the end of the winter season, much of the grass will no longer have any inflorescences. Furthermore, large areas will have burnt, probably including some of the transects;
- The optimal time window is likely to be from April to June;
- Transects in the Midlands and Cheringoma Plateau regions can be first sampled while transects in the floodplain are to be sampled last;
- Being the most constrained by logistical and practical aspects, the timing of the sampling of the ground transects should ideally dictate the timing of sampling at the other spatial levels. The aerial videography can be done at the same time. The remote sensing should probably take place as soon as possible after the rainy season when cloud cover diminishes and before fire scars become too extensive. However, extensive flooding (particularly following an above-average wet summer) would mask underlying features.

The following applies to logistical arrangements (see also Table 1& 2):

- Although the transects are mostly placed so that they are accessible from the road network, the individual sample plots within a transect may be located a considerable distance from the road. These plots must be monitored in the presence of an armed escort;
- Many of the transects will take considerable time to reach from Chitengo. Therefore, such a transect (consisting of 3 to 6 sample plots) should be designed such that it can be completed within a single day. The team should be sufficiently large to allow for efficient sampling. It should probably consist at the minimum of a senior technician or scientist with two junior technicians;
- A good team should be able to sample 2 transects daily (the full set of approximately 40 transects should not require more than 20 sampling days). However, the initial survey will probably require 1 day per transect;
- The initial lay-out and sampling will thus be very time consuming and is probably not feasible within the first season. The transects will have to gradually come 'on-line' as road access improves and resources are available;
- One could also monitor half of the transects in one year, and the other half in the following year (this would decrease overall personnel requirements as much other work will have to be done during this time 'window' when the roads are open and the Park is at its most accessible);
- Monitoring equipment must include the following:
  - GPS;
  - Digital camera;
  - Compass;
  - Measuring tapes (50m long) (x2)
  - Calibrated rod with height classes (x2);
  - Disc pasture meter.

3.3. Aerial transects

At the next higher spatial level, longer and wider fixed transects will be surveyed by means of high-resolution aerial photographs and videography. These transects will encompass the ground transects but will also cover inaccessible areas where there are no ground transects (Fig. 2). They should be assessed on a three to five year cycle. The ground and aerial scales will be linked by common elements such as percentage woody cover.

The position of these aerial transects will be based on a combination of required spatial coverage as determined from the LISS IV satellite image and issues of cost, flying time, on-board data storage systems et

The technology is rapidly evolving in this field. The following is envisaged based on current techniques[1]: a spatial digital video recorder (sDVR) is used to streamline and automate the process of spatially referencing multimedia. The sDVR and associated software allows one to georeference still images, up to four streams of video as well as audio from the aircraft intercom system. The data is recorded to removable hard-drives and each 80GB disk can store up to 20 hours of high-quality video, replacing bulky tape archives with a searchable digital mapping database. The georeferenced video output can be spatially accessed in a mapping environment (Red Hen Media Mapper or Geo Video for ArcGIS) and users will be able to follow the flight path and watch the high quality video as it was captured. This means that the data can be accessed on the ground by all the different specialist parties, which eliminates the need for all these parties to actually be present onboard during the survey. The interpretation and evaluation of this data can be conducted at any later stage.

Whereas a fixed-wing aircraft will be initially used, the use of a ‘drone’ (or UAV – Unmanned Aerial Vehicle) may become more cost-effective as the techniques and UAV’s are further developed.

The data are used in the preparation of multimedia maps. These answer the question ‘What does it look like there?’ by linking streaming video and photographs with the place that they came from. It allows one to populate a GIS database with multimedia providing an intuitive connection among maps and field collected images, audio, video and tabular summaries. The aerial videography integrated (as it is properly georeferenced) with all the other information available in the Gorongosa GIS environment.

The multimedia data is also easily disseminated and is a perfect medium for sharing among non-scientific interested and affected parties. Multimedia maps can be exported to HTML format and then be hosted on the Internet for public access.

During the survey, vertical aerial imagery can also be captured in 600m swaths and this planimetric imagery can be seamlessly mosaiced and referenced to existing satellite imagery to provide very high resolution image transects in areas less accessible from the ground as well along the proposed ground plots.

[1] Conservation Air Patrol

Table 1: Personnel requirements for proposed tiered vegetation monitoring system.

Resource → **Scale** ↓	Armed escort(s)	Monitoring technician(s)	Ecologist/ botanist	GIS and/or remote sensing specialist
Ground transects	**X**	**X**	**X**	
Aerial transects			**X**	**X**
Remote sensing			**X**	**X**

Note: Monitoring technicians could be 'on staff' or students

Table 2: Estimate time requirements for the monitoring of the ground transects.

	Annually required person-days		
	Ground transects (initial survey)	**Ground transects follow-up survey (all transects annually)**	**Ground transects follow-up survey (half of transects = 2-year cycle)**
Armed escorts	80	40	20
Technician / students	80	40	20
Ecologist / scientist	40	20	10

<u>Assumptions:</u>

- Total of 40 ground transects with and average of 5 plots per transect
- Access possible by vehicle close to survey sites
- Monitoring team = 1 ecologist/scientist + 2 technicians/students + 2 armed escorts
- Average of 1 transect (x 5 plots) per day per monitoring team (initial survey)
- Average of 2 transects (x 5 plots) per day per monitoring team (follow-up survey)

3.4. Full remote sensing coverage

The aerial transects will be scaled up to achieve full coverage of the Greater Gorongosa Ecosystem on a decadal time scale using satellite imagery. Woody cover will again represent a linking element between the ground and aerial transects and the full Park coverage. A new multi-spectral image of the entire ecosystem has been acquired by the Indian LISS IV satellite with a resolution of 5.8 m.

A complete coverage of the Greater Gorongosa Ecosystem is also available through a series of 1:50;000 aerial photographs dating back to 1960, which are in the process of being stitched together and geo-referenced to the 2006 LISS IV image, to enable time-series assessment of long-term vegetation change at the landscape level.

With the rapid evolution of remote sensing platforms one cannot at this stage anticipate what instrument will be used in 10 years time to achieve a full coverage of the Greater Gorongosa Ecosystem.

These fine-scaled remote sensing images allow for the quantification of certain landscape parameters of the Park that cannot normally be measured by ground work. The landscape ‘metrics’ are often highly significant in the way in which they translate in terms of habitat requirements for rare and sensitive birds and mammals. The landscape metrics influence fire behaviour and are in turn modified through fire.

Landscape metrics that can be assessed include:

- Fragmentation;
- Permeability;
- Size distribution of patches;
- Abruptness of edges.

Given the very large extent of the park and the massive amount of information involved, the analysis of ‘change’ at that scale poses certain problems. Obviously automated procedures can be followed that are based on raw computing power. However, the interpretation of the results still poses a challenge. A practical and feasible approach is to make use of a number of ‘change boxes’ that encompass smaller areas of the park.

A similar approach was successfully followed to assess the change of vegetation in the Zambezi Delta to the north-east of Gorongosa (Beilfuss et al. 2001). These ‘change boxes’ (called ‘inset boxes’ in Beilfuss et al. (2001) worked well in a situation similar to that of Gorongosa (Fig. 7)). The challenge remains to select a scale and level of detail that are appropriate. In the instance of Gorongosa the ‘change boxes’ must cover areas that are at an order of magnitude larger than the aerial transects in order to achieve the benefits of the scaled approach proposed for the vegetation monitoring.

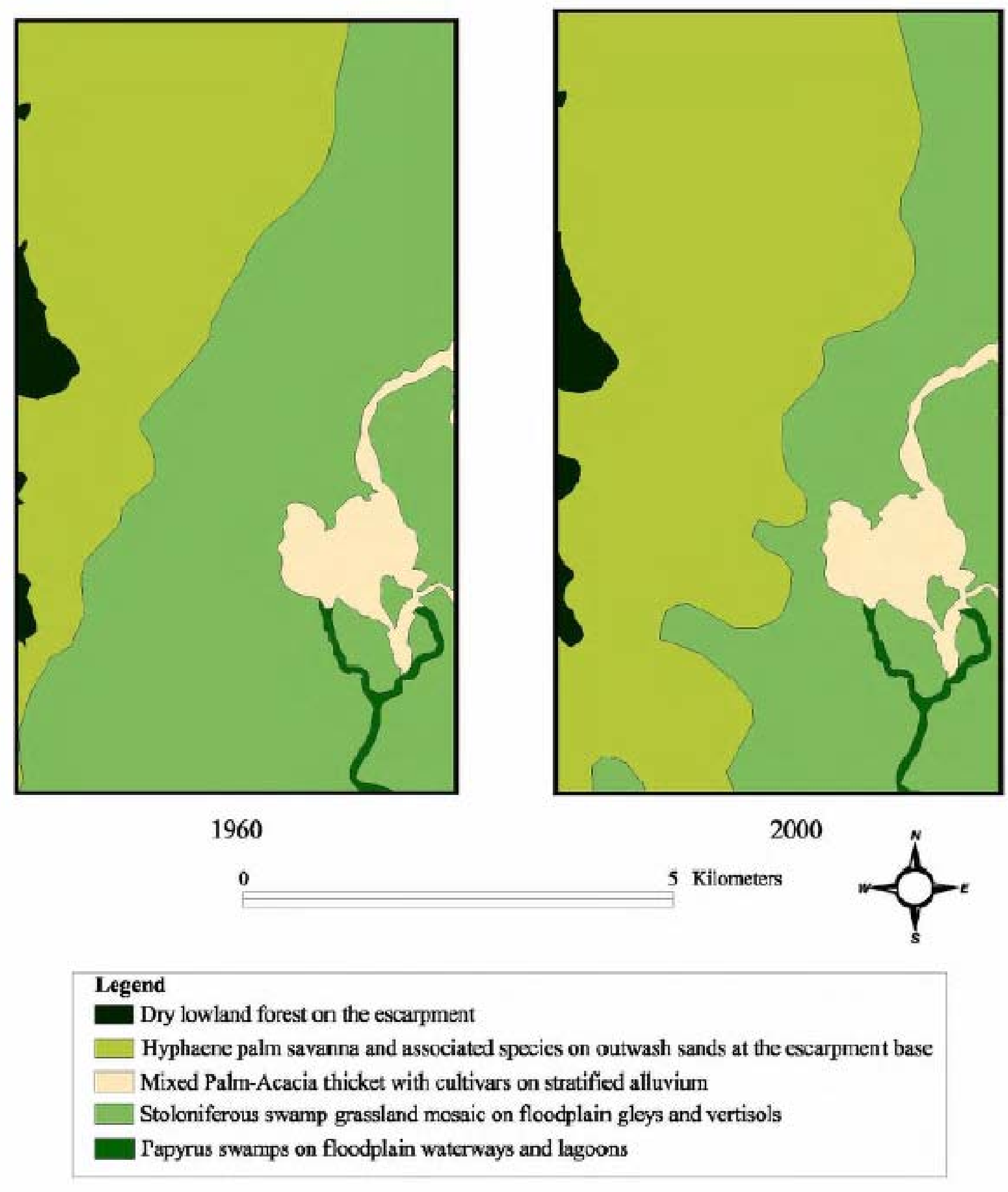

Fig. 7: Example of 'change boxes' across the Zambezi Delta with illustration of actual change in vegetation from 1960 to 2000 (from Beilfuss et al. 2001).

3.5. Additional vegetation monitoring

3.5.1. Large Census Plots

Large census plots are also an important tool for understanding long-term patterns of vegetation change in the Gorongosa landscape. The goal of a large-scale census plot is to provide demographically useful samples of a large number of co-occurring tree species by marking an entire population of individuals. Because tropical forests and miombo woodlands are diverse, with hundreds of tree species sharing a community, there is no way to study the demography of even half of the species except by censusing a very large number of stems. A single large plot is a comprehensive and precise way of sampling a large number of stems (Condit 1998).

The large census plots includes the comprehensive marking of all free-standing woody species (including trees and shrubs but not lianas) greater or equal to 10 mm in diameter at breast height (1.3 m from the ground) within a designated area of 1-50 ha. This provides demographic data on juveniles as well as adult trees. With long-term data on the density and spatial distribution of adults and juveniles of a large number of species, demographic models can be that incorporate spatial variation and density-dependence can be developed. Each plot becomes a focus of basic research on many different topics, including community ecology, genetics, physiology, phenology, and animal-plant interactions.

The plots require the enormous initial effort of locating each stem, tagging it, and measuring its diameter at breast height over a large area. Once established, however, these plots can be assessed for decades to provide long-term data to monitoring changes caused by climatic shifts, human disturbance, hydrological changes, elephant activity, herbivory, fire, and other ecological factors.

The Center for Tropical Forest Science (CTFS) maintains a global network of *Tropical Forest Census Plots* (most are 50 ha. in size) to cover the major tropical forest regions of the world (Condit 1998). The Afromontane forests of Gorongosa Mountain have been proposed for inclusion in this network (Dr. Stuart Davies, Director, CTFS, pers. comm.). A Tropical Forest Census Plot (50 ha.) will be established on Gorongosa Mountain and integrated with this network as soon as a site can be fully secured from deforestation.

An additional large census plots (up to 50 ha.), outside of the CTFS network, will be established on the woodland-floodplain ecotone, and will be linked to the accessible trail system in the southwest of the Park (near Transect 8, Figure . The site will capture the dynamic interactions between woody and grassland species over time. The plot will be located near Transect 8 (Figure 3).

All of the large census plots will include biodiversity sampling at multiple scales. An example of how a multi-scale, integrated sampling system might be nested for a large census plot is shown in Table 3. Specific sampling techniques for the herbaceous layer, soil biogeochemical sampling, and various animal taxa are beyond the scope of this report and will be determined in conjunction with individual researchers.

In addition to census plots that are newly established through this long-term vegetation monitoring program, we will collaborate with the University of Edinburg which has established a series of large census plots (1 ha size) in the miombo woodlands on the western boundary of the park (Nhambita Community). The Edinburg project is analyzing the dynamics of fire in miombo woodland, and has expressed interest in collaborating to sample the herbacius species layer of these plots and perhaps other taxa.

Table 3: Example of large census plot with multi-scale, integrated biodiversity sampling

Samping target	Spatial sampling scale	Temporal sampling scale
Woody species	50 ha. (marked individuals)	Decadal
Herbacius layer	1 m^2 fixed subplots	Biennial
Invertebrates	100 m^2 fixed subplots	Biennial, seasonal
Amphibians and reptiles	1 ha. fixed subplot	Biennial; seasonal
Small mammals	1 ha. fixed subplot	Biennial; seasonal
Birds	50 ha.	Biennial; seasonal
Large mammals	50 ha.	Annual, seasonal
Soil biogeochemistry	1 m^2 fixed subplots	Semi-decadal

3.5.2. Fixed-point photography

Fixed photos represent a cost-effective way of objectively documenting the visual appearance and change over time of the vegetation in particular and the surrounding environment in general. Human memory is fickle. Combine this with the staff turnover that inevitably happens over time, and it becomes impossible to have a clear picture in mind on how an area might have looked like several years ago.

The photos taken at regular intervals at specific fixed points can illustrate seasonal changes in the vegetation (in reaction to differences in rainfall), changes as a consequence of specific management actions (e.g. burning), or the effect of restoration and rehabilitation (increased wildlife and restored grazing succession in the Park).

A number of fixed photo points that are representative for the Park will be established and photographs will be taken at regular intervals and safely stored:

- Establishment of fixed photo points that capture the diversity of the Park (major plant communities, forest edges, problem areas (for example to monitor alien *Mimosa pigra* invasion and its control).
- It is recommended that each of the monitoring plots in the ground transects also becomes a photo monitoring point;
- Each photo point must receive a permanent marker, preferably small, unobtrusive and in concrete;
- A file will be opened to store the photo point information;
- Each photo point to have the following information documented;
    - Photo point number,
    - GPS locality (latitude / longitude);
    - Description of how to locate the permanent marker;
    - Date established;
    - Photo of the photo point itself in its landscape context;
    - Information on the number of photo's to be taken at each point and the direction in which each photo is taken;
    - Date of each photo survey;
- Each photo point will be regularly surveyed. This will be once a year, unless specific conditions require a more regular action (for example documenting recovery of an area following restoration work);
- The photographs will be printed and stored in a file. They will be kept together per photo point and will clearly labeled as to date and orientation of the photo.

3.5.3. Exclosures

The use of exclosures where the large herbivore component is physically kept out by means of a fence can provide useful insights in the vegetation dynamics. At present, the question regarding the relative impact of for example elephant has become a burning issue in many southern African parks. Unfortunately, the necessary scientific data to answer some of the questions are often not available.

Exclosures will be located where they are easily accessible along the game-viewing roads as it is necessary to frequently check on the integrity of the fences. Each exclosure should preferably coincide with one of the ground transects, as the latter will provide the information on changes (or lack thereof) in the system with herbivores present (whereas they are excluded from the exclosure).

No special effort will be made to protect the exclosure from fire except to prevent damage to the fence itself. If the area surrounding the exclosure is burnt and the exclosure itself is not affected, Gorongosa Park management will deliberately burn the exclosure as soon as possible and under conditions approximating that of the area burnt outside. There is little point in attempting any long-term fire exclosure studies on Gorongosa. The Park represents a system that has evolved with fire and that actually requires it for the maintenance of diversity and processes.

Exclosures will probably need to be in the order of 50m x 50m (0.25 ha). They need to be large enough to capture the woody-grass pattern at a local scale. They must not so large that they become prohibitively expensive to fence and difficult to maintain.

Initially, three exclosures are recommended (Fig. 8):

- Saline grassland in open woodland with termitaria clumps;
- Mature *Acacia xanthophloea* woodland;
- Young (invading) *Acacia xanthophloea* cohort.

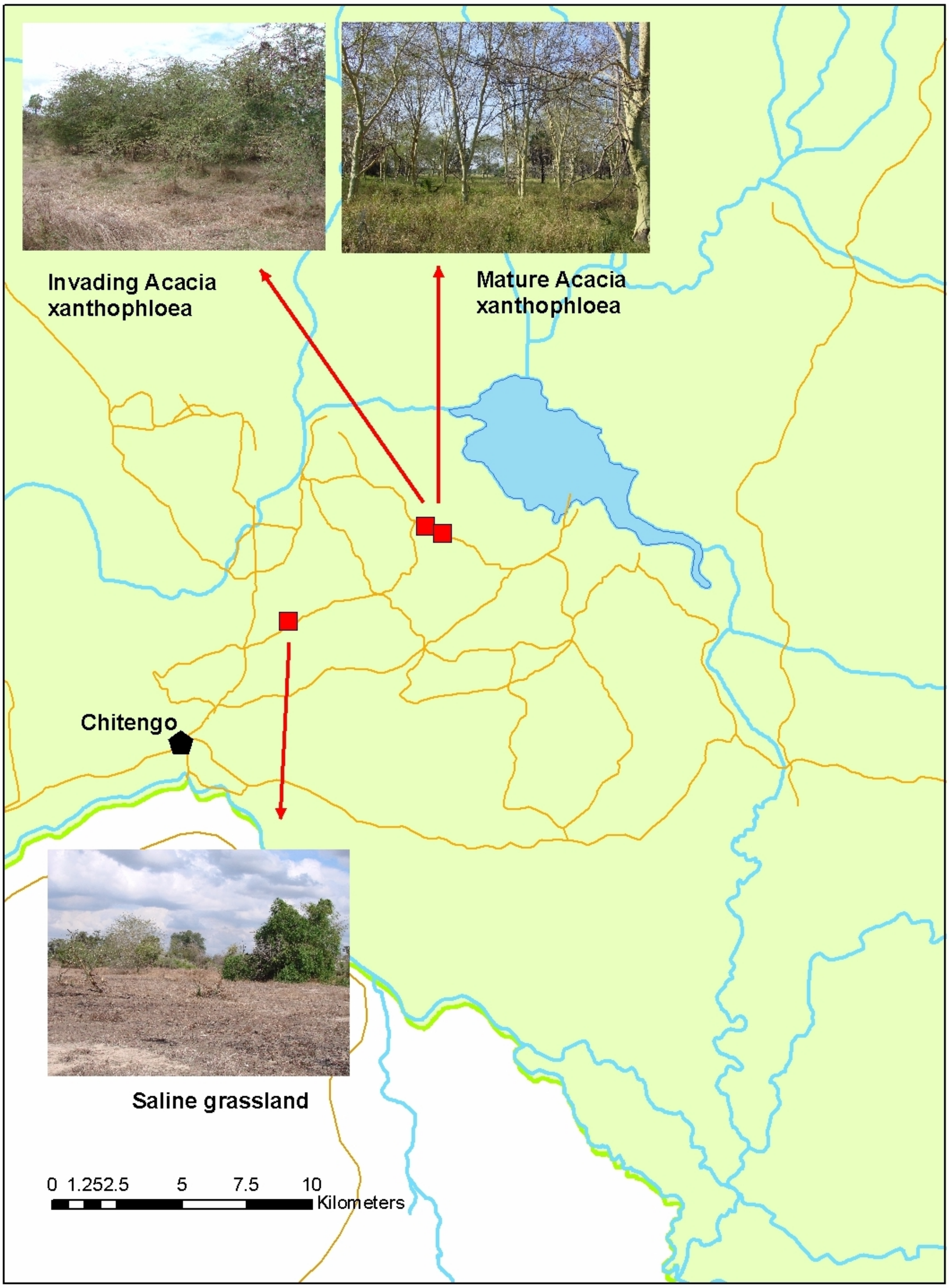

Fig. 8: Location of proposed exclosures and vegetation elements that will be included.

4. DATA MANAGEMENT AND QUALITY CONTROL

Data capture, quality control, and safe storage are a critical element of any monitoring system. Sadly, this very important aspect is often overlooked and neglected.

Historically, data for environmental sciences in southern Africa were generally not well curated (Philips 1988). Useful data inventories are often not available, and communication and sharing have been problematic because of the use of different storage systems and software packages. Monitoring programs can become ends in themselves rather than being the means to achieving specific management goals (Witkowski *et al.* 1997, Rogers & Biggs 1999). This is a very common situation for most African game parks and reserves. Even in the prestigious Kruger National Park there has been until fairly recently neglect of the analysis and synthesis of the large body of data gathered (Freitag 1998).

The following procedures should therefore be applied in Gorongosa with regard to the ground transect data:

- GIS Manager provides training to sampling team in database entry and appropriate metadata as well as database query techniques;
- Sampling team enters sampling data into database, ideally within no more than one week of data collection;
- Raw data forms are stored at the Gorongosa Research Center (Department of Scientific Services);
- Data reviewed by GIS Technician for errors and omissions;
- Data reviewed by Vegetation Ecologist for accuracy;
- Annual summary of vegetation monitoring results provided to Director of Scientific Services.

The videography data will be integrated in the overall database. These multimedia data are also easily disseminated and are a perfect medium for sharing among non-scientific interested and affected parties. Multimedia maps can be exported to HTML format and then be hosted on the Internet for public access.

5. CONCLUDING REMARKS

The proposed vegetation monitoring system represents only one aspect of a much larger monitoring and research system.

The individual plots of the ground transects will supply valuable baseline information for other studies. These plots should preferably also be used as the anchor localities for other surveys and monitoring efforts (for example on reptile, amphibian and insect diversity and dynamics). Obviously, the requirements of other research projects may dictate additional sampling localities. Nevertheless, it is strongly recommended that where possible the ground plots be incorporated in any other project. This will enable the compilation of a large body of data linked to specific localities.

A landscape ecological approach that heavily relies on an integrated approach to data collection, input, storage and analysis can contribute to a better understanding of the position and importance of different landscape elements in the vegetation-herbivore interrelationships of a Park. This insight is critical in guiding management which traditionally would focus on perceived localised problems without a contextual view and without recognising scaling aspects (Stalmans *et al.* 2001).

As stated earlier, the principle of 'Adaptive management' has been adopted for the PNG. A cycle of setting Thresholds of Potential Concern[1], managing according to those, and monitoring the results thereof can be used. Each cycle will lead to interpretation and adaptation of the TPC's (resulting in adapted management) and a new cycle (Fig. 8). This should lead to a continuous improvement of knowledge concerning the Parque Nacional da Gorongosa.

[1] *Thresholds for Potential Concern* (TPC's) have been defined as those upper and lower levels in a selected environmental indicator which, when reached, prompts an assessment of the causes which led to such an *extent* of change, and results in either management action to moderate such cause(s), or re-calibration of the threshold to a more realistic or meaningful level.

Essentially, TPC's are 'worry' levels that alert managers of potential problems and cause them to re-evaluate the current management and to look for remedial measures if appropriate. TPC's do not tell you what management measures should be applied. They merely inform one that a level has been reached (or will be research if present trends continue) for some indicator that is of concern to the continued attainment of the goals and objectives set for an area, a community or a species.

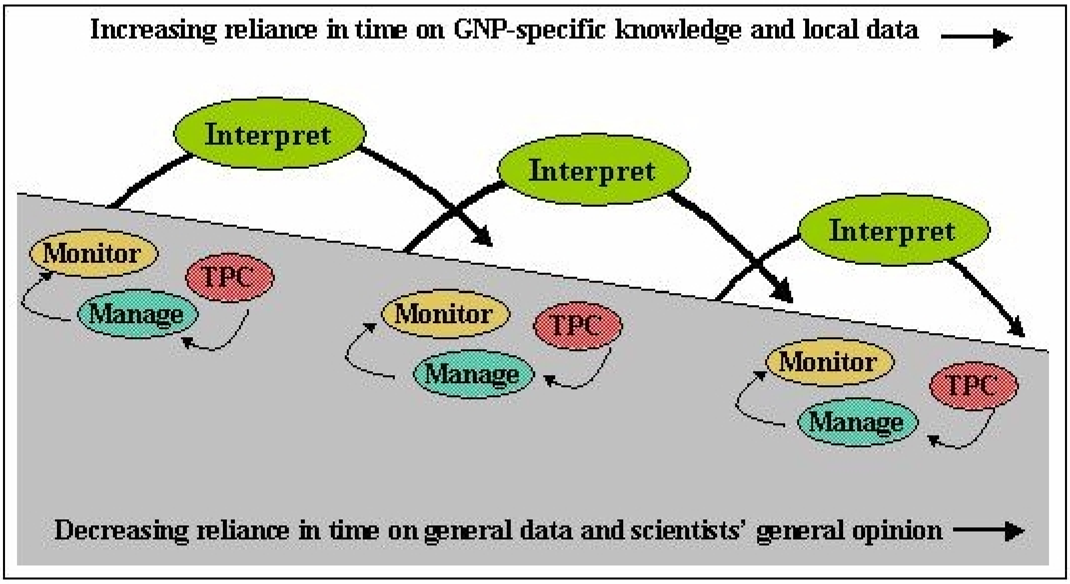

Fig. 8: Adaptive management approach with continuous improvement in knowledge and understanding of the environment (modified from Bormann *et al.* 2007).

6. REFERENCES

Austin, M.P. & Heyligers, P.C. 1989. Vegetation survey design for conservation: gradsect sampling of forests in north-eastern New South Wales. Biological Conservation 50: 13–32.

Beilfuss R., Moore D., Bento C. & Dutton P. 2001. Patterns of vegetation change in the Zambezi Delta, Mozambique. Program for the sustainable management of Cahora Bassa Dam and the Lower Zambezi Valley. Working Paper 3.

Beilfuss R. 2006. Implementing the Adaptive Management System for Gorongosa NP. Unpublished report to the Carr Foundation.

Bormann B.T., Haynes R.W. & Martin J.R. 2007. Adaptive management of forest ecosystems: did some rubber hit the road? BioScience 57(2):186-191.

Christensen N.L. 1997. Managing for heterogeneity and complexity in dynamic landscapes. Pages 167-186 *in* S.T.A. Pickett, R.S. Ostfeld, M. Shachak and G.E. Likens (eds.) The ecological basis of conservation. Chapman & Hall, New York.

Condit, R. 1998. Tropical Forest Census Plots. Springer, Berlin.

Delcourt H.R. & Delcourt P.A. 1988. Quaternary landscape ecology: relevant scales in space and time. Landscape Ecology 2(1):23-44.

Freitag, S. 1998. The Kruger National Park and the analysis of historic data sets: where are we going? South African Journal of Science 94:146-156.

Margoluis R. & Salafsky N. 1998. Mesures of success – designing, managing, and monitoring conservation and development projects. Island Press, Washington D.C.

Philips, M. 1988. Data storage. Pages 467-468 *in* I.A.W. McDonald and R.J.M. Crawford (eds.) Long-term data series relating to southern Africa's renewable natural resources. South African National Scientific Programmes Report 157.

Pickett S.T.A. & Cadenasso M.L. 1995. Landscape ecology: spatial heterogeneity in ecological systems. Science 269: 331-334.

Rogers, K., and Biggs, H. 1999. Integrating indicators, endpoints and value systems in strategic management of the rivers of the Kruger National Park. *Freshwater Biology* 41:439-451.

Senft R.L., Coughenour M.B., Bailey D.W., Rittenhouse L.R., Sala O.E., & Swift D.M. 1987. Large herbivore foraging and ecological hierarchies. BioScience 37(11):789-799.

Stalmans M., Balkwill K., Witkowski E.T.F. & Rogers K.H. 2001. A Landscape Ecological Approach to Address Scaling Problems in Conservation Management and Monitoring. Environmental Management. 28(3):389-401.

Stohlgren T.J., Kaye M.W., McCrumb A.D., Otsuki Y., Pfister B. & Villa C.A. 2000. Using new video mapping technology in landscape ecology. BioScience 50(6): 529-536.

Tinley. K.L. 1977. Framework of the Gorongosa Ecosystem. Ph.d. thesis. University of Pretoria.

Tongway D.J. & Hindley N.L. 2004. Landscape Function Analysis – procedures for monitoring and assessing landscapes with special reference to mine sites a rangelands. CSIRO Sustainable Ecosystems. Canberra. 82pp.

Wiens J.A., Crawford C.S. & Gosz J.R. 1985. Boundary dynamics: a conceptual framework for studying landscape ecosystems. Oikos 45:421-427.

Wiens J.A., & Milne B.T. 1989. Scaling of 'landscapes' in landscape ecology, or, landscape ecology from a beetle's perspective. Landscape Ecology 3(2):87-96.

Witkowski, E., Knowles, L., and Liston, R.J. 1997. Threatened plants in the northern provinces of South Africa: case studies and future approaches. Pages 446-451 *in* P. Hale and D. Lamb (eds.) Conservation outside nature reserves. Centre for Conservation Biology, University of Queensland.

APPENDIX A: GPS COORDINATES FOR PROPOSED GROUND TRANSECTS

Transect	Start					End			
	Latitude	Longitude	x_proj	y_proj		Latitude	Longitude	x_proj	y_proj
1	-19.00070	34.39873	7898509.44277	647227.14353		-19.01173	34.38543	7897299.87889	645816.98793
2	-18.92711	34.38783	7906663.27599	646143.51551		-18.94713	34.39439	7904441.88216	646817.71629
3	-19.01203	34.46988	7897194.44861	654707.40850		-19.03699	34.45587	7894444.76004	653209.50451
4	-19.01171	34.50606	7897197.84524	658516.15108		-19.03053	34.50432	7895116.62529	658315.35542
5	-18.99688	34.53499	7898812.58516	661575.45549		-19.02090	34.53265	7896157.19516	661306.05282
6	-18.94670	34.54793	7904355.60123	662986.49993		-18.92942	34.54361	7906271.38651	662549.00169
7	-18.93159	34.50183	7906069.46926	658146.73730		-18.91425	34.49600	7907993.58126	657548.28134
8	-18.93303	34.45034	7905955.70072	652721.58519		-18.91120	34.46242	7908360.41621	654013.90397
9	-18.89116	34.43291	7910603.94352	650924.12041		-18.90545	34.41098	7909040.89936	648601.33726
10	-19.00007	34.32662	7898638.15951	639636.61357		-18.98334	34.31765	7900497.15098	638706.52210
11	-18.86082	34.34942	7914030.97743	642154.44674		-18.85026	34.38154	7915173.27801	645547.97151
12	-18.88213	34.57348	7911477.96923	665741.55540		-18.87078	34.55009	7912756.03633	663288.42282
13	-18.90404	34.56604	7909060.12967	664935.63454		-18.90908	34.54374	7908522.68112	662582.23538
14	-18.80992	34.53830	7919502.19714	662103.85643		-18.80502	34.57831	7920007.29621	666326.13007
15	-18.75105	34.64430	7925918.05060	673336.65003		-18.77293	34.59148	7923547.55711	667745.86919
16	-18.70545	34.62448	7930983.97798	671292.99216		-18.68370	34.59094	7933423.08543	667777.00788
17	-18.65306	34.66839	7936740.82731	675978.56434		-18.65425	34.63414	7936642.48483	672363.84496
18	-18.58542	34.62380	7944269.52199	671341.67659		-18.59905	34.61388	7942771.30288	670280.95906
19	-18.83439	34.64046	7916698.19304	672847.06070		-18.81899	34.64953	7918393.97596	673818.70898
20	-18.83414	34.69455	7916671.42481	678548.40078		-18.85427	34.69269	7914445.35223	678330.91047
21	-18.89440	34.76302	7909931.72785	685697.86086		-18.91757	34.75897	7907370.80236	685245.64045
22	-18.77093	34.83634	7923519.54883	693563.57598		-18.77827	34.82071	7922723.93394	691907.71580
23	-18.97368	34.76351	7901155.96055	685661.44741		-18.98985	34.77879	7899349.82639	687252.88467
24	-18.97681	34.70660	7900868.09275	679665.27786		-18.98985	34.71076	7899421.06886	680089.91854

25	-19.00521	34.64440	7897787.14580	673086.77813		-19.02064	34.63859	7896085.07592	672459.26886
26	-18.67823	34.86158	7933753.35176	696332.65674		-18.67738	34.84638	7933863.92762	694729.62980
27	-18.73154	34.21279	7928442.52303	627857.38428		-18.73311	34.23435	7928252.56993	630128.49455
28	-18.85459	34.28945	7914767.38419	635841.35336		-18.87236	34.32661	7912772.36097	639741.51849
29	-18.52975	34.36131	7950661.20842	643686.73290		-18.50706	34.36401	7953169.58402	643990.54143
30	-18.56288	34.49977	7946878.62008	658272.31436		-18.55089	34.51663	7948190.11039	660063.46516
31	-19.06009	34.23007	7892070.16613	629425.90838		-19.04414	34.23387	7893832.50822	629837.97883
32	-18.96978	34.21630	7902074.56562	628046.47648		-18.94910	34.22583	7904355.94187	629065.20172
33	-18.97376	34.28782	7901580.62133	635573.42826		-18.98235	34.26926	7900644.14634	633611.83430

x_proj and y_proj refer to co-ordinates in UTM 36S projection used for Gorogonsa GIS system