Mapping the Vegetation and Extent of Agriculture in the Niassa Reserve Using Landsat Imagery

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By

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Summary

This report discusses the aims, methods and findings of the vegetation study conducted as part of the 2003-4 biodiversity survey of the Niassa Reserve in northern Mozambique. The broad aims of this study were to map (1) the vegetation of the reserve; and, (2) the extent of agriculture in the reserve. In both studies analyses were based on interpretation of two satellite image mosaics covering the reserve: A Landsat5 mosaic from 1993 and a Landsat7 mosaic from 2001.

The Niassa Reserve is divided into 13 regions. These regions reflect the major topographic landscapes of the reserve as defined by the major river valleys, mountain ranges and plains, and can be useful for defining broad ecological units or management zones. Below this level 33 land-classes are defined and mapped. Land-classes were defined based on combinations of landscape topographic features and dominant vegetation communities. Each land-class usually comprises one dominant topographic feature such as one of five different types of plains landscapes or an inselberg complex. The majority of land-classes have a tendency to represent vegetation containing mosaics of subtypes (habitats or communities) with different dominance patterns. Fifteen broad vegetation communities are defined for the reserve ranging from evergreen forest through different Miombo woodland types to lowland thicket. Land-classes were mapped using heads-up onscreen digitizing to a minimum accuracy of approximately 1:100 000 to 250 000. The land-classes are arranged within a five-tiered classification hierarchy. Therefore, they can be grouped to together based on where they are linked within the hierarchy. Levels in the hierarchy include, for example, the split between plains vs. mountains vs. inselberg landscapes; or, the division between landscapes with dambos and those without.

An attempt is also made of interpreting land-classes with the context of Wild and Barbosa's Flora Zambesiaca vegetation map. The classification of land-classes here is based on interpretation of the notes accompanying this map and a combination of altitude, rainfall and NDVI. Six Flora Zambesiaca vegetation categories are predicted to occur in the reserve including montane evergreen forest and grassland; three types of Miombo woodland; and, one lowland thicket type.

The land-class map produced for this study can be used or interpreted for a multitude of purposes including:

1. As a crude-map of the diversity and location of biodiversity within the reserve;
2. To provide a coarse categorisation of the reserve for the purposes of defining management zones;
3. To be able to identify areas within the reserve that are important for the conservation of biodiversity;
4. To provide maps that can simply and efficiently convey the character of the Niassa Reserve landscape to a range of persons ranging from staff or tourists through to legislators and politicians; and,
5. To provide a means for extrapolating the findings of biodiversity inventories to other parts of the reserve, e.g. where important plants or animals can be linked to specific elements of the vegetation map.
6. To be used to make ecological models or predictions, for example, if used in conjunction with other data such as rainfall, to estimate the animal carrying capacity of the reserve.

Overall there has been a decrease in the extent of active agriculture in the reserve between 1993 and 2001 (42107 ha to 39807 ha). This decrease is driven primarily by the depopulation of the Msawize area (19110 ha to 4492 ha).

Although there is an overall decrease in the extent of agriculture there is, however, an overall expansion in the total amount of area impacted by agriculture (42107 ha to 60370 ha). This represents a 43% increase in the amount of transformed land between 1993 and 2001. This results from the trend that recolonisation is often located in pristine areas rather than in areas used previously for agriculture. Recolonisation is probably driven by changes in the regional infrastructure such as the upgrading of the Mecula road and the mothballing the Msawize military base.

There are three major centres of human settlement in the reserve: Mavago, Msawize and the Marrupa-Gomba road (Mecula Corridor). Both Mavago and the Mecula Corridor have expanded by a third over the observation period whereas Msawize has contracted dramaticallyby >75%.

This report is divided into four sections: (1) the vegetation map; (2) mapping the extent of agriculture; (3) additional plant species observations and collections from the field survey; and, (4) suggestions for further research involving remote sensing aimed at addressing management questions.

The following suggestions for further research are made:

1. Monitoring of key biodiversity areas.
2. Assessing the impact of fire on the vegetation of the reserve
3. Monitoring and modelling the spread of agriculture in the reserve
4. Locating sites for infrastructure such as for tourism or research
5. Examining options for reserve expansion

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- Keith and Colleen Begg for insights into the ecology of the reserve.

1 Introduction

This report discusses the aims, methods and findings of the vegetation study component of the Niassa Reserve biodiversity base-line study.

The broad aims of this study were to map:

1. the vegetation of the reserve; and,
2. the extent of agriculture in the reserve.

Given the allocated time, extent of the reserve and the financial limitations of the biodiversity base-line study, a detailed vegetation mapping process involving rigorous field sampling combined with aerial photograph-based mapping was not possible. Instead, it was decided to map broad vegetation/ landscape categories from satellite imagery. This imagery is easily accessible for the entire reserve and allows one to map features in the landscape to a minimum accuracy of approximately the 1:250 000 scale. Each pixel in a satellite image measure approximately 30x30m on the ground. Thus any feature that is more than 100m diameter is clearly discernable on the image allowing, when necessary, to map features to be mapped at a much higher accuracy of approximately 1:100 to 50 000 scale, i.e. the boundary drawn on the map is within 50-100m of the actual boundary.

Technically, the product of this mapping process is a land-class map rather than a vegetation map. It is a land-class map as units were defined based on the spectral and compositional properties of features in the satellite image (i.e. each units "texture") that were interpreted based on an understanding of the structure of the physical landscape of the reserve. It is not a true vegetation map, as it is not linked to an inventory of the plant species or communities present within each mapped category. It is therefore not possible at this stage to draw quantitative distinctions between mapped classes or units in term of species present. In certain cases, however, expert input from the plant survey team allows one to identify categories that are significantly different or unique relative to the other units present in the reserve, e.g. evergreen forest or riparian woodland vs. Miombo woodland. At the scale of the whole reserve, however, as there are major differences, more so structural rather than species composition, between the vegetation of the different units it would not be incorrect to refer to this map as a vegetation map.

The spread of slash-burn agriculture or machambas is regarded as a significant management issue in the reserve. As part of the mapping process the same satellite imagery that was used for the vegetation mapping was also used to map the extent of current agriculture. Using satellite images from different time periods it was also possible to examine the dynamics of agriculture over the period spanning the images (1993 to 2001). Estimating rates of agriculture spread is a powerful tool for the reserve managers to anticipate where future conflicts between agriculture and the reserves conservation objectives are likely to occur.

This report is divided into two major parts. The first part deals with the vegetation mapping process and base-line spatial data gathered for the task. The second part deals with the mapping of the past and present extent of agriculture in the reserve. There is also a small section containing plant species collected or recorded during the field component of this study to add to the global species list for the reserve. The final concluding section contains a number of recommendations for future research in the reserve involving remote sensing aimed at addressing immediate management concerns.

Part A: Mapping the Vegetation

Vegetation can be viewed as a continuum from, at the smallest scale, the individual plant to a patch of plants to a recognisable community of plants through to the larger ecosystem, landscape and biome scales. How one chooses to divide this continuum into mappable vegetation classes depends on several factors:

1. What the vegetation map will be used for;
2. The data available for creating the vegetation map;
3. The amount of time and budget available for the project; and,
4. The presence of natural discontinuities between the desired vegetation classes.

Given the limitations in available data for the reserve; the extent of the study area; and, the time available for the study it was not possible at this stage to produce a true vegetation map that maps recognised vegetation units, i.e. areas of land comprising similar combinations or repeating units of the same topographic or landscape units and vegetation communities. Although some distinct vegetation communities can be differentiated on the satellite imagery, such as dambos vs. woodland or bamboo thicket vs. woodland, the time involved in mapping these plant communities over the whole reserve would be prohibitive. In addition, the resultant map would probably be too fine scale for the purposes envisioned for this map. Conversely, it is difficult to differentiate other communities such as Brachystegia vs non-Brachystegia Miombo woodland. Thus, as is explained in Section 2.4, the resultant map should be regarded as a broad-habitat or land-class map and not as a true vegetation map.

Naturally, the resultant land-classes do relate to observed vegetation patterns, however, any unit may contain a combination of several distinct and easily recognisable vegetation communities. The combination of these communities does differ between land-classes in relation to the underlying physiography of the landscape. For example, two adjacent units may share the same vegetation communities, however, the physiographic landscape of each unit differs significantly such that the manner in which the communities occur together is distinctly different between the units.

At the scale of the whole reserve, similarities or differences in the vegetation between land-classes means that the land-class map does provide a broad-scale picture of the vegetation of the reserve and can if necessary be viewed as a "vegetation map".

The land-class map produced for this study can be used or interpreted for a multitude of purposes including:

1. As a crude-map of the diversity and location of biodiversity within the reserve;
2. To provide a coarse categorisation of the reserve for the purposes of defining management zones;
3. To be able to identify areas within the reserve that are important for the conservation of biodiversity;
4. To provide maps that can simply and efficiently convey the character of the Niassa Reserve landscape to a range of persons ranging from staff or tourists through to legislators and politicians; and,
5. To provide a means for extrapolating the findings of biodiversity inventories to other parts of the reserve, e.g. where important plants or animals can be linked to specific elements of the vegetation map.

6. To be used to make ecological models or predictions, for example, if used in conjunction with other data such as rainfall, to estimate the animal carrying capacity of the reserve.

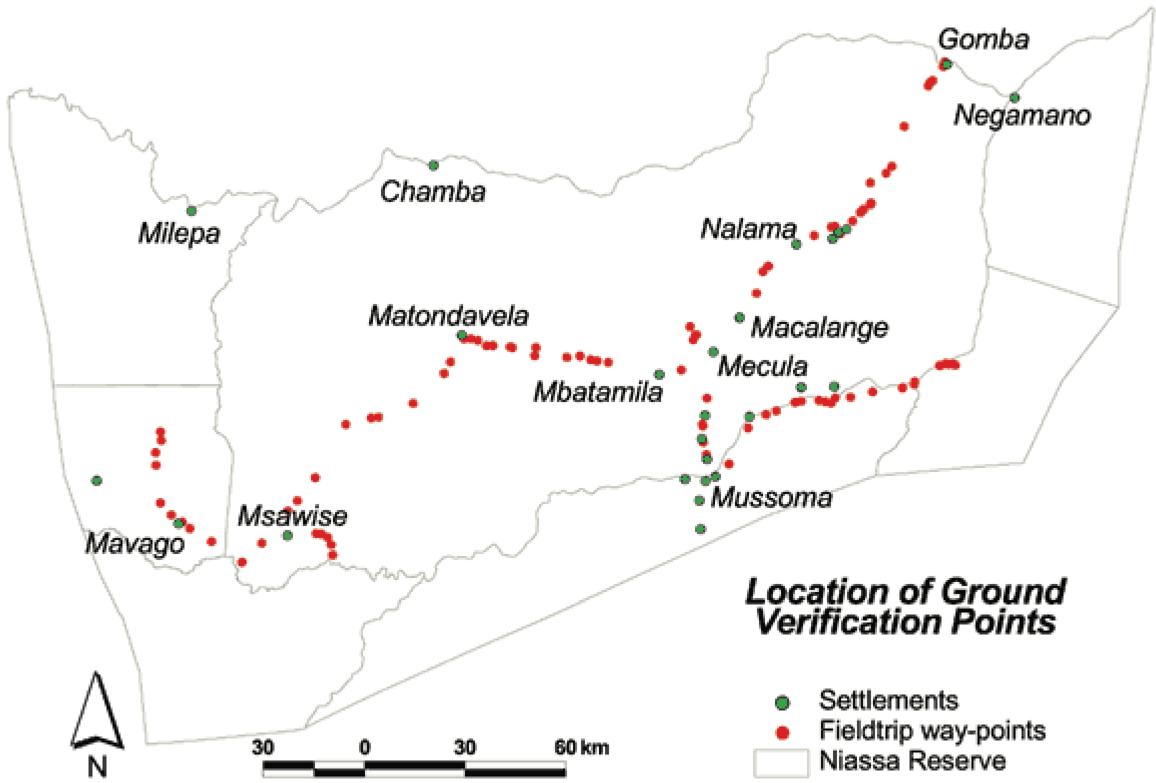
2 Mapping vegetation methods

2.1 Overview of mapping process

The mapping process involved the following three basic steps:

1. Visiting the reserve to gain a first-hand experience of the landscape and collect ground verification data on the landscape and vegetation.
2. Gathering spatial data necessary to create the map.
3. Translating the observed patterns in the landscape/vegetation into mappable land-classes based on the fieldtrip observations, consultation with other experts and available literature.
4. Mapping the boundaries of the land-classes by means of on-screen or heads-up digitizing into a GIS using the satellite imagery as a backdrop.

Figure 1: The location of ground verification points sampled during the field survey.



2.2 Field Survey

The field survey comprised a two-week visit to the reserve in October-November 2003. During this visit as many areas of the reserve were accessed by road or foot and at various sample sites data were gathered on the landscape and vegetation structure; basic species composition; and, presence of existing or past agriculture. The location of these ground control points is indicated in Figure 1. An example of the data form used for the field survey is presented in Appendix 1.

2.3 Spatial data

2.3.1 Satellite imagery

Two satellite image mosaics were obtained from Computamaps (www.computamaps.com) in Cape Town for the study. The first mosaic comprised a Landsat5 natural and false-colour mosaic from 13 scenes, dated 1991-1993. The second mosaic comprised a Landsat7 mosaic from 4 scenes, dated November-December 2001.

The ImageWarp 2.0 extension in ArcView was used to rubbersheet the Landsat7 mosaic to match the Landsat5 mosaic as they two images did not overlay each other exactly. There is, however, still a small degree of mismatch between the two images (up to 300m) although this is located in the south-west corner of the Landsat7 mosaic and is probably related to the this scene being slightly mis-aligned. Elsewhere in the Landsat7 mosaic (i.e. the other 3 scenes) the mismatch is less than 100m.

The Lansat7 mosaic was received as two separate image files. These were stached in ArcView using the Image Analysist extension to create a single image comprising 6 bands. The order of the Landsat7 bands in this stacked imaged differs to that of raw landsat images. This difference is important to not for further analyses using this image and is detailed in Table 1.

Table 1: The order of Landsat7 bands in the resultant image stack.

Image Layer	L7 Band	Band Description
1	7	Mid-infrared (2-2.35)
2	3	Red (R)
3	1	Blue-green
4	5	Mid-infrared (1.5-1.75)
5	4	Near-infrared (NIR)
6	2	Green

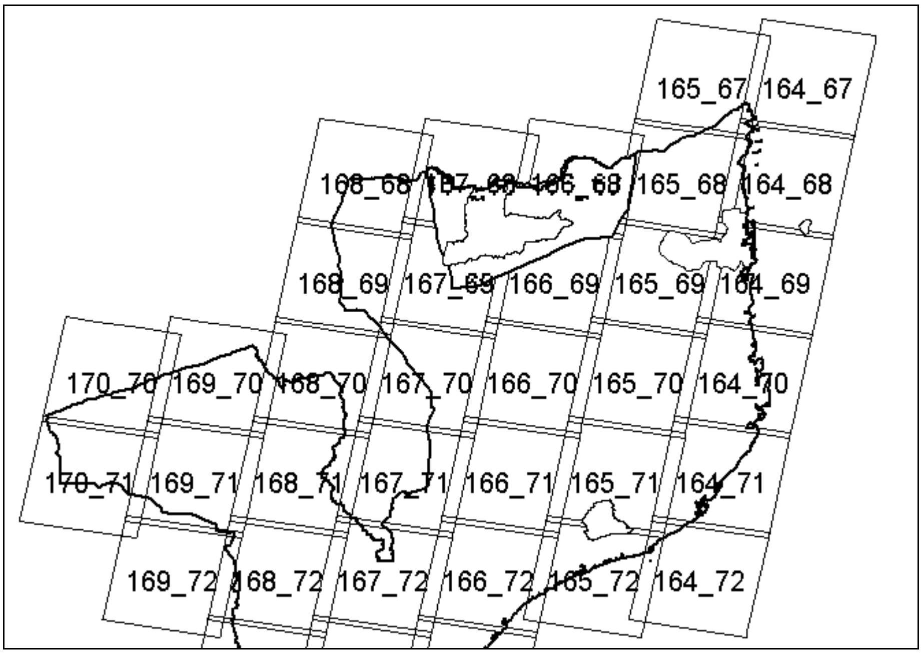
The Landsat7 image was used to calculate the NDVI (Normalized Difference Vegetation Index) for the reserve at the time of the image being taken. This was done using the Image Analyst extension in ArcView that uses the formula [(NIR-R)/(NIR+R)]. This index is a measure of the degree of photosynthetically active vegetation and is useful for distinguishing, at the time that the image was taken, evergreen from tardily deciduous from fully deciduous vegetation.

Subsequent to the mapping process a further set of Landsat7 scenes for the reserve were obtained from Jo Tagg (Directorate of Environmental Affairs, Windhoek, Namibia). These scenes cover a much larger area of northern Mozambique extending from the coast to Lake Malawi. In addition, these scenes are from different time periods to those already obtained for this project. This will allow for a more detailed year-on-year analysis of the rate of agricultural spread in the reserve. This analysis was not done for this study. The dates when the scenes were obtained are listed in Table 2, and their location illustrated in Figure 2.

Table 2: The aquisition dates for the Landsat7 scenes obtained from Jo Tagg. For location of scenes refer to Figure 2.

NAME	Acquisition date		NAME	Acquisition date
164_67	18-May-01		165_69	15-Jul-02
164_68	7-Dec-99		166_68	30-Jun-00
164_69	31-May-00		166_69	30-Jun-00
164_70	2-May-01		167_68	1-Dec-01
164_71	5-Jul-01		167_69	11-Jun-02
165_67	22-May-00		168_68	31-Aug-00
165_68	12-May-02		168_69	31-Aug-00

Figure 2: The location of the Landsat7 scenes obtained from Jo Tagg.



2.3.2 Digital elevation model

To assist in the mapping process a digital elevation model (DEM) was obtained from Computamaps. The DEM was developed from the contours on the 1:250 000 maps for Mozambique with a grid resolution of 200m. At the time of commencing with this project this was the best available DEM for the region. It is, however, fairly inaccurate with inselbergs on the DEM appearing up to several kilometres from their true location on the satellite image. Also, drainage lines derived from the DEM do not match their true location on the satellite image. This DEM was suitable none the less to get a better understanding of the overall topography of the landscape. It was also used to interpolate a rainfall surface for the reserve.

Subsequent to the mapping process a much finer scale and more accurate DEM was obtained from the United States Geological Survey. This DEM was developed from SRTM data collected by the space shuttle Endeavour in 2000, and is freely available over the web (ftp://edcsgs9.cr.usgs.gov/pub/data/srtm/) for the entire globe. The grid for this DEM is at a 90m resolution thus even very small topographic features such as small inselbergs are accurately captured in this DEM. This DEM is a very useful base-line spatial product for any further GIS-based analysis or modelling studies to be conducted in the reserve.

The SRTM DEM was downloaded as 1x1 degree *.hgt files from the ftp site and mosaiced in 3DEM (http://www.visualizationsoftware.com/3dem/). The DEM mosaic was then exported as a geotiff image file, loaded into ArcView and saved as a grid. This method proved to be the simplest was of importing the data into ArcView.

2.3.3 Rainfall

Rainfall is an important predictor of all biodiversity. Using observed mean annual rainfall data from weather station in east Africa around the reserve and the 200m DEM, a mean annual rainfall map for the reserve was interpolated using the Anusplin software package (http://www.cres.anu.edu.oz). A summary of the interpolation analyses is contained in Appendix 2.

Figure 3: The location of weather stations used to interpolate the rainfall surface.

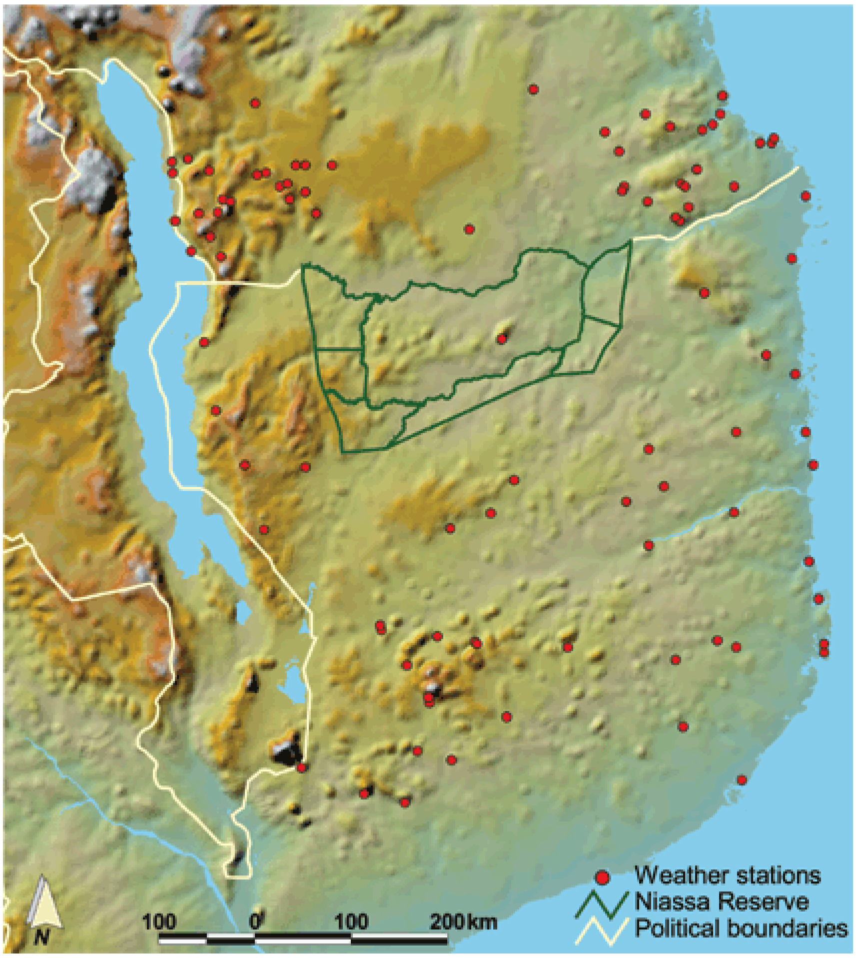
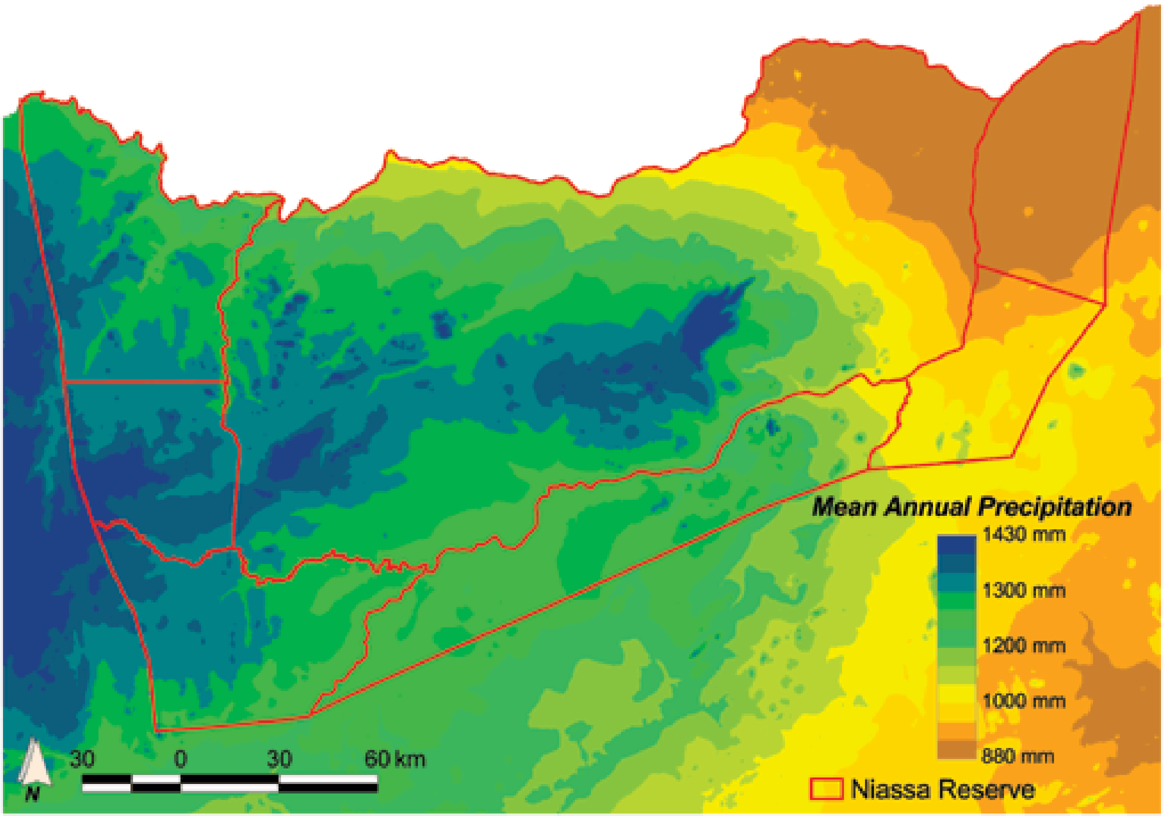


Figure 4: Interpolated mean annual rainfall (mm per annum) for the Niassa Reserve.



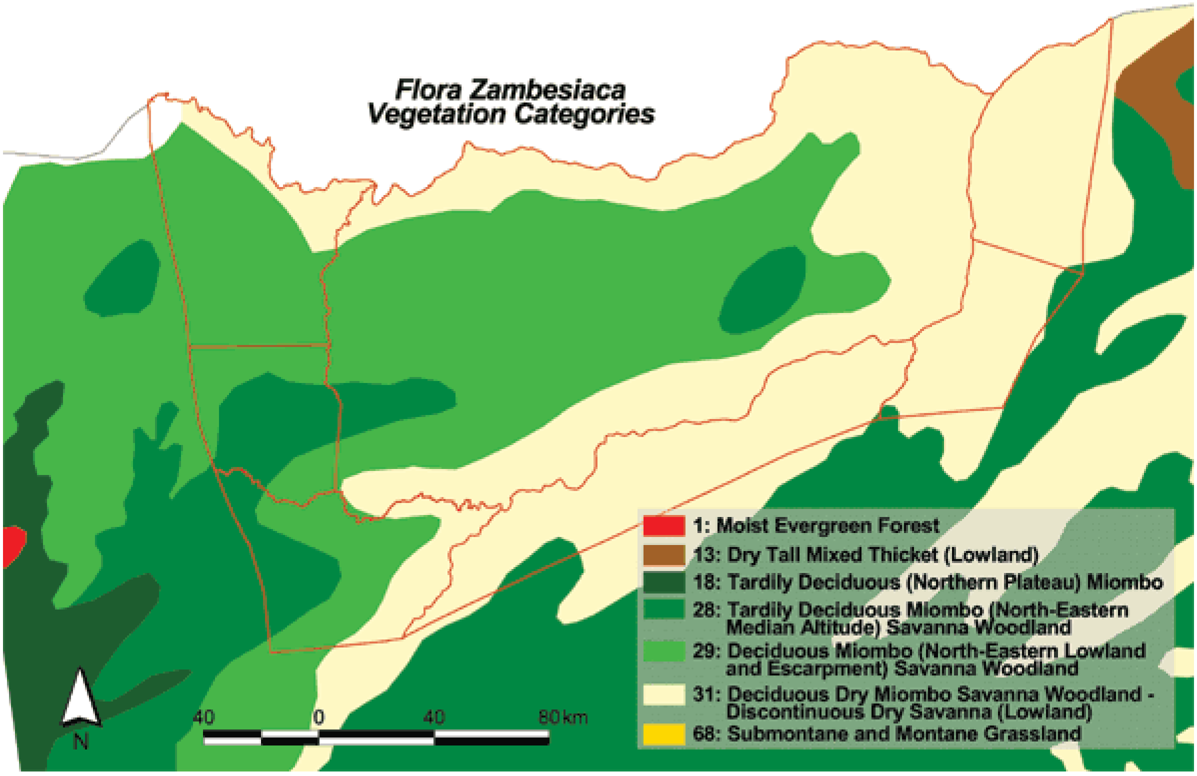
2.3.4 Existing vegetation maps

White's (1983) floristic zones and Wild and Barbosa's (1967) Flora Zambesiaca (FLZA) vegetation categories constitute the only published vegetation maps for the Niassa region. Both of these maps were scanned, geo-referenced and converted to shape-files to provide a broad-scale guide to the vegetation of the reserve. After the discussions at the biodiversity survey report-back workshop in April 2004 it was decided that White's map was of little value to the present mapping process especially as this map appeared to be grossly inaccurate for the reserve in terms of its prediction as to the extent to which lowland vegetation elements penetrate the reserve. Wild and Barbosa's map (Figure 5) was considered more useful and it was used to help guide a classification of the vegetation of the reserve in terms of the FLZA vegetation categories.

2.3.5 Map projections

For all spatial data a UTM projection was used for presentation and analyses (UTM 37 south, Central meridian: 39; Reference latitude: 0; Scale factor: 0.9996; False easting: 500 000; False northing: 10 000 000; Spheroid: WGS84)

Figure 5: Wild and Barbosa's (1967) Flora Zambesiaca vegetation map for the Niassa Reserve.



2.4 The mapping process

The objective of the mapping process was to distil from the millions of pixels or "objects" in the satellite image, a few meaningful objects that relate to actual features or areas of like landscape on the ground. Conceptually a simple process, but it requires that one is able to identify real features in the satellite image such as rivers, fields or forest.

At the finest scale of interpretation, it is possible to recognise relatively small features such as small patches of forest, roads and even individual termitaria. At a slightly larger scale it is possible to recognise major plant communities such as dambos vs. woodland vs. bamboo. As the scale of interpretation increase so the size of the features recognized increases till as the largest scale we can recognize whole mountains ranges or regions with different geology. Choosing the scale at which to interpret the satellite data for Niassa was determined primarily by the time and budget available for the mapping process; secondly by the management objectives for the map; and, thirdly by the limitations of the mapping process.

Several semi-automated interpretation methods were experimented with using the Ecognitn software package. Although very effective at discriminating plant community types the time required to perform the mapping process for such a large area and the temporal variability (resulting in spectral variability) in the satellite image mosaic (i.e. require different interpretation parameters in different parts of the image to recognise the same features.) would be (a) to time consuming and (b) provide too much detail for what is presently required by the reserve.

Finally, it was decided simply to perform a heads-up or on screen mapping process whereby the satellite image was displayed as a backdrop in the GIS and lines drawn manually around the features being mapped. Boundary accuracy with this technique is variable depending on the distinctness of the actual boundary between features on the ground. For example, where the boundary is discrete, such as between forest and grassland it is possible to draw a line on the map that is within 100m of where the true boundary is. Where the boundary between features is diffuse or fuzzy such as between two areas of similar woodland in different physiographic landscapes where the change from one mapped feature to the next is gradual, where the line drawn on the map is essentially arbitrary and could be up to a kilometre or more from where an observer on the ground may interpret the boundary to be.

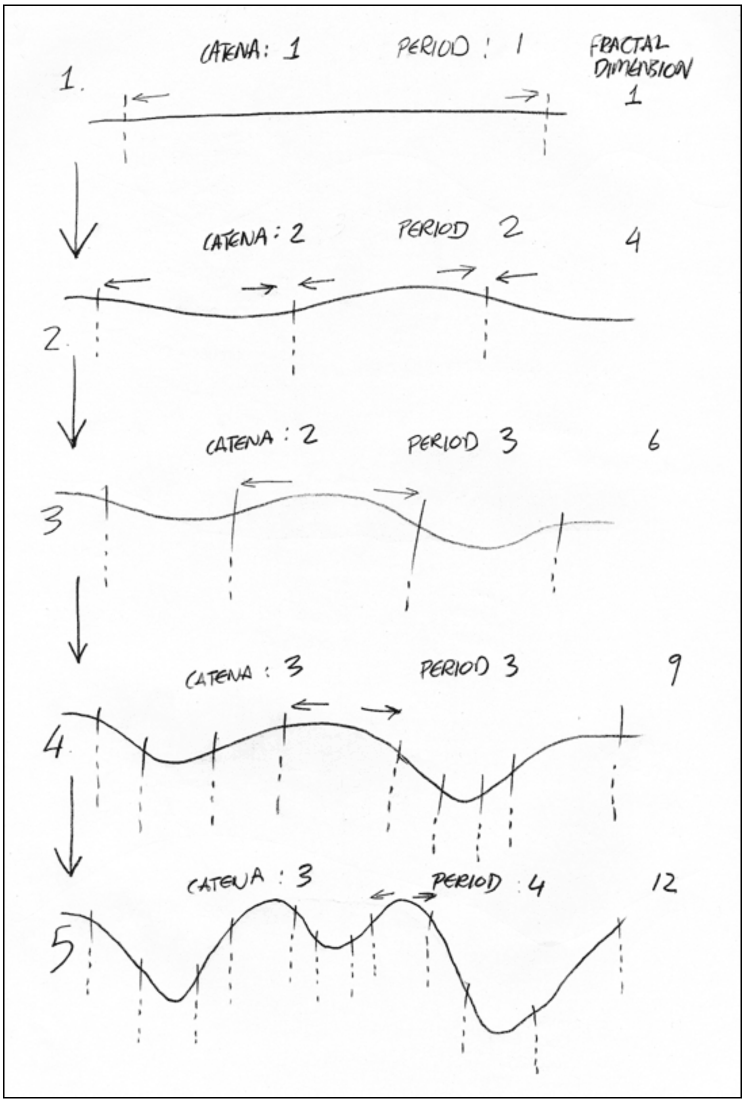
The resultant mapping process involved identifying and mapping different landscapes within the reserve. These landscapes are higher order organisational units than plant communities. Some landscapes such as major rivers, inselbergs or mountain ranges are fairly distinct and well known to most map users in the reserve. However, gently undulating plains cover by far the majority of the reserve. The process of dividing the plains into meaningful land-classes involved interpretation of how broad vegetation patterns vary in response to the physical landscape, since the physical landscape determines which plant communities are present and the manner in which different communities occur together.

It is important to understand how geological-scale erosional processes have shaped the Naissa landscape in order to understand macro-scale vegetation patterns in the reserve. At the plant community scale it is well known in savannas how soil patterns down a catena determine the position of different vegetation communities. The typical example of this in the reserve is the dambo landscape with woodland on the top of the catena on deeper sandy soils and the dambo at the bottom of the catena in seasonally waterlogged heavier soils. Dambo landscapes are relatively easy to distinguish on the satellite image and repeating units of the same type of catena organisation as described here together comprise a sinlge identifiable land-class.

At a higher level of landscape organisation, the dambo landscape can be differentiated from other plains landscape primarily by the absence of dambos. Some plains landscapes are relatively flat and are covered by uninterrupted woodland. Other plains landscapes are undulating with continuous woodland and well wooded streams and still other undulating landscapes are deeply incised and the catenas here sometimes show the development of sodic soils in the bottonlands or the development of hydromorphic grasslands in seasonally waterlogged soils at the bottom of the catena. These differ from the dambo grasslands by being narrower bands of vegetation on steeper and shorter catena slopes and a distinct drainage channel with woody vegetation occupying the bottom of the slope. At this larger level of organisation, the general model for landscape evolution progresses from near flat (continuous woody vegetation) to gently undulating (dambo landscapes) to undulating and finally incised (sodic soils present).

From an image interpretation perspective, this erosional progression of the landscape coupled with the change in juxtaposition of plant communities present could be described as some type of fractal progression. Flat landscapes having relatively few internal boundaries represent the structurally simplest landscapes whereas the incised landscapes having many internal boundaries represent structurally more complex plains landscapes. This concept is illustrated schematically in Figure 6.

Figure 6: A schematic representation of landscape evolution within the plains landscape of the Niassa Reserve. "Catena" refers to the number of individual catenas likely to be encountered within in the same given length of plains landscape. As the number of catenas increases (i.e. as they get shorter due to more undulating landscape) so the complexity or "fractal dimension" of what is observed in the satellite image increases. Undulation of the plain landscape is a result of deeper erosion or incision of the originally flat landscape.



3 The vegetation map

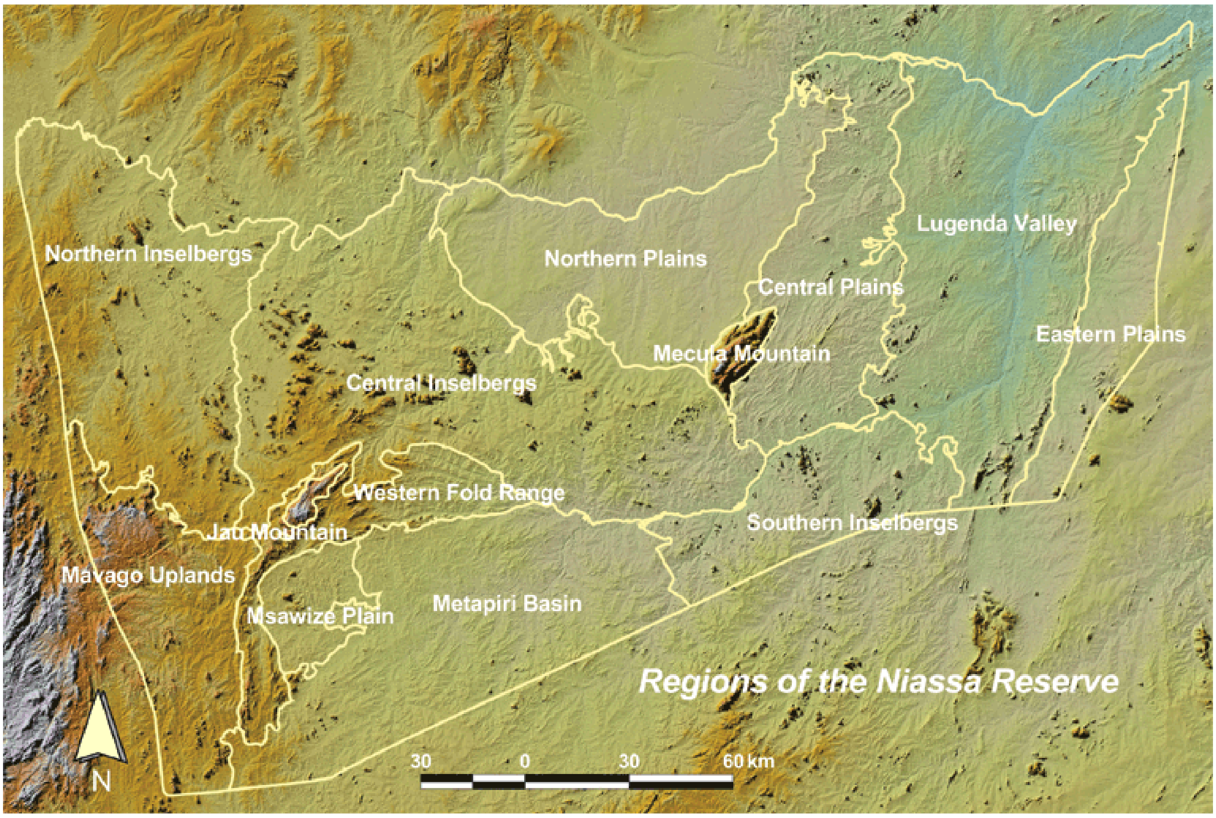
3.1 Classification of land-classes

The final classification of land-classes is based on the above basic interpretation of landscape physiographic evolution. The classification itself is hierarchical progressing from the broadest possible unit, essentially regions within the reserve, through to the finest scale of classification unit. Thirteen regions are mapped within the reserve (Table 3, Figure 7). These regions reflect the major topographic landscapes of the reserve as defined by the major river valleys, mountain ranges and plains, and can be useful for defining broad ecological units or management zones.

Table 3: Regions within the Niassa Reserve.

	REGION
1	Central Inselbergs
2	Central Plains
3	Eastern Plains
4	Jau Mountain
5	Lugenda Valley
6	Mavago Uplands
7	Mecula Mountain
8	Metapiri Basin
9	Msawize Plain
10	Northern Inselbergs
11	Northern Plains
12	Southern Inselbergs
13	Western Fold Range

Figure 7: The 13 regions of the Niassa Reserve as defined by the major river valleys, mountains ranges and plains.



Below the regional level, there are 33 land-classes defined for the reserve, 26 for the terrestrial landscape and seven for the river-scape of the Rovuma and Lugenda Rivers (Table 4, Figure 8). These land-classes are nested with a four-tiered hierarchy enabling one to group land-classes into higher order landscape types. The definition of land-classes is based primarily on the physiography of the landscape with vegetation attributes playing a less important role. In some cases, however, such as the mountain forest or grassland the definition is based exclusively on vegetation attributes.

Within each land-class one or more basic vegetation community can occur. Based on the vegetation survey report (Timberlake *et al.* 2004) and observations made during the fieldtrip, 15 basic plant community types are recognised (Table 5). Table 6 indicates which of these basic communities occur within each land-class.

Table 4: Land-classes (vegetation categories) of the Niassa Reserve.

No.	CLASS1	CLASS2	CLASS3	CLASS4	Land-classes
1	Alluvial	woodland			Alluvial woodland
2	Inselberg	granite domed	large		Inselberg granite domed large
3			small		Inselberg granite domed small
4			western upland		Inselberg granite domed western upland
5		wooded hills			Inselberg wooded hills
6	Mountain	forest	montane		Mountain forest montane
7			gully		Mountain forest gully
8		grassland			Mountain grassland
9		woodland	high mountain		Mountain woodland high mountain
10			western uplands	dambos	Mountain woodland western uplands dambos
11				wet	Mountain woodland western uplands wet
12					Mountain woodland western uplands
13			Western Folded Mountains	dry	Mountain woodland Western Folded Mountains dry
14				wet	Mountain woodland Western Folded Mountains wet
15	Plains	woodland	flat	homogeneous	Plains woodland flat homogeneous
16				heterogeneous	Plains woodland flat heterogeneous
17			dambos		Plains woodland dambos
18				transitional	Plains woodland dambos transitional
19			undulating	no dambos	Plains woodland undulating no dambos
20				no dambos non-Miombo	Plains woodland undulating no dambos non-Miombo
21				wooded streams	Plains woodland undulating wooded streams
22			incised		Plains woodland incised
23				upland-lowland transition	Plains woodland incised upland-lowland transition
24	Riverine	eastern lowland			Riverine eastern lowland
25		western upland			Riverine western upland
26		oxbow			Riverine oxbow
27	River	Lugenda	channel		River Lugenda channel
28			rapids		River Lugenda rapids
29			sandbanks		River Lugenda sandbanks
30		Rovuma	channel		River Rovuma channel
31			islands		River Rovuma islands
32			rapids		River Rovuma rapids
33			sandbanks		River Rovuma sandbanks

Table 5: Basic plant communities recognised as occurring in the Niassa Reserve.

No	Broad Vegetation Type	Basic Community Types	Phenology	Indicative dominant Species
1	Forest	Montane Forest	Evergreen	Unknown
2		Gully Forest	Evergreen	Unknown
3		Inselberg Gully Forest	Evergreen	Bequaertiodendron spp.
4		Lowland Riverine Forest	Evergreen	Sterculia appendiculata
5		Upland Riverine Forest	Evergreen	Unknown
6	Woodland	Plains Riparian Woodland	Evergreen	Syzygium spp.
7		Short Miombo	Deciduous	Brachystegia & Julbernardia spp.
8		Tall Miombo	Deciduous	Brachystegia & Julbernardia spp.
9		Mixed Lowland Woodland	Deciduous	Pterocarpus angolensis Afzelia quanzensis
10		Knobthorn Woodland	Deciduous	Acacia nigrescens Euphorbia cooperi

11		Panga-Panga Riverine Woodland	Deciduous	Millettia stuhlmannii
12	Grassland	Montane Grassland	Deciduous	Unknown
13		Dambo	Seasonally waterlogged	Unknown
14		Hydromorphic Grassland	Seasonally waterlogged	Unknown
15	Pans	Pan	Seasonally waterlogged	Unknown

Table 6: Basic plant communities represented within each land-class.

	Basic Vegetation Communities														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Land-Classes	Montane Forest	Gully Forest	Inselberg Gully Forest	Lowland Riverine Forest	Upland Riverine Forest	Plains Riparian Woodland	Short Miombo	Tall Miombo	Mixed Lowland Woodland	Knobthorn Woodland	Panga-Panga Riverine Woodland	Montane Grassland	Dambo	Hydromorphic Grassland	Pan
1 Alluvial woodland				X			X			X	X				X
2 Inselberg granite domed large			X					X							
3 Inselberg granite domed small			X					X							
4 Inselberg granite domed western upland			X					X							
5 Inselberg wooded hills			X					X							
6 Mountain forest montane	X														
7 Mountain forest gully		X													
8 Mountain grassland												X			
9 Mountain woodland high mountain		X						X							
10 Mountain woodland western uplands dambos					X			X					X		
11 Mountain woodland western uplands wet		X			X			X							
12 Mountain woodland western uplands					X			X							
13 Mountain woodland Western Folded Mountains dry								X							
14 Mountain woodland Western Folded Mountains wet					X			X							
15 Plains woodland flat homogeneous							X								
16 Plains woodland flat heterogeneous						X	X	X						X	
17 Plains woodland dambos						X		X					X		
18 Plains woodland dambos transitional						X	X	X					X	X	
19 Plains woodland undulating no dambos						X	X	X						X	
20 Plains woodland undulating no dambos non-Miombo						X			X						
21 Plains woodland undulating wooded streams						X	X	X						X	
22 Plains woodland incised						X	X	X						X	
23 Plains woodland incised upland-lowland transition						X		X						X	
24 Riverine eastern lowland				X						X	X				X
25 Riverine western upland					X										
26 Riverine oxbow					X										X
27 River Lugenda channel															
28 River Lugenda rapids			X	X											
29 River Lugenda sandbanks															
30 River Rovuma channel															
31 River Rovuma islands			X	X											
32 River Rovuma rapids			X	X											
33 River Rovuma sandbanks															

No further descriptions of land-classes are presented here. For working with the map the basic descriptive parameters presented in Table 4, Table 5 and Table 6 provide a level of detail sufficient for the user to develop a basic understanding of what the landscapes/vegetation look like within each respective land-class. Examples of what the landscapes look like within the different land-classes are presented as cross-section drawings of the landscape in Appendix 3. Also, given the amount of baseline descriptive information that went into defining the various land-classes the author is not confident with providing more detailed descriptions of the land-classes, especially of the vegetation present, For more detailed introductions of the actual vegetation communities present in the reserve consult Timberlake *et. al.* (2004), Lobão Tello and Dutton (1979) and Wild and Barbosa (1967).

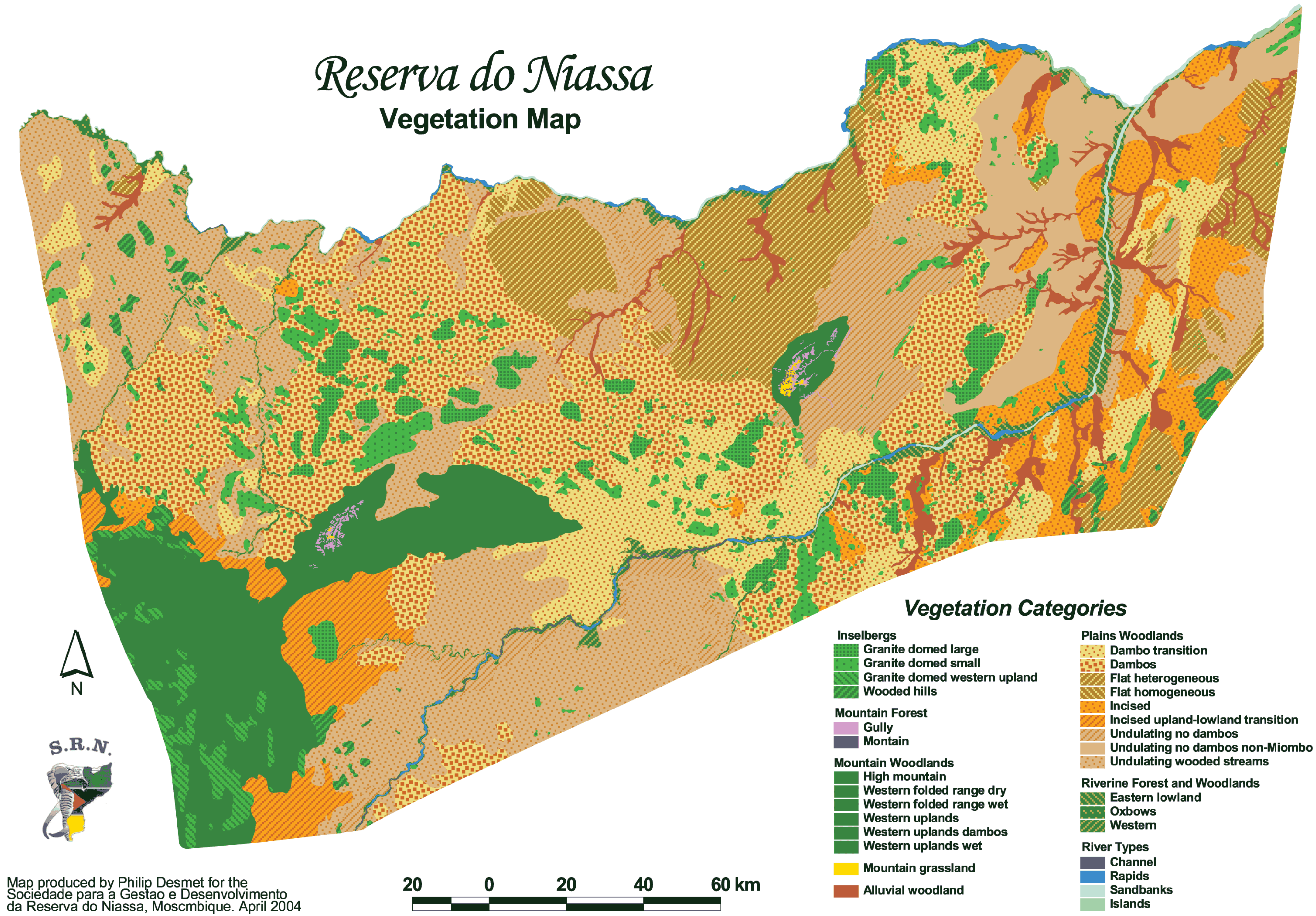
3.2 Classification according to the Flora Zambesiaca vegetation categories

From a biodiversity conservation perspective it is necessary to understand the vegetation of the reserve within a broader regional context - How many of the regional vegetation types are represented within the reserve? This is especially important for the government in terms of assessing their formal contribution (i.e. statutory reserves) towards achieving national and international conservation goals and obligations. The land-classes developed here for reserve management are at a classification level much finer than that presented in either of the vegetation maps by White (1983) or Wild and Barbosa (1967), and as they were developed exclusively for the reserve it is difficult to establish the regional context of the vegetation of the reserve using this data. It is therefore necessary to attempt a classification of the vegetation of the reserve according to an existing regional classification.

Despite the lack of quantitative floristic data at hand it is still possible given the information presented in Wild and Barbosa (1967), field experience and discussions with botanical experts to attempt a preliminary classification of the vegetation of the Niassa Reserve in terms of the Flora Zambesiaca (FLZA) classification scheme presented by Wild and Barbosa (1967).

Using the map published in Wild and Barbosa (1967); the descriptions of the vegetation categories presented in the text accompanying the map; and, the environmental data gathered for the reserve (altitude, rainfall and NDVI), individual polygons were classified into one of six FLZA vegetation categories deemed to occur in the reserve. The rules used for classification are presented in Table 7. NDVI for the vegetation during the late dry season proved to be very useful in discriminating the different vegetation categories. In Figure 9 the evergreen forest (1), deciduous thicket (13) and semi-deciduous miombo woodland (28) vegetation categories are clearly discriminated by NDVI, in other words by the amount of photosynthetic-active vegetation.

Figure 8: Land-classes (vegetation categories) of the Niassa Reserve (following page).



Reserva do Niassa
Vegetation Map
Vegetation Categories
Inselbergs
Granite domed large
Granite domed small
Granite domed western upland
Wooded hills
Mountain Forest
Gully
Montain
Mountain Woodlands
High mountain
Western folded range dry
Western folded range wet
Western uplands
Western uplands dambos
Western uplands wet
Mountain grassland
Alluvial woodland
Plains Woodlands
Dambo transition
Dambos
Flat heterogeneous
Flat homogeneous
Incised
Incised upland-lowland transition
Undulating no dambos
Undulating no dambos non-Miombo
Undulating wooded streams
Riverine Forest and Woodlands
Eastern lowland
Oxbows
Western
River Types
Channel
Rapids
Sandbanks
Islands
N
S.R.N.
20 0 20 40 60 km
Map produced by Philip Desmet for the
Sociedade para a Gestao e Desenvolvimento
da Reserva do Niassa, Moscmbique. April 2004

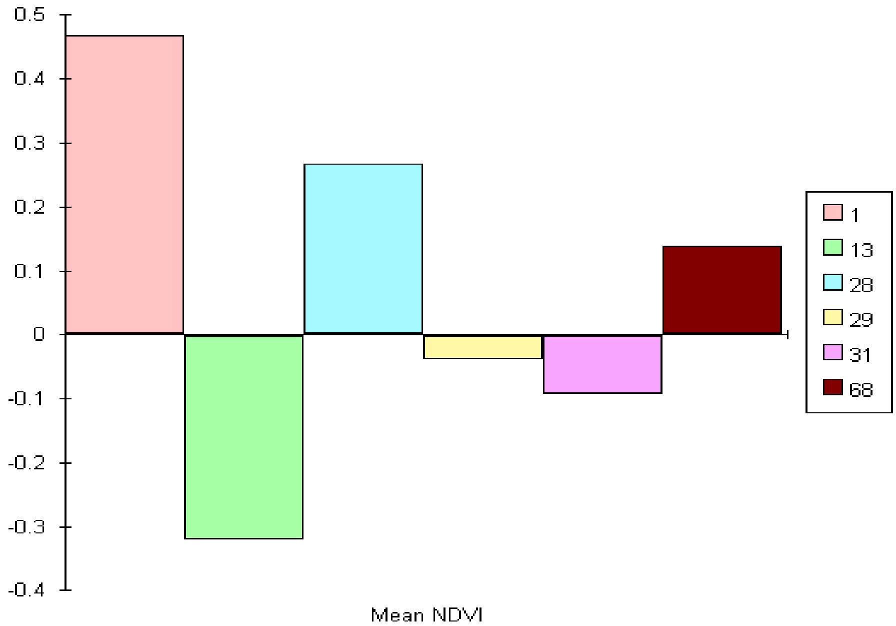


Figure 9: Mean NDVI values for the six FLZA vegetation categories occurring in the Niassa Reserve. NDVI values were calculated using Landsat7 satellite image from the late dry season. Vegetation category numbers correspond to those presented in Table 7.

The resultant FLZA vegetation classification of the reserve is presented in Figure 10. The major finding of this classification exercise agrees with the opinions expressed during the April 2004 Expert Workshop that the extent to which lowland vegetation extends westwards is not nearly as extensive as predicted by the White or Wild and Barbosa maps. Also, there are small occurrences of montane evergreen forest (1), thicket (13) and montane grassland (68) in the reserve that are not predicted by the FLZA vegetation map (Figure 5). Naturally, the classification of the reserve is based on very limited hard floristic data and therefore it should be regarded as a working model that will require further investigation and refinement.

Figure 10: The vegetation of the Niassa Reserve classified according to the Flora Zambesiaca vegetation categories. Compare this map to that in Figure 5.

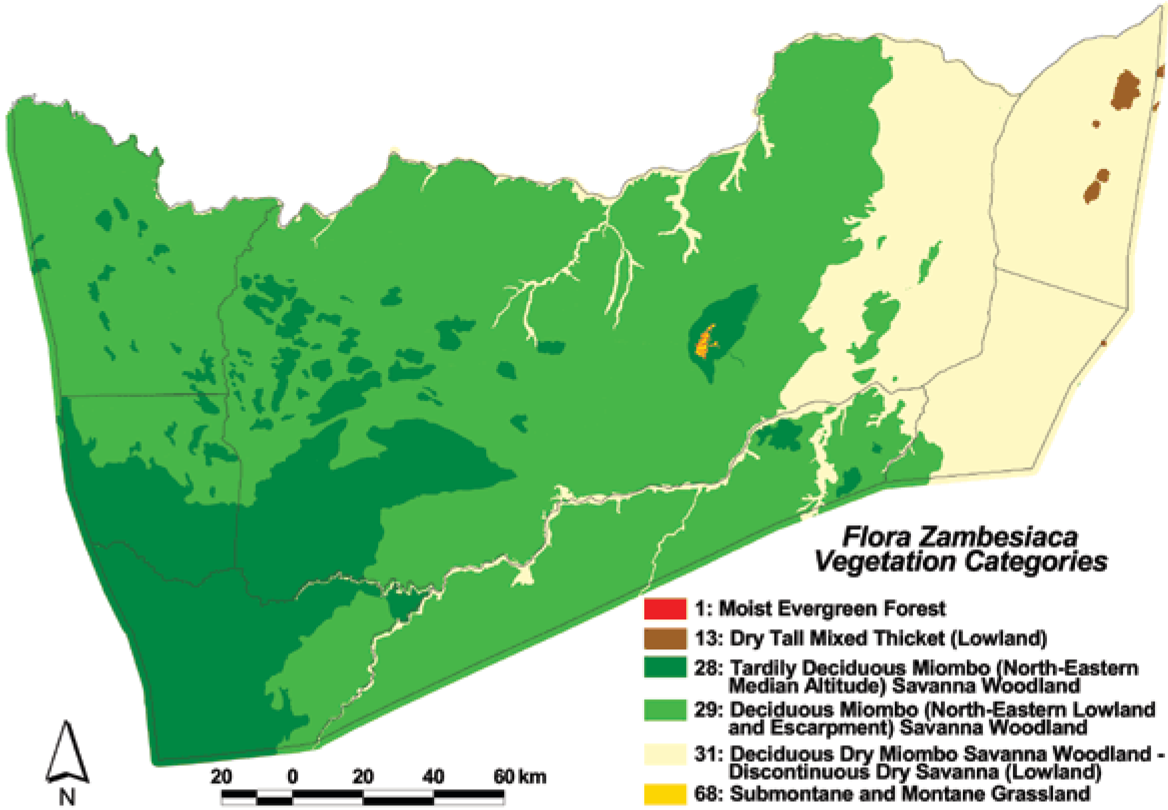


Table 7: The Flora Zambesiaca vegetation categories represented within the Niassa Reserve with the rules used in this study for assigning individual polygons to categories based on (1) Wild and Barbosa (1967) and (2) correlates estimated by this study.

FLZA Vegetation Number	Vegetation Type Name	Environmental Correlates as stated by Wild and Barbosa	Additional Rules used to Classify Polygons
1	Moist Evergreen Forest		Mean cell NDVI per polygon >0.4 (i.e. entirely continuous evergreen canopy)
13	Dry Tall Mixed Thicket (Lowland)	small elevation range on sandstones and Cretaceous sands, with rainfall of 500-800mm	Mean cell NDVI per polygon <-0.3 (i.e. strongly deciduous canopy) Land-class – plains woodland flat homogeneous
28	Tardily Deciduous Miombo (North-Eastern Median Altitude) Savanna Woodland	Mesoplanaltic areas above 500m, soils ferralitic; derived from the granite-gneissic complex; rainfall 900-1400mm p.a.	NDVI >0.2 (semi-deciduous)
29	Deciduous Miombo (North-Eastern Lowland and Escarpment) Savanna Woodland	Escarpment of Vila Cabral plateau facing Lake Malawi between 500-1000m Rainfall between 800-1000mm p.a.	NDVI <0 Well developed dambos in landscape
31	Deciduous Dry Miombo Savanna Woodland – Discontinuous Dry Savanna (Lowland)	Subplanaltic areas between 150-700m Soils red to grey and derived from the granitic-gneissic complex Rainfall about 900mm p.a.	NDVI <0 Riverine and alluvial land-classes <500m Rainfall <1200mm, mostly <1100mm
68	Submontane and Montane Grassland		Land-class – mountain grassland

Part B: Mapping Agriculture

Understanding patterns and rates of human modification of the Niassa landscape are key components in developing a management strategy for the Niassa Reserve. An analysis of the extent and change in patterns of agriculture in the reserve are based on visual interpretation of the 1993 and 2001 satellite images originally obtained for this project. The analyses presented are intended to provide an initial reserve-scale picture of the current extent of agriculture and changes in this extent over the last 10 years.

4 Mapping agriculture methods

Visual inspection of the satellite images showed that agriculture covers a relatively small area of the total reserve. It was therefore decided to capture the extent of agriculture using heads-up on-screen digitizing rather than using an automated image interpretation technique. The location of human settlement and consequently agriculture is strongly related to the location of roads thus facilitating the digitizing process. The current road coverage for the reserve, although recognized as being inaccurate, was used as a backdrop to indicate the approximate current or past location of roads in the reserve. The waypoints collected during the fieldtrip were also used to indicate the current location of major roads. The extent of agriculture for the entire reserve was captured on both the Landsat5 and Landsat7 satellite images allowing one to compare the change in extent of agriculture in the reserve between 1993 and 2001.

Ground control points for current and past agriculture were collected during the fieldtrip. These data were used to assess the accuracy of the mapping exercise by comparing the areas captured by the mapping process to the areas of known agriculture on the ground. These data were not used to guide the mapping process, as they would not then be an independent test of the accuracy of the map.

5 Extent of agriculture

Overall there has been a decrease in the extent of active agriculture in the reserve between 1993 and 2001 (42107 ha to 39807 ha). This decrease is driven primarily by the depopulation of the Msawize area (19110 ha to 4492 ha).

Although there is an overall decrease in the extent of agriculture there is, however, an overall expansion in the total amount of area impacted by agriculture (42107 ha to 60370 ha, Figure 12). This represents a 43% increase in the amount of transformed land between 1993 and 2001. This results from the trend that recolonisation is often located in pristine areas rather than in areas used previously for agriculture. Recolonisation is probably driven by changes in the regional infrastructure such as the upgrading of the Mecula road and the mothballing the Msawize military base.

Figure 11: The change in extent of agriculture between 1993 and 2001 in the respective management zones of the Niassa Reserve.

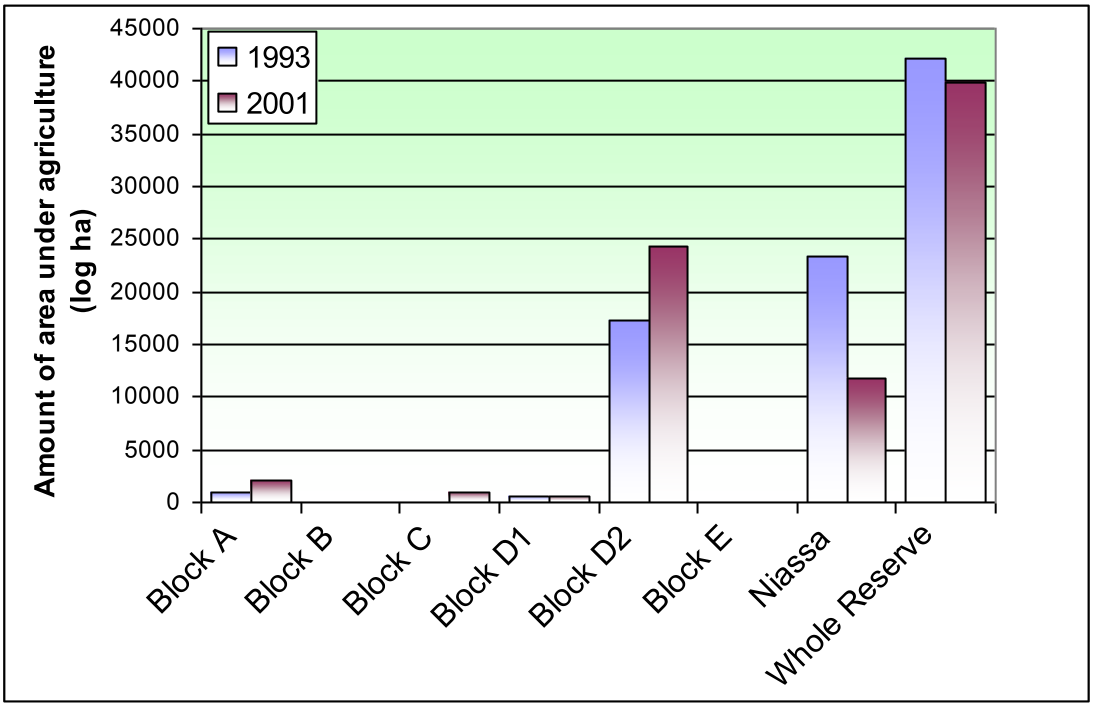


Figure 12: A breakdown of the total agricultural impact in the reserve in terms of current agricultural activity.

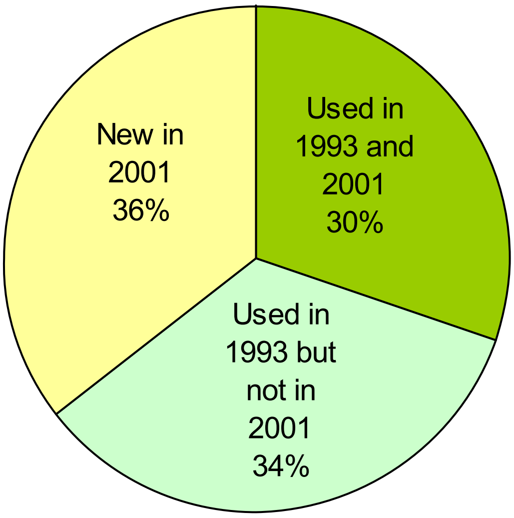


Figure 13: A comparison of the change in the amount of area under agriculture between 1993 and 2001 for three selected regions in the reserve (see Figure 14)

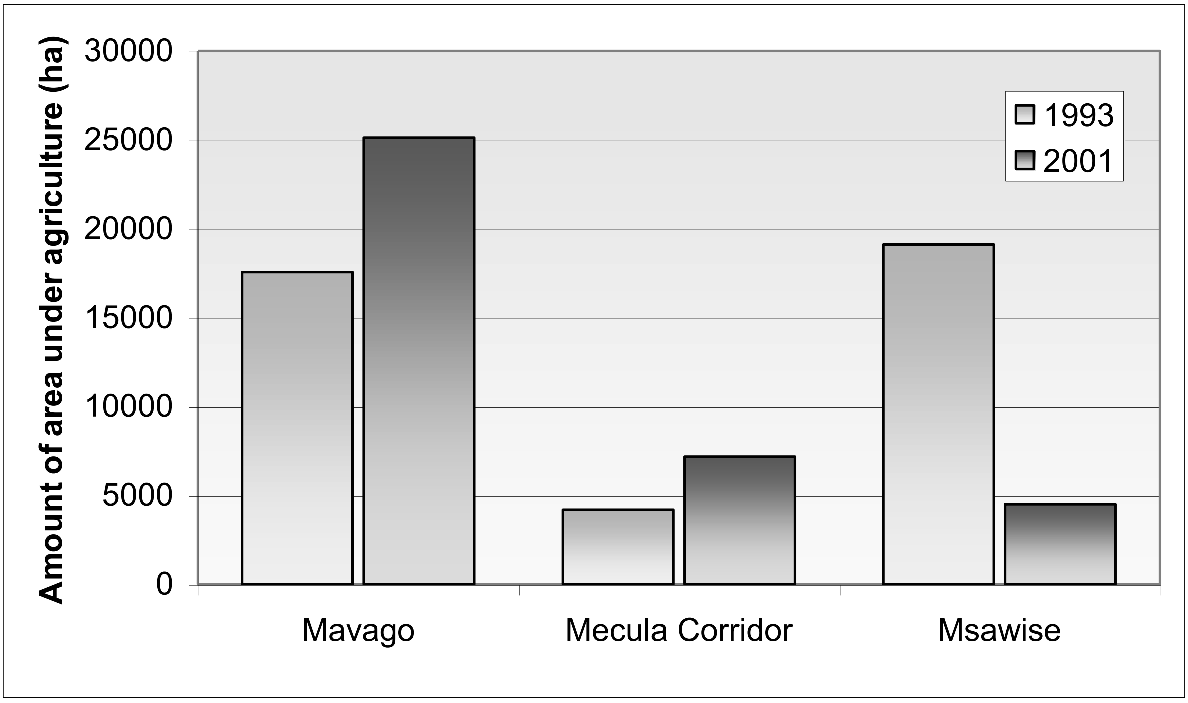
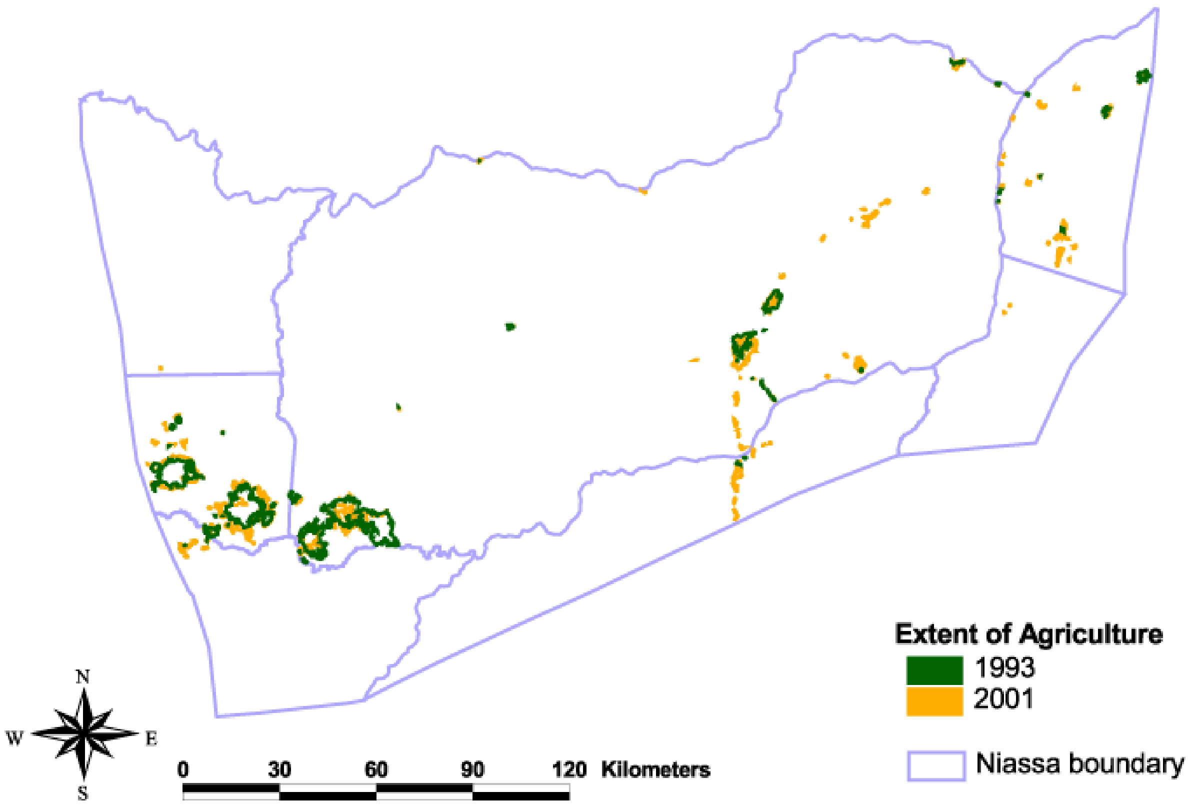


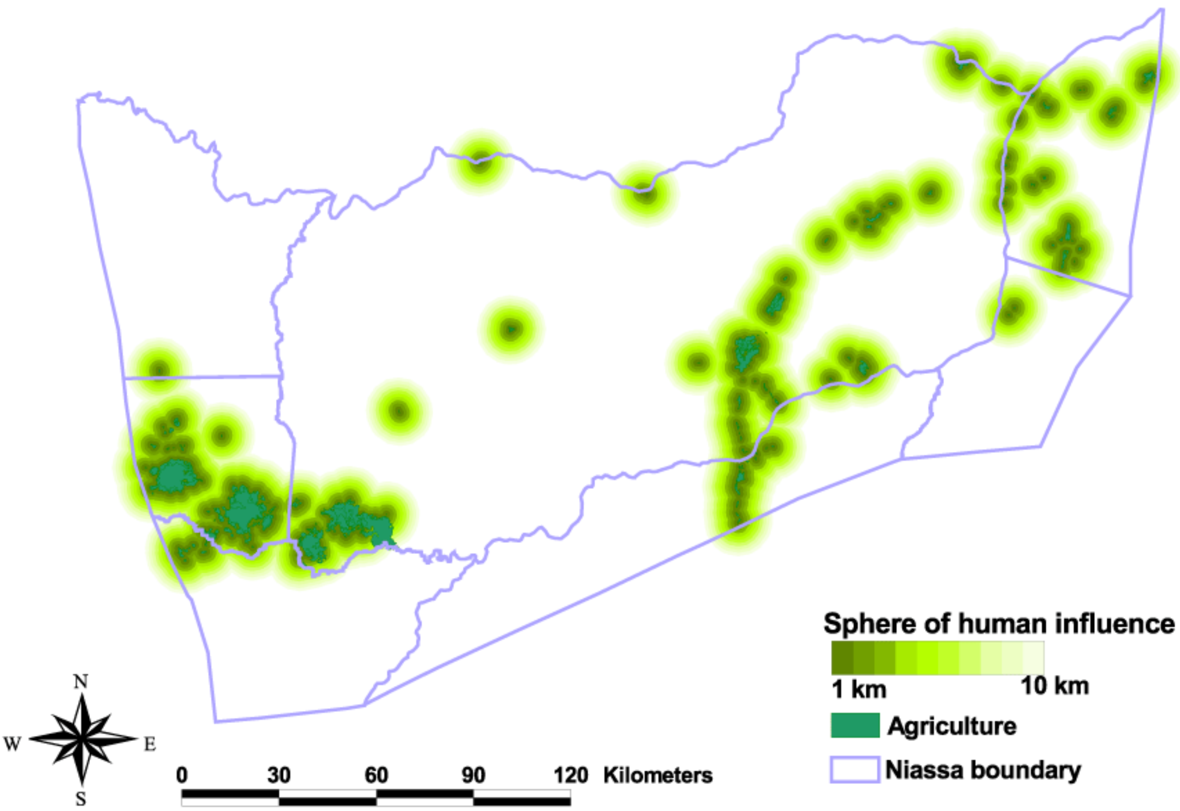
Figure 14: The extent of agriculture in the Niassa Reserve.



If we look at transformation relative to the three major regions of human activity (Figure 13) – Mavago, Msawize and the Marrupa-Gomba road (Mecula Corridor) we see that in both Mavago and Mecula Corridor areas there is significant expansion in human settlement

The extent of agriculture in Figure 14 can be modified using a simplistic "buffer" model to estimate the sphere of human impact in the reserve of permanent settlements (Figure 15). Although this buffer model is potentially arbitrary it does begin to highlight areas of the reserve where conflicts could arise between human agricultural activities and reserve management objectives. It is plain to see in Figure 15 that the Mavago-Msawize area is heavily impacted as well as the Mecula Corridor. There is a very real danger in the Mecula Corridor that the reserve will effectively be cut in two at some stage by the linking of machambas into a near continuous ribbon of agricultural development. This will have significant impacts on the movement of wildlife and also result in increased human-wildlife conflict as wildlife is forced to move through machambas in order to cross this road. Managing the spread of agriculture in this corridor should be a priority for reserve management.

Figure 15: The estimated spheres of human influence in the Niassa Reserve modelled by buffering the 2001 extent of agriculture by 10 km.



It is not possible to use the data on rate of spread of agriculture gathered for this project to predict the rate of agricultural spread into the future. The period over which the analyses were done here (1993-2001) spans the period marking the end of the civil war in Mozambique. It is likely that the end of hostilities precipitated a significant shift in human settlement patterns. This view is shared with reserve management. Where people are settled today is very different to where this was happening in 1993. The current snapshot view of agricultural is real, however, different areas are most certainly experiencing different rates of expansion or contraction and the present analyses give a general picture of agricultural trends within the reserve. Thus, it is important to better understand year-on-year rates of change rather than long-term averages of change as presented here. To this end the satellite imagery obtained from Jo Tagg will prove most useful. Using this additional data to better estimate year-on-year changes in agriculture will prove most useful for management purposes in that it will be possible to better predict where key areas of expansion are located. Given that it will be difficult for management to address agricultural expansion over the entire extent of the reserve, this data will help focus management resources on areas where they are likely to have the greatest positive impact on the management objectives of the reserve.

Current agriculture is generally always located along the roads that run through the reserve. This simple observation allows reserve managers to predict where agriculture will most likely conflict with the reserve's management goals in the future. If this observation were to be combined with information on the year-on-year increase in size of machambas (i.e. the rate at which agriculture is spreading in the reserve) it would be possible to predict, for example, ten years from now how much of the reserve will be occupied by agriculture given the current rate of growth. Although a potentially academic exercise, it could be used to demonstrate to reserve management, potential funders and government what the reserve may look like in 10 or 20 years should the current rate of agricultural expansion persist.

Deciding what was agriculture on the satellite image was not a straightforward task. The nature of the "machamba" or shifting agriculture practiced by the local population means that after a few years the fields are abandoned and allowed to return to woodland. With time the woodland on abandoned lands becomes indistinguishable from surrounding undisturbed woodland on the satellite image. How long this takes is unknown. From the exercise done here any area identified as a field in 1993 could still be recognized as being "different" in 2001 even if the woodland had been allowed to return. Thus, on the 1993 satellite image we could assume that any area that had been cultivated within the last 20 years could confidently be identified on the image. Thus, the "extent of agriculture" mapped here indicates those areas that are currently or have been cultivated within the last 40 years.

Patch size also influences whether an agricultural area was picked up during the mapping process. Although every effort was made to locate even the smallest patches of agriculture (<5ha) it is likely that some small areas were not captured. These areas will most likely be located along the major rivers where it was difficult to distinguish small machambas from the background patchiness of the riverine vegetation. Other areas where this may be a problem are the Northern Inselberg and Lugenda Valley regions where the occurrence of sodic soils creates a patchiness in the satellite image similar to that of agricultural areas. For this same reason, it is also likely that some areas mapped as agriculture are not. As this error is limited to very small patches of agriculture the overall error in the agricultural map due to this problem is probably less than 1%. Patches of agriculture larger than approximately 10ha emerge from the background patchiness of the vegetation and can therefore be easily detected which is why this problem is limited to small patches.

At this stage no quantitative estimation of the extent of very old agriculture (>50 years ago) can be made. Jonathan Timberlake made the assertion that elsewhere in the Miombo dense bamboo thickets are usually associated with past agriculture. Within the reserve there are two major areas of bamboo thickets – one in the northern plains region west of Mecula mountain and another in the eastern plains on the far eastern border of the reserve. Both these areas are currently used as major transport corridors through the reserve and archaeological evidence may support the hypothesis that these two areas supported large areas of agriculture in the distant past. The western highland region also has extensive bamboo thickets, but these are associated with riparian zones along mountain streams. Given that current agricultural practices in this area favour flat terrain it is unlikely that these thickets represent areas of past cultivation.

Part C Miscellaneous botanical notes

During the field trip some plant species that were in flower were collected for the herbarium (Table 8) and others identified in the field (Table 9). These observations should be added to the global plant species list for the reserve. The herbarium specimens were sent to the herbarium in Maputo via the SRN Office. In Table 8, the Pancratium and Scadoxus were identified from photographs sent to Dee Snijman at the Compton Herbarium at Kirstenbosch.

Table 8 Plants specimens collected for the herbarium in Maputo during the field trip.

Number	Name	Family	Habitat	Locality
3523	Erythrococca cf. zambesiaca	Euphorbiaceae	Miombo	Mbatamila camp
3524	Kyllinga sp.	Cyperaceae	Dambo	Mbatamila camp
3525	Rothmania sp.	Rubiaceae	Riverine woodland	Ntapata Camp, Luwire
3526	Tricalysa sp.	Rubiaceae	Riverine woodland	Ntapata Camp, Luwire
3527	Bulbophyllum sp.	Orchidaceae	Evergreen forest	Mecula summit
3528	Diplorhynchus condylocarpon	Apocynaceae	Riverine woodland	Ntapata Camp, Luwire
3529	Strophanthus cf. luteolus	Apocynaceae	Riverine woodland	Ntapata Camp, Luwire
3530	Gardenia sp.	Rubiaceae	Riverine woodland	Nicondocho River
3531	Pancratium tenuifolium	Amaryllidaceae	Miombo	near Ntapata Camp, Luwire
3532	Scadoxus multiflorus subsp multiflorus	Amaryllidaceae	Miombo	near Ntapata Camp, Luwire
3533	Rangaeris sp.	Orchidaceae	Cliff	Mecula summit
3534	Microcoelia sp.	Orchidaceae	Evergreen forest	Mecula summit
3535	unknown	Zingiberaceae	Termitaria	Mavago
3536	Siphonochilus cf. aethiopicus	Zingiberaceae	Mountain grassland	Mecula summit

Table 9 Additional plant species observed in the reserve not on the Timberlate *et. al.* (2004) list.

Family	Species
Cyperaceae	Kyllinga sp. (Desmet & Sonnenberg 3524)
	Cyperus textilis
Aloeaceae	Aloe chabaudii
	Aloe mawii
Amaryllidaceae	Cyrtanthus (Desmet & Sonnenberg 3531)
	Scadoxus cf. multiflorus ((Desmet & Sonnenberg 3532)
Apocynaceae	Strophanthus cf. luteolus (Desmet & Sonnenberg 3529)
	Tabernaemontana elegans
	Adenium multiflorum
Combretaceae	Combretum imberbe
Ebenaceae	Diospyros kirkii
Euphorbiaceae	Erythrococca zambesiaca
	Euphorbia ingens
	Euphorbia aff. knuthii
Fabaceae (Caesalpinioideae)	Erythrophleum africanum
Meliaceae	Turraea nilotica
Musaceae	Ensete ventricosum
Orchidaceae	Bulbophyllum sp. (Desmet & Sonnenberg 3527)
	Rangaeris sp. (Desmet & Sonnenberg 3533)
	Micrococelia sp. (Desmet & Sonnenberg 3534)
	Ansellia gigantea
Rubiaceae	Polysphaera lanceolata
Simaroubaceae	Harrisonia abyssinica
Verbenaceae	Vitex doniana
Zingiberaceae	unknown (Desmet & Sonnenberg 3535)
	Siphonochilus cf. aethiopicus (Desmet & Sonnenberg 3536)

Part D Recommendations

6 Suggestions for further research

Based on the findings of this project the following suggestions are made for further research using remote sensing techniques aimed at addressing management questions and needs.

6.1 Monitoring of key biodiversity areas.

Remote sensing can be effectively used as part of a larger biodiversity-monitoring program in the reserve. Even in the absence of on-the-ground data such as survey transects or plots, satellite imagery and aerial photography can provide useful information on ecological change. This type of data can be gathered at a fraction of the cost of undertaking detailed field surveys. However, when gathered seasonally, annually or at 2 to 5 year intervals for identified monitoring areas it can provide useful coarse-scale baseline data for monitoring aspects of the reserve's ecology such as fire or elephant impacts on vegetation or the dynamics of the human population. The most important aspect of remote sensed data is that it is a simple technique for recording that state of areas at any given time. Even if no one is actively analysing the data it will still provide a record of an area so that in future there will be data on hand to be able to assess change. The ultimate application of this data will be to inform the reserves management policy. Mecula Mountain and the lower Lugenda are two areas identified by the biodiversity survey team as key areas within the reserve. It is recommended that the reserve management prioritise the development of some type of monitoring program. Many of the questions raised at the April Biodiversity Workshop can only adequately be answered through effective monitoring.

Any monitoring project in the reserve should also be seen as an opportunity to verify and refine the vegetation map presented here. This map was generated with very little hard biological survey data. At some point it would be desirable to append floristic data to the mapped land-classes such as dominant species present or lists of species encountered in the different plant communities represented within each land-class. For the present this is probably not a priority, but should be implemented opportunistically as vegetation studies are carried out within the reserve.

6.2 Assessing the impact of fire on the vegetation of the reserve

Undoubtedly, the greatest concern expressed by the participants of the Biodiversity Survey was the effect of fire on the vegetation of the reserve, especially the impact of frequent fires on the persistence of evergreen forest on the summit of Mecula. Remote sensing can be used to monitor, but also gain a perspective on the change in the extent of this vegetation over the last 50 years.

The 1:250 000 scale map sheets for Mozambique had to be generated from aerial photography. Therefore, either the Surveyor General in Maputo or the previous regimes' archive in Portugal should have copies these aerial photographs. These photographs represent a vitally important source of long-term monitoring data for the reserve as they probably date from the 1950's or 60's and are thus a record of how the landscape looked 50 years ago. Comparing the extent of the forest on Mecula as represented in these photographs to its current extent based on new aerial photography of the mountain will provide a quantitative assessment of change in extent of this vegetation over this period. Naturally this assumes that the fire regime has changes little over the intervening period and that the current frequency of burning reflects the historical trend for the area. It also assumes that fire is the most important determinant of the extent of this vegetation on the summit.

This analysis will require that new aerial photography (film or digital format) be obtained for the mountain. This should not require more than two days of flying time, but requires that suitable equipment and an aeroplane is available for the job. The survey should also be conducted during the latter part of the dry season when the distinction between evergreen and deciduous vegetation types is greatest.
This project should not be conducted in isolation from a broader project that focuses on getting a better handle on the role of fire in the whole reserve. This broader project should seek to develop a set of management guidelines and recommendations that includes the following:

1. A desktop study that summarises the expansive literature on "the role of fire in the ecology Miombo woodlands".
2. An expert workshop or consultation process that draws on the experiences of the many researchers and reserve managers who have grappled with the issue.
3. Establishment of long-term monitoring sites and plots that measure actual vegetation responses and change at the species level.

Given the concern around the role of fire in the Niassa ecosystem it would be advisable that the present management plan prioritises a project aimed at addressing this issue.

6.3 Monitoring and modelling the spread of agriculture in the reserve

Next to fire, the spread of agriculture in the reserve is a key management issue. As discussed in Section 5, keeping abreast of current patterns of agriculture and attempting to predict future patterns underpins effective management of the reserve. Although the present study provides a good overview of the current extent and longer-term trends in agriculture in the reserve, quantifying year-on-year rates of change in different areas will be necessary to priorities management activities.

With the satellite data obtained for this project as well as that obtained from Jo Tagg it will be possible to gain a more accurate assessment of current (i.e. last 4 years) trends. As satellite imagery is relatively inexpensive it is be possible to track changes in agriculture on a seasonal or annual basis if necessary. Tracking the dynamics of agriculture in the reserve should be conducted as part of the broader reserve monitoring program. Remote sensing monitoring of agriculture should be combined with social data such as migration patterns, population growth rates and census data in order to better understand trends in the human population of the reserve.

6.4 Locating sites for infrastructure such as for tourism or research

Given the large area of the reserve and the general lack of detailed knowledge of the entire Niassa landscape, a GIS can be used to assist management in locating landscapes of particular scenic and game viewing appeal for tourists, or location sites for the creation of research stations. Combining expert knowledge and GIS-based analysis techniques it would be possible to locate areas that fulfil a particular set of criteria for either of these objectives. For example, tourists would enjoy a camp that has striking views of uninhabited landscape and the cooler tsetse fly-free climate at higher altitudes. Using the vegetation, agriculture, infrastructure and DEM it would be possible to search for areas that fulfil such criteria. The north-eastern part Jau mountain near Msawize would fulfil these criteria. Another approach may be to use current knowledge of came density and the vegetation map to predict where other potentially good game viewing areas may occur. Alternatively, one could simply examine the vegetation map to locate unique and potentially scenic landscapes such as the Riverine oxbow lake region in the very north-west of the reserve. The broad, flat alluvial plain in this area contains a variety of riparian forest, woodland, pan and seasonal lakes that could provide novel scenic areas within the reserve. The rapid-free river in this flat landscape would be ideal for fisherman canoe-based safaris.

Using such rule-based, and primarily expert derived, criteria it is possible to explore Niassa landscape to assist in making a multitude of management and planning related decisions that require a spatial context. The existing expert knowledge base and growing spatial database for the reserve are sufficient to begin exploring scenarios for the future management and development of the reserve.

6.5 Examining options for reserve expansion

The primary objective of the Niassa Reserve should be the conservation of biodiversity. To this end the reserve management as well as the Mozambique government should consider ways in which to increase the variety of biodiversity captured within the reserve by exploring options for reserve expansion that capture species/landscapes/vegetation types/land-classes not already represented within the reserve. There are three potential options for expanding the reserve within Mozambique:

1. The Mavago area is the most densely population and transformed area of the reserve. Management has suggested excising this portion of the reserve. This is probably a pragmatic approach. The excised portion could be replaced by expanding the reserve into the high mountains east of Lichinga (Figure 17).
2. The Mueda Plateau located to the east of the reserve is a major regional biodiversity hotspot in northern Mozambique. Although it is not currently recognised as part of Conservation International's Eastern Arc Mountains and Coastal Forests hotspot (http://www.biodiversityhotspots.org) or WWF's Eastern Arc Forests ecoregion (http://www.worldwildlife.org) it should be considered part of this global centre of biodiversity. It was probably never included as part of this hotspot due to the lack of biodiversity data on this area (J. Timberlake and N. Burgess pers. comm.). Given its position on the southern flank of the Rovuma River opposite the Ronda and Makondo Plateaus in south-eastern Tanzania, biologically it should have much in common with these coastal forest hotspots (Figure 16). Expanding the reserve eastwards would

certainly include several different vegetation types and many species currently not conserved in any reserve (Figure 17).
3. The Niassa Reserve is less than 100km from the Quirimbas National Park (Figure 17). Expanding the reserve eastwards by creating a corridor to link with this park will certainly improve the persistence of large-scale ecological process such as elephant and large-carnivore meta-populations and migration.

Unlike with the proposed trans-frontier corridor to the Selous Reserve in Tanzania, all three of these expansion options cover terrain that is sparsely populated. Given that alternative land-use options for this landscape are limited by poor infrastructure and tsetse fly, expanding the Niassa Reserve by expanding the core reserve as well as hunting concessions will certainly contribute to the future economic potential of the region. Also, linking the Niassa Reserve to the global conservation priority in the east will certainly open the door to access significant additional sources of funding. To secure funding from international conservation donors requires that systematic conservation plans be in place to demonstrate that the proposed expansion options meet recognised biodiversity conservation objectives. Thus, exploring expansion options for the reserve in this manner would assist in motivating for additional sources of funding for the reserve.

Figure 16: The location of the Niassa Reserve relative to the Eastern Arc and Coastal Forest conservation hotspot. The Mueda Plateau south of the Rovuma River in Mozambique should be included as the southern limit of this conservation priority.

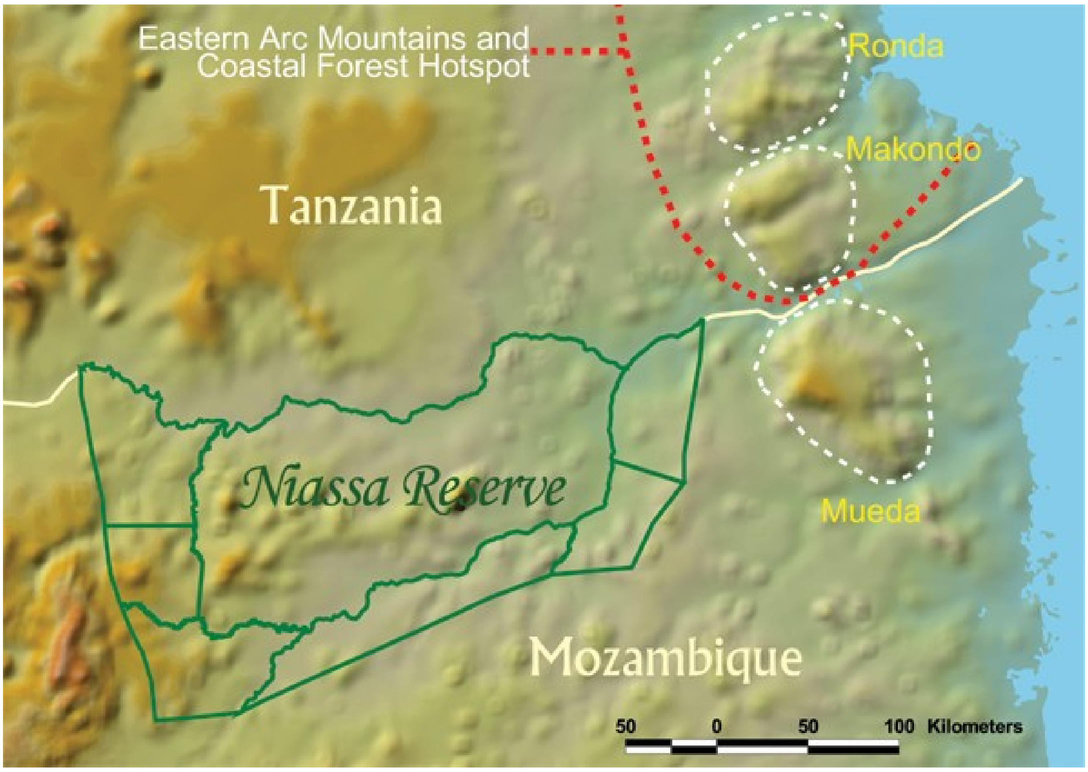
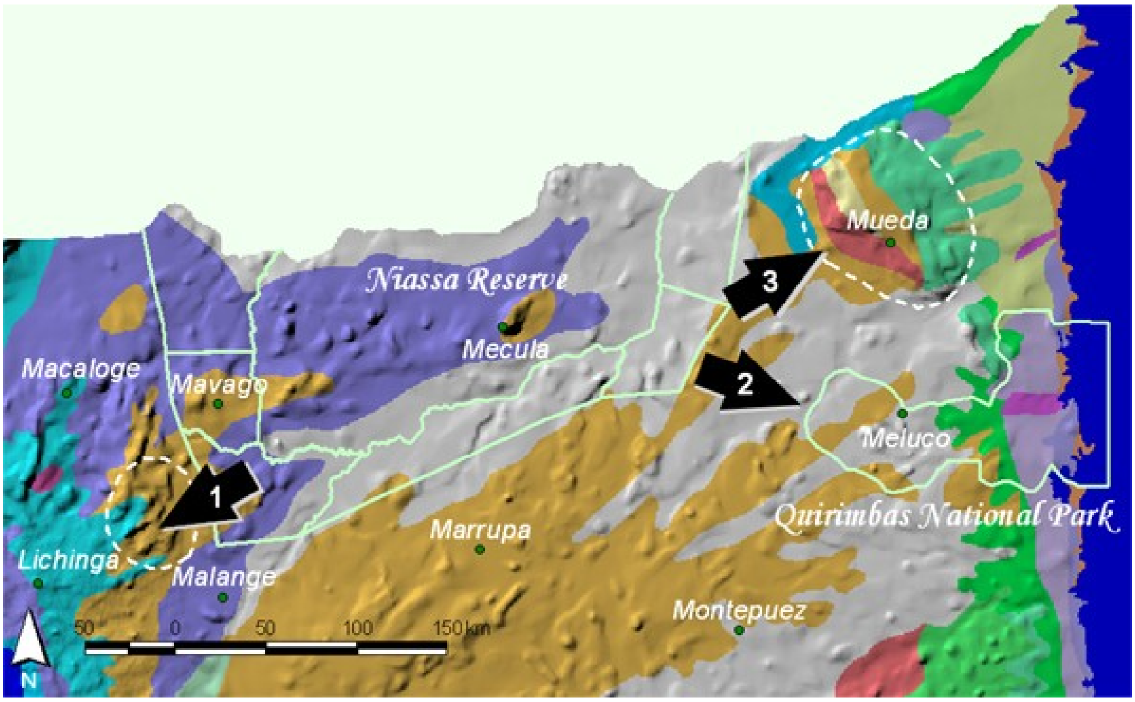


Figure 17: Three potential expansion options for the Niassa Reserve. (1) Excising the Mavago area and replacing it by expanding the reserve into the high mountains east of Lichinga. (2) Creating a corridor that links with the Quirimbas National Park. (3) Creating a corridor that links with the Mueda Plateau. The colour categories on this map represent Wild and Barbosa (1967) Flora Zambesiaca vegetation types.



7 References

Hutchinson, M. F. (2001). ANUSPLIN VERSION 4.2 USER GUIDE. Canberra, Centre for Resource and Environmental Studies, The Australian National University.

Lobão Tello, J. and Dutton, T. (1979). Reconhecimento Ecológico da Região Rovuma/Lugenda com vista a criação de um Parque Nacional/Internacional. Maputo, Mozambique, Direcção Nacional de Pecuaria, Serviço de Conservação da Fauna Bravia, Ministério da Agricultura.

Timberlake, J., Golding, J. and Clarke, P. (2004). Niassa Botanical Expedition June 2003. Maputo, Sociedade para a Gestão e Desenvolvimento da Reserva do Niassa, Moçambique.

White, F. (1983). The vegetation of Africa. A descriptive memoir to accompany the Unesco/AETFAT/UNSO vegetaion map of Africa. Paris, Unesco.

Wild, H. and Barbosa, L. (1967). "Vegetation map for the Flora Zambesiaca area." Flora Zambesiaca **Supplement**: 1-68.

Appendix 1 An example of the ground control point site data sheet used during the field survey.

Site Number:	Time:	Date:
Locality Name:		
Site Description:		
Specimen Collection Nos:		

Lat:	**Long:**

Alt (m):		Aspect:	N	NE	E	SE	S	SW	W	NW	None

Slope (Gradient):	Flat (<3°)	Gentle (<10°)	Moderate (<30°)	Steep (>30°)

Catena Position:	Top	Mid	Bottom

Broad Landscape Type:

Inselberg	Low rocky hills	Plains	Floodplain	Edge of River	Human Modified
Other:					

Broad Vegetation Type:

Acacia savanna	Brachystegia Miombo	Open Miombo/Chipya	Lowland Forest
Mountain forest	Riparian forest	Grassland	Dambo
Reed Marsh/Swamp	Agricultural field	Urban settlement	Water body
Other:			

Vegetation Structure:

Canopy Cover:	Sparse (<5%)	<20%	<50%	>50%	Continuous (>80%)

Canopy Phenology:	Mixed	Deciduous	Evergreen	Stems	Multi	Single	Mixed

Avg Canopy Height (m):		Avg. Canopy Stem Diameter (m):	

Understory Canopy Height (m):		Understory density:	Sparse	Dense

Grass Layer:	

Vegetation Type Name:
Dominant or Characteristic Species:

Notes:

Appendix 2: Derivation of the Niassa Rainfall MAP Surface.

ANUSPLIN was used to interpolate a rainfall surface for Niassa using weather station monthly summary data for stations in Tanzania and Mozambique (Figure 3).

Weather stations data came from the FAOCLIM 2 (Agrometeorology Group, SDRN, FAO; E-mail: AGROMET@fao.org) database obtained from Karen Richardson at the University of Queensland.

Mean Annual Rainfall (MAP) was interpolated using tri-variate (latitude, longitude, altitude) partial spline smoothing of (a) monthly mean rainfall data and summing the 12 monthly surfaces to obtain an annual total; and, (b) the annual total provided in the database. The product is an interpolated MAP surface for the study area plus 12 monthly rainfall surfaces.

Please consult the user manual (Hutchinson 2001) for interpretation of command file dialogues. Examples of these files are given below. As there was no monthly series data for all stations to determine weightings for different months no user specified weightings were used. Also, the rainfall data was square root or natural log transformed and this resulted in a small reduction of the transformed data error. See the example below of the analysis log files for details on the final spline parameters used to interpolate the MAP surface.

For the altitude variable, used both the value supplied in the climate database and that derived from the DEM. The climate database altitude was marginally better (i.e. lower root mean square error) for creating the spline than the DEM values.

	RTMSE	
MONTH	DATABASE	DEM
1	0.385	0.465
2	0.484	0.491
3	0.572	0.655
4	0.424	0.744
5	0.000066	7.05E-05
6	0.344	0.36
7	0.368	0.409
8	0.0000727	0.193
9	0.279	0.285
10	0.398	0.413
11	0.488	0.55
12	0.456	0.447

For the final MAP surface (Test4a) a single MAP surface was interpolated rather than producing 12 monthly surfaces and adding to produce MAP. In this analysis the data was natural log transfored. Adding the totals of the 12 monthly surfaces is not used as this compounds the error in the final prediction.

Summary spline statistics

The rainfall data in Test 4 and 2 are square root transformed, and Test1a and 4a is natural log transformed. Test 1 is untransformed rainfall data. SIGNAL values with an asterisk indicate that the spline for that surface is unreliable (i.e. number of knots equals the number of data points). Hence test 4a is probably the best rainfall surface generated.

Test 4 and 4a summary stats

	TEST4a	TEST4
SURF	MAP	MAP
RHO	1.57E-03	9.68E-11
ERROR	11	0
SIGNAL	78	89.0*
MEAN	1132.4	1132.4
STD DEV	246.4	246.4
GCV	1.36E-02	3.89
MSR	2.05E-04	4.48E-16
VAR	1.67E-03	4.18E-08
RTGCV	0.116	1.97
RTMSR	1.43E-02	2.12E-08
RTVAR	4.08E-02	2.04E-04
MSE	1.46E-03	4.18E-08
RTMSE	3.82E-02	2.04E-04

Test2 summary stats

SURF	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RHO	3.66E-03	2.00E-02	5.56E-03	1.25E-03	9.64E-11	3.68E-03	4.32E-03	9.64E-11	1.18E-02	1.40E-02	7.67E-03	8.32E-03
ERROR	19.8	45.3	25.3	9.3	0	19.9	21.9	0	36.7	39.5	30	31.2
SIGNAL	70.2	44.7	64.7	80.7	90.0*	70.1	68.1	90.0*	53.3	50.5	60	58.8
MEAN	234.83	219.72	227.14	124.67	27.422	11.233	9.4	6.6778	6.5778	15.578	69.056	184.47
STD DEV	48.6	48.96	57.58	49.37	18.17	14.97	11.35	9.038	5.858	9.455	30.43	46.85
GCV	0.865	0.939	1.62	1.93	0.408	0.687	0.734	0.496	0.322	0.644	1.07	0.919
MSR	4.18E-02	0.238	0.128	2.08E-02	4.64E-17	3.35E-02	4.34E-02	5.64E-17	5.36E-02	0.124	0.119	0.111
VAR	0.19	0.473	0.455	0.2	4.35E-09	0.152	0.178	5.29E-09	0.131	0.283	0.358	0.319
RTGCV	0.93	0.969	1.27	1.39	0.639	0.829	0.857	0.704	0.567	0.802	1.04	0.959
RTMSR	0.205	0.488	0.357	0.144	6.81E-09	0.183	0.208	7.51E-09	0.231	0.352	0.345	0.333
RTVAR	0.436	0.687	0.674	0.448	6.60E-05	0.389	0.422	7.27E-05	0.362	0.532	0.598	0.565
MSE	0.148	0.235	0.327	0.18	4.35E-09	0.118	0.135	5.29E-09	7.77E-02	0.159	0.238	0.208
RTMSE	0.385	0.484	0.572	0.424	6.60E-05	0.344	0.368	7.27E-05	0.279	0.398	0.488	0.456

Test1 summary stats

SURF	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RHO	3.22E-03	1.90E-02	5.31E-03	9.64E-11	9.64E-11	6.39E-03	1.45E-03	9.64E-11	1.62E-02	1.56E-02	4.60E-03	8.61E-03
ERROR	18.3	44.5	24.7	0	0	27.3	10.4	0	41.9	41.3	22.7	31.8
SIGNAL	71.7	45.5	65.3	90.0*	90.0*	62.7	79.6	90.0*	48.1	48.7	67.3	58.2
MEAN	234.83	219.72	227.14	124.67	27.422	11.233	9.4	6.6778	6.5778	15.578	69.056	184.47
STD DEV	48.6	48.96	57.58	49.37	18.17	14.97	11.35	9.038	5.858	9.455	30.43	46.85
GCV	764	902	1.63E+03	1.03E+03	45.7	51.6	21.5	20.4	8.56	46.3	322	704
MSR	31.4	220	123	1.17E-13	5.20E-15	4.75	0.289	2.33E-15	1.85	9.74	20.5	87.7
VAR	155	446	447	1.10E-05	4.88E-07	15.6	2.49	2.18E-07	3.98	21.2	81.2	248
RTGCV	27.6	30	40.4	32.1	6.76	7.18	4.64	4.52	2.93	6.81	17.9	26.5
RTMSR	5.61	14.8	11.1	3.43E-07	7.21E-08	2.18	0.537	4.82E-08	1.36	3.12	4.53	9.37
RTVAR	12.5	21.1	21.1	3.32E-03	6.98E-04	3.96	1.58	4.67E-04	2	4.61	9.01	15.8
MSE	124	225	325	1.10E-05	4.88E-07	10.9	2.2	2.18E-07	2.13	11.5	60.7	161
RTMSE	11.1	15	18	3.32E-03	6.98E-04	3.3	1.48	4.67E-04	1.46	3.39	7.79	12.7

Test1a summary stats

SURF	1	2	3	4	5	6	7	8	9	10	11	12
RHO	3.68E-03	2.09E-02	6.28E-03	3.79E-03	9.64E-11	4.04E-03	1.09E-02	2.36E-03	1.19E-02	1.09E-02	1.11E-02	8.66E-03
ERROR	19.9	46	27	20.2	0	21	35.5	14.9	36.9	35.5	35.8	31.9

SIGNAL	70.1	44	63	69.8	90*	69	54.5	75.1	53.1	54.5	54.2	58.1
MEAN	234.83	219.72	227.14	124.67	27.422	11.256	9.4444	6.7556	6.5889	15.578	69.056	184.47
STD DEV	48.6	48.96	57.58	49.37	18.17	14.96	11.32	8.984	5.846	9.455	30.43	46.85
GCV	1.62E-02	1.63E-02	2.68E-02	6.42E-02	9.35E-02	0.338	0.563	0.278	0.304	0.178	6.69E-02	2.04E-02
MSR	7.89E-04	4.25E-03	2.42E-03	3.24E-03	1.06E-17	1.85E-02	8.78E-02	7.57E-03	5.11E-02	2.77E-02	1.06E-02	2.56E-03
VAR	3.57E-03	8.32E-03	8.05E-03	1.44E-02	9.98E-10	7.90E-02	0.222	4.59E-02	0.125	7.02E-02	2.66E-02	7.24E-03
RTGCV	0.127	0.128	0.164	0.253	0.306	0.582	0.75	0.527	0.551	0.422	0.259	0.143
RTMSR	2.81E-02	6.52E-02	4.92E-02	5.69E-02	3.26E-09	0.136	0.296	8.70E-02	0.226	0.167	0.103	5.06E-02
RTVAR	5.98E-02	9.12E-02	8.97E-02	0.12	3.16E-05	0.281	0.471	0.214	0.353	0.265	0.163	8.51E-02
MSE	2.78E-03	4.07E-03	5.63E-03	1.12E-02	9.98E-10	6.06E-02	0.134	3.83E-02	7.35E-02	4.25E-02	1.60E-02	4.67E-03
RTMSE	5.28E-02	6.38E-02	7.51E-02	0.106	3.16E-05	0.246	0.367	0.196	0.271	0.206	0.127	6.84E-02

Examples of command files

The flow of commands used for generating the ASCII grid rainfall surfaces. ASCII files were imported as grids into ArcView.

Command	Input Files	Output Files
1. splina <test2splin.cmd> test2splina.log	test2.dat	test2splina.log test2.sur test2.res test2.opt test2.cov test2.lis
2. avgcva <test2gvc.cmd> test2gvc.log	test2.opt	test2gvc.log test2.gvc
3. lapgrd <test2grd.cmd> test2grd.log	test2.sur test2.cov dem200.asc	test2grd.log test2*.asc x12 test2e*.asc x12

Examples of command (*.cmd) files used. All command files are archived in the ../test* directories.

Contents of command file test2spin.cmd

```
Mean Monthly Rainfall
7
3
0
0
0
34.25 41.00 0 5
-16.25 -9.75 0 5
0 3000 1 1
1000.0
2
2
12
0
1
1
test2.dat
92
```

```
8

test2.res
test2.opt
test2.sur
test2.lis
test2.cov
```

Contents of command file test2gcv.cmd

```
test2.opt
test2.gcv
```

Contents of command file test2grd.cmd

```
test2.sur
0
1
1
test2.cov
2

1
1
34.947019897829 38.9993650374457
0.0017986440921512
2
-14.038644698531 -10.9737551655054
0.0017986440921512
0

2
dem200.asc
2
-9999.00
test2jan.asc
test2feb.asc
test2mar.asc
test2apr.asc
test2may.asc
test2jun.asc
test2jul.asc
test2aug.asc
test2sep.asc
test2oct.asc
test2nov.asc
test2dec.asc
(10f8.2)
2
-9.000
```

test2ejan.asc
test2efeb.asc
test2emar.asc
test2eapr.asc
test2emay.asc
test2ejun.asc
test2ejul.asc
test2eaug.asc
test2esep.asc
test2eoct.asc
test2enov.asc
test2edec.asc
(10f8.3)

Log File Transcript examples

Contents of test4splin_a.log

```
SPLINA  VERSION 4.2  09/09/01
COPYRIGHT AUSTRALIAN NATIONAL UNIVERSITY

TITLE OF FITTED SURFACES (60 CHARS):
----------------------------------
Mean Monthly Rainfall natural log transformed

SURFACE VALUE UNITS CODE:
------------------------
  0 - UNDEFINED
  1 - METRES
  2 - FEET
  3 - KILOMETRES
  4 - MILES
  5 - DEGREES
  6 - RADIANS
  7 - MILLIMETRES
  8 - MEGAJOULES
    7

INDEPENDENT VARIABLES
---------------------
NUMBER OF INDEPENDENT SPLINE VARIABLES (0 TO 10):
    3

NUMBER OF INDEPENDENT COVARIATES (0 TO  7):
    0

NUMBER OF SURFACE SPLINE VARIABLES (0 TO  7):
    0

NUMBER OF SURFACE COVARIATES (0 TO  7):
    0
```

```
TRANSFORMATION CODES            REFERENCE UNIT CODES
--------------------            --------------------
  0 - NO TRANSFORMATION           0 - UNDEFINED
  1 - X/A                         1 - METRES
  2 - X*A                         2 - FEET
  3 - A*LOG(X + B)                3 - KILOMETRES
  4 - (X/B)**A                    4 - MILES
  5 - A*EXP(X/B)                  5 - DEGREES
  6 - A*TANH(X/B)                 6 - RADIANS
  7 - ANISOTROPY ANGLE            7 - MILLIMETRES
  8 - ANISOTROPY FACTOR           8 - MEGAJOULES

LOWER & UPPER LIMITS, TRANSF CODE, REF UNIT, MARGIN(S) FOR VARIABLE  1:
   34.2500       41.0000        0         5

LOWER & UPPER LIMITS, TRANSF CODE, REF UNIT, MARGIN(S) FOR VARIABLE  2:
  -16.2500      -9.75000        0         5

LOWER & UPPER LIMITS, TRANSF CODE, REF UNIT, MARGIN(S) FOR VARIABLE  3:
   0.00000       3000.00        1         1
ENTER  1 TRANSFORMATION COEFFICIENT(S):
   1000.00

SURFACE DIRECTIVES
------------------
DEPENDENT VARIABLE TRANSFORMATION:
  0 - NO TRANSFORMATION
  1 - NATURAL LOGARITHM
  2 - SQUARE ROOT
    1

ORDER OF SPLINE (AT LEAST 2):
    2

NUMBER OF SURFACES (AT LEAST 1):
    1

NUMBER OF RELATIVE VARIANCES (0 OR 1):
    0

OPTIMIZATION DIRECTIVE (NORMALLY 1):
  0 - COMMON SMOOTHING PARAMETER FOR ALL SURFACES
  1 - COMMON SMOOTHING DIRECTIVE FOR ALL SURFACES
  2 - DIFFERENT SMOOTHING DIRECTIVE FOR EACH SURFACE
    1

SMOOTHING DIRECTIVE (NORMALLY 1):
  0 - FIXED SMOOTHING PARAMETER FOR EACH SURFACE
  1 - MINIMIZE GCV FOR EACH SURFACE
  2 - MINIMIZE TRUE MEAN SQUARE ERROR FOR EACH SURFACE
  3 - FIXED SIGNAL FOR EACH SURFACE
```

```
   1

DATA FILE NAME:
--------------
test4.dat

MAXIMUM NUMBER OF DATA POINTS (AT LEAST  4):
      92

NO. OF CHARACTERS IN SITE LABEL (0 TO 20):
   8

DATA FORMAT (LABEL,  3 INDEP VARS,  1 SURFACES,  0 REL VARIANCES):


OUTPUT LARGE RESIDUAL FILE NAME (BLANK IF NOT REQUIRED):
test4a.res

OUTPUT OPTIMIZATION PARAMETERS FILE NAME (BLANK IF NOT REQUIRED):
test4a.opt

OUTPUT SURFACE COEFFICIENTS FILE NAME (BLANK IF NOT REQUIRED):
test4a.sur

OUTPUT DATA LIST FILE NAME (BLANK IF NOT REQUIRED):
test4a.lis

OUTPUT ERROR COVARIANCE FILE NAME (BLANK IF NOT REQUIRED):
test4a.cov

VALIDATION DATA FILE NAME (BLANK IF NOT REQUIRED):
-----------------------------------------------


DATA SUMMARY
------------
NUMBER OF DATA POINTS READ      =     92
NUMBER OF POINTS WITHIN LIMITS =     89

 SURF  MEAN RELATIVE VARIANCE  ROOT MEAN REL VAR
    1               1.00                1.00

SURFACE STATISTICS
------------------
SURF       RHO     ERROR    SIGNAL     SURF     MEAN     STD DEV
   1 0.157E-02      11.0      78.0        1   1132.4       246.4

SURF       GCV       MSR       VAR     SURF   RTGCV     RTMSR     RTVAR
   1     0.136E-01 0.205E-03 0.167E-02    1    0.116     0.143E-01 0.408E-01

SURF       MSE     RTMSE
   1     0.146E-02 0.382E-01
```

APPROXIMATE UNTRANSFORMED STATISTICS

SURF	GCV	MSR	VAR	SURF	RTGCV	RTMSR	RTVAR
1	0.177E+05	263.	0.214E+04	1	133.	16.2	46.3

SURF	MSE	RTMSE
1	0.188E+04	43.4

RANKED ROOT MEAN SQUARE RESIDUALS FOR ALL SURFACES

1	5	TZ09LDMB	0.550E-01
2	38	TZ09NWL0	0.396E-01
3	4	TZ09KTNG	0.369E-01
4	92	MZ56VLJN	0.357E-01
5	44	TZ05SNGG	0.274E-01
6	57	MZ56LM00	0.267E-01
7	43	TZ05SNGR	0.266E-01
8	22	TZ08MSSD	0.262E-01
9	75	MZ49MCT0	0.255E-01
10	74	MZ40MSSR	0.234E-01
11	30	TZ09MTPW	0.231E-01
12	23	TZ05MTGR	0.226E-01
13	66	MZ49MCNT	0.209E-01
14	21	TZ08MSS0	0.205E-01
15	13	TZ09LGLM	0.172E-01
16	59	MZ50LMB0	0.156E-01
17	10	TZ04LTH0	0.155E-01
18	31	TZ00MTWR	0.152E-01
19	41	TZ05PRMH	0.134E-01
20	33	TZ00MWT0	0.131E-01

PROGRAM SPLINA VERSION 4.2 DATE 08/01/2004 TIME 08.36.10

Contents of test4agrd.log

LAPGRD VERSION 4.2 31/10/01
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SURFACE FILE NAME:
----
test4a.sur

SURFACE TITLE = Mean Monthly Rainfall untransfromed
SURFACE UNITS = mm

NUMBER OF SURFACES = 1
ORDER OF DERIVATIVE = 2
NUMBER OF KNOTS = 89

DEPENDENT VARIABLE TRANSFORMATION = 1

```
NUMBER OF SPLINE INDEPENDENT VARIABLES =   3
NUMBER OF INDEPENDENT COVARIATES       =   0

VAR   LOWER LIMIT   UPPER LIMIT  TRANSF    UNITS   MARGINS
  1   34.2500       41.0000          0     deg     0.000       0.000
  2  -16.2500      -9.75000          0     deg     0.000       0.000
  3   0.00000       3000.00          1     m       0.000       0.000
   TRANSFORMATION CONSTANT  =   1000.00

SURFACE NUMBERS (0 T0  1):
0

TRANSFORM SURFACE VALUES (0-NO, 1-YES):
    1

TYPE OF SURFACE CALCULATION (0-1):
  0 - SUMMARY STATISTICS ONLY
  1 - ALL SURFACE VALUES
    1

ERROR COVARIANCE FILE (BLANK IF NO ERRORS REQUIRED):
--------------------------------------------------
test4a.cov

TYPE OF ERROR CALCULATION (0-4):
  0 - STANDARD ERROR OF AVERAGE ONLY
  1 - MODEL STANDARD ERRORS
  2 - PREDICTION STANDARD ERRORS
  3 - 95% MODEL CONFIDENCE INTERVALS
  4 - 95% PREDICTION CONFIDENCE INTERVALS
    2

MAXIMUM STANDARD ERROR (BLANK OR 1 STANDARD ERROR):


GRID SPECIFICATIONS
-------------------
POSITION OPTION (0 - AT CELL CORNERS, 1 - AT CELL CENTRES):
    1

INDEX OF FIRST GRID VARIABLE (NORMALLY 1):
    1

LOWER LIMIT, UPPER LIMIT AND SPACING OF FIRST GRID VARIABLE:
   34.947019897829       38.999365037446      0.1798644E-02

INDEX OF SECOND GRID VARIABLE (NORMALLY 2):
    2

LOWER LIMIT, UPPER LIMIT AND SPACING OF SECOND GRID VARIABLE:
  -14.038644698531      -10.973755165505      0.1798644E-02
```

```
NUMBER OF COLUMNS =  2253
NUMBER OF  ROWS    =  1704

INPUT INDEPENDENT VARIABLE GRIDS
--------------------------------
MODE OF MASK GRID (0-3):
  0 - MASK GRID NOT SUPPLIED
  1 - GENERIC MASK GRID
  2 - ARC/INFO MASK GRID
  3 - IDRISI MASK IMAGE
    0

MODE OF 3RD INDEPENDENT VARIABLE (0-3):
  0 - USER SUPPLIED CONSTANT
  1 - GENERIC INDEPENDENT VARIABLE GRID
  2 - ARC/INFO INDEPENDENT VARIABLE GRID
  3 - IDRISI INDEPENDENT VARIABLE IMAGE
    2
INPUT GRID FILE NAME:
dem200.asc

OUTPUT SURFACE GRIDS
--------------------
MODE OF OUTPUT GRIDS (0-3):
  0 - X,Y,Z FORMAT
  1 - GENERIC GRID BY ROWS
  2 - ARC/INFO GRID
  3 - IDRISI IMAGE
    2

SPECIAL VALUE FOR OUTPUT GRIDS:
  -9999.00

NAME OF OUTPUT GRID FILE FOR SURFACE 1:
test4amap.asc

OUTPUT ARC/INFO GRID FORMAT (BLANK FOR BINARY):
(10f8.2)

OUTPUT ERROR GRIDS
------------------
MODE OF OUTPUT GRIDS (0-3):
  0 - X,Y,Z FORMAT
  1 - GENERIC GRID BY ROWS
  2 - ARC/INFO GRID
  3 - IDRISI IMAGE
    2

SPECIAL VALUE FOR OUTPUT GRIDS:
  -9.00000
```

NAME OF OUTPUT GRID FILE FOR SURFACE 1:
test4aemap.asc

OUTPUT ARC/INFO GRID FORMAT (BLANK FOR BINARY):
(10f8.3)

EXPONENTIAL V1, V2, V3, SD = 16.60 0.2970 0.2738E-01 16.60

LAPGRD SUMMARY STATISTICS

OUTPUT SURFACE AND ERROR GRIDS FOR SURFACE 1
NUMBER OF CELLS = 3068288 MEAN ERROR = 40.
MINIMUM ERROR = 30. MAXIMUM ERROR = 56.
MINIMUM VALUE = 885. MAXIMUM VALUE = 0.150E+04
MEAN SURF VALUE = 0.117E+04 STANDARD ERROR = 17.

PROGRAM LAPGRD VERSION 4.2 DATE 08/01/2004 TIME 08.44.34

Appendix 3: Examples of landscapes within land-classes.

Below are a collection cross-section diagrams drawn during the field survey. These have been extracted directly from the field book and are intended as merely as a general introduction to what the Niassa Landscape looks like on the ground within different mapped land-classes. They do not provide a comprehensive stylised perspective of the landscape as not all areas of the reserve were visited.

Diagram 1: A general cross-section north-south through the reserve at about Matondovela. The "types" in the diagram refer to plains types illustrated in Figure 6.

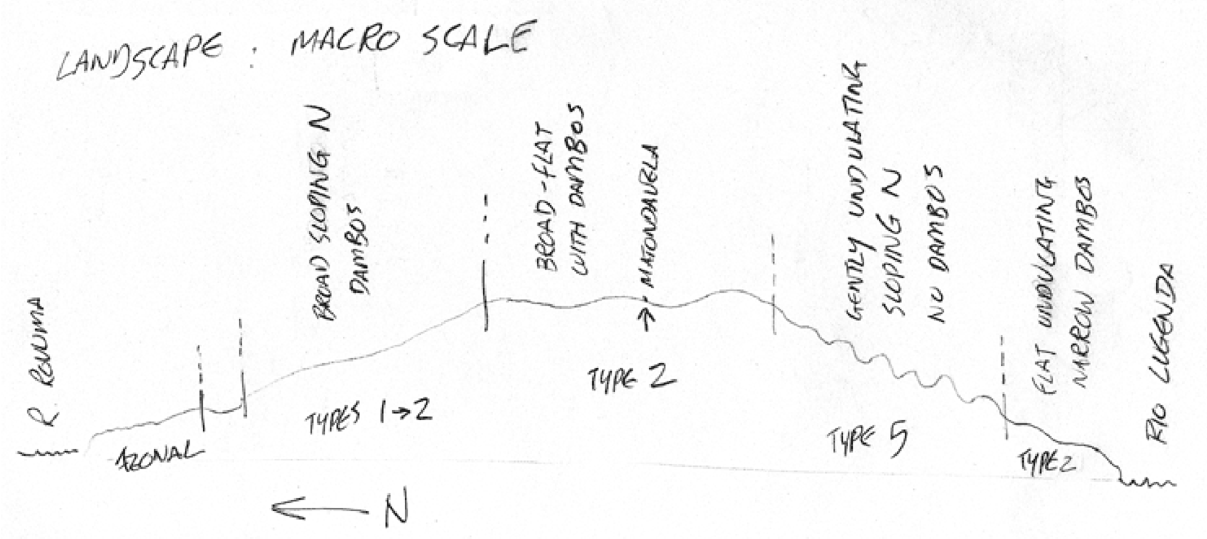

Diagram 2: Flat woodland in the extreme east of the reserve in the Eastern Plains region. The "Miombo" in the diagram is probably lowland thicket vegetation (FLZA vegetation number 13).

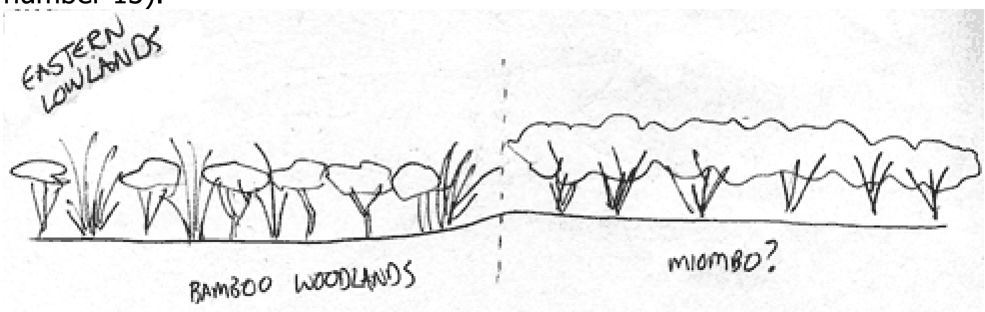

Diagram 3: Alluvial vegetation on black heavy soils in the Lugenda Valley region of the reserve.

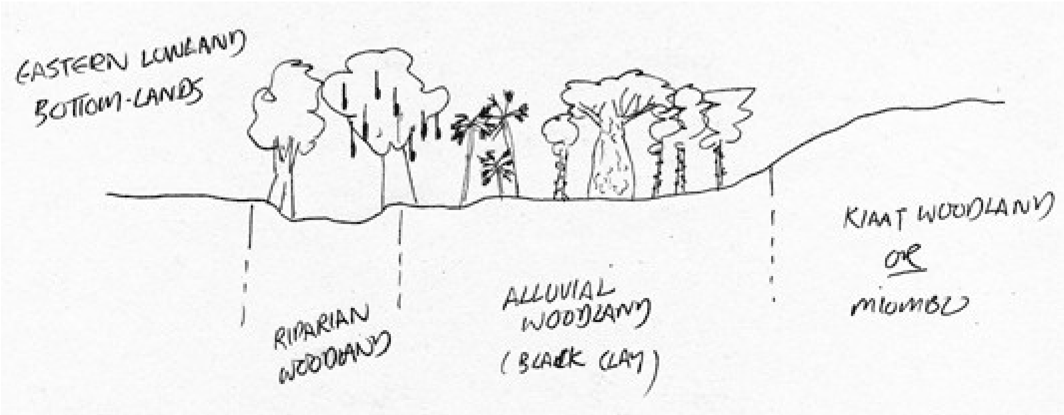

Diagram 4: Dambo-free non-Miombo woodland on basalt (?) in the Lugenda Valley region of the reserve.

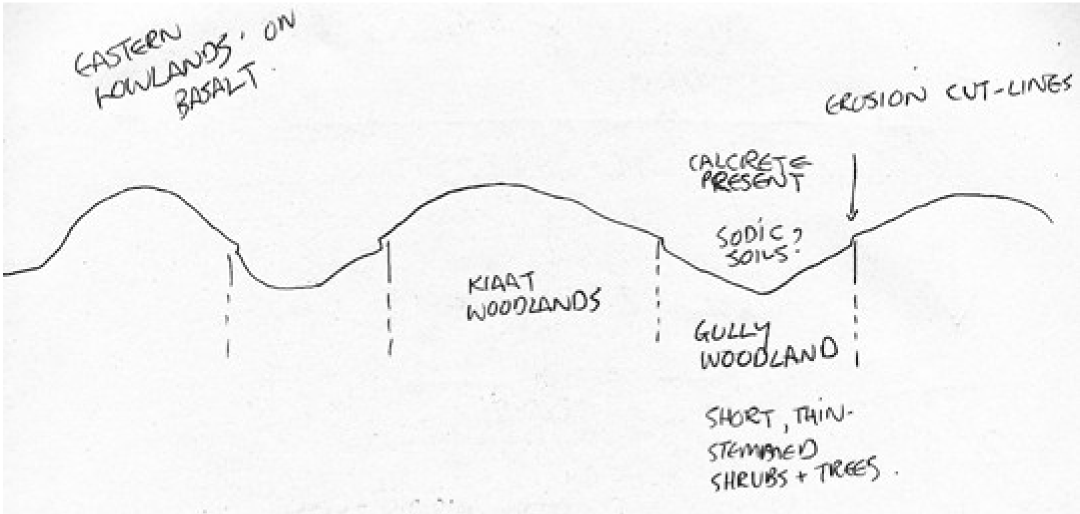

Diagram 5: A typical Inselberg in the central Inselberg belt of the reserve.

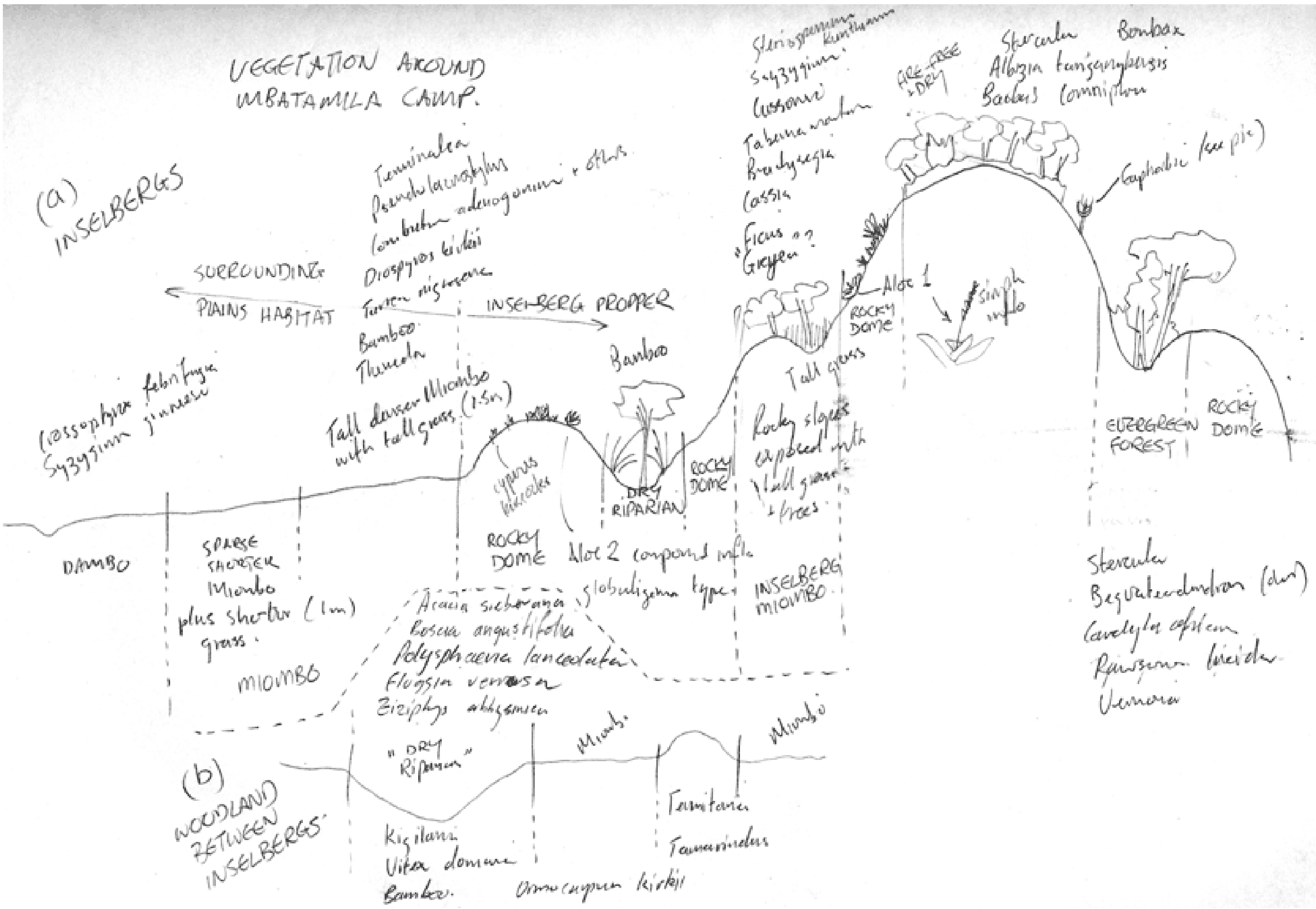

Diagram 6: Riparian woodland along the lower Lugenda River

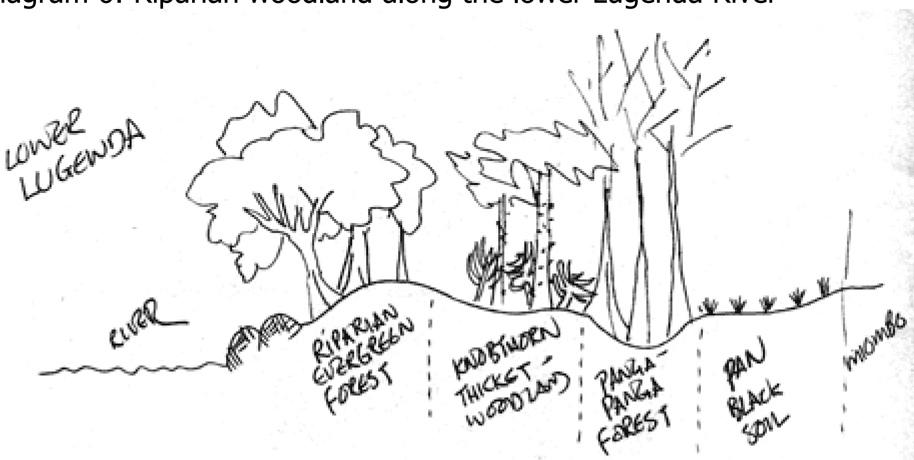

Diagram 7: The summit of Mecula Mountain with evergreen forest patches and montane grassland on the summit, and gully forest patches and tardy deciduous Miombo woodland on the slopes.

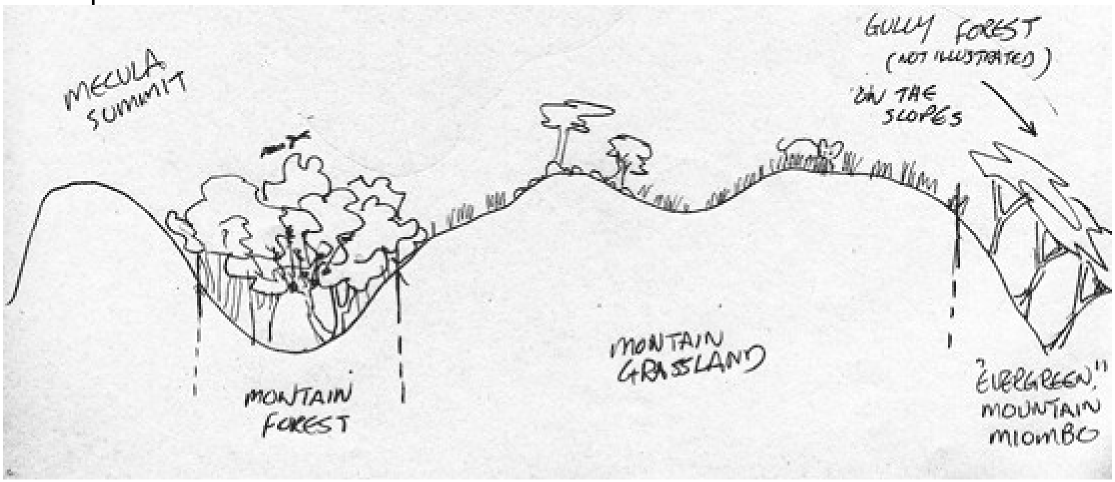

Diagram 8: Typical dambo landscape on plains

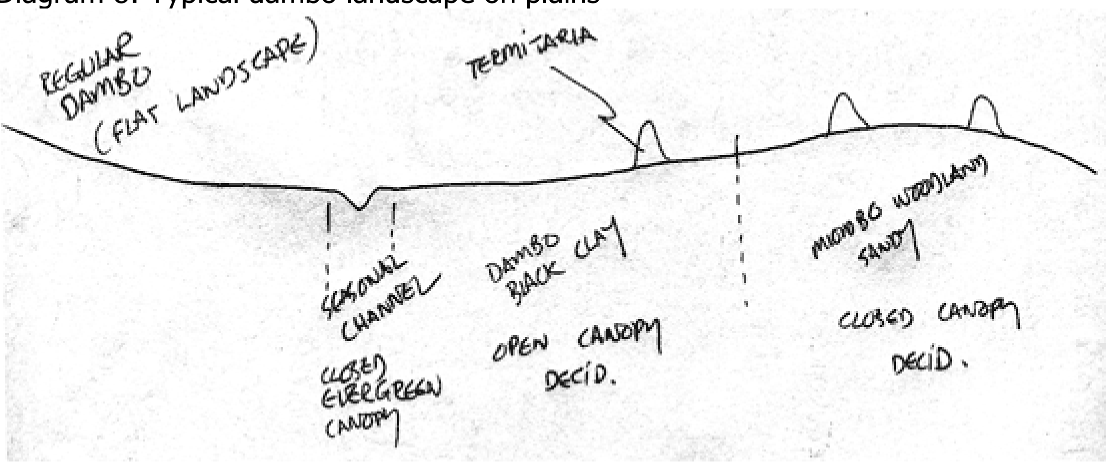

Diagram 9: Undulating dambo-free Miombo woodland on incised plains

Diagram 10: Steep undulating landscape with tall Miombo woodland typical of the Western Fold Mountain and Jau Mountain region

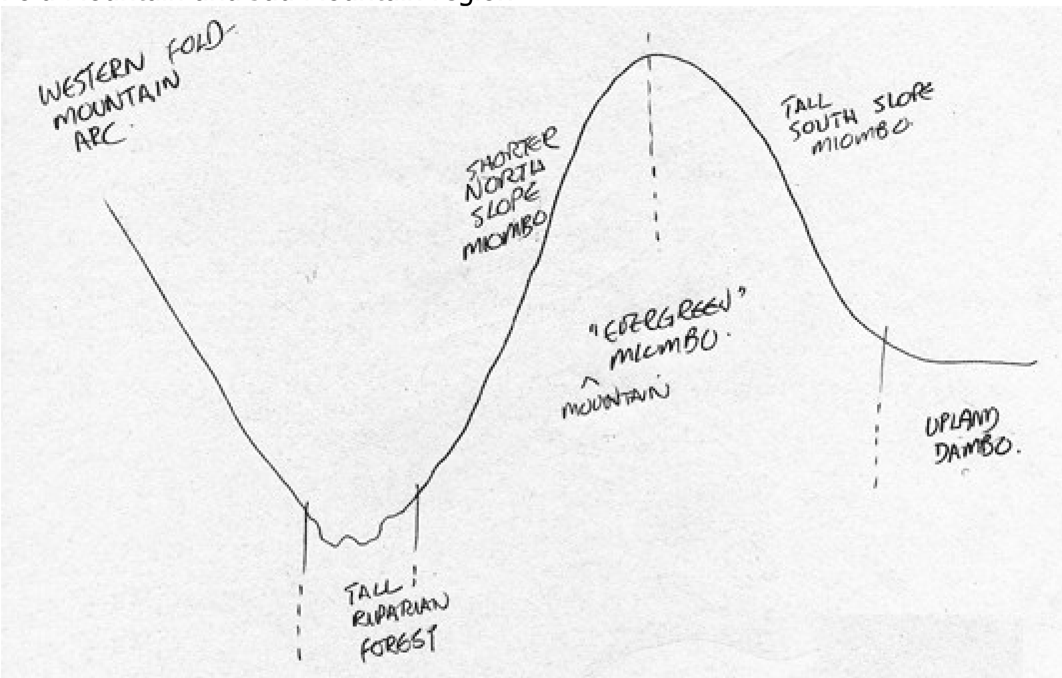

Diagram 11: Tall Miombo woodland typical of the Mavago Uplands region