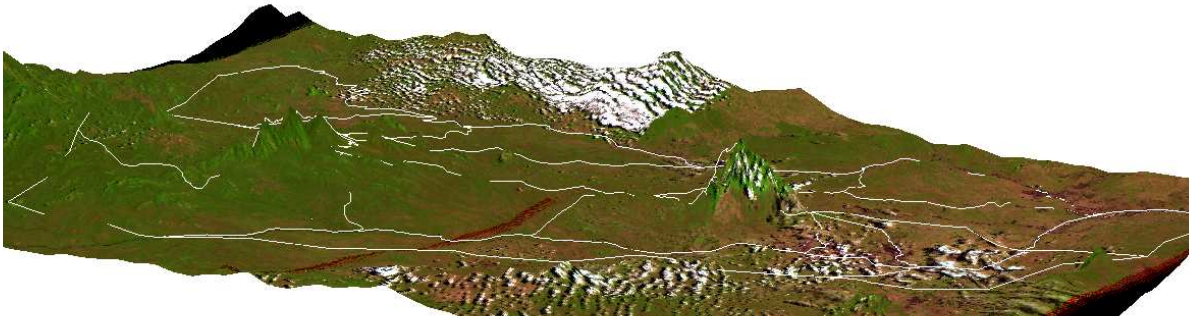
Niassa National Reserve
BUFFALO PROJECT



VEGETATION SURVEY REPORT
June 2010

Vegetation survey of Niassa National Reserve oriented for vegetation mapping and range resources assessment using satellite imagery

Nicolas Ganzin (Geographer) and Pierre Poilecot (Botanist)
In collaboration with ***Thomas Prin (Ecologist)***

Mission carried out in Niassa National reserve, Mozambique
12th to 26th of June 2010

Contents

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The authors wish to warmly thank all the collaborators with whom they have had the opportunity to work and share pleasant moments during this 2 week stay in Northern Mozambique in June 2010.

*As first, we wish to thank **Thomas Prin** whose warm welcome and great organisation made our stay exciting, efficient and relaxed; everything went smoothly for the entire period, it was not an easy task, and we believe it was a great achievement for which we are grateful. Our camps along the Rio Lugenda, especially, are quite unforgettable…*

*Many thanks as well to **Wim**, **Jumbo** and **Barbara**, and all the other operators in the hunting camps for their great help, especially in providing precious information on the state of the road infrasture, but not only…*

*"Muito Obrigado" as well to the 3 mozambican team members, **Sila** (o "senhor professor"), **Daimo** and **Agostinho** whose great spirits and hard work have made our stay a success and a really pleasant time, especially deep in the bush and in the evenings at the river camps.*

*Many thanks as well to the **Sociedade para a Gestão e Desenvolvimento da Reserva do Niassa** and to the **Metapiri Ecotourism Society** for making this trip and work possible.*

*Last but not least, many thanks also to **IGF** for inviting us to carry out this mission in a really interesting environment and for giving us the opportunity to see so much, to be in contact with all the great people we have met.*

Background

The vegetation survey described in this report was achieved between the 11th and 27th of June (travel included), by french scientists Nicolas Ganzin, geographer, and Pierre Poilecot, botanist, in close collaboration with Thomas Prin, ecologist, locally based PhD student.

The survey was carried out within the "**Buffalo project**" of Niassa National Reserve, Mozambique, under the auspices of the ***Sociedade para a Gestão e Desenvolvimento da Reserva do Niassa*** (SGDRN, Maputo). It was planned and organised by **Thomas Prin**, field officer of the **IGF** (International Foundation for the Conservation of Wildlife, Paris, France), technical operator of the project, which acts in close partnership with the **Metapiri Ecotourism Society**.

The main objective of the "**Buffalo Project**" is to try and understand the mechanisms that limit the population of buffaloes in the Niassa National Reserve. Within this objective lies the research topic of Thomas Prin, as a PhD Canditate at the University of Lyon, France, with the preliminary title :

"**Role of the spatial heterogeneity of the resources and of the natural and human predation risk on the distribution of the buffalo populations in Niassa National Reserve**".

The vegetation survey described here was carried out within this research, with a specific aim of providing information for the first aspect of the research, related to **spatial heterogeneity**. It is therefore NOT a botanical inventory as such, but more of a collection of **information for mapping** purposes. As a matter of fact, accurate information on the vegetation and forage resources is essential in order to be able to analyse data on the buffaloes themselves, mainly through GPS "collars" that provide positions of 8 sample buffalo herds since 2009 (cf. Prin, 210 :Collaring Operation Report).

Although it does involve recognition and inventory of woody and herbaceous species, this vegetation survey is therefore done according to a specific method, proposed for the collection of data adapted for the compilation of an updated **vegetation map**, and an **estimated assessment of the forage resources**, both processes being related to one another and based on **satellite imagery**.

Introduction and overall objective

Niassa National Reserve covers approximately 42 000 km^2, more than the area of Switzerland. Such a large surface of rangelands represents ample forage resources and should be able to sustain high numbers of large herbivores. Nevertheless, the reality of the present day shows otherwise, with populations that are quite low.

For what concerns buffaloes (*Syncerus caffer caffer*), the latest aerial counts (*G.C.Craig, october 2009, report not yet available to us)* provide an estimated population of ***6833 +/- 2700***[1] individuals for the entire reserve, which corresponds to an estimated average buffalo density of **0.16** individuals per square kilometer[2]. Compared to other protected areas in Africa with similar vegetation types, this figure appears to be quite low. In **Hwange** National Park, in Zimbabwe, for example, the densities of buffaloes are estimated between **0.4** and **1.0** (Fritz, personal communication). In **Kruger** National Park, in South Africa, the figures are between **0.6** and **1.1** (Fritz, personal communication). In **Selous** Game Reserve, in Tanzania, depending on the years of counts, the densities appear to be 20 times larger (or more) than in Niassa (Plan de maneio da RNN 2007-2012).

The question therefore arises as to why there can be such a difference, in order to eventually propose management solutions to obtain an increase in numbers. Several reasons can be hypothesised to explain for the limited populations, of course. An essential one is related to the habitat, and especially to the vegetation and its various types and distribution in space. Thus the idea, within the “buffalo project”, of studying the relationship between the presence of buffalo and the vegetation type and corresponding forage resources.

In order to carry out this analysis, data are necessary on both the location of the buffaloes and on the type of habitat that corresponds to this location. The fisrt type of information, on the one hand, the **buffalo positions and movements** in the Reserve, is being collected, and some is already available. Thanks to the GPS collars put on representative individuals of several herds during the collaring campaign of 2009 (18 collars at the present time), the coordinates of the collared individuals are known at regular time intervals (every 4 hours for GPS/satellite collars and every hour for GPS/UHF collars) thus giving information on their movements and zones of preferred stay (Prin, 2010). The second type of information, on the other hand, the **mapped background information** required to interpret the positions of buffaloes according to the **vegetation,** appears to be scarce and to this date insufficient for an efficient analysis.

Of course, some useful information on the vegetation does exist, thanks to recent vegetation surveys (Timberlake et al., 2004; Ribeiro, 2005) that provide a good knowledge base, with a description of the *Miombo* environment prevalent in the Niassa Reserve and an accurate inventory of the species present. This information is unfortunately not directly usable for this type spatial analysis since it is **not in mapped format**. Vegetation maps are nevertheless also available, in the form of two vegetation

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[1] equivalent to +/- 40%

[2] computed on the exact area of ***42612*** km^2 of Niassa National Reserve

maps retrieved in GIS format (and therefore potentially usable for spatial analysis) for which we unfortunately have little reference material to rely on at the present date.

The first of these two maps (referred to as the “**all region**” map) is believed to have been compiled in 2004 by digitization of major vegetation zones on 1:100 000 maps (date unknown) provided by the CENACARTA office (Games, 2004). This map is presented hereafter on **figure 1**, after being edited under the ARCVIEW GIS software. It provides an interesting segmentation of the vegetation according to the structure, defined by the density of woody vegetation (Forest, woodland, medium woodland, open woodland, wooded grassland and grassland) which is well adapted to our type of spatial analysis.

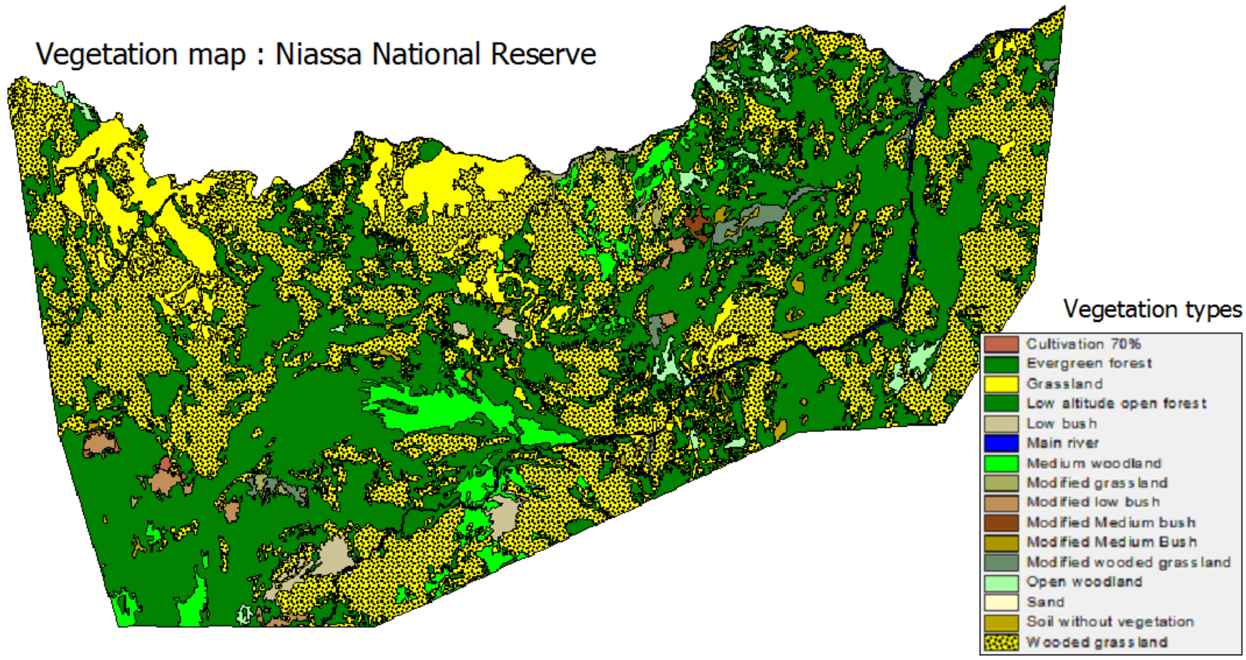

***Figure 1 :** The “all region” vegetation map.*

The second map, therefater referred to as “**Desmet map**” (Desmet, 2004) was compiled in the recent years by photo-interpretation of LANDSAT satellite imagery and hand delimitation of zones. It is presented here on **figure 2**, also after being edited with ARCVIEW. It gives a finer segmentation of the habitat into vegetation types than the previous, but without a clear notion of vegetation structure.

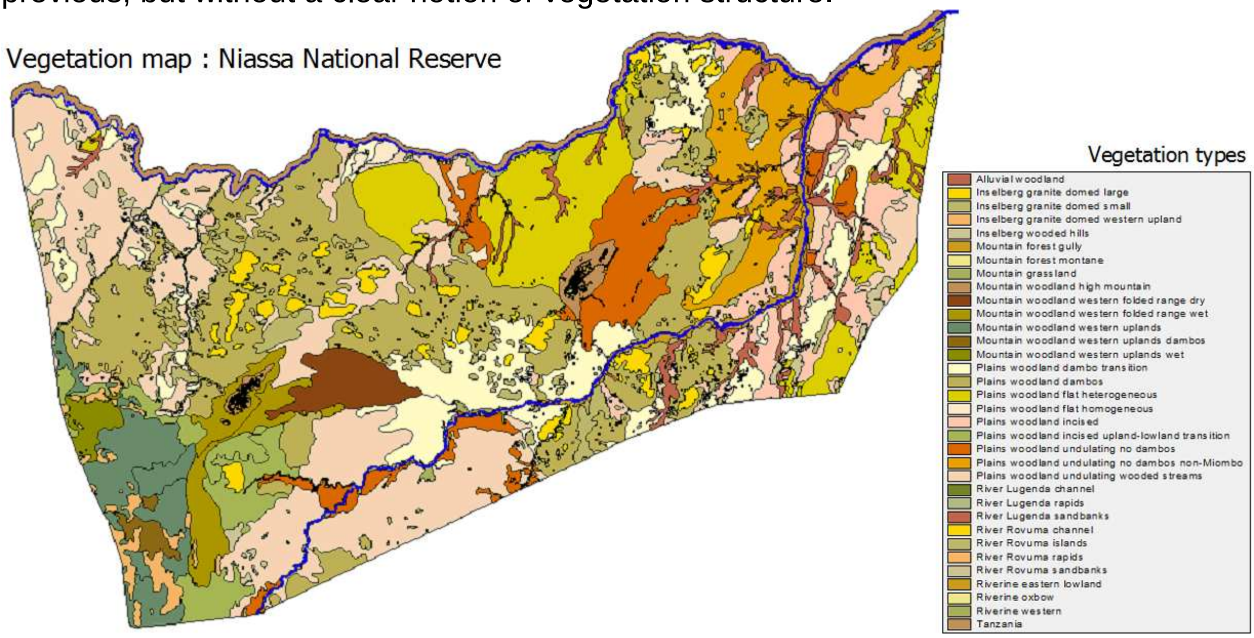

***Figure 2 :** The “Desmet” vegetation map.*

Both these maps have been quite useful for the present survey in providing a good basic description of the environment[3], but they appear to be insufficiently accurate for the purpose of spatial analysis of the positions of buffaloes. Despite a good stratification of the habitat, their description of the vegetation structure (proportion of shrubs and trees) and types (main woody species) is not fine enough. This can be illustrated clearly by comparing the details visible on a LANDSAT satellite image at 30m resolution (image of June 2008 downloaded for the project) and the description of the vegetation by the "all regions" map (see figure 1). This is illustrated graphically of **figure 3** with the example of a small area of Eastern Niassa :

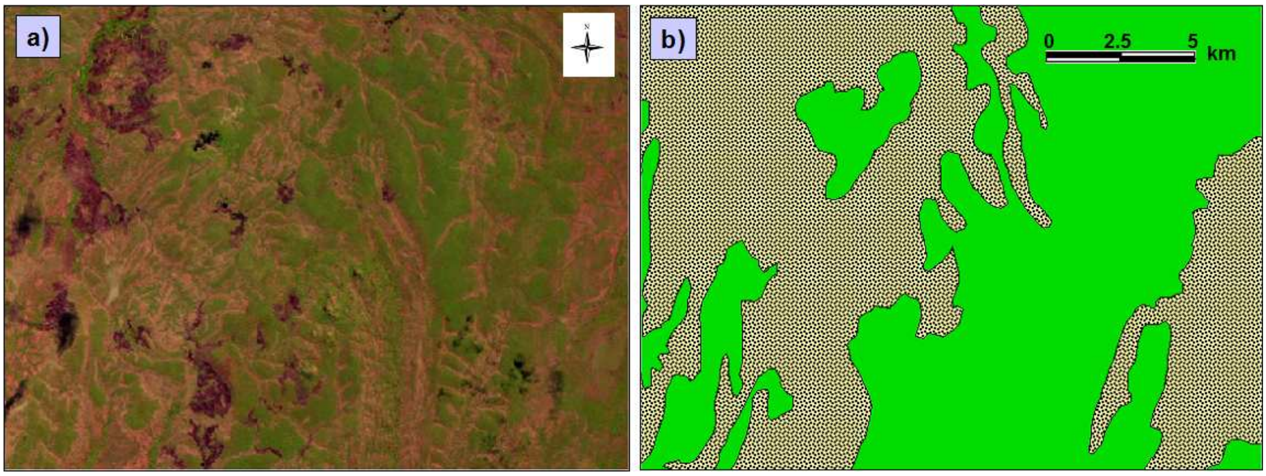

Figure 3 : *Comparison of an RGB color composite of a LANDSAT TM satellite image of June 2008 (**a**) and the "all region" vegetation map on a small area of Eastern Niassa (**b**).The brown spots on the satellite image are fire scars.*

On **figure 3**, one can easily see that the spatial variability in the satellite image is a lot higher than on the vegetation map. This suggests that, based on such satellite data, vegetation mapping could be done with better accuracy, with a finer description of the habitat and especially of the heterogeneity in space of the vegetation.

It was therefore decided, within the "buffalo project" and in relation with the PhD research subject of Thomas Prin[4], to try and compile a **new vegetation map** adapted for the analysis and derived from high resolution satellite imagery. The proposed approach is similar to that applied in a similar exercise carried out in Hwange National Park, Zimbabwe (Ganzin et al., 2008) and in which a **simplified** vegetation map was obtained by **digital processing** of satellite imagery (as opposed to photo-interpretation and hand delineation techniques). The process applied is the **Supervised Classification**, for which satellite imagery is transformed into a thematic map by extrapolation of sample field information to the entire image. The result is a pixel-fine vegetation map showing the distribution of the various types of vegetation identified in the field.

In order to collect the basic information for the final image processing step, a **vegetation survey** is therefore indispensable, and the main aim of this report is to describe the first "satellite data processing" adapted vegetation survey organised and carried out in June 2010 by a team of 5 (see **figure 4**) in the central and eastern parts of Niassa National Reserve. Pierre Poilecot, botanist of team, was of course a key contributor in

[3] and have been very useful in the planning of the location of sampling points for the present vegetation surveys! Many thanks to their authors for, providing us with this information.

[4] "***Role of the spatial heterogeneity of the resources and of the natural and human predation risk on the distribution of the buffalo populations in niassa national Reserve***". *University of Lyon, France*

determining species and taking samples for later determinations, the same evening at camp, using appropriate books, whenever immediate recognition of the plants was not possible.

Figure 4 : *The 2010 vegetation survey team in a grassland close to Mbatamila : from left to right : Pierre, Nicolas, Thomas, Daimo and Sila.*

Although at this stage the actual image processing and mapping work is only at its very early stages, this report will also present some **preliminary**[5] results of vegetation mapping using a LANDSAT satellite image that could be found in free satellite data archives through the internet.

It will also, in the "perspectives" chapter, present how the obtained vegetation map can also be used as background information on the vegetation types for an estimation of the forage resources of the Reserve. In this chapter, we shall briefly describe the methodology used to compute Biomass Production Estimates (BPE) from coarse resolution satellite imagery, and how the BPEs can then be "corrected" of the reality of the field. The proposed method makes use of the vegetation map in which field acquired data are integrated in order to take into account the quality and accessibility of the biomass to herbivores, for a realistic estimation of the forage resources.

[5] at this stage, the results of vegetation mapping will only be partial since the satellite imagery found is not ideal and the processing will only be done as a test, for demonstration purposes, with VASTLY insufficient amounts of field data...

1. Vegetation survey

The vegetation of Niassa National Reserve is generally described as being mainly composed of *Miombo woodland*, and more specifically of "*Dry Miombo woodland*[6]" corresponding to average yearly rainfalls below 1000 mm and extending from southern Malawi to Zimbabwe, as described by White (1983). Its densities vary, with woodlands, open woodlands and wooded grasslands characterised by the presence of woody species such as *Brachystegia spp*., *Julbernardia globiflora* or *Diplorrynchus condylocarpon*. Botanical inventories have been carried out, and the herbaceous and woody species composition is quite well known thanks to several surveys, among which two recent and well documented ones by Timberlake *et al.* (2004) and Ribeiro (2005).

As mentioned in the introduction, the objective of the vegetation survey undertaken here is NOT a botanical inventory as such. The final objective of the work is to obtain a simplified vegetation map and an evaluation of the rangeland resources[7], information which will be used at a later stage for spatial analysis on buffalo distribution, and possibly other ecology related matters.

The vegetation survey was therefore carried out according to a specific methodology designed for the purpose, and especially to :

- collect information on the **structure** of the vegetation (proportion of **shrubs** and **trees** in the cover) in order to define structural vegetation classes (woodlands, open woodlands, wooded grasslands, shrublands, etc...) from which the **accessibility** of the leaves to the herbivores will depend;
- make an inventory of the main species present, herbaceous and woody, in order to identify the **main vegetation types** and to characterise each of them from the forage value point of view.

The first objective of the survey is therefore to identify *classes* of vegetation to be used as the base for mapping from satellite imagery. In this regard, Timberlake *et al.* (2004) already gave a decription of the vegetation of the reserve by separating it into 4 main classes related to structure and main species composition :

- deciduous woodlands (miombo);
- riverine woodland and thicket;
- vegetation on inselbergs;
- vegetation on Serra Mecula.

Nevertheless, in this exercise, an attempt is made describing the vegetation in more details in order to provide more refined information for spatial analysis of the buffalo locations. The vegetation survey therefore aims at refining this description of the main vegetation types, especially when it comes to **structure**, and especially in the dominating *Miombo* environment that varies from dense woodlands to open woodlands and even wooded grasslands, depending on the topography, soils, and sometimes human effects in inhabited areas.

[6] as opposed to the « *Wet Miombo* » that occupies Eastern Angola, Northern Zambia, South-Western Tanzania and central Malawi, with mean yearly rainfalls above 1000 mm. The vegetation is richer in floristic terms, and the height of the dominant trees (>15m) reflects deeper and moister soils.

[7] The proposed methodology for the use of this information for forage resources assessment (after biomass production estimation from satellite imagery) is described briefly in **chapter 3**.

In this chapter, we present the vegetation survey with its first results, starting with a detailed description of the proposed "mapping adapted" field sampling methodology. The main field survey campaign is then presented, with a map of the location of the sampling sites. A complementary survey of "quick verification points" to be used at a later stage of the study is also briefly described with a site location map. Finally, a list of the main vegetation classes (deducted from the main survey) to be considered for the mapping exercise is proposed, with a quick description of each class and a typical photographic view.

Before entering the core of the subject, the authors wish to undurline that, at the period at which the survey was carried out, it was **not possible to obtain a precise botanical composition of the herbaceous layer**. As a matter of fact, the time of the year was good but not ideal, and the herbaceous species, whether mono or di-cotylodenous, were at the end of their cycle and therefore not easy to identify. For example, in the dense *Miombo* formations, a high proportion of a *Digitaria* species was found and allocated to *Digitaria eriantha* Steud in this survey, although it could also have belonged to a group comprising *Digitaria milanjiana, D. natalensis, D. polyphylla, D. swazilandensis, D. argyrograpra* et *D. megasthenes*. The dried inflorescences didn't allow to make differences in this case and in a few others, but this can be considered as of relatively low impact since those species are similar in terms of forage value.

1.1. Field measurement methodology

The field measurement protocol used to collect data is designed to characterise vegetation both as *habitat* and as *forage* resource. In other words, the observations are not only aimed at determining a vegetation type according to structure and main woody species, but also at evaluating the quality and the accessibility of the biomass available to the animals to graze or browse.

- ***General principle***

In order to characterise the vegetation, measurements are carried out on both the Herbaceous and Woody layers, but only the data collected on the woody component are actually of use for mapping purposes. As a matter of fact, vegetation types are defined :

- from the structure of the vegetation, mainly the proportion of shrubs and trees in the canopy;
- from the dominant species of trees, shrubs or both in the woody layer.

- ***Sampling methodology***

In order to carry out the measurements, field sampling sites are selected with the objective of creating a set of samples of the entire area to be represented. They must be situated at least 100m from the roads, rivers, or other features that may create a disturbance rendering the site non representative of the area.

The sampling method is based on **linear transects** along which vegetation parameters are estimated over 100 points. In actual practice, a 20 meter long string (becalled the "high tech" when first designed in Zimbabwe in 2006) marked every meter is spread 5 times, always in the same direction (as perpendicular as possible to the road to walk away from it) using a predefined direction followed with a compass, as shown hereafter on the pictures of **figure 5**.

Figure 5 : *During the transect based vegetation surveys in the field*

The entire set of material necessary for this type of survey is show hereafter in **figure 6**.

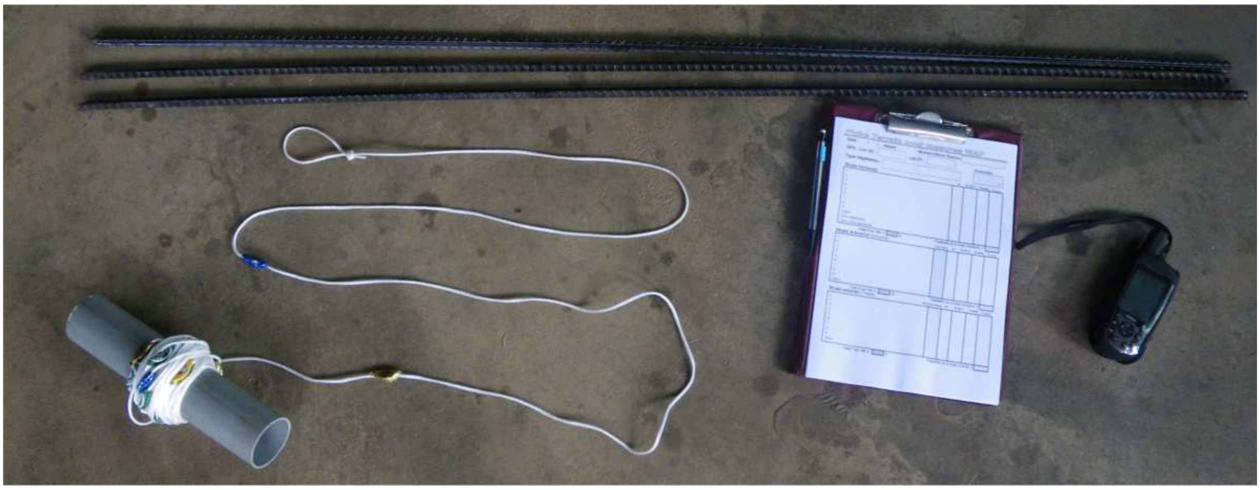

Figure 6 : *The field measurement material: the "High Tech" 20 meter string marked with bottle caps, the measurement poles, the notepad with specifically designed field forms, and the GPS...*

During the measurements, where the string marks fall, visual observations of the following parameters are recorded on the specifically designed field forms :

- presence of tree or shrub cover above or under the string marker;
- species of shrub and/or tree;
- species of grass/forb (although this not used for mapping purposes).

A blank **field form** is shown in **appendix 1**, while an example filled-in form, is provided in **appendix 2** for reference.

100 points per sampling site is considered "light" sampling[8]. It only gives an approximate evaluation of the vegetation parameters. There are two main reasons for the application of this quick and fairly light method :

- the vegetation in savannah environments is sometimes quite dense and applying long transects would involve tedious work and certain difficulties;
- in this "mapping oriented" exercise, the representativity in space is of much greater importance than the accuracy of the measurement; in other words, the priority is to have many sample points that well represent all the different parts of the study area (and it should be many in a large area like Niassa), not to have accurate measurements on only a few points.

[8] Similar work carried out in collaboration with the Ministry of Agriculture, Water and Forestry in Namibia, for example, is based on transects of 500 points.

1.2. Main vegetation survey

The June 2010 field campaign resulted in the recording of 30 sampling points in the Central and Eastern parts of the Reserve. A map of the location of the sampling sites is shown hereafter in **figure 7**.

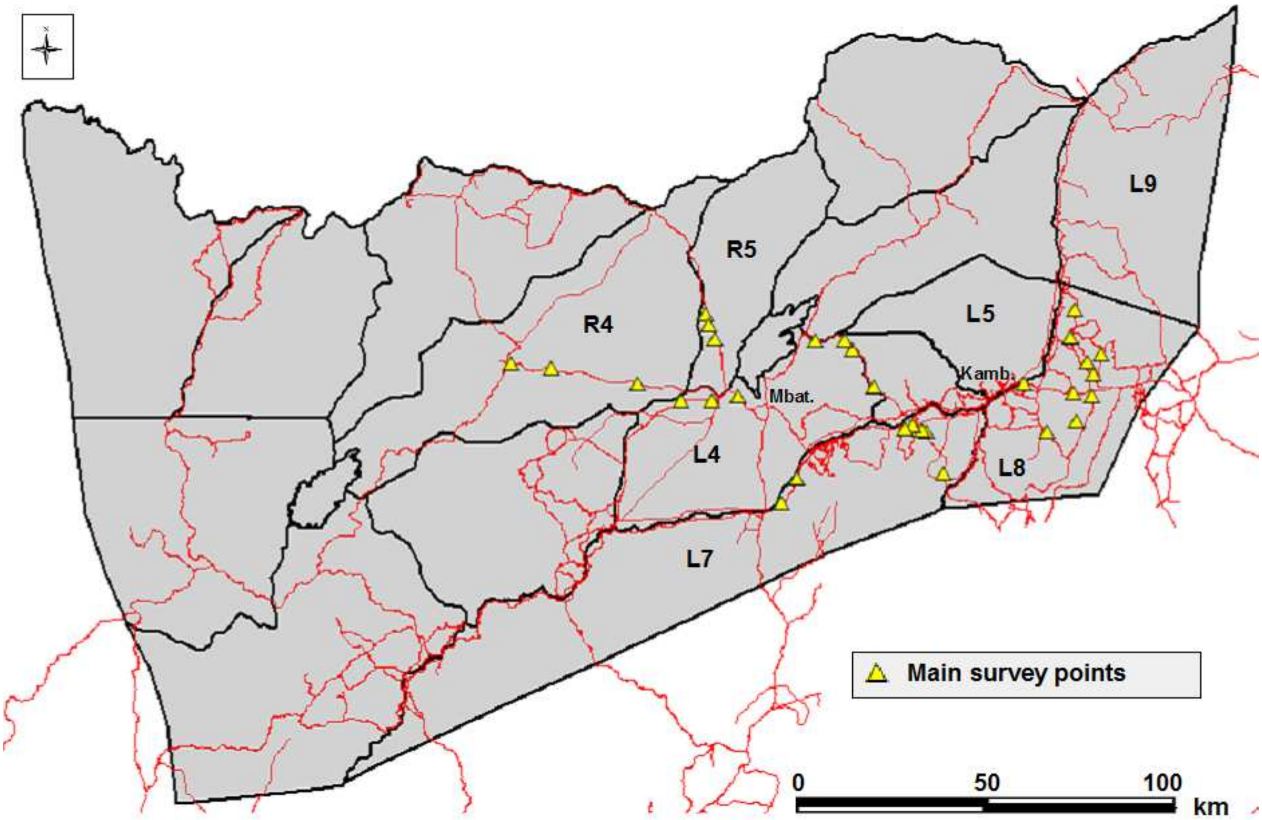

Figure 7 : *Locations of the various* ***"thourough measurement" field sampling sites*** *visited during the June 2010 Niassa vegetation survey.*

On a total of 9 days of surveying, 4 were organised from Mbatamila base and concentrated on blocks L4, L5, R4 and R5 (See appendix 6 for a complete reference map). The planning of the points of survey benefited a lot from the help of the main parks authorities, and especially up to date information on roads accessibility. The remaining 5 days were dedicated to the south and east of the Lugenda River, with two base camps set along the river, and precious help provided at Kambako camp for roads accessibility information. Points were surveyed in block L7 on the way and then in block L8. Although some points were planned in Block L9, it was unfortunately not surveyed because of lack of accessibility by road from L8. A map of the 30 surveyed sites is give.

1.3. Complementary vegetation survey

The main vegetation survey involved a considerable amount of travelling by car which was put to use to record a number of "quick verification points". These consisted of a quick visual estimation of the structure and type of vegetation, recorded with a GPS coordinate for later use. More than 400 points were recorded, which showed how variable in space the vegetation is compared to its representation by the "all regions" and "Desmet" maps. The locations of the "quick points" are shown hereafter on **figure 8**.

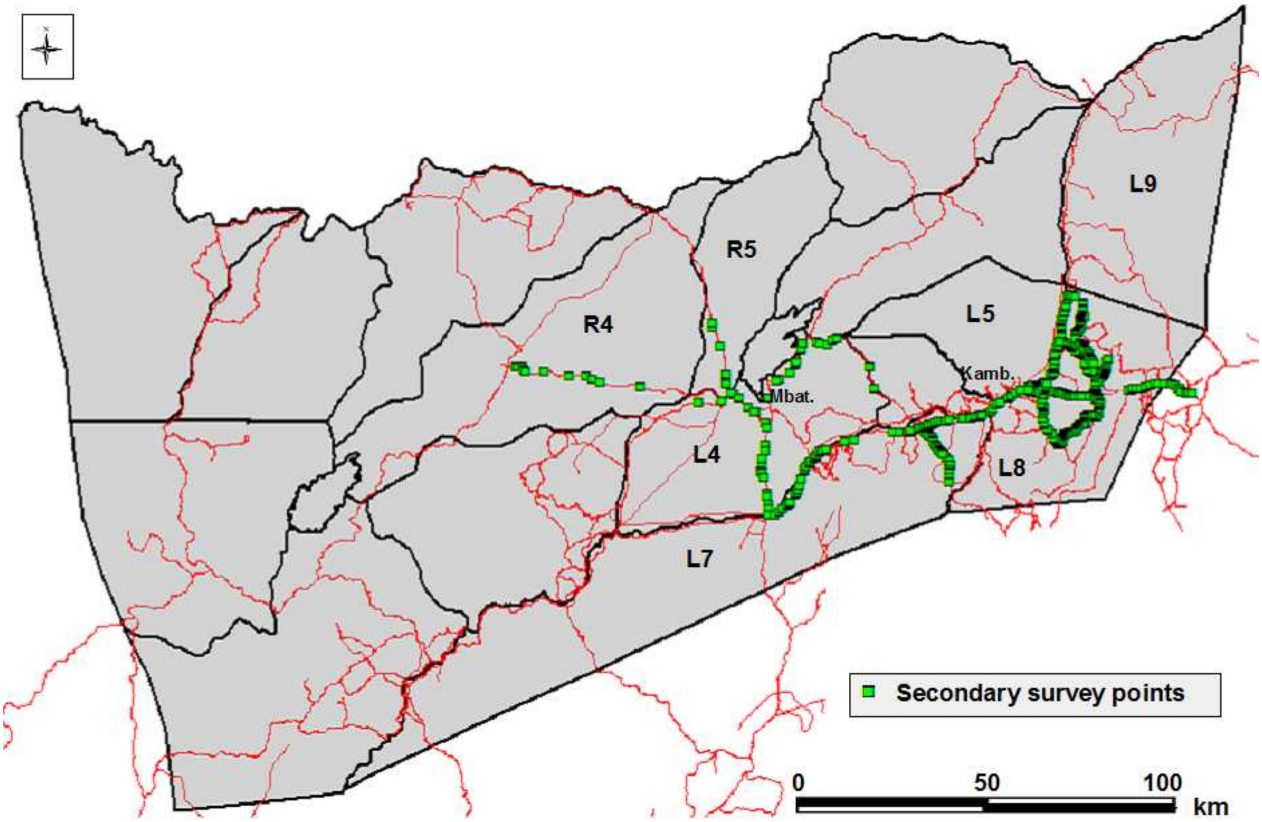

Figure 8 : *Locations of the various* ***"quick verification" (secondary) points*** *visited during the June 2010 Niassa vegetation survey.*

This second vegetation survey is complementary to the main vegetation survey : it provides a large number of points to be used for verification of the results of vegetation mapping, whenever a proper map is available. The vegetation types recorded at the "quick points" will allow to validate the results obtained through satellite image classification, at a later stage.

1.4. Main vegetation classes to be considered for mapping

A preliminary information extraction from the 30 field forms obtained during the main vegetation survey allowed to propose a list of main vegetation types to be considered as "classes" for the processing of satellite images for vegetation mapping (for details on the process, see **chapter 2**). For the mapping exercise, only part of the information contained in the forms is actually extracted : the vegetation type, based on the sole analysis of the woody layer.

As already described in Timberlake et al. (2004) and Ribeiro (2005) the vegetation of the Niassa National Reserve is largely dominated by *Miombo* environments[9], with more or less dense deciduous woodlands showing a limited shrub layer, probably due to the fire maintenance applied in most places. In this type of vegetation, the understory herbaceous layer is mostly dominated by perennial grasses of good forage value. Exceptions are found in the riverine and mountain areas, with very different types of vegetation in terms of structure and botanical composition. As mentioned above in this chapter, Timberlake *et al.* (2004) actually summarised this description by separating the vegetation of the reserve into 4 main classes related to structure and main species

[9] Although in places, similar vegetation but without any of the typical Miombo species have been observed, but this remains occasional.

composition and climatic type : deciduous woodlands (miombo); riverine woodland and thicket; vegetation on inselbergs; vegetation on Serra mecula.

The present survey suggested a slightly more detailed description of the vegetation. The overall analysis of the field forms, by extraction of the information on the woody layer and especially the proportion of shrubs and trees in the canopy, lead to a first list of **9 main vegetation classes** :

Dense Miombo Woodland
Miombo Woodland
Miombo Open woodland
Wooded grassland
Grassland
Dense evergreen Riverine Forest
Dense riverine grassland
Dense evergreen mountain slope forest
Jesse Bush

Each of these vegetation classes is described hereafter in more detail with a typical photographic view given as an example.

- ***Dense Miombo Woodland***

Dense Miombo woolands are characterised by an upper canopy of umbrella-shaped trees, 15 to 20 meters high, dominated by the usual Miombo tree species *Brachystegia spiciformis, B. boehmii* and *Julbernardia globiflora* (Fabaceae, subfamily Caesalpinioidae). Other species, including *Diplorhynchus condylocarpon* and *Pseudolachnostylis maprouneifolia*, are well represented in the subcanopy trees. The woody canopy cover can be as high as 80%. The shrub layer underneath the trees is often limited, discontinuous, leaving a very accessible rangeland with fairly abundant and generally good to medium quality grasses in the herbaceous layer, such as *Digitaria eriantha, Themeda triandra, Andropogon chinensis* or *Diheteropogon amplectens*.

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Figure 9 : *Typical dense Miombo woodland*

- ***Miombo Woodland***

Miombo woodlands are similar to the previously described “dense Miombo woodlands” but with a less developed canopy cover, reaching approximately 60%. The understory shrub layer is limited, and the herbaceous cover is fairly abundant with generally medium to good grass species.

Figure 10 : *Typical Miombo woodland*

- ***Miombo Open Woodland***

Miombo open woodlands are again typical Miombo woodlands but with limited woody covers of approximately 30 to 40% shrubs and trees cover. They are open and highly penetrable with a generally abundant grass cover of medium to good quality.

Figure 11 : *Typical open Miombo woodland*

- ***Wooded grassland***

Wooded grasslands, located on poor and often stony soils, are characterised by a limited tree and shrub cover, with woody proportions of approximately 20% of the canopy.Typical Miombo species are observed in this type of environment, but are not necessarily present and can be replaced by *Acacia* or *Combretum* species, for example. The shrub layer is limited but generally present, offering interesting dry season forage. The grass layer is mainly composed of *Andropogon chinensis, Loudetia flavida, L. simplex, Diheteropogon amplectaens* and some other secondary species including *Stereochlaena cameronii*, *Andropogon pseudapricus* and *Heteropogon contortus.*

Figure 12 : *Typical Wooded grassland*

- ***Grassland***

Grasslands are open environments with almost absent woody cover, typically of 10% or less. They are usually found at the bottom of slopes, in the more humid and probably more fertile places, normally appearing after a gradient of less and less dense Miombo woodlands. They are most of the time composed of good quality perennial grass species such as *Hyparrhenia rufa, H. glabriuscula, H. filipendula, H. nyassae, Loudetia simplex.* Occasionally, on poor rocky soils, they can be dominated by low production and low quality annual grasses.

Figure 13 : *Typical Grassland*

- ***Dense Riverine Forest***

Dense riverine forests are found on the side of permanent or non permanent rivers. They are mostly composed of evergreen trees and shrubs, and the canopy cover is very high, close to 100%. The main species of the overstorey include *Faidherbia albida, Lonchocarpus capassa, Millettia stuhlmannii, Ficus sycomorus, Xanthocercis zambesiaca, Kigelia Africana.* The understorey comprises *Xylopia parviflora, Voacanga thouarsii, Tricalysia lanceolata, Trichilia emetica, Friesoldielsia obovata, Cleistochlamys kirkii, Bridelia micrantha, Bauhinia tomentosa, Antidesma venosum.* On the river banks, in direct contact with water, are found *Ficus capreifolia, Phyllanthus reticulates, Combretum obovatum and Mimosa pigra.*

Figure 14 : *Typical dense riverine forest on the sides of a dry river bed*

- ***Dense riverine grassland***

Dense riverine grasslands are highly productive grasslands found in the vicinity of large rivers such as the Lugenda. They are usually of limited surface but composed of highly productive and highly palatable species such as *Panicum* maximum, *Urochloa mossambicensis, Hyparrhenia rufa, Sorghum arundinaceum, Eriochloa rovumensis* and *Cynodon dactylon.*

Figure 15 : *Typical dense riverine grassland*

- ***Dense evergreen mountain slope forest***

Mountain slopes, especially of the Mecula Mountain, have not been surveyed in detail. Nevertheless, they appear quite different at first sight on satellite images and have therefore been considered as a class of their own for mapping. According to Timberlake et al. (2004), they consist of evergreen forests on the mountain slopes, corresponding to higher rainfall regimes and benefiting from mountain runoff for good moisture.

Figure 16 : *Distant view of fhe evergreen mountain forest of the Mecula mountain*

- ***Jesse bush***

The “Jesse bush” is a type of more or less dense dry forest with an often thick bush layer, usually found in the vicinity of large rivers such as the Lugenda.

Figure 17 : *An example of Jesse bush (Photo : Pierre Poilecot)*

Large trees including *Adansonia digitata, Acacia nigrescens, Berchemia discolor, Hyphaene petersiana, Millettia stuhlmanni, Afzelia quanzensis* dominate an undestorey and a shrub layer composed of *Dalbergia nitidula, Euphorbia cooperi, Cleistochlamys kirkii*, *Combretum mossambicense, Croton pseudopulchellus, Dichrostachys cinerea, Pteleopsis myrtifolia, Schrebera trichoclada.* The grass cover is generally poorly developed.

2. Vegetation Mapping

This chapter presents some preliminary results of vegetation mapping, based on a LANDSAT satellite image of June 2008 and on the integration of the information available from the vegetation survey described above. The satellite image was identified and downloaded from the free archives of the **United States Geological Survey (USGS)**, which the authors wish to acknowledge making such precious information freely available to the scientific world.

After presenting elements on the search for high resolution satellite data suitable for mapping vegetation and covering the entire Niassa National reserve, we shall briefly describe the image processing method (supervised classification) applied to obtain the preliminary map, which will then be presented and commented, mainly on the present limitations and difficulties encountered.

2.1. Satellite data search

For mapping purposes, the satellite data to be used are **high resolution** images, classically with spatial resolutions of 5 to 30 meters. A preliminary data search was therefore carried out on the catalogs of the most commonly accessible high resolution sensors :

- Spot HRVIR
- Aster VNIR
- Landsat TM / ETM+

Since the spatial resolution is inversely related to the area coverage of the images, a compromise has to be found between the precision of the description of the surface, and the amount of surface covered by one image. Each type of image has its advantages and backdraws.

With a resolution of 20 meters (or even 10 meters for the most recent sensors), **SPOT HRVIR** appeared like a suitable source of data but seemed complex to acquire if the entire study area of Niassa was to be covered. The SPOT scenes covering 60 x 60 km, an estimated 15 to 20 of them would be necessary to cover the entire Reserve, rendering it difficult to find scenes acquired at approximately the same date, and making the processing quite complex when related to masaicking the images together.

ASTER VNIR images appeared to be suitable as well with a resolution of 15 meters, but with again a scene coverage of 60 x 60 km which makes it complicated to cover the entire area, as can be seen in the following figure obtained from the United States geological Survey (USGS) Global Visualization Viewer (GLOVIS).

Figure 18 : *Screen copy of the GLOVIS catalog showing ASTER VNIR scenes and the (old) limits of the Niassa National Reserve*

A good compromise can be found with the **LANDSAT** sensors, with a resolution of 30 meters and a scene coverage of 180x180 km. With such a large area coverage, 4 LANDSAT scenes are sufficient to cover the entire Reserve, as shown on **figure 19**, making it relatively easy to find images at close dates and making the mosaicking work fairly easy.

Another great advantage of LANDSAT is, obviously, that images have become entirely free of charge in the recent years.

LANDSDAT was therefore the obvious choice on which the preliminary image search efforts concentrated.

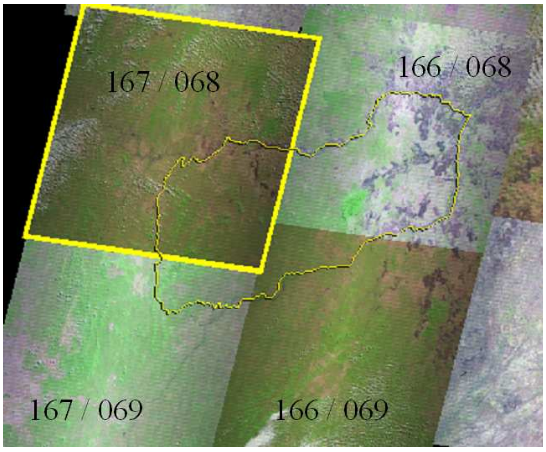

Figure 19 : *Screen copy of the GLOVIS catalog showing LANDSAT scenes and the (old) limits of the Niassa National Reserve*

Images from the latest Landsat sensor, **ETM+,** are available for very recent dates, but are unfortunately of low quality due to a breakdown on the LANDSAT 7 platform which degrades the information in the images[10] as shown on **figure 20** below.

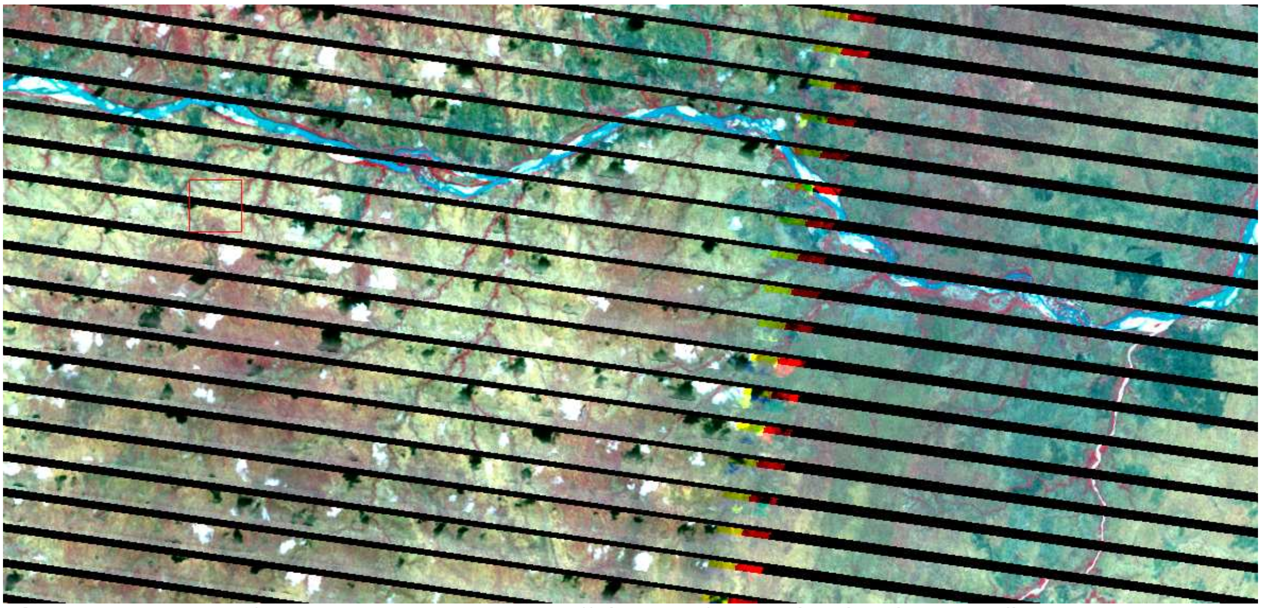

Figure 20 *: Extract of a LANDSAT ETM+ "SLC off" image of 2006 showing the "scan lines".*

Fortunately, recent images are also acquired with the older versions of the LANDSAT Thematic Mapper (TM) sensors which are still fully operational and provide imagery at 30 meters resolution with no "scan lines". After a thorough search of the available data, the choice was made to download 4 scenes of June 2008 acquired with the TM sensor of LANDSAT 5. The acquired images are shown hereafter on **figure 21**, already in the format of a mosaic of the 4 scenes, in UTM projection, zone 37 South (Datum WGS 84, units meters).

[10] The **Scan Line Corrector** (SLC) has broken down since july 2003 on the ETM+ sensor ; images are still available in « **SLC Off** » mode but their quality is degraded by noise lines appearing at the edges of the images.

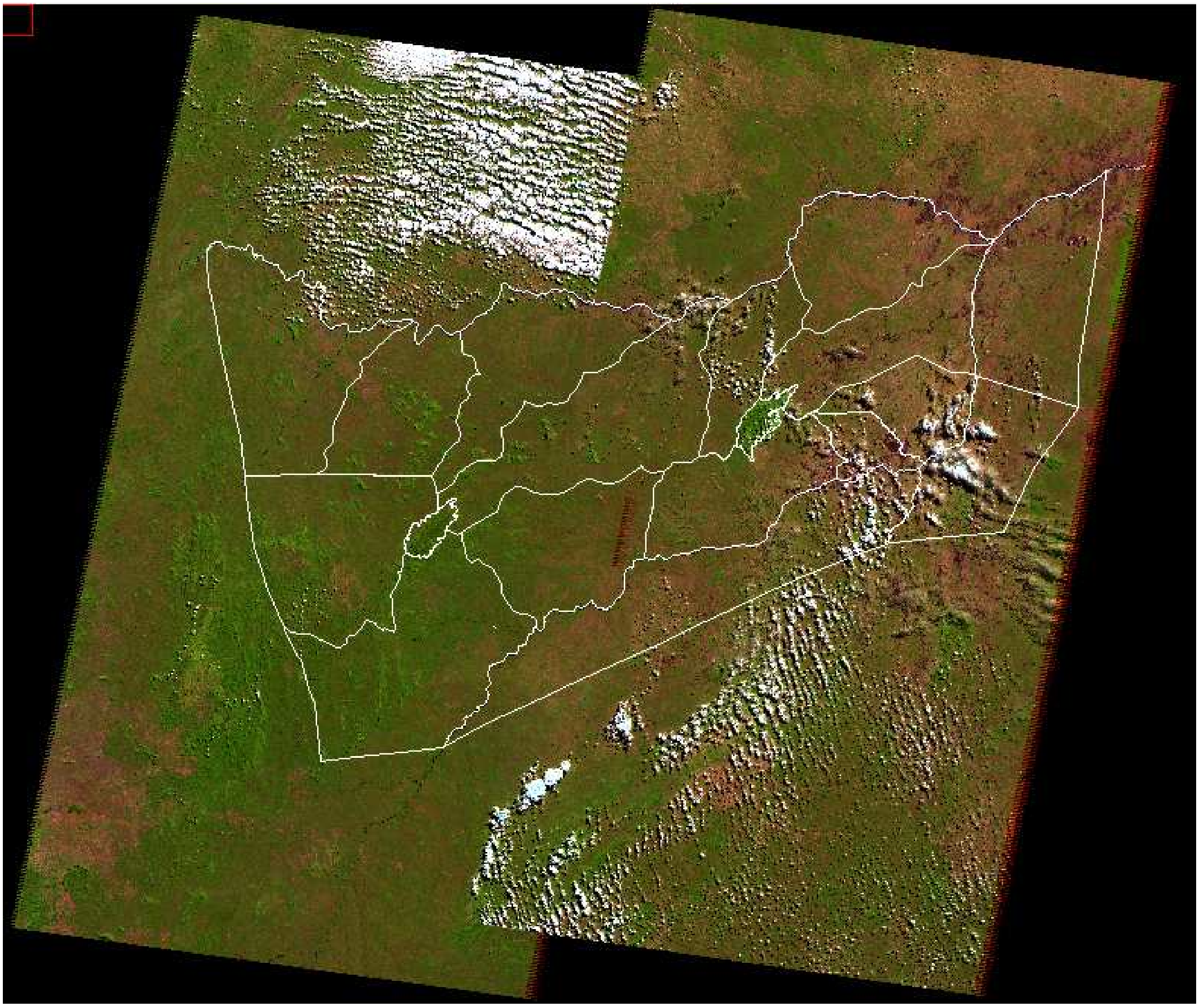

***Figure 21** : Mosaic of 4 LANDSAT scenes of June 2008 in UTM 37S Projection, with limits of Niassa National Reserve and management blocks overlaid.*

As can be seen on **figure 21**, the image of June 2008 is not entirely free of clouds, and some fire scars can be seen in the Eastern parts of the Reserve. Both Clouds and fire scars are a problem for mapping purposes. The clouds create a double inconvenience : wherever they occur they cover the ground entirely, masking the information, and they generate a shadow that drastically modifies the radiometric response of the surface and makes it impossible to apply image processing. Fire scars, on the other hand, create a similar problem since the burnt surfaces appear quite different from the original canopy and therefore cannot be compared.

The image of June 2007 acquired for this exercise is therefore not the ideal image for mapping purposes, but it was the best that could be found at the time. It still can be considered as quite suitable, with a cloud cover that remains limited and relatively few fire scars compared to other images, like for example a TM image of September 2008 that was also found and considered.

2.2. Image processing method: supervised classification

The process chosen to derive a vegetation map from satellite imagery in this exercise is radically different from the process used to obtain the existing vegetation maps presented in the introduction chapter. Those were obtained by photo-interpretation and hand digitisation of limits of vegetation types visible on maps and/or satellite images.

Here, the process is one of **digital image processing** : the ***supervised* classification**, which was applied using the **ENVI** image processing software.

The **classification** process is a statistical process that allocates the pixels of the satellite image(s) used to a certain thematic class, according to their digital values. In the **supervised** process, information on the vegetation is given to the system according to prior knowledge, *i.e.* the field work done. Providing this information to the system is called the “training” step, and it is done by allocating a class to samples of pixels digitised by the user and resulting in polygons that regroup pixels belonging to the same class. The classification process then extrapolates the sample information to the rest of the image, allocating each pixel to a class based on its resemblance to one of the pixels defined in the “training”.

2.3. Preliminary vegetation map of the Central and Eastern NNR

Due to the fact that the field work done during the June 2010 vegetation survey only covered a limited part of the Niassa National Reserve, it was decided, for a preliminary map elaborated only for demonstration purposes, to work on a subset of the satellite image on the central and eastern parts of the Reserve. The extent of the subset is shown here on **figure 22**.

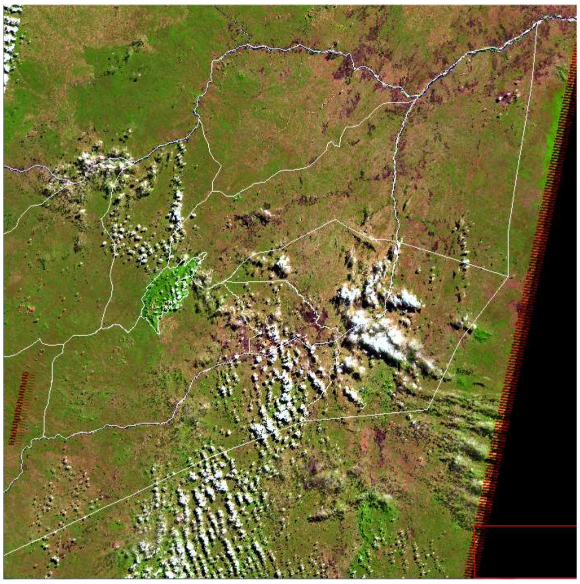

Figure 22 : *the central-eastern image subset*

- ***List of simplified vegetation types for the classification process***

Obviously, a list of vegetation types that well describes the entire Niassa National Reserve would be made of a large number of different classes. Nevertheless, in this attempt at compiling a simplified and resources oriented map with satellite imagery, a simplified nomenclature deducted from the above described vegetation survey is used. For this simplified classification exercise, only **8 classes** of natural vegetation are therefore considered, mainly based on the vegetation structure :

Dense Miombo Woodland
Miombo Woodland
Miombo Open woodland
Wooded grassland
Grassland
Dense Riverine Forest
Dense Mountain slope forest
Jesse Bush

to which 3 types of non vegetated or non-natural vegetation[11] land cover classes can be added :

Cultivated areas
Bare Rock (inselberg)
Sand
Water

Due to the presence of clouds and fire scars which mask the ground or degrade the quality of the radiometric signal in the LANDSAT image, another 3 classes representing "masked out" areas had to be included in the list :

Cloud
Cloud shadow
Burnt area

This results in a total of 15 simplified vegetation and/or land cover and/or "masking" classes to describe Niassa National Reserve (+ 1 class created automatically by the system for the "unclassified" pixels).

- ***Training process : providing field information to the system***

The "training" process is a very important one in the supervised classification process : it consists of delimiting small polygons on the image and to allocate one of the above listed vegetation classes to each of them according to the knowledge acquired in the field. This is a long process that has to be done quite accurately and requires photo-interpretation skills in order to define the sample areas according to their resemblance to the pixels around the point where vegetation was observed in the field.

The "training" process is also the step during which a *colour* is allocated to each of the pre-defined classes, resulting in the colour table that defines the legend. The colours used for the elaboration of this preliminary test map is show opposite on **figure 23**.

***Figure 23 :** the legend and colors of the classification*

- ***Supervised classification test and preliminary results***

As previously mentioned, the vegetation survey was only carried out in a fraction of the Reserve, only covering the central and south-eastern parts. The classification was therefore applied only to the subset of the 4-scene LANDSAT mosaic of June 2008 shown above on figure 22.

[11] In this regard, the "modified" grassland, wooded grasslands or open woodlands that occur close to inhabited areas can create some confusion in the process since they usually result from the rehabilitation of previously cultivated areas. This matter should be investigated more in depth if possible, and the "modified" areas may have to be considered as specific vegetation classes.

The Supervised Classification method applied for the tests was the Maximum Likelihood classification, which was applied :

- to 5 out of 7 bands of the Landsat ETM sensor, excluding the "thermal" bands (Bans 6 and 7) and using all the others, from the visible to the near and medium infra-red;
- with a permissive statistical threshold of 80% (more often thresholds are chosen to be 90 or 95%) to avoid too much "unclassified" to appear in the result in this preliminary test exercise.

The preliminary results are shown hereafter in **figure 24**.

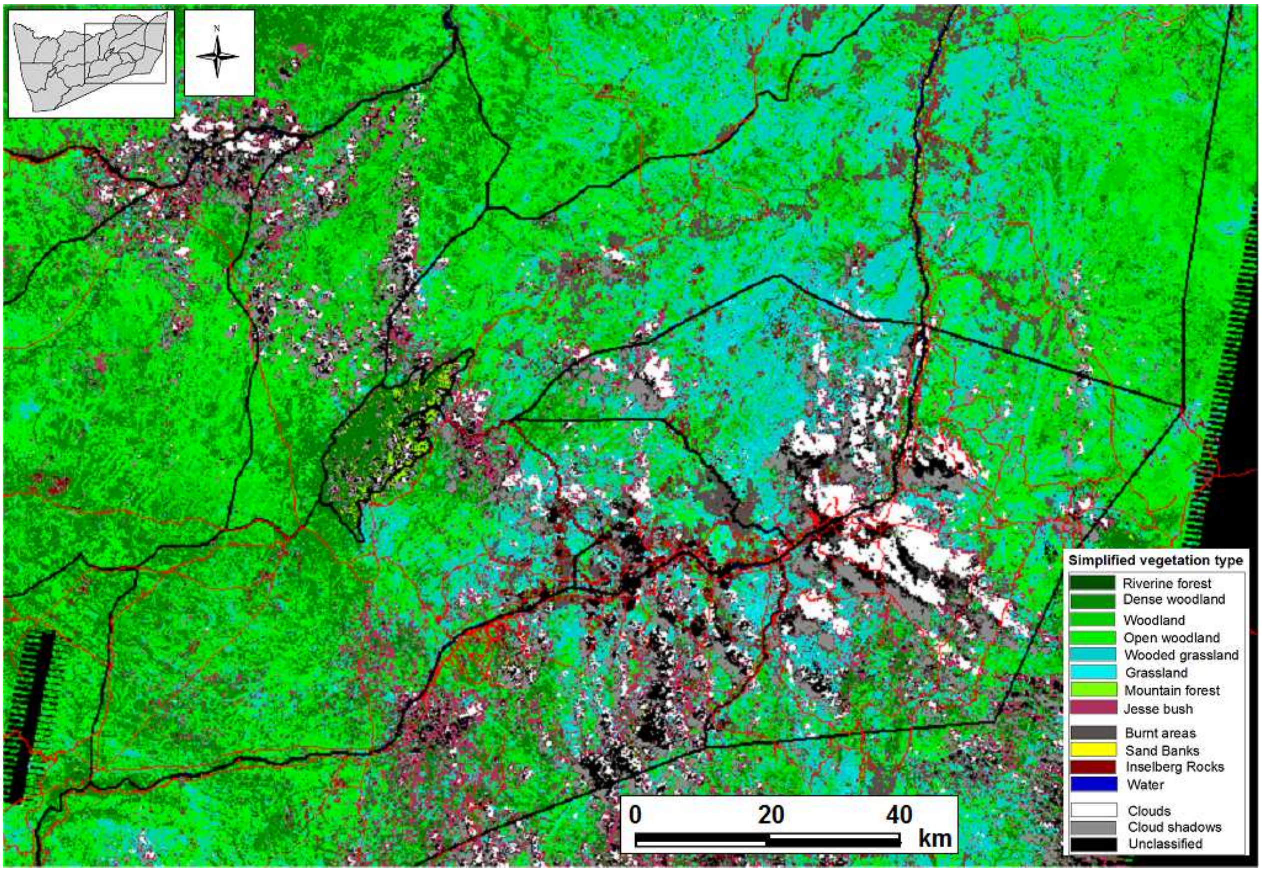

Figure 24 *: Preliminary simplified vegetation map of the Central and Eastern extract of Niassa National Reserve, obtained from supervised classification of Landsat ETM imagery of June 2008. Map projection : Universal Transverse Mercator (UTM) Zone 37 South - Datum : WGS84.*

Although the presence of clouds, cloud shadows and burnt areas degrades the quality of the image on some 20% of the surface of the sub-zone, these preliminary results are quite encouraging. The first observations show that there is a generally good indication of the **structure**, which will be an important aspect of the interpretation of the buffalo positions according to the environment. At a glance, one can say that the main types of vegetation (often Miombo related), the dense woodlands, woodlands, open woodlands, wooded grasslands and grasslands, are fairly well mapped.

The other vegetation types, more specific, like the riverine forests, mountain forests and jesse bush are also well represented in space, with still some confusions, especially between evergreen mountain and riverine forests.

However, considering that this is only a preliminary vegetation map, these first results can be considered as quite satisfactory and an excellent start towards a better, more accurate map, on the entire Niassa Reserve whenever more satellite images and field data are available. One important aspect to consider in this first map draft is that the **precision in space** of the vegetation description is largely improved compared to previous mapped documents. A zoomed extract of the map, shown in **figure 25**, clearly illustrates this aspect by showing very detailed variations in space, with a succession of riverine forests and more or less open woodlands.

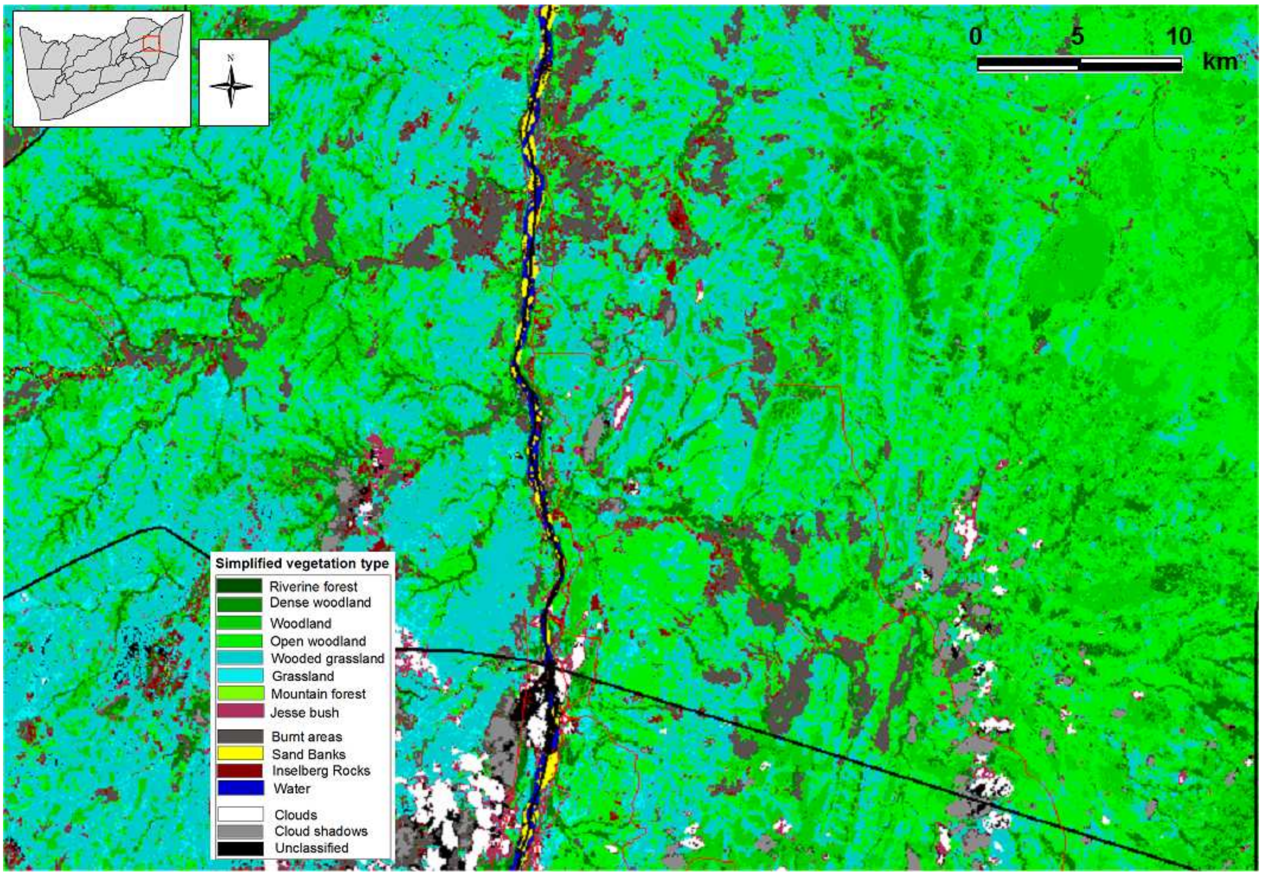

***Figure 25** : Zoom on a subset of the preliminary simplified vegetation map of the Central and Eastern extract of Niassa National Reserve, obtained from supervised classification of Landsat ETM imagery of June 2008. Map projection : Universal Transverse Mercator (UTM) Zone 37 South - Datum : WGS84.*

In order to give more practical means of evaluation of these preliminary results, the map extract presented above is given again in **appendix 7**, together with a color composite of the original satellite image and the 2 vegetation maps already available on the same zone. The visual comparison allows to judge of the improvements in the accuracy of the vegetation mapping in terms of variations in space.

3. Proposed methodology for the quantitative estimation of rangeland resources

For the buffalo project, the analysis of the positions of the buffaloes could benefit from an additional characterisation of the environment : a quantitative evaluation of the forage resources. The interpretation of the herds movements will certainly be done on the vegetation type and structure for habitat preference aspects, but the availabbility of forage can be an interesting complement to it. A quantitative evaluation of forage resources can be obtained on large areas thanks to the availability of suitable satellite data. This chapter aims at presenting an original approach to this, which actually involves the use of the above presented vegetation map, and uses the field data collected during the vegetation survey. It consists of 2 consecutive processes :

- the estimation of the **seasonal biomass production** based on coarse resolution satellite images in the form of vegetation index data;
- the **correction** of the “raw” biomass production, taking into account the specificities of each identified type of vegetation in terms of forage value.

3.1. *Biomass production estimation with satellite imagery*

Low resolution (also called “coarse resolution” or “Wide field”) satellite images provide excellent data for the monitoring of vegetation activity throughout the growing season. Their spatial resolution is low to medium (typically 1 km to 250 m), but they benefit from a **high temporal resolution** (images are available often, more or less daily) that makes them suitable for the monitoring of seasonal vegetation activity changes. **Vegetation index** images, indicators of the “greenness” (and therefore activity) of the vegetation are particularly handy and can be obtained very easily and free of charge over the entire globe. They are often provided in the form of “composited” images, synthetic images made of the best information compiled over a period of time. The following **figure 26** shows an example of 10-day composited vegetation index images covering the whole 1998-1999 growing season on Hwange National Park, Zimbabwe.

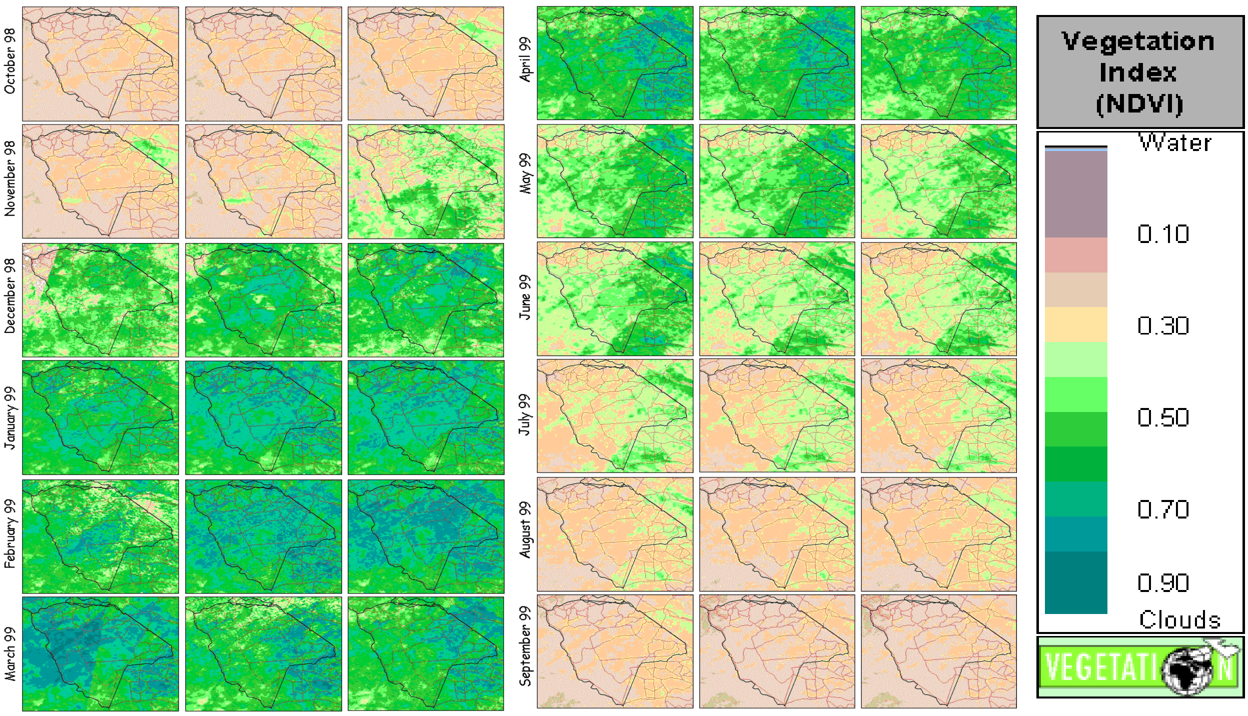

Figure 26 : *10-day composited vegetation index images (SPOT-4 / VEGETATION sensor) for the 1998-1999 growing season on a window covering Hwange National Park, Zimbabwe.*

When compiled over the entire growing season, thus integrating both intensity and duration of the vegetation activity, satellite vegetation index data give an indication of the potential for plant biomass production for the season. They can even be used to compile a quantitative estimate of the biomass production using a vegetation production model (for more details, see for example Ganzin and Mulama, 2002 ; Ganzin et al., 2005) with 10-day composited vegetation index data as input. The result is an image of the estimated biomass production for the corresponding growing season, expressed in kilograms per hectare. Examples of biomass production estimates (BPE) are shown on **figure 27** on Hwange National Park in which inter-seasonal differences due to differences in rainfall can be easily seen. The input data are this time MODIS[12] Enhanced Vegetation Index (EVI) data at finer resolution (250 m).

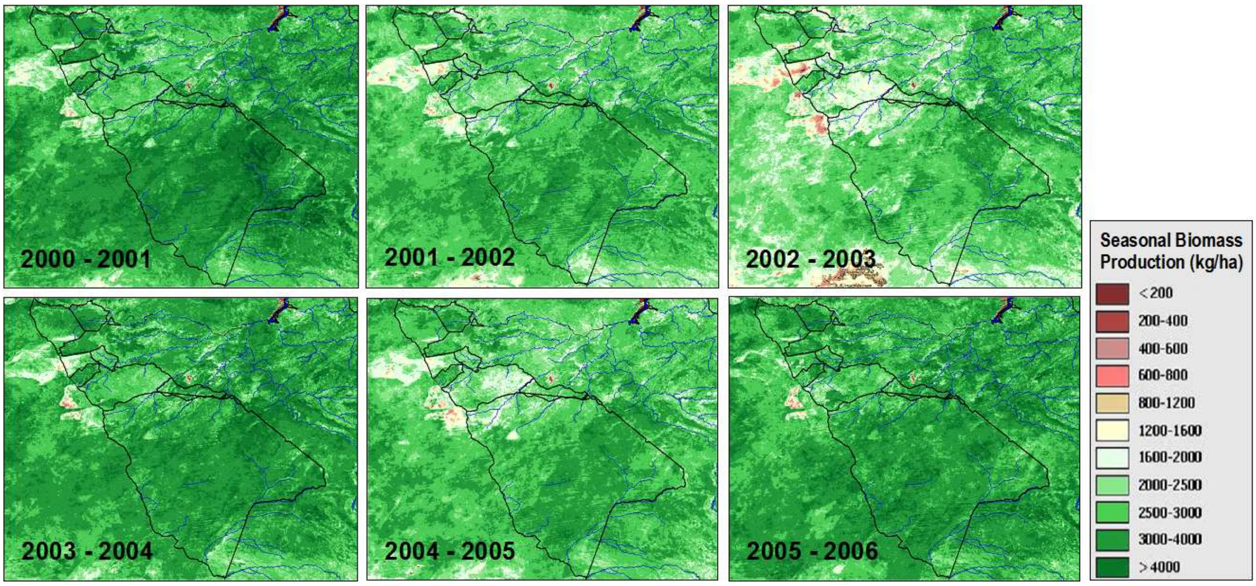

Figure 27 *: Seasonal Biomass Production Estimates on Hwange National Park (Zimbabwe) and surrounding protected areas for 6 recent seasons (Satellite data used: MODIS EVI, resolution 250m)*

Similar work has already been started for Niassa National Reserve for which the entire MODIS 16-day composite EVI data set (2000 – 2009) at 250 meters resolution have been downloaded from the archives in the USA, and pre-processed to be ready for use. Two examples of EVI images, illustrating the vegetation index in dry and wet season, are shown on **figure 28**.

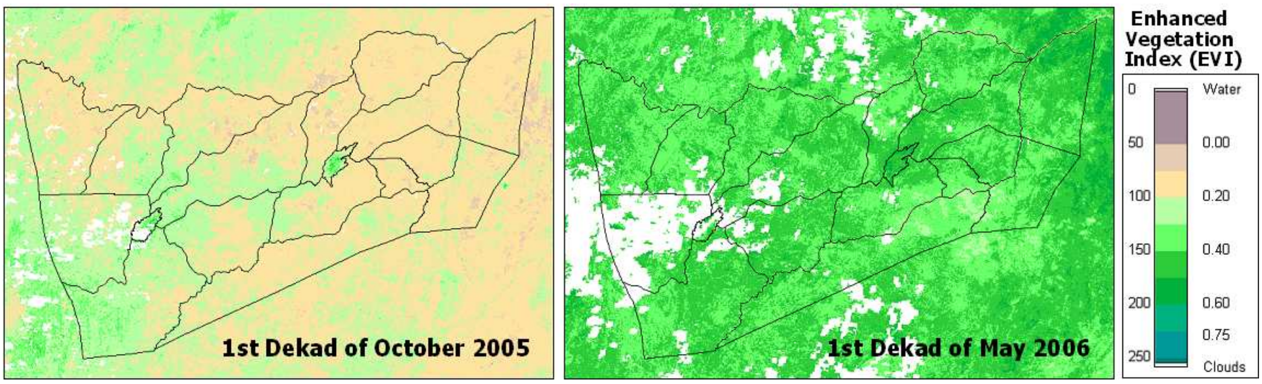

Figure 28 *: Examples of MODIS Enhanced Vegetation Index images of dry season (October 2005) and end of rainy season (May 2006)*

[12] MODIS : MODerate Resolution Imaging Spectro-radiometer (NASA, USA)

In principle, the data necessary to start computing Biomass Production Estimates (this being one of the short-term perspectives of the project) are therefore available, with great details thanks to the 250 meters resolution, and on 10 years between 2000 and 2009.

3.2. The WAP correction : accounting for differences in vegetation

The biomass production estimates are, nevertheless, still **rough estimates** of the actual forage production, especially in complex savannah environments like the ones prevalent in Hwange or in Niassa. In such ecosystems, the availability of forage to the herbivores is not only related to the biomass production : it also highly depends on the type of vegetation, namely its **structure** (proportion of herbaceous and woody plants, trees and shrubs), and the **forage quality** of the plants present. The local variability in vegetation types must therefore be taken into account to readjust the biomass production into a realistic assessment of the forage resources.

In order to account for the specificities of each type of vegetation, an original readjustment method was proposed, originally in Kenya (Ganzin and Mulama, 2002; for more details see also Ganzin, 2004). The proposed process was called the "WAP correction method" since it consists of a 3-step post-process based on 3 correction parameters :

- the **woody cover** (**W**), which determines the productivity of the vegetation (woody species are known to be less productive that herbaceous species);

- the **accessibility** (**A**), which is related to tree height and bush thickness, and which determines what part of the biomass is available to the herbivores;

- the **palatability** (**P**), summarising the forage attractiveness and nutritious quality, and which also directly determines the level of the resources.

To take these local variations in vegetation quality and structure into account, it is indispensable to have ancillary information in the format of a **mapped document** giving the extent of each vegetation type and the value of the W, A and P parameters for each. Then, in the "raw" biomass production image, the data can be corrected pixel by pixel according to the underlying information on the vegetation.

This is where the vegetation survey and the newly generated vegetation map for Niassa will, at a later stage, be of great use. The vegetation survey is designed to evaluate the values of W, A and P, which can then be averaged for each identified type of vegetation and then be integrated in the map in its GIS format and used for the process.

The "WAP" correction process actually is a GIS related process based on correction "masks", images of woody cover, accessibility and palatability at the same resolution as the biomass production images, and derived from the map itself. The 3 masks are used as background information in the 3 correction steps, as summarised hereafter in **figure 29**, on the study area of Nakuru national Park (Kenya), the small protected area on which it was originally designed (Ganzin and Mulama, 2002).

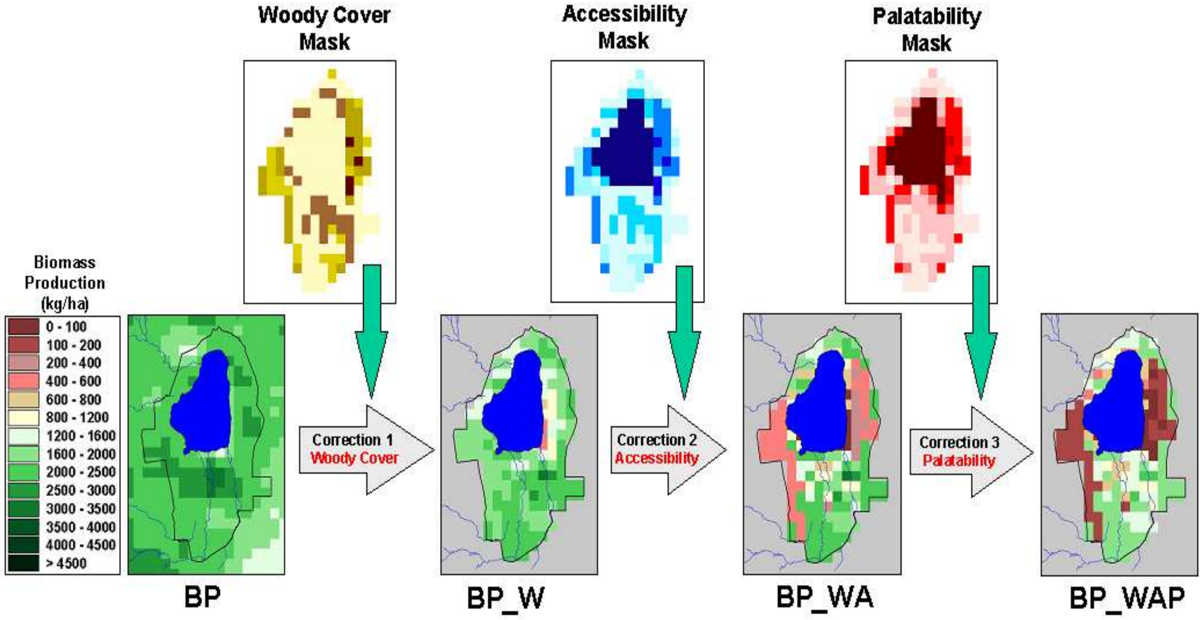

***Figure 29** : Summary of the WAP correction process, applied on Nakuru National Park (Kenya)*
***BP** : Image of "raw" biomass production derived from coarse resolution satellite imagery*
***BP_W** : Biomass Production corrected of the Woody Cover factor*
***BP_WA** : Biomass Production corrected of the Woody Cover and Accessibility factors*
***BP_WAP** : Biomass Production corrected of the Woody Cover, Accessibility and Palatability factors*

For Niassa National Reserve, one can consider that most of the elements are in place to allaow to compute a forage resource assessment for the entire zone. Once a validated vegetation map is availble, once the biomass production estimaes have been computed, and once the field information has been integrated in the map in order to generate the correction masks, a quantitative estimate of the forage available should be obtained.

4. Conclusion and Perspectives

The vegetation survey described in this document must only be considered as a start. Although some significant results have been obtained in terms of description of the vegetation types and the forage value that can be given to each of them, the amount of collected data is still very limited for an area as large a Niassa National Reserve, and considerable additional data collection and processing still must be done.

In terms of mapping, the results presented are, as it was insisted upon, only preliminary. They nevertheless demonstrate how much more accurate in space a map can be when using techniques of image processing such as the digital image classification. Compared to previously used techniques involving photo-interpretation and hand digitisation, the new vegetation map shows much more detail in terms of space variability of vegetation in space. This will, once the map improved and finalised, offer a much more suitable source of information for the analysis of the positions of buffaloes in the Reserve.

The map obviously needs to be improved before being actually used for the analysis. But a first exercise of validation of the preliminary map could nevertheless be envisaged using the “quick verification points” acquired during the survey. These data could be included in a statistical analysis to try and compare the vegetation types recorded in the “quick points” with the vegetation type shown on the map at the corresponding coordinates. This can be done by automatic extraction of pixel values at the GPS locations of the field points, and this statistical analysis can be considered as one of the tasks to be included in the short term perspectives for the project.

The quality and accuracy of the map could obviously be improved by finding better quality satellite data as a start. The clouds and fire scars remain a significant problem that jeopardises the availability of suitable satellite imagery. The early fires set by the area managers in end of may or beginning of June certainly do not help in finding good quality imagery, knowing that June is a good period in which the cloud cover decreases but the fire scars appear. Another important source of improvement of the discrimination of various vegetation types would also be the use of a second date for the same satellite scenes[13].

When it comes to quantitative rangeland resources estimation, which is another important parameter for this analysis and interpretation of buffalo positions, most of the work still has to be done. Some of it has already been started, 10 years of MODIS coarse resolution vegetation index data being already downloaded, extracted, pre-processed and ready for use for seasonal biomass production estimation. But before the WAP correction process can be applied, a lot remains to do. First of all, the “palatability” information must be extracted from the field form, which involves a substantial amount of work to define the palatability of the species found during the survey and a substantial amount of data entering into spread-sheet files designed for the calculation of overall palatability for each type of vegetation.

[13] The vegetation map recently compiled for Hwange National Park and surroundings with a similar approach is actually based on an image of end of dry season AND an image of the end of the wet season. The results of the classification attempts with one date only and with both dates showed significant improvements in the discrimination of vegetation classes in the second case.

To conclude, one could say that the vegetation survey carried out in June 2010 was a good and useful exploratory attempt at describing vegetation for mapping and forage resources mapping, but that more data and processing are needed to obtain usable results for the “buffalo project”. More vegetation points should be surveyed in order to better cover the area already visited, and to start covering the rest of the reserve, especially the northern and western parts. Thomas Prin and his colleagues, based in the reserve and trained to the surveying techniques, will certainly acquire data on more accessible points in the central and eastern parts where buffalo herds are also monitored. This will will provide useful complementary data, but will only be possible for a short time, while herbaceous species still have an inflorescence and woody plant leaves allow to determine species.

In the medium term perspectives, an additional vegetation survey should therefore be planned, at the same time of the year or maybe slightly earlier (end of may), while the vegetation still is in its optimal state for species identification. One should nevertheless consider the accessibility problems, the roads only starting to be reopened after the rains, at this specific period of the year. But a complementary set of measured points would certainly bring lots of matter for improvement, knowing that in a second field survey, we would benefit from a substantial advantage : an existing preliminary map for planning purposes and selection of sites for survey and verifications.

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http://www.mobot.org/MOBOT/Madagasc/vegmad6.html

http://www.fao.org/docrep/v5360f/v5360f0j.htm

Appendix 1 : blank vegetation survey field form

WAP parameters field Measurement form

Date : / / **Time :** : **Plot Name/Number :**

GPS : Lon (X) : **Lat (Y) :**

Vegetation type :

Overall **Penetrability** %

Herbaceous layer :

	Count	% of H	Palatability	$P_{weighed}$
1				
2				
3				
4				
5				
6				
7				
8				
9				
Other				
Pal. Forbes				
Unpal. Forbes				

Total H counts from 100 → **H** Overall Herbaceous layer Palatability →

Shrub layer :

	Under Tree	Count	% of S	Palatability	$P_{weighed}$
1					
2					
3					
4					
5					
6					
7					
8					
9					
Other					

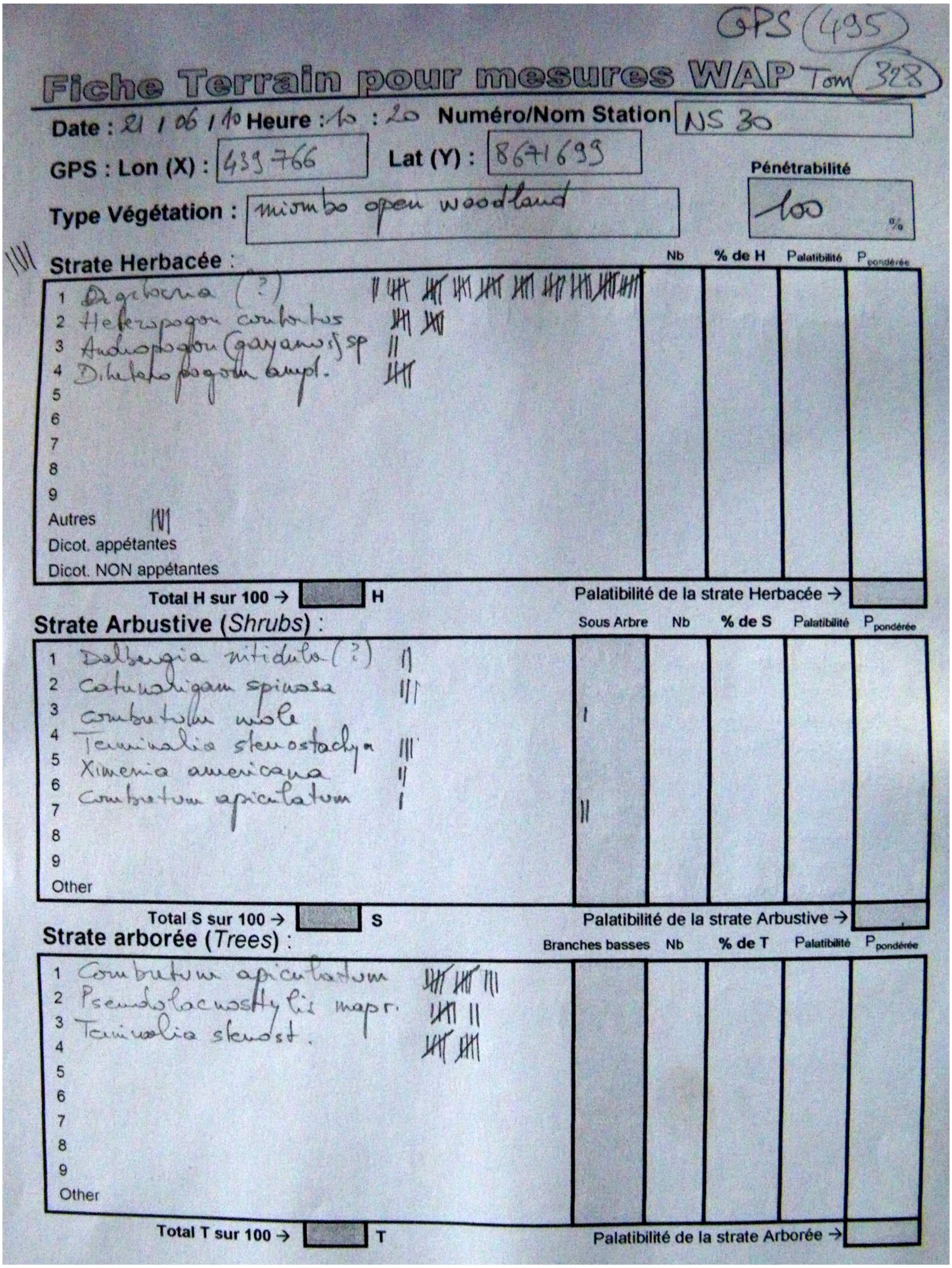
Total S counts from 100 → **S** Overall Shrub Layer Palatability →

Tree layer :

	Low Branches	Count	% of T	Palatability	$P_{weighed}$
1					
2					
3					
4					
5					
6					
7					
8					
9					
Other					

Total T counts from 100 → **T** Overall Tree Layer Palatability →

Appendix 2 : example of filled vegetation survey field form



GPS (495)

Fiche Terrain pour mesures WAP Tom (328)

Date : 21 / 06 / 10 **Heure :** 10 : 20 **Numéro/Nom Station** NS 30

GPS : Lon (X) : 439 766 **Lat (Y) :** 8671699

Pénétrabilité 100 %

Type Végétation : miombo open woodland

Strate Herbacée :

		Nb	% de H	Palatibilité	Ppondérée
1	Digitaria (?)				
2	Heteropogon contortus				
3	Andropogon (gayanus) sp				
4	Dichelopogon ampl.				
5					
6					
7					
8					
9					
Autres					
Dicot. appétantes					
Dicot. NON appétantes					

Total H sur 100 → H **Palatibilité de la strate Herbacée →**

Strate Arbustive (*Shrubs*) :

		Sous Arbre	Nb	% de S	Palatibilité	Ppondérée
1	Dalbergia nitidula (?)					
2	Catunaregam spinosa					
3	Combretum molle	I				
4	Terminalia stenostachya					
5	Ximenia americana					
6	Combretum apiculatum					
7		II				
8						
9						
Other						

Total S sur 100 → S **Palatibilité de la strate Arbustive →**

Strate arborée (*Trees*) :

		Branches basses	Nb	% de T	Palatibilité	Ppondérée
1	Combretum apiculatum					
2	Pseudolachnostylis mapr.					
3	Terminalia stenost.					
4						
5						
6						
7						
8						
9						
Other						

Total T sur 100 → T **Palatibilité de la strate Arborée →**

Appendix 3 : Botanical inventory of species found in the *Miombo* woodland environments

The following inventory is the result of the surveys in the savanna types referred to as "Miombo", with vegetation structures ranging from grasslands to dense woodlands.

It gives separately the Woody and Herbaceaous species inventory.

Where determination left a doubt or is currently being verufied, the species name was written in red and is sometimes partial.

Woody Species	Authors	Family
Acacia erubescens	Welw. ex Oliv.	Mimosaceae
Acacia gerrardii	Benth.	Mimosaceae
Acacia goetzei	Harms	Mimosaceae
Acacia nigrescens	Oliv.	Mimosaceae
Adansonia digitata	L.	Bombacaceae
Baphia massaiensis	Taub.	Fabaceae
Bauhinia petersiana	Bolle	Caesalpiniaceae
Bolusanthus speciosus	(Bolus) Harms	Fabaceae
Brachystegia allenii	Burtt Davy & Hutch.	Caesalpiniaceae
Brachystegia boehmii	Taub.	Caesalpiniaceae
Brachystegia spiciformis	Benth.	Caesalpiniaceae
Bridelia scleroneura	Müll. Arg.	Euphorbiaceae
Burkea africana	Hook.	Caesalpiniaceae
Cassia abbreviata	Oliv.	Caesalpiniaceae
Catunaregam spinosa	(Thunb.) Tirveng.	Rubiaceae
Combretum adenogonium	Steud. ex A. Rich.	Combretaceae
Combretum apiculatum	Sond.	Combretaceae
Combretum collinum	Fresen.	Combretaceae
Combretum hereroense	Schinz	Combretaceae
Combretum imberbe	Wawra	Combretaceae
Combretum molle	R. Br. ex G. Don	Combretaceae
Combretum mossambicense	(Klotzsch) Engl.	Combretaceae
Combretum zeyheri	Sond.	Combretaceae
Commiphora mossambicensis	Mendes	Burseraceae
Commiphora cf. pyracanthoides	Engl.	Burseraceae
Crossopteryx febrifuga	(G. Don) Benth.	Rubiaceae
Dalbergia melanoxylon	Guill. & Perr.	Fabaceae
Dalbergia nitidula	Bak.	Fabaceae
Dalbergiella nyassae	Bak. f.	Fabaceae
Dichrostachys cinerea	(L.) Wight & Arn.	Mimosaceae
Diospyros cf. anitae	White	Ebenaceae
Diospyros kirkii	Hiern	Ebenaceae
Diplorhynchus condylocarpon	(Muell. Arg.) Pichon	Apocynaceae
Eugenia capensis	(Eckl. & Zeyh.) Sond.	Myrtaceae
Euphorbia cooperi	N. E. Br.	Euphorbiaceae
Flacourtia indica	(Burm. f.) Merr.	Flacourtiaceae
Flueggea virosa	(Roxb. ex Willd.) Voigt	Euphorbiaceae
Gardenia ternifolia	Schum. & Thonn.	Rubiaceae
Gardenia volkensii	K. Schum.	Rubiaceae
Grewia villosa	Willd.	Tiliaceae

Reissantia indica	(Willd.) N. Hallé	Hippocrateaceae
Holarrhena pubescens	(Buch.-Ham.) Wall. ex G. Don	Apocynaceae
Hugonia orientalis	Engl.	Linaceae
Hymenocardia acida	Tul.	Hymenocardiaceae
Hyphaene petersiana	Mart.	Palmae
Julbernardia globifera	(Benth.) Troupin	Caesalpiniaceae
Lannea discolor	(Sond.) Engl.	Anacardiaceae
Lonchocarpus bussei	Harms	Fabaceae
Maytenus senegalensis	(Lam.) Exell	Celastraceae
Monotes glaber	Sprague	Dipterocarpceae
Mundulea sericea	(Willd.) A. Chev.	Fabaceae
Ochna schweinfurthiana	F. Hoffm.	Ochanceae
Ormocarpum kirkii	S. Moore	Fabaceae
Ozoroa insignis	Del.	Anacardiaceae
Pericopsis angolensis	(Bak.) van Meeuwen	Fabaceae
Pseudolachnostylis maprouneifolia	Pax	Euphorbiaceae
Psychotria cf. kirkii	Hiern	Rubiaceae
Pteleopsis myrtifolia	(Laws) Engl. & Diels	Combretaceae
Pterocarpus angolensis	DC.	Fabaceae
Salvadora persica	L.	Salvadoraceae
Sclerocarya birrea (A.) Rich.) Hochst. subsp. caffra	(Sond.) Kokwaro	Anacardiaceae
Senna petersiana	(Bolle) Lock	Caesalpiniaceae
Sterculia africana	(Lour.) Fiori	Sterculiaceae
Sterculia quinqueloba	(Garcke) K. Schum.	Sterculiaceae
Strychnos spinosa	Lam.	Loganiaceae
Suregada zanzibariensis	Baill.	Euphorbiaceae
Syzygium guineense	(Willd.) DC.	Myrtaceae
Terminalia sericea	Burch. ex DC.	Combretaceae
Terminalia stenosatchya	Engl. & Diels	Combretaceae
Thespesia garckeana	F. Hoffm.	Malvaceae
Uapaca kirkiana	Müll. Arg.	Euphorbiaceae
Vangueria infausta	Burchell	Rubiaceae
Vitex madiensis	Oliv.	Verbenaceae
Xerophyta cf. scabrida	(Pax) Th. Dur. & Schinz	Velloziaceae
Ximenia americana	L.	Olacaceae
Zanha africana	(Radkl.) Exell	Sapindaceae
Ziziphus mucronata	Willd.	Rhamnaceae

Herbaceous Species	**Authors**	**Family**
		Poaceae
Andropogon canaliculatus	Schumach.	Poaceae
Andropogon chinensis	(Nees) Merr.	Poaceae
Andropogon gayanus Kunth. var. polycladus	(Hack.) Clayton	Poaceae
Andropogon perligulatus	Stapf	Poaceae
Andropogon pseudapricus	Stapf	Poaceae
Aristida adscensionis	L.	Poaceae
Aristida barbicollis	Trin. & Rupr.	Poaceae
Aristida congesta	Roem. & Schult.	Poaceae
Bewsia biflora	(Hack.) Goossens	Poaceae
Chloris sp.		Poaceae
Cymbopogon sp.		Poaceae
Digitaria eriantha	Steud.	Poaceae
Diheteropogon amplectens	(Nees) Clayton	Poaceae
Echinochloa colona	(L.) Link	Poaceae
Eragrostis chapelieri	(Kunth) Nees	Poaceae
Eragrostis homblei	De Wild.	Poaceae

Eragrostis lappula	Nees	Poaceae
Eragrostis sp.		Poaceae
Eriochloa rovumensis	(Pilg.) Clayton	Poaceae
Heteropogon contortus	(L.) Roem. & Schult.	Poaceae
Hyparrhenia cf. barteri	(Hack.) Stapf	Poaceae
Hyparrhenia filipendula	(Hochst.) Stapf	Poaceae
Hyparrhenia glabriuscula	(Hochst. ex A. Rich.) Anderss ex Stapf	Poaceae
Hyparrhenia newtonii	(Hack.) Stapf	Poaceae
Hyparrhenia rufa	(Nees) Stapf	Poaceae
Loudetia flavida	(Stapf) Hubb.	Poaceae
Loudetia simplex	(Nees) Hubb.	Poaceae
Panicum phragmitoides	Stapf	Poaceae
Panicum sp.		Poaceae
Pogonarthria squarrosa	(Licht. ex Roem. & Schult.) Pilg.	Poaceae
Schizachyrium brevifolium	(Sw.) Büse	Poaceae
Schizachyrium exile	(Hochst.) Pilger	Poaceae
Stereochlaena cameronii	(Stapf) Pilger	Poaceae
Themeda triandra	Forssk.	Poaceae
Tristachya nodiglumis	K. Schum.	Poaceae
Tristachya thollonii	Franch.	Poaceae
Zonotriche inamoena	(K. Schum.) Clayton	Poaceae
		Cyperaceae
Cyperus sp.		Cyperaceae
Rhynchospora triflora	Vahl	Cyperaceae
Scleria bulbifera	Hochst. ex A. Rich.	Cyperaceae
Scleria globonux	C. B. Cl.	Cyperaceae
Scleria sp.		Cyperaceae

Appendix 4 : Botanical inventory of the species found in the *Riverine* environments

Riverine environments correspond to mostly evergreen dense forests with alternating productive grasslands that are generally found close to river beds.
Woody species and herbaceous species are presented separately. They result from quick and non-comprehensive surveys that deserve to be redone with more precision in the future since these environments can be intensively utilised by buffalo and elephant.

Riverine Forest species(Woody)	**Authors**	**Family**
Antidesma venosum	E. Mey ex Tul.	Euphorbiaceae
Balanites maughamii	Sprague	Balanitaceae
Bauhinia tomentosa	L.	Caesalpiniaceae
Bridelia micrantha	(Hochst.) Baill.	Euphorbiaceae
Cleistochlamys kirkii	(Benth.) Oliv.	Annonaceae
Combretum adenogonium	Steud. ex A. Rich.	Combretaceae
Combretum mossambicensis	(Klotzsch) Engl.	Combretaceae
Combretum obovatum ®	F. Hoffm.	Combretaceae
Combretum zeyheri	Sond.	Combretaceae
Dalbergia melanoxylon	Guill. & Perr.	Fabaceae
Diospyros mespiliformis	Hochst. ex A. DC.	Ebenaceae
Faidherbia albida	(Del.) A. Chev.	Mimosaceae
Ficus capreifolia ®	Del.	Moraceae
Ficus spp.		Moraceae
Ficus sycomorus	L.	Moraceae
Flueggea virosa	(Roxb. ex Willd.) Voigt	Euphorbiaceae
Friesoldielsia obovata	(Benth.) Verdc.	Annonaceae
Kigelia africana	(Lam.) Benth.	Bignoniaceae
Lonchocarpus capassa	Rolfe	Fabaceae
Markhamia zanzibaricca	(Bojer ex DC.) K. Schum.	Bignoniaceae
Milletia stuhlmannii	Taub.	Fabaceae
Mimosa pigra ®	L.	Mimosaceae
Oncoba spinosa	Forssk.	Flacourtiaceae
Phyllanthus reticulatus ®	Poir.	Euphorbiaceae
Thespesia garckeana	F. Hoffm.	Malvaceae
Tricalysia lanceolata	(Sond.) Burtt Davy	Rubioaceae
Trichilia emetica	Vahl	Meliaceae
Voacanga thouarsii	Roem. & Schult.	Apocynaceae
Xanthocercis zambesiaca	(Bak.) Dumaz-le-Grand	Fabaceae
Xylopia aethiopica	(Dun.) A. Rich.	Annonaceae
Xylopia parviflora	(A. Rich.) Benth.	Annonaceae

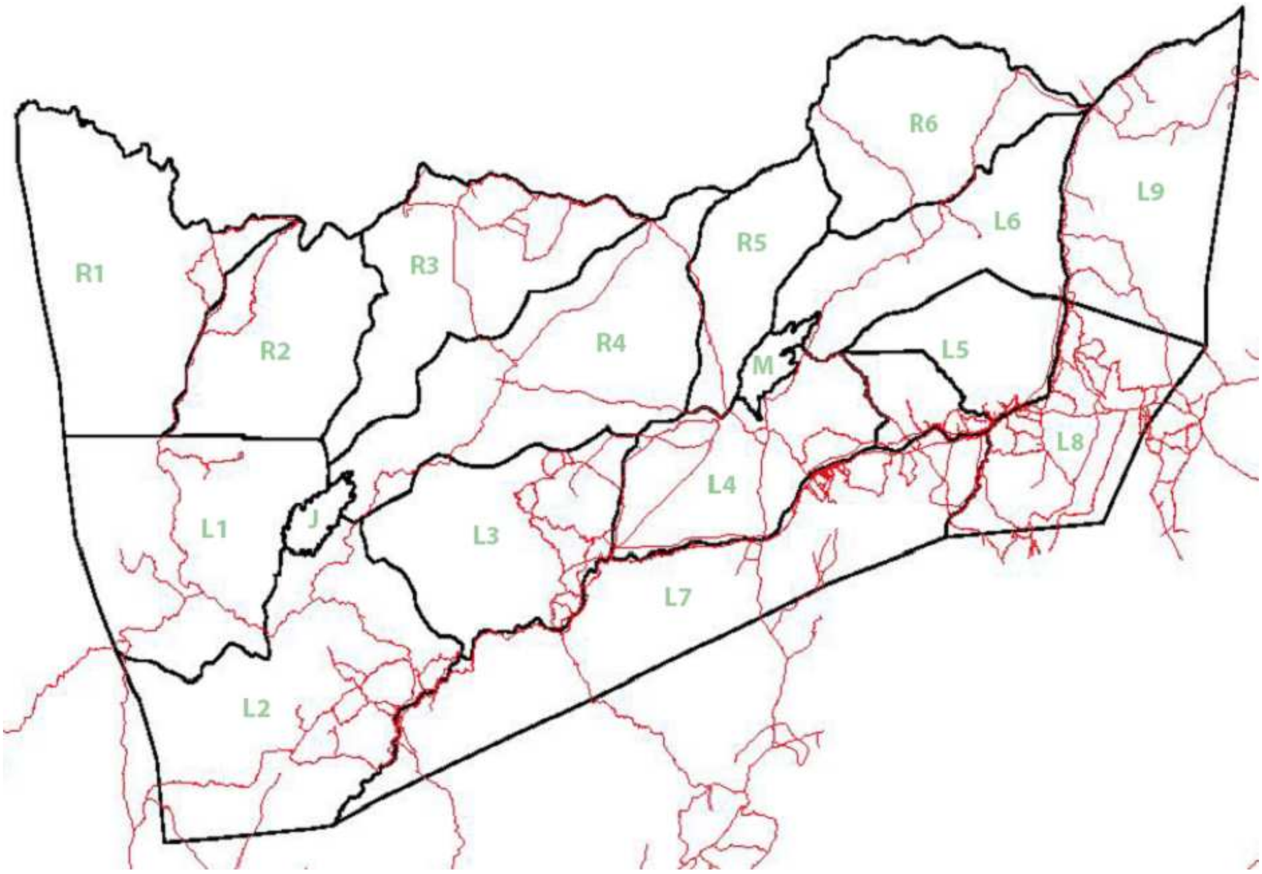
Riverine Herbaceous species	**Authors**	**Family**
Cynodon dactylon	(L.) Pers.	Poaceae
Eriochloa rovumemsis	(Pilg.) Clayton	Poaceae
Hyparrhenia rufa	(Nees) Stapf	Poaceae
Panicum maximum	Jacq.	Poaceae
Urochloa mossambicensis	(Hack.) Dandy	Poaceae

Appendix 5 : Botanical inventory of the species found in the "*Jesse Bush*" environments

The "Jesse Bush" environments correspond to a dry forest environment often characterised with dense bush and the presence of species such Euphorbias and baobabs. They are usually present close to river beds.

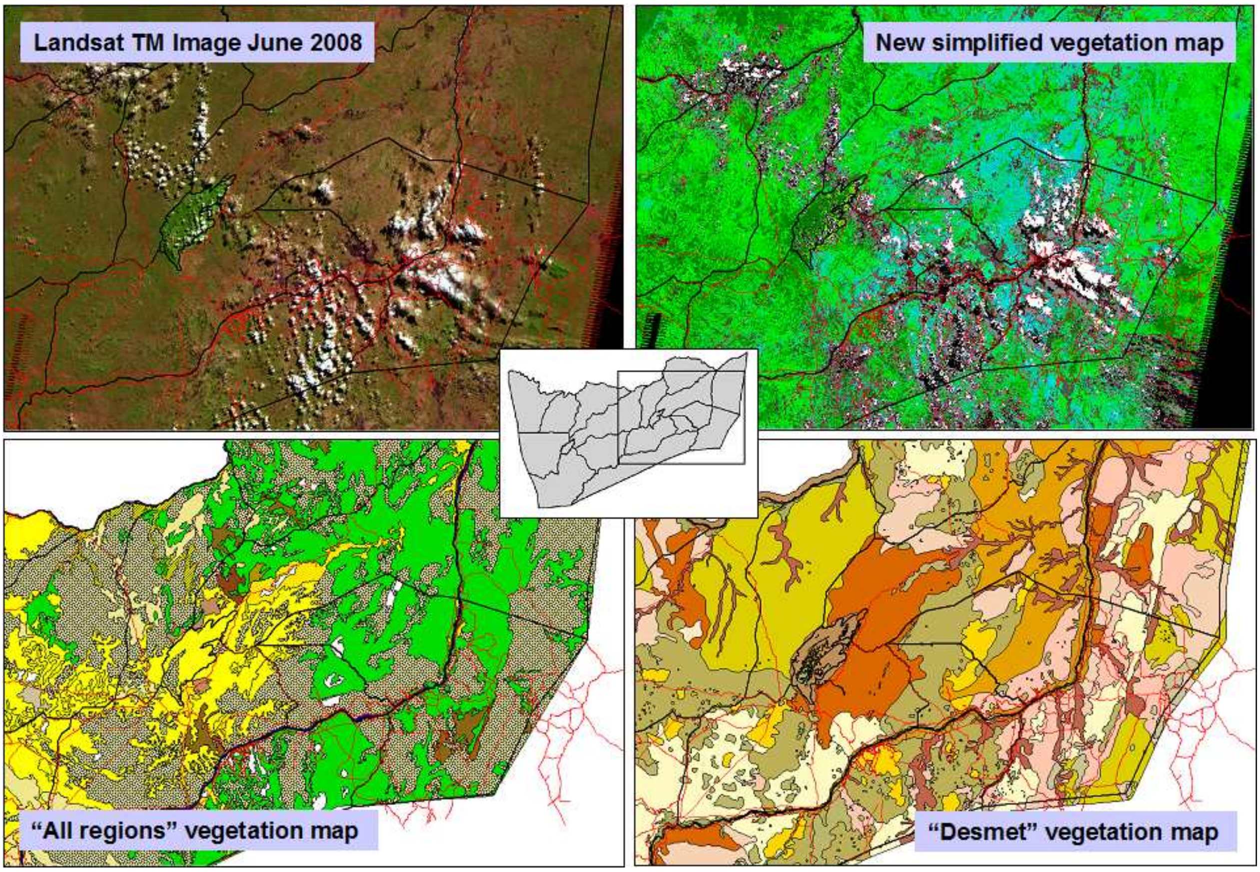
Species (woody)	**Authors**	**Family**
Acacia nigrescens	Oliv.	Mimosaceae
Adansonia digitata	L.	Bombacaceae
Afzelia quanzensis	Welw.	Caesalpiniaceae
Berchemia discolor	(Klotzsch) Hemsl.	Rhamnaceae
Cleistochlamys kirkii	(Benth.) Oliv.	Annonaceae
Combretum elaeagnoides	Klotzsch	Combretaceae
Combretum mossambicense	(Klotzsch) Engl.	Combretaceae
Croton gratissimus	Burch.	Euphorbiaceae
Croton pseudopulchellus	Pax	Euphorbiaceae
Dalbergia nitidula	Bak.	Fabaceae
Dichrostachys cinerea	(L.) Wight & Arn.	Mimosaceae
Diospyros mespiliformis	Hochst. ex A. DC.	Ebenaceae
Diospyros quiloensis	(Hiern) F. White	Ebenaceae
Diospyros villosa	(L.) de Winter	Ebenaceae
Entandrophragma caudatum	(Sprague) Sprague	Meliaceae
Euphorbia cooperi	N. E. Br.	Euphorbiaceae
Hyphaene petersiana	Mart.	Palmae
Karonia tettensis	(Klotzsch) R. B. Fernand	Verbenaceae
Kirkia acuminata	Oliv.	Simaroubaceae
Lonchocarpus bussei	Harms	Fabaceae
Lonchocarpus capassa	Rolfe	Fabaceae
Millettia stuhlmannii	Taub.	Fabaceae
Oxytenanthera abyssinica	(A. Rich.) Munro	Poaceae
Piliostigma thonningii	(Schumach.) Milne-Redh.	Caesalpiniaceae
Pteleopsis myrtifolia	(Laws) Engl. & Diels	Combretaceae
Pterocarpus lucens	Guill. & Perr.	Fabaceae
Schrebera trichoclada	Welw.	Oleaceae
Sterculia africana	(Lour.) Fiori	Sterculiaceae
Sterculia quinqueloba	(Garcke) K. Schum.	Sterculiaceae
Tamarindus indica	L.	Caesalpiniaceae
Terminalia brachystemma	Welw. ex Hiern	Combretaceae
Xeroderris stuhlmannii	(Taub.) Mendonça & E. P. Sousa	Fabaceae

Appendix 6 : Niassa National Reserve Reference map: roads and management blocks

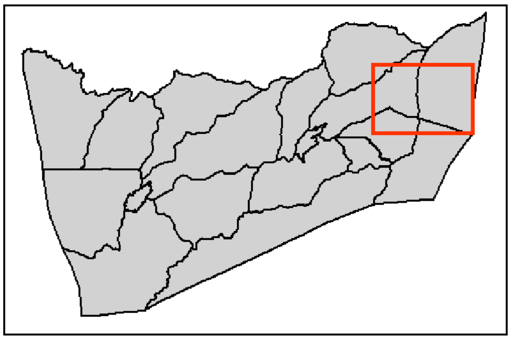


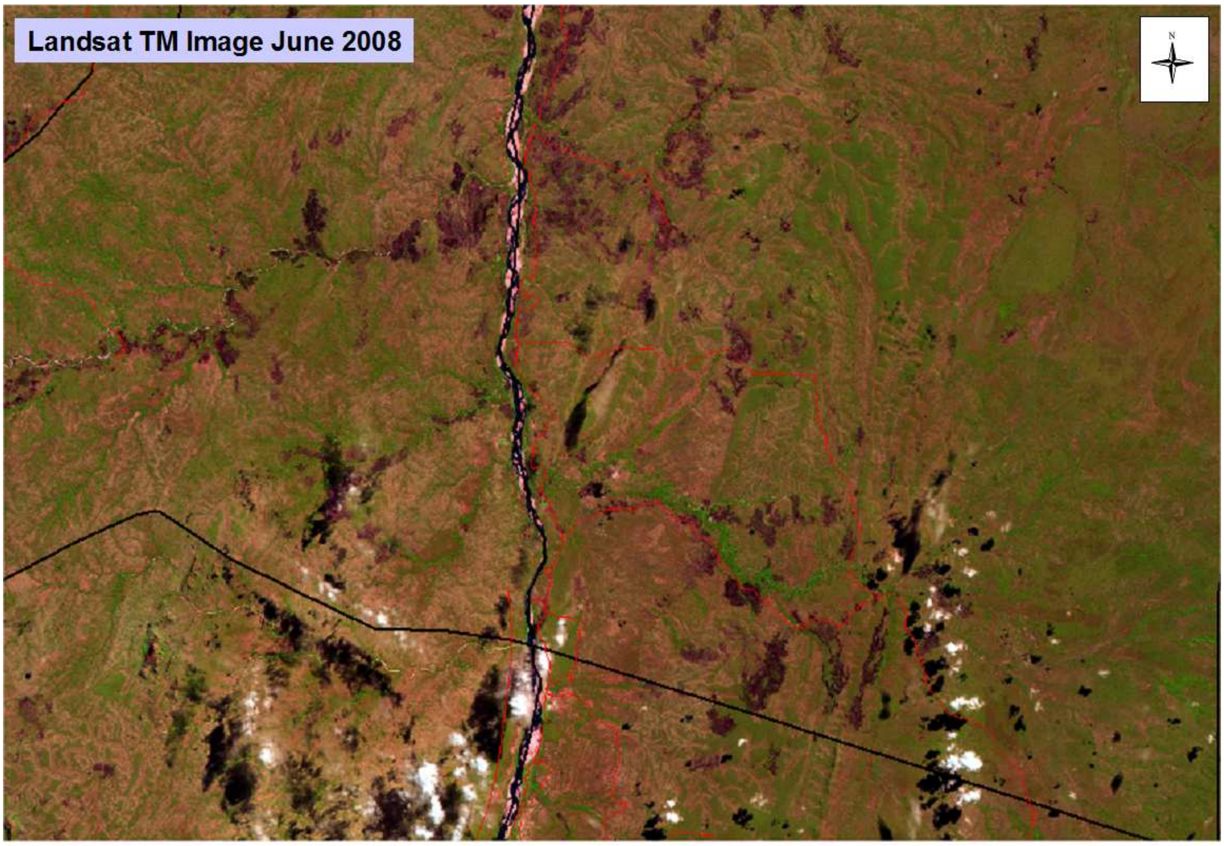
Appendix 7 : Visual evaluation of the precision of the newly created (preliminary) simplified vegetation map

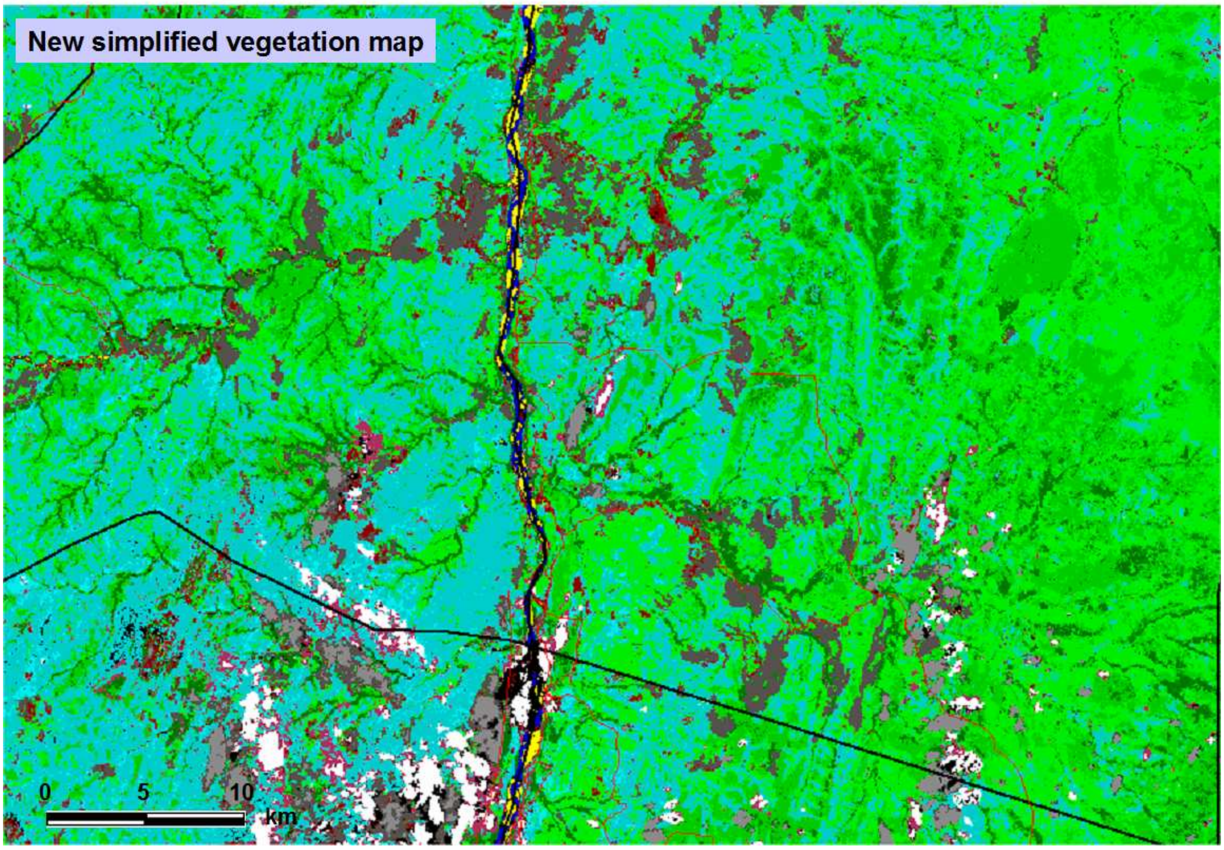
Comparison between the satellite image, the preliminary result of the image classification (new simplified vegetation map) and the previously available vegetation maps.

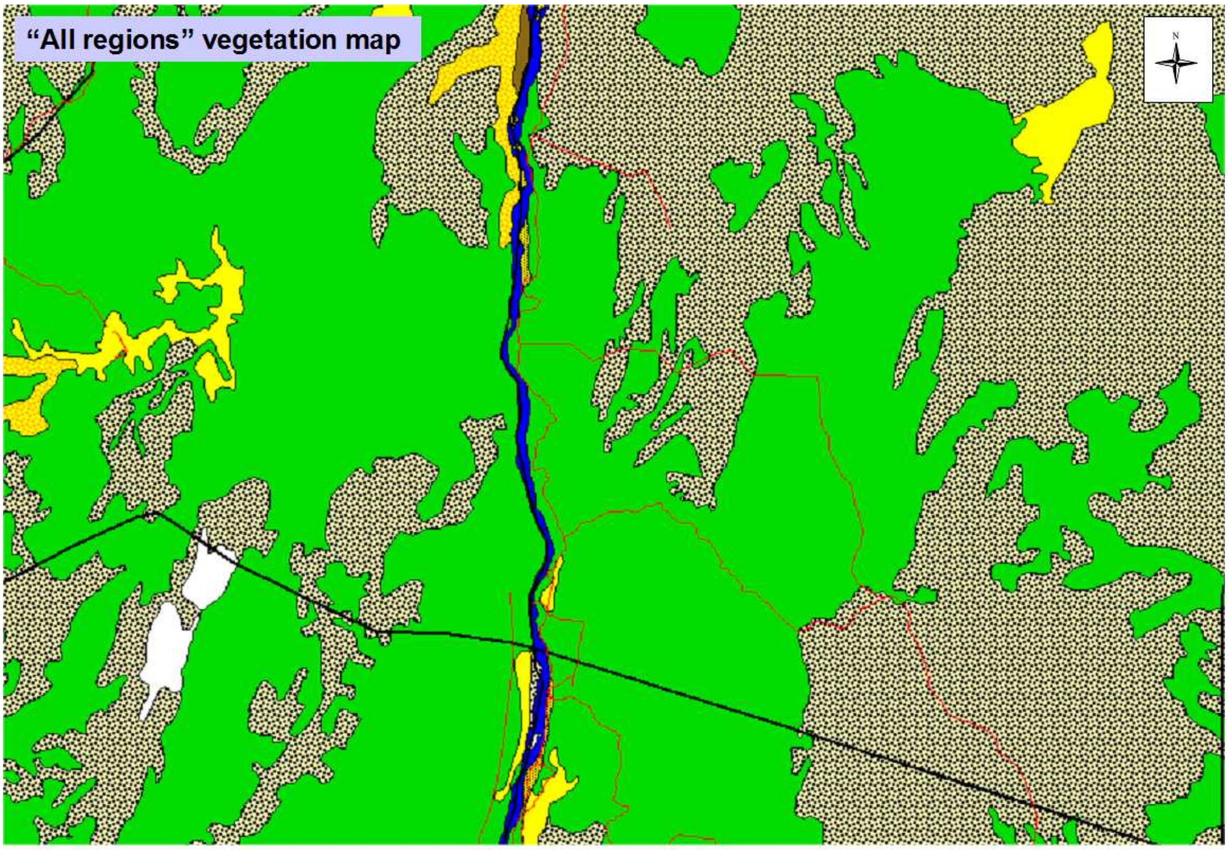


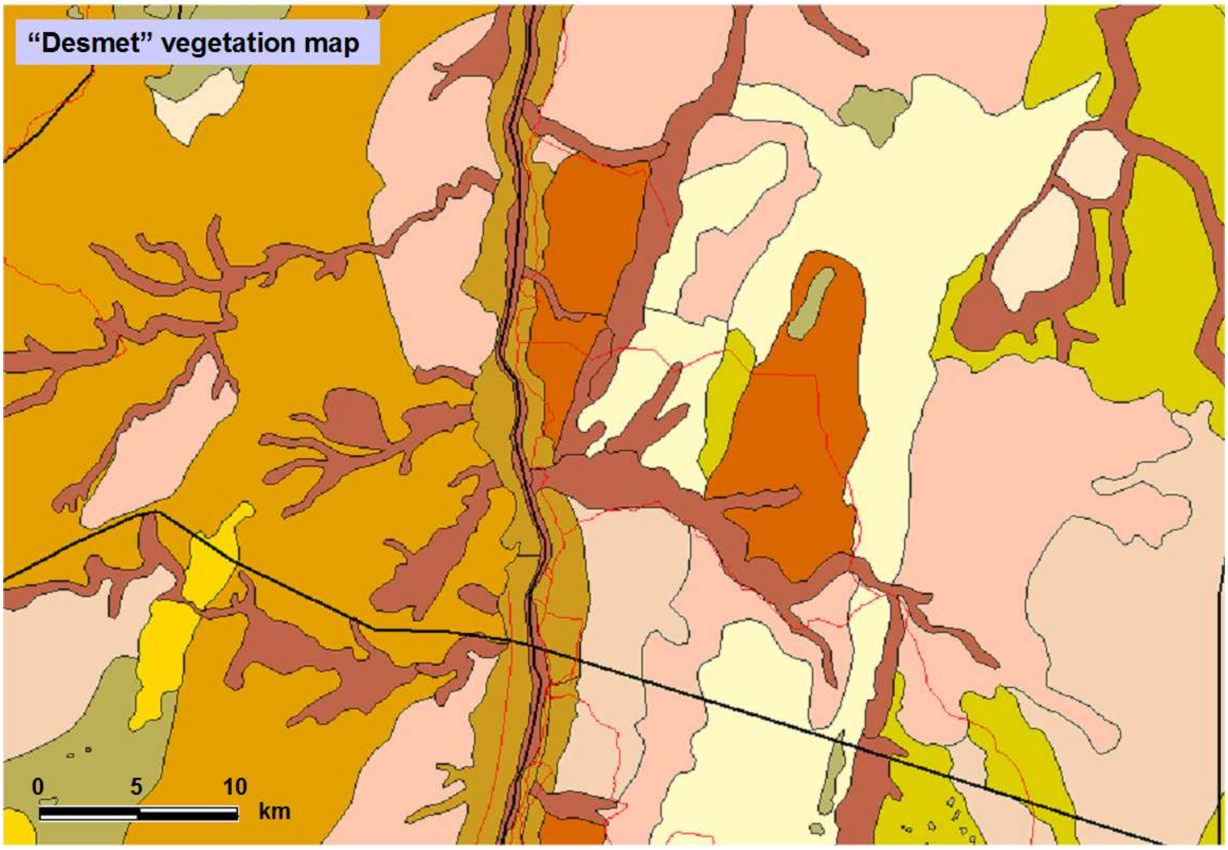
The following 2 pages show a zoom of a smaller subset (as shown opposite) of the area covered for this preliminary mapping attempt, at a more precise scale for better visual evaluation of the differences between products.




Landsat TM Image June 2008
N


New simplified vegetation map
0
5
10
km


"All regions" vegetation map
N


"Desmet" vegetation map
0
5
10
km