Forest Monitoring in Malawi using Long Time Series Vegetation Index Data

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Introduction

With growing population pressures, the need for responsible management of our natural resource base is increasingly of concern. Fortunately, recent developments in environmental information technologies offer a range of exciting new products and procedures to assist this management process. Yet with the intrigue of the new, it is easy to lose sight of the issues of timeliness and cost effectiveness. However, as these technologies become operational and filter down from experimental studies to a broader application arena, these issues become increasingly important. Perhaps nowhere is this more evident than in the developing world.

For the past two years, the Clark Labs have been engaged in research to develop and transfer appropriate techniques for environmental monitoring in Malawi. With financial assistance from the United States Agency for International Development, and in collaboration with the Office of Arid Lands Studies at the University of Arizona, the Clark Labs is assisting the Government of Malawi to more effectively carry out routine tasks related to environmental monitoring and to strengthen the efficient flow of information to effect environmental decision making.

This implementation of new technologies and techniques is being conducted as a subactivity under the Malawi Environmental Monitoring Program (MEMP), a collaborative activity of six participating Malawi government agencies: the Ministry of Research and Environmental Affairs, Department of Surveys, Department of Meteorology, Department of Water, Department of Forestry, and the Land Resources Conservation Branch. The task of this technology transfer k,subactivity is to allow the participating agencies, in a coordinated fashion, to employ new geographic technologies to analyze data and provide environmental information in contribution to MEMP, and in the long-term, provide the important elements for a broader national-level environmental information system.

The development of MEMP as a sustainable activity is particularly challenging at this time, in large part because of the recent change to a democratically elected government. Major governmental restructuring has resulted in extremely limited financial resources. While international donor funding can and does support substantial projects using new environmental information technologies such as GIS, Remote Sensing and GPS, the use of these technologies outside of donor-funded activities is virtually non-existent. In an attempt to foster a naturally sustainable use of these procedures, the Clark Labs has worked with Malawian counterparts to explore the use of inexpensive readily accessible data in conjunction with low cost microcomputer-based GIS and Image Processing software to produce needed information products.

An obvious candidate for consideration in this exploration was Normalized Difference Vegetation Index (NDVI) data produced from the AVHRR sensor of the NOAA series satellites. Through a program sponsored by the Southern African Development Corporation (SADC), with assistance from the United Nations Food and Agricultural Organization (FAO), 7.6 km resolution imagery for all of Southern Africa is sent free of charge to the Meteorological Department of each member country every dekad (10 days). While these data are spatially very coarse, they have a temporal resolution that is extraordinarily fine (daily images composited to form fairly cloud-free dekadal images). In addition, with a readily available archive that dates back to 1981, these data represent one of the most extraordinary records of the environment ever produced. In a series of studies conducted by the Clark Labs, it has been shown that when analyzed as a time series, these data can yield remarkably subtle details of environmental change. However, this work has largely been conducted at regional to continental and even global scales, where the 7.6 km resolution seems entirely appropriate. Our work with our Malawian colleagues was a first look at what might be discerned at a more local scale using a similar procedure. The result was a surprise to all.

The Data

The data set used in this analysis is derived from NOAA AVHRR imagery and consists of an index of vegetation biomass produced by dividing the difference in the reflectances between the infrared and red spectral bands by their sum. The resulting *normalized difference* acts as an excellent quantitative indicator of vegetation biomass. As a consequence of the wide interest in this product, the US Government now produces a Global Vegetation Index (GVI) image data product by compositing daily AVHRR imagery to 10-day (dekadal) composites at a 7.6 km resolution (see the sidebar for details on how to acquire these data). In this study, dekadal images were further composited to monthly images by taking the maximum value of the three images for each pixel in each month. The resulting monthly composite (Figure 1) is then substantially free of cloud effects (based on the logic that clouds always lower the NDVI value).

The Time Series Analysis Procedure

To analyze these data, and take full advantage of the temporal dimension, a time series analysis procedure based on principal components analysis (PCA) was used. PCA is a procedure related to Factor Analysis in which a set of input variables (in this case NDVI images of varying date) is linearly transformed into a new set of variables (called *components)* which are perfectly uncorrelated with one another and which are ordered in terms of the degree to which they explain the variance in the original variable set.

PCA has traditionally been employed in Remote Sensing as a data reduction technique. Because of correlation between spectral bands, most multispectral images contain substantial redundancy (i.e., information that is essentially the same as that contained in other bands). As a result, the first few components will typically contain most, if not all, of the actual information in the original band set. Later components, dominated by noise, can thus be rejected, leading to a reduction in data while maintaining the inherent information content of the input data. In many landscapes, for example, the seven bands of Landsat TM data can be shown to have an inherent information content of about 2-3 components.

In the case of the data considered here, the data differ in time, but not spectral content (they all measure NDVI). As a consequence, the components produced reduce redundancy by describing patterns in NDVI that recur over time -- hence the value of this procedure as a time series analysis technique.

The key to using PCA as a time series analysis technique is to examine both the temporal and the spatial characteristics of each component. For example, Figure 2 illustrates the first two components of an analysis of the entire continent of Africa for the period 1986-90. The temporal characteristics of these components are described in a *loading chart* -- a graph of the correlation between the component image and each of the original input images. Thus the Y axis indicates the degree of correlation while the X axis indicates time, from the beginning to the end of the series. As can be seen in this chart, the first component correlates strongly and essentially identically with each of the 60 input images. Thus the first component represents the characteristic NDVI over the continent, regardless of the season and other variations that may be present. In contrast, the second component shows a strong sinusoidal pattern, correlating positively with the northern hemisphere summer months and negatively with the winter months. Thus we can see that the biggest deviation from the characteristic NDVI shown in the first component is that which arises from the apparent movement of the sun -- the winter/summer seasons.

This logic carries through for all remaining components -- i.e., each is a residual (left over) pattern after the effects of all previous components have been removed. Thus, for example, the image of the eighth component in Figure 3 represents a residual pattern that lies seven levels deep in the data -- a concept that gives real meaning to the term *data mining*. Interestingly, this deep residual pattern can be shown to represent very clearly the effects of the El Niño / Southern Oscillation (ENSO) phenomenon that brings drought to Southern Africa. To substantiate this, the Southern Oscillation Index (SOI), an index to the nature of this phenomenon derived from atmospheric pressure readings in the Pacific Ocean, is plotted as a second element on the loading chart. The relationship is clear, as is the location of the drought in Southern Africa that took place during the El Niño of 1986/87 and the wetter conditions that followed during the La Niña of 1988/89.

An important feature of this time series analysis procedure is that the results are very much scale dependent, both in space and time. At a continental scale, local effects such as changes in land cover lack the coherence over space and time that would cause them to come out in the early component patterns. In essence, they are noise to the main signal of events such as the seasons and large-scale continental influences such as El Niño. However, if the same analysis is conducted for a more limited region, it is logical to expect that more localized phenomena may have the *weight* they require to come out in the early components. Thus when exploring the potential applications of the NDVI imagery with our Malawian counterparts, we examined analyses both at the regional and national scales. Regionally, the procedure has clear importance for understanding the dynamics of the ENSO phenomenon and its implications for food security. Malawi is a predominantly agrarian society that is strongly affected by the El Niño drought phenomenon. However, when we came to examine the potential of these data at a national level, we had no clear sense of what to expect, other than that we should see more localized effects such as land cover change. What became immediately clear is that the procedure holds enormous potential for the monitoring of forest cover change.

NDVI Time Series Analysis for Forest Monitoring in Malawi

For this more local exploration, a subset of the 7.6 km NDVI archive was extracted for the seven year period from October 1987 to September 1994 (the agricultural year runs from October to September). In addition, the subset was restricted to Malawi only, with pixels outside the national boundary being assigned a constant value of 0 (thus effectively removing these cells from consideration). A Standardized Principal Components was then run on the 84 subsetted images using the IDRISI GIS and Image Processing software system.

As with the continental scale analysis, the first component of the Malawi-specific analysis illustrated characteristic NDVI, with the next four components representing seasonal changes and anomalous effects such as recurrent cloud effects and inconsistencies in the calibration of the AVHRR sensor system. The first component with a non-artifactual interannual element was Component 6 (Figure 4).

Unlike the continental scale analysis, where the first inter-annual component relates to El Niño, Component 6 in the Malawian study is not related to ENSO. Rather, it highlights a number of isolated but very strong negative anomalies that are associated with a steadily increasing trend over time (Figure 5). Comparison of these locations to map data showed that the negative anomalies were predominantly associated with forest reserves, game reserves and national parks. These boundaries are delineated in Figure 4. The data suggested then that there was a progressive decrease in NDVI in the reserves. To confirm this, two further analyses were undertaken. First, temporal profiles were constructed for five of the major reserves, measuring the average NDVI within the reserve over the 84 months in the series. These are plotted in Figure 6 along with the mean trend. The second analysis consisted of a more detailed examination of the Phirilongwe forest reserve -- one of the smaller anomalies to be highlighted by the analysis. Figure 7 shows a Landsat MSS false color composite image for 1981 and a Landsat TM image for 1991 resampled to the same resolution. In false color multi-spectral images such as this, vegetation appears red. The change between the dates is strongly evident.

Malawi is a country in which significant deforestation has taken place over the past 30 years. However, the Department of Forestry is significantly hindered by a lack of funds to do forest inventorying and monitoring throughout the country. Current methods entail detailed inventorying of forested areas using a variety of manual techniques including on-site surveying, and when further funds permit, aerial surveying. But these techniques have not been very effective for routine monitoring. Aerial surveying is done on an ad hoc basis, but on average every ten years. These methods are significantly more expensive and not very efficient when constant monitoring is essential. Furthermore, since they rely on the visual delineation of forest stands, they are unable to detect changes in the density of forest cover.

Although the time series analysis conducted here was based on very coarse imagery, the fine temporal detail has allowed it to pick up a very subtle effect: loss of forest cover in the reserves -- not by clear cut, but rather, by progressive thinning due to poaching by local residents. Over 90% of Malawi's energy needs are met by wood and the illegal sale of public wood products has become an important cash crop in most rural areas. Our colleagues in the Forestry Department were aware that such poaching was taking place, but were surprised at the extent. In fact, using the temporal profiles for the five reserves in Figure 6, the estimated rate of decline is between 2-3 percent per year -- a rate that they have indicated is consistent with the losses experienced by clear cutting over the previous 30 years.

The value of this analysis, however, does not stop with the simple awareness that this level of poaching is going on. Clearly there are differences from one reserve to another. Why do some reserves experience lower rates of loss (some in fact would appear to be stable)? Is this the result of differences in management and enforcement? The analysis can very effectively target more detailed investigations, as well as provide the basis for further monitoring to gauge the effect of different intervention strategies.

Conclusion

As a result of this exploration, we have been able to develop a simple and cost-effective procedure for the monitoring of a very important resource in Malawi -- the national forest reserves. The imagery is free to the Government of Malawi and requires only a simple microcomputer and suitable software for the analysis to be undertaken. Similar explorations are being undertaken with other agencies using a variety of inexpensive image data, including METEOSAT Cold Cloud Duration (CCD) data for precipitation mapping, and 1.1 km multispectral AVHRR imagery for land cover monitoring.

However, a more general finding from this work is that the information that data can yield is not solely a function of the data alone, but also of the analytical procedure employed. It also suggests that we need to be more liberal in our thinking about the concept of resolution. The 7.6 km NDVI data, such as those used in this study, are available free of charge to anyone world wide (*see the sidebar*). They are very coarse in the spatial domain. However, they are extraordinarily fine in the temporal domain. This study has shown that subtle, but important, effects, both global and local, can effectively be monitored by using this temporal information. As a consequence, current attempts to develop and maintain inexpensive time series archives should be encouraged.

BIO:

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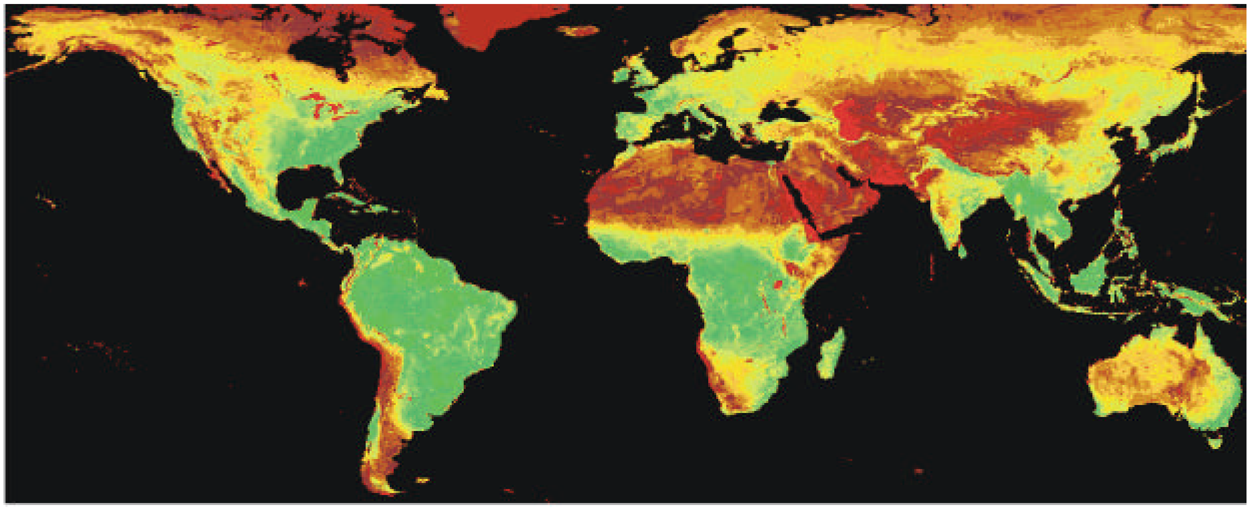


Figure 1 : A Global NDVI Image. This image was produced by taking the first principal component from a series of 36 monthly images from 1986 through 1988. As such, it represents the characteristic NDVI over the entire period for each region.

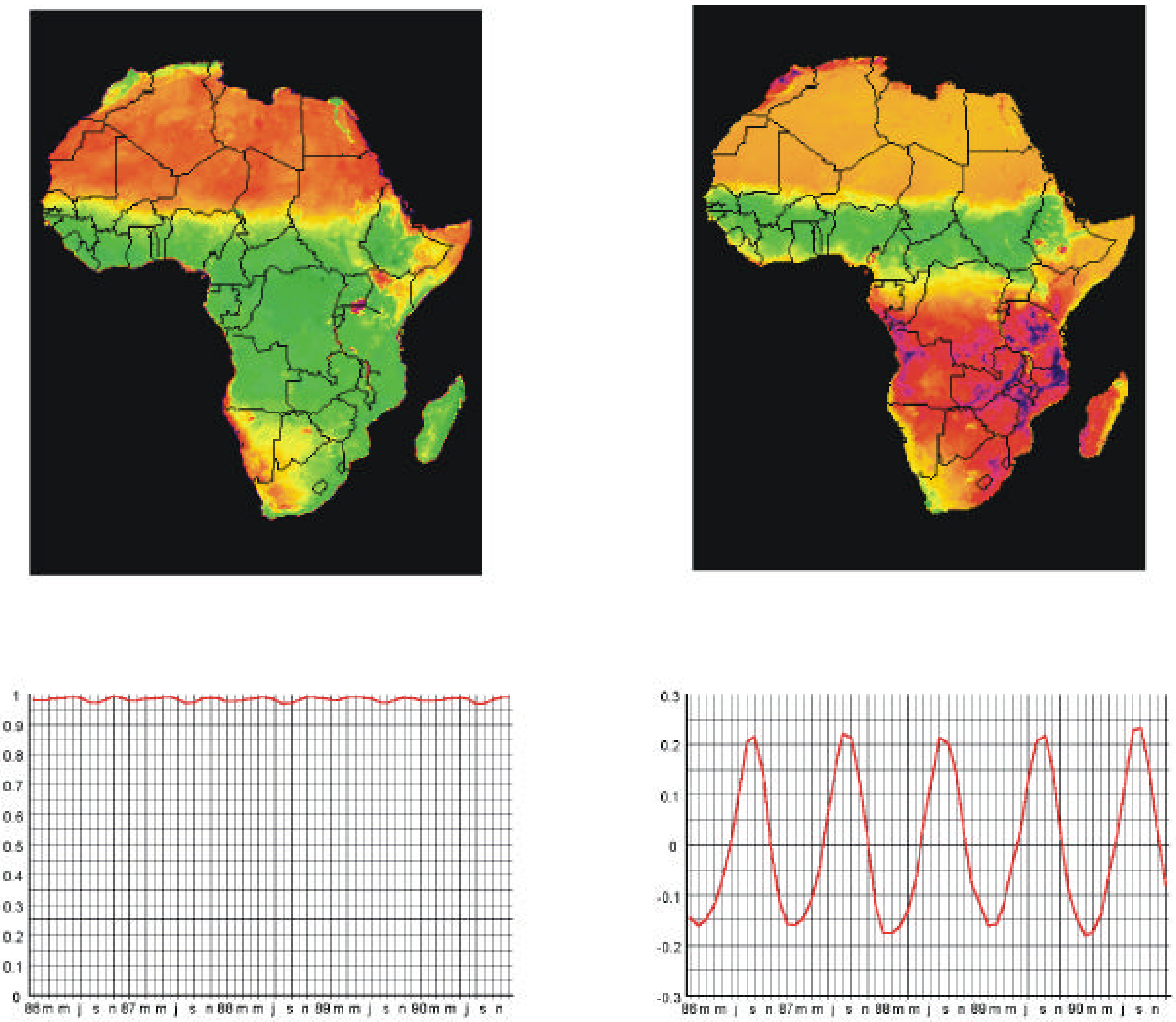


Figure 2: Component 1 (left) and component 2 (right) of a time-series analysis for the continent of Africa for the period 1986-1990.

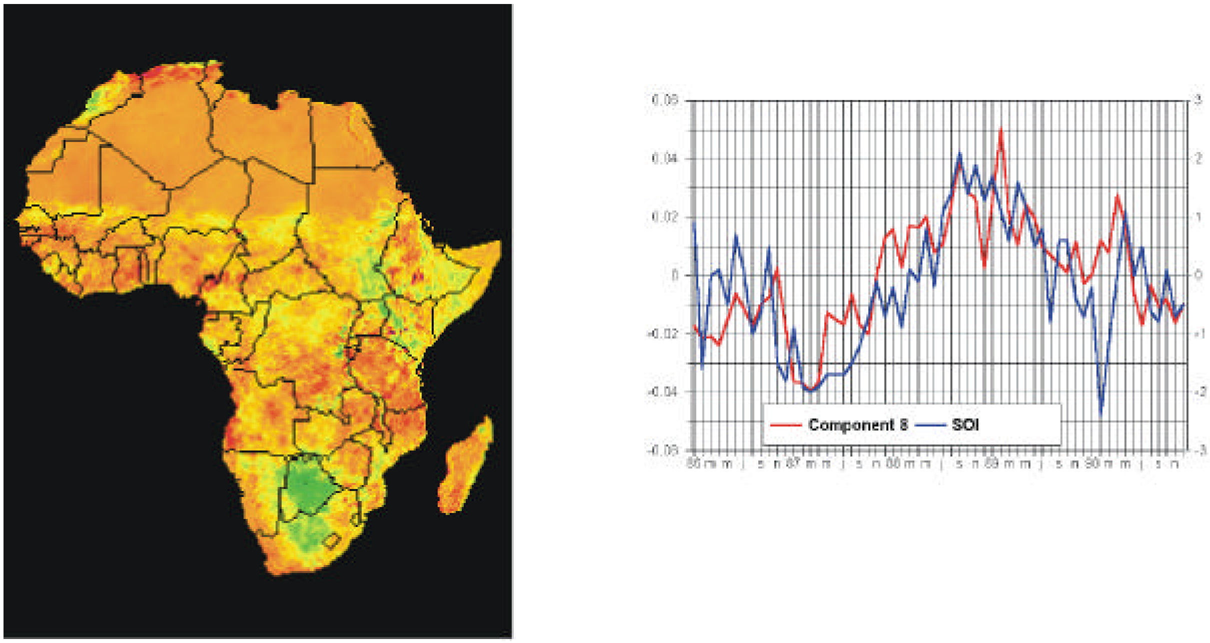


Figure 3: Component 8 from the Africa data set.

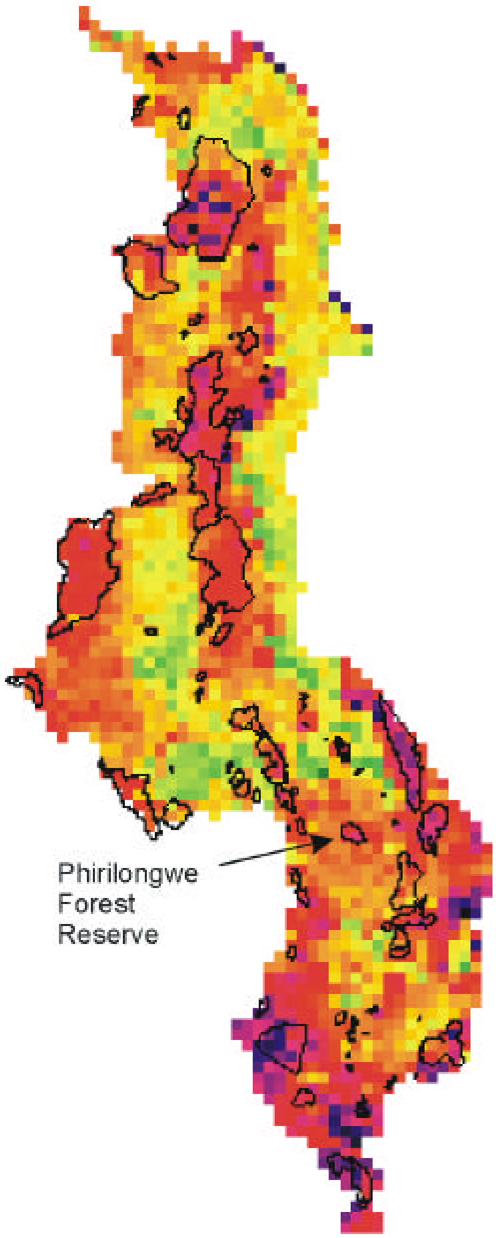


Figure 4: Component 6 of a 7.6 km resolution time series analysis of monthly data from October 1987 to September 1994. Forest reserves, game reserves and national parks are outlined.

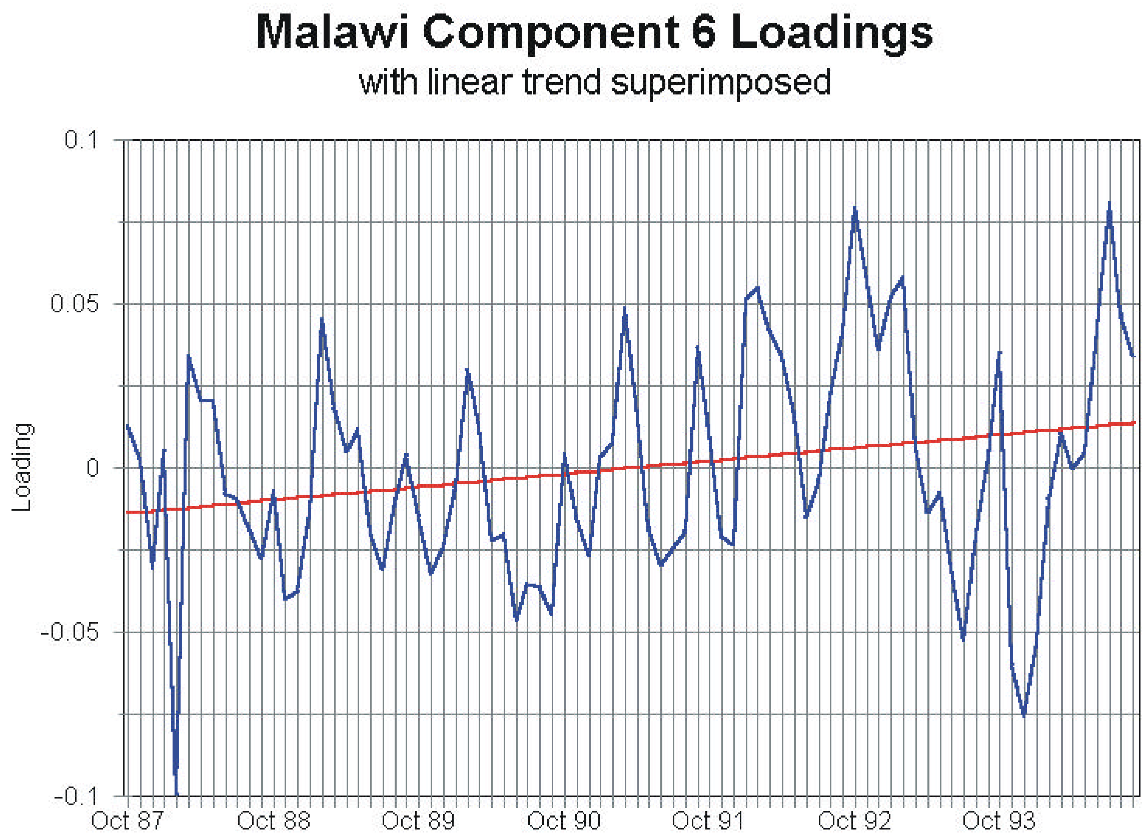


Figure 5: Component 6 loadings graph showing a steadily increasing trend for which forested areas are negatively associated.

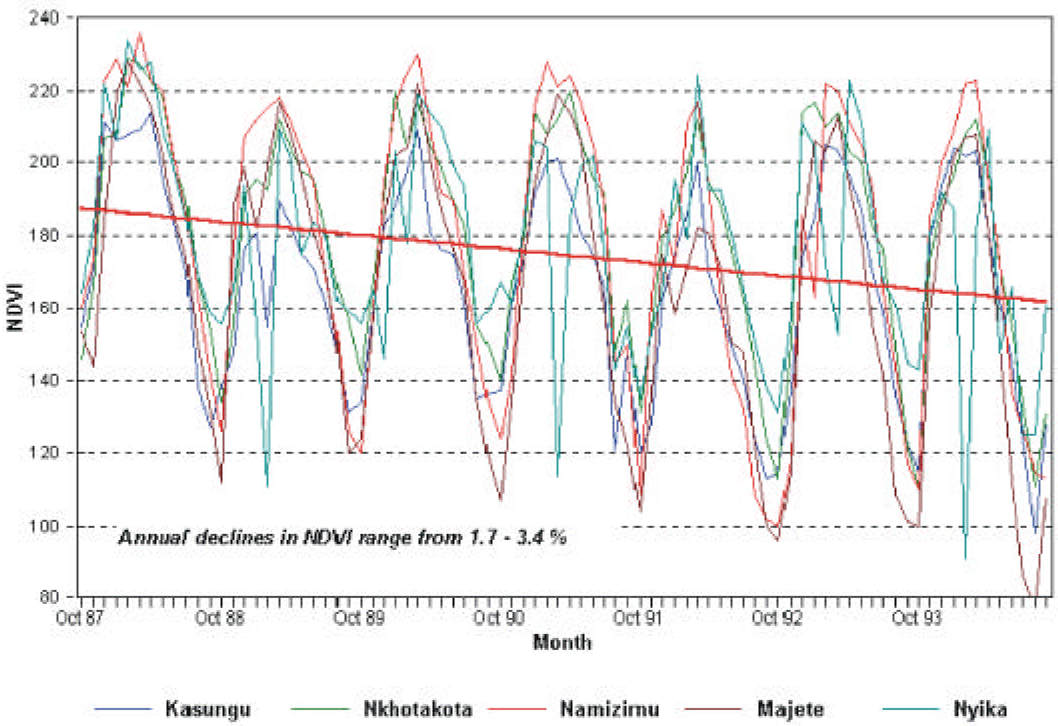
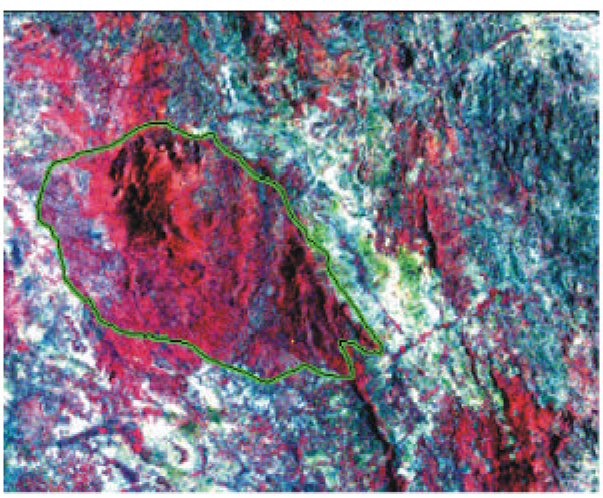


Figure 6: Temporal profiles for five selected reserves. The graphs clearly show a progressive history of decline in NDVI similar to the trend in the Component 6 loading.



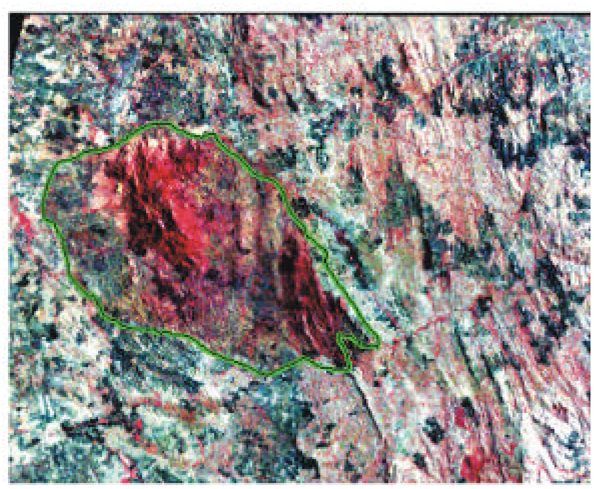


Figure 7 : Landsat MSS false color composite of the Phirilongwe Reserve, Malawi for 1981 (left) and Landsat TM false color composite (resampled to MSS resolution) for 1991 (right).