Case study on changes in NDVI values in the period 1998 – 2009: the case of Maasai Mau, South-western Mau and Eastern Mau

Mwangi J Kinyanjui
DRSRS, Nairobi, Kenya

Introduction

The Mau Forest Complex lies at approximately 0.0° to 0.91° South and 35.30° to 36.10° East in the South Rift region of the Rift Valley Province of Kenya. It is the most extensive block of montane forests in East Africa covering about 400,000 hectares (Wass, 1995). It is the catchment area for at least 12 rivers making it the largest of the water towers of Kenya (DRSRS and KFWG, 2006). Some of the rivers drain into Lake Victoria; Sondu, Nyando and Mara, while others drain into Rift Valley Lakes; Njoro, Molo, and Kerio. In effect, the Mau Forest Complex supports tourism and economic activities associated with the Mara Game Reserve, Lake Nakuru bird sanctuary and national park, and the Sondu Miriu Hydro Power project among others. Lake Nakuru is significant for its tourism potential being the largest bird sanctuary in the world. River Mara provides the crossing point of the wildebeests in their seasonal migration, and is the only dry season water source for wildlife in the extensive Mara National Reserve.

Climate and soil

The rainfall pattern is bimodal in distribution, peaking in April and August, and ranges from 1000 to 2000 mm. The rain days range from 120 to 200 per year. This rainfall pattern supports healthy forest vegetation. The temperatures range from 16°C to 22°C with July being the coldest month. The potential evapotranspiration is 1400 to 1800 mm per annum. The soil is mainly Mollic Andosols derived from tertiary volcanic parent material (Somroek *et al.,* 1980). In general, the soil is well drained, fine textured and of high agricultural potential.

Demographic characteristics

The rural population adjacent to the forest is generally poor. Bomet District, one of the districts adjacent to the forest was ranked third poorest district in 1999 with a very high prevalence of food poverty (M.F.P., 2000). Moreover, there has been land related violence among the resident communities since 1992. The violence results in burning of property and abandonment of land, which make the residents poorer. The adjacent forest is the only source of building material for reconstruction of destroyed buildings when peace prevails. Some of the fires lit during the violence spread to the nearby forests and destroy them.

Forest vegetation

The vegetation of the natural forest in the Mau Forest Complex is classified as afromontane mixed forest (White, 1983). Mutangah *et al,* (1993) used the dominant tree species to delineate forest formations. The forests on the windward side of L. Victoria are mainly moist mixed forests dominated by *Tabernamontana – Allophylus – Drypetes* forest formations (Kinyanjui, 2009) while the Eastern Mau is dominated by a dry upland conifer forest dominated by *Juniperus procera* (Hochst.ex Endl.) and *Podocarpus latifolius* (Thunb. Mirb). Primary colonizers like *Neoboutonia macrocalyx* (Pax), *Macaranga kilimandischarica* (Pax) and *Dombeya torrida* (J.F. Gmel.) are characteristic for degraded forests. Beentje (1994) listed over 61 tree species and 80 climbers and shrubs in the forests. The vegetation of the forest has been described as highly encroached due to high pressure from the forest adjacent communities (DRSRS and KFWG, 2006). Slash and burn techniques used by forest dwelling communities have also resulted in forest degradation. The communities occasionally use fires to improve pasture and prepare land for cultivation. This has resulted to existence in wide glades in the forest.

Indicators of forest vegetation changes

To limit the pressure on the forest, a sustainable management plan is required. To propose appropriate forest conservation measures, one should take into account the characteristics of forest vegetation, seasonal changes and between the years, and the response of the forest to the changing physical and human environment. Such information may amongst others be based on vegetation indicators derived from satellite imagery. A useful indicator is the Normalised Difference Vegetation Index (NDVI).

The NDVI has widely been used to detect changes in vegetation health and stocking (Anyamba and Tucker, 2005; Lotsch *et al*., 2003). It uses the principle that healthy vegetation absorbs most of the incident visible light emitted by the sun, and reflects a large portion of the near infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. The difference between healthy or well-stocked vegetation and that of unhealthy or sparse vegetation can be assessed by means of the NDVI

$$NDVI = (NIR - RED) / (NIR + RED)$$

where NIR is the near-infrared reflectance and RED is the reflectance of the red portion of visible light. The NDVI values generally range between -0.1 and 0.92, with higher values indicating denser and healthier vegetation like in tropical forests, moderate values (around 0.2 and 0.3) showing shrubs and grasslands, while very low values of 0.1 and below are typical to non-vegetated areas.

Study area

The study to identify trends of vegetation changes was set up in four selected blocks of the Mau forest complex in the period 1998-2009 (figure 1). These four blocks; Southwest Mau, Western Mau East Mau and Maasai Mau, are significant due to their role as water catchment. The forest varies in species composition and experiences varying levels of human degradation (Mutangah *et al.,* 1993; White, 1983).

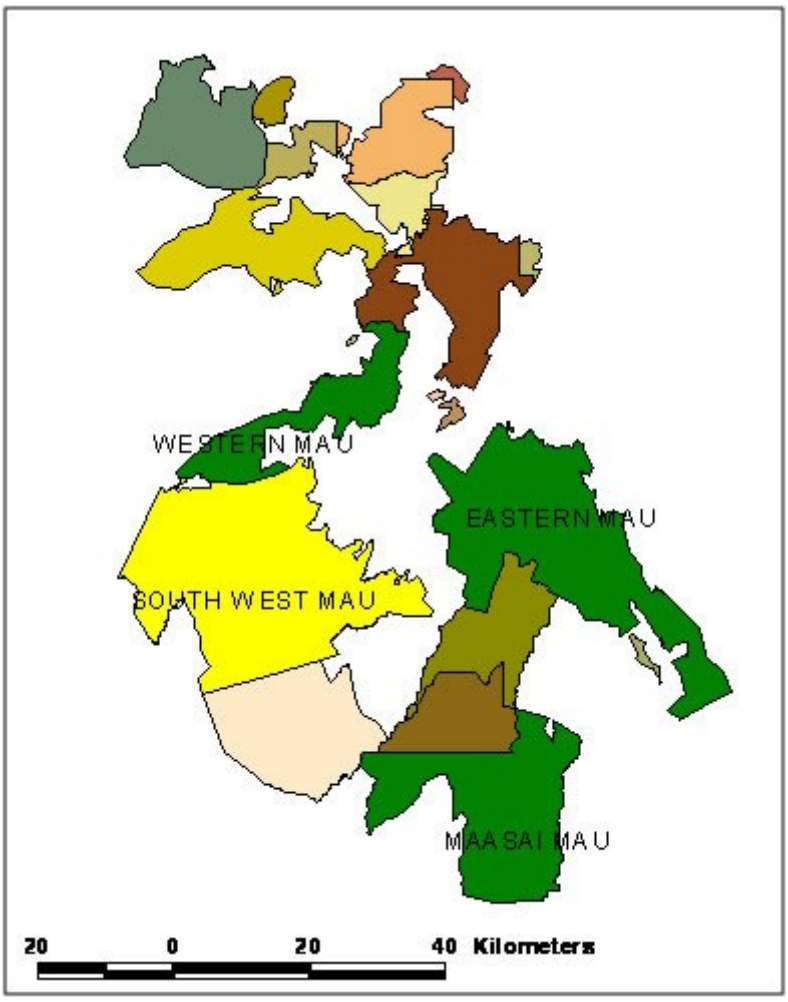


Figure 1. Study area.

Methods

Data was obtained from the ENDELEO project (http://endeleo.vgt.vito.be/) that provides remote sensing based data and tools to monitor the vegetation dynamics in Kenyan ecosystems. One of the products

available are the ten daily NDVI composites since April 1998 obtained from the 1 km resolution SPOT-VEGETATION sensor.

This study focuses on the NDVI of the closed woody forest vegetation type for the four Mau sections. The dataset was smoothed over time, to remove possible dips related to bad values, e.g. due to undetected clouds, with an algorithm inspired like BISE (Viovy et all., 1992). It inspects each pixel's profile and removes all abrupt local minima (supposedly clouds), as far as they don't persist longer than four decades.

First the annual average NDVI values were compared, to define the obvious differences in the vegetation conditions for the different forest blocks.
Subsequently it was evaluated per forest block if there is a general trend in the status of the closed woody vegetation. The average NDVI values per decade over the 11 year period were standardized to the Standardized Difference Vegetation Index' or SDVI (Z-scores).

$$SDVI = (NDVIcurrent - \text{NDVI mean}) / \text{NDVI standard deviation}$$

The SDVI gives a relative measure of the increase or decrease as compared to the mean NDVI for the same decade and levels out the seasonality in the dataset.
Finally the NDVI values of the closed woody forests vegetation type for the selected forests were examined for three different months; March the driest season, July the wettest season and October the short rains period. The monthly NDVI averages were plotted over the different years and extreme values ($|SDVI| > 2$) were eliminated. A linear regression was calculated. The R^2 was calculated to see whether the regression can be regarded as a trend line and an F-test was performed to test if decrease or increase in the trend line is significant.

Results and discussion

Differences in yearly average NDVI

Figure 2 shows that the average annual NDVI values vary from year to year and after a decline in one year, there is a gradual improvement in the successive year. As a result, it is difficult to identify any positive or negative change in the forest health and stocking.
A notable finding from figure 2 is that East Mau has NDVI values that are lower than the other three forests and that it has larger variations. The extreme dry conditions in 2000 and 2009 have affected the vegetation conditions of East Mau more than in the other forest blocks. This forest block seems to be more fragile. It is located on the leeward side of Lake Victoria and the rainfall received here might not be compared to what is received in the other forest blocks to facilitate vegetation growth. This assumption however can only be confirmed by comparing the rainfall data with the NDVI data. The East Mau forest block is more of a dry upland forest dominated by conifers like *P. latifolius* and *J. procera*, which may not have reflectance characteristics like N. macrocalyx and M. kilimandischarica, pioneer species that dominate degraded forests in the other forest blocks. Ground truth data shows that fires also affected parts of the forest in the late 1990s and much of the vegetation has not recovered. Furthermore it can be observed that Masaai Mau followed the same trend as Western and Eastern Mau until 2007. From 2008 onward the NDVI has become slightly lower. This may be a subject for further investigation.

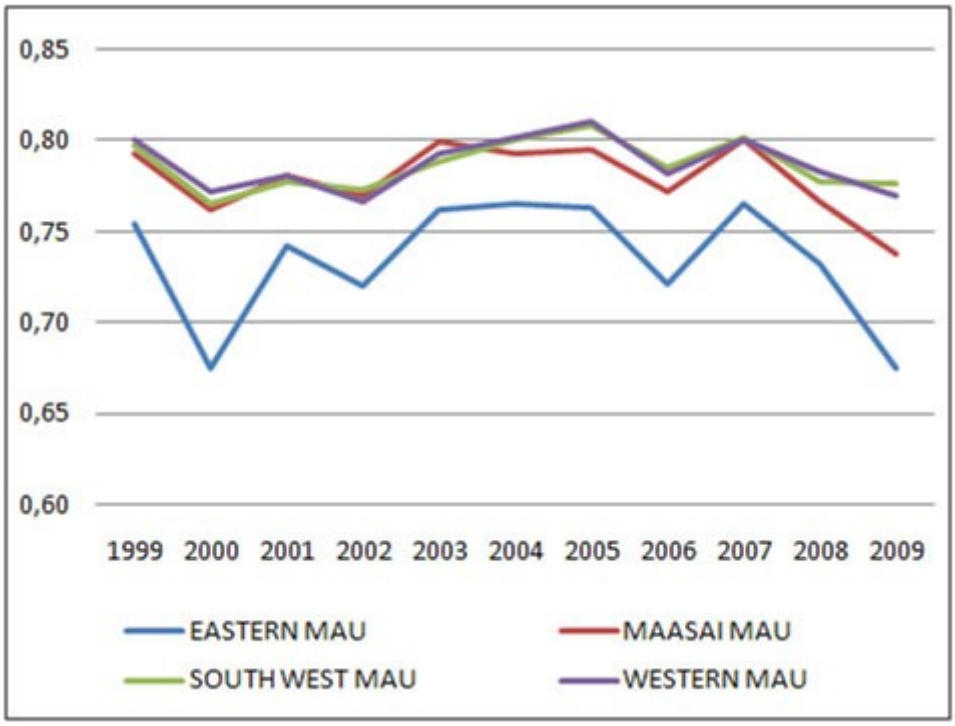
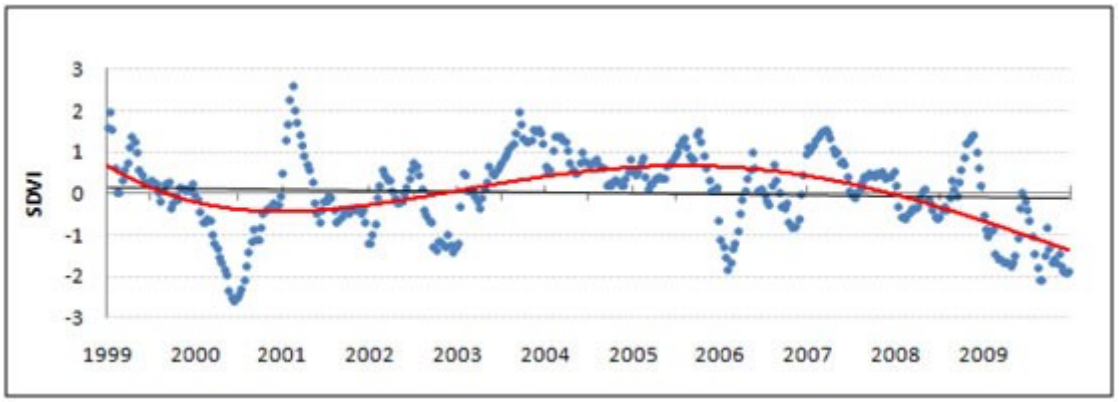


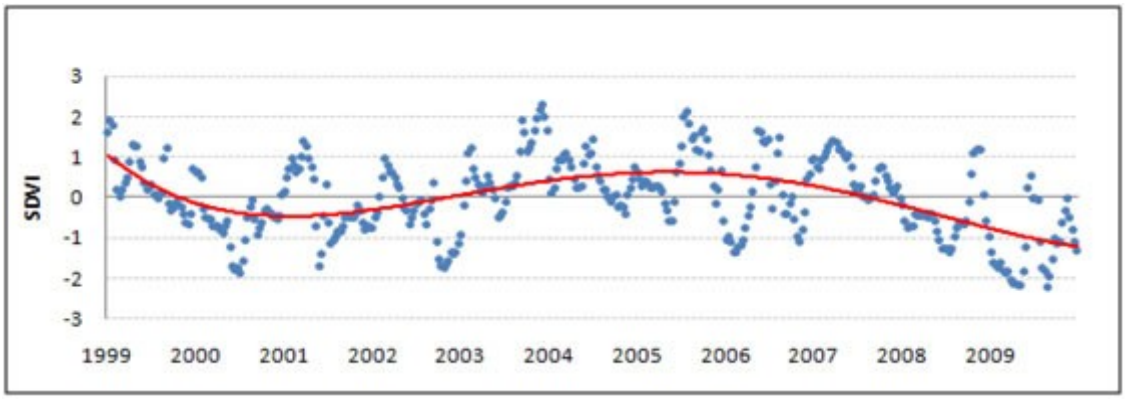
Figure 2. The average trends comparing NDVI values in the four forest blocks over the study period.

Trend of ten daily NDVI values

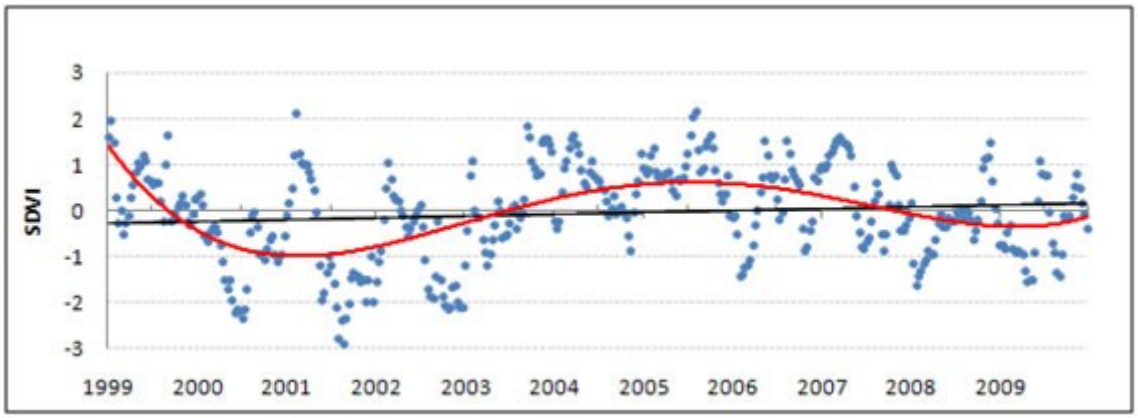
The SDVI plots in figure 3 show large variations between the different years. These are most likely related to the erratic rainfall conditions which are characteristic for the Horn of Africa. The trend of the SDVI that may be observed over the years is rather cyclic, corresponding to the rainfall variations with alternating wet and drier years. In the period from 2000-2003 and from 2008 on, the vegetation seems to perform less good. It takes a number of years before the forest recovers. For East Mau and Masaai Mau, the trend line does not show an upward movement at the end of 2009 and the SDVI values are still negative. The forest does not seem to recover yet from the latest drought. For West and Southwest Mau, an upward trend can already be observed. Because of this cyclic behaviour of the vegetation conditions, it is difficult to derive if there is a long term overall decrease or increase in the NDVI. This could be an indicator of respectively an improvement or a decline in the vegetation health or stocking density in the forests studied over the ten year period. An analysis approach should be used which eliminates the effect of rainfall variability. It can only be confirmed over a longer period of monitoring. Alder and Synnott (1992) note that changes in a natural forest are gradual and slow and require at least five years to be noticeable.



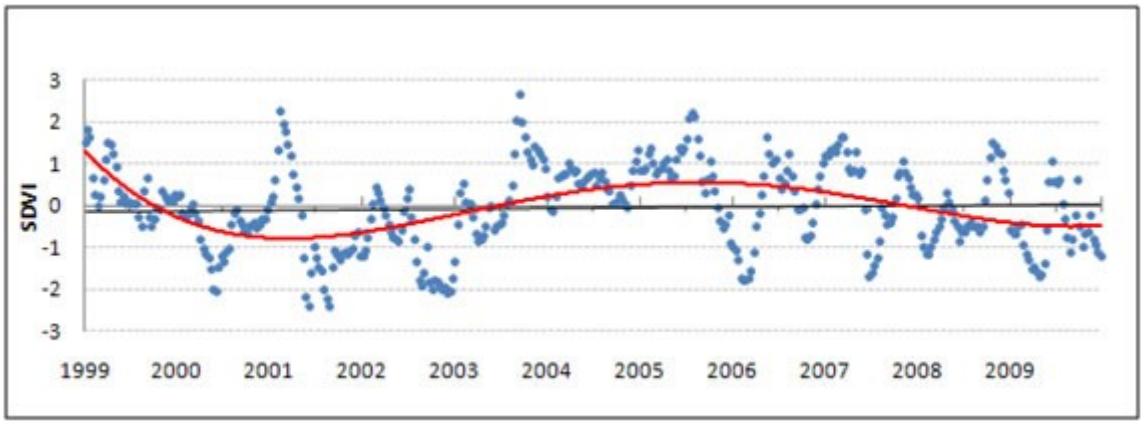
East Mau



Masaai Mau



Southwest Mau



West Mau

Figure 3. Scatter plots and polynomial lines showing the variability and the trend of the SDVI values over the study period in the four blocks of Mau forest Complex.

Seasonal variations in NDVI

In the month of March, being the driest month, the NDVI values strongly vary from year to year (figure 4). The results may imply that the drought conditions differ over the years, dependant on the performance of the preceding rain season, or that the onset of the growing season is variable. There is no clear trend in the values over the study period. Only in West Mau a minor correlation indicates a possible decline in the NDVI. This possibly signifies that the rainy season is starting later or the dry

conditions in vegetation are becoming more severe over time making the vegetation more stressed. Though, the correlation and significance of the trend are too low to make strong conclusions.

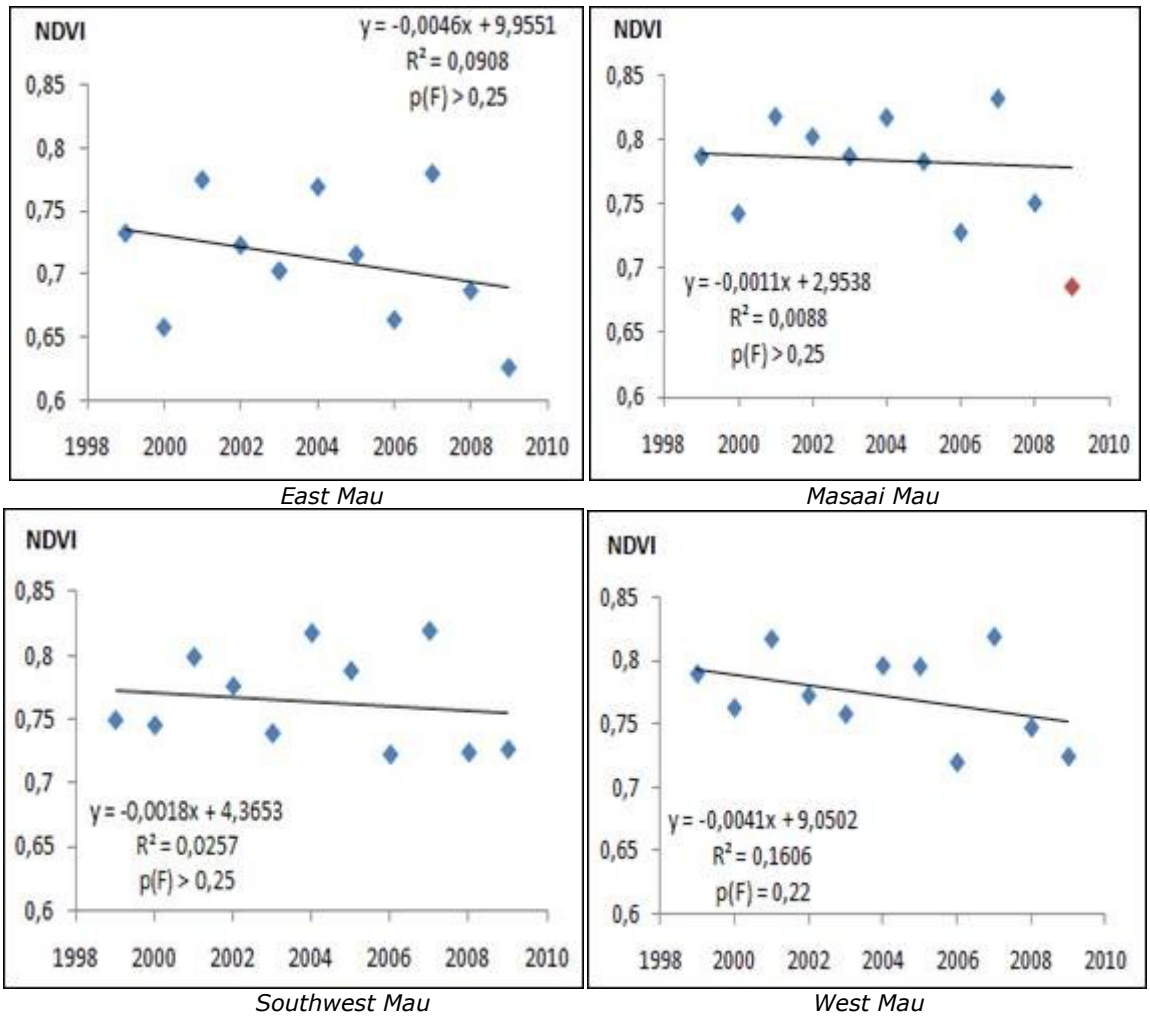


Figure 4. Trend of NDVI values over the study period for the month of March. NDVI values with |Z-score| > 2 are represented are not taken into account for the regression line (red dots). p(F) is probability of F-test.

In July, the variability in NDVI is lower over the years. This means that vegetation conditions during the rainy season are less dependent on the performance of these rains than during the dry season. Minor correlation and positive trend line in the scatter plot of Southwest Mau may show an increase in the NDVI values over the study period while for East Mau forests there might be a decline (figure 5). For Masaai Mau and West Mau, no trend is observed. July is always a wet month and the vegetation is expected to be recovering from the drought stress. The increasing trend in NDVI values in the Southwest Mau block may possible signify that the forest has been responding better and the vegetation is improving over the ten year study period. The opposite might be true for East Mau. The results should be interpreted carefully due to the low correlations.

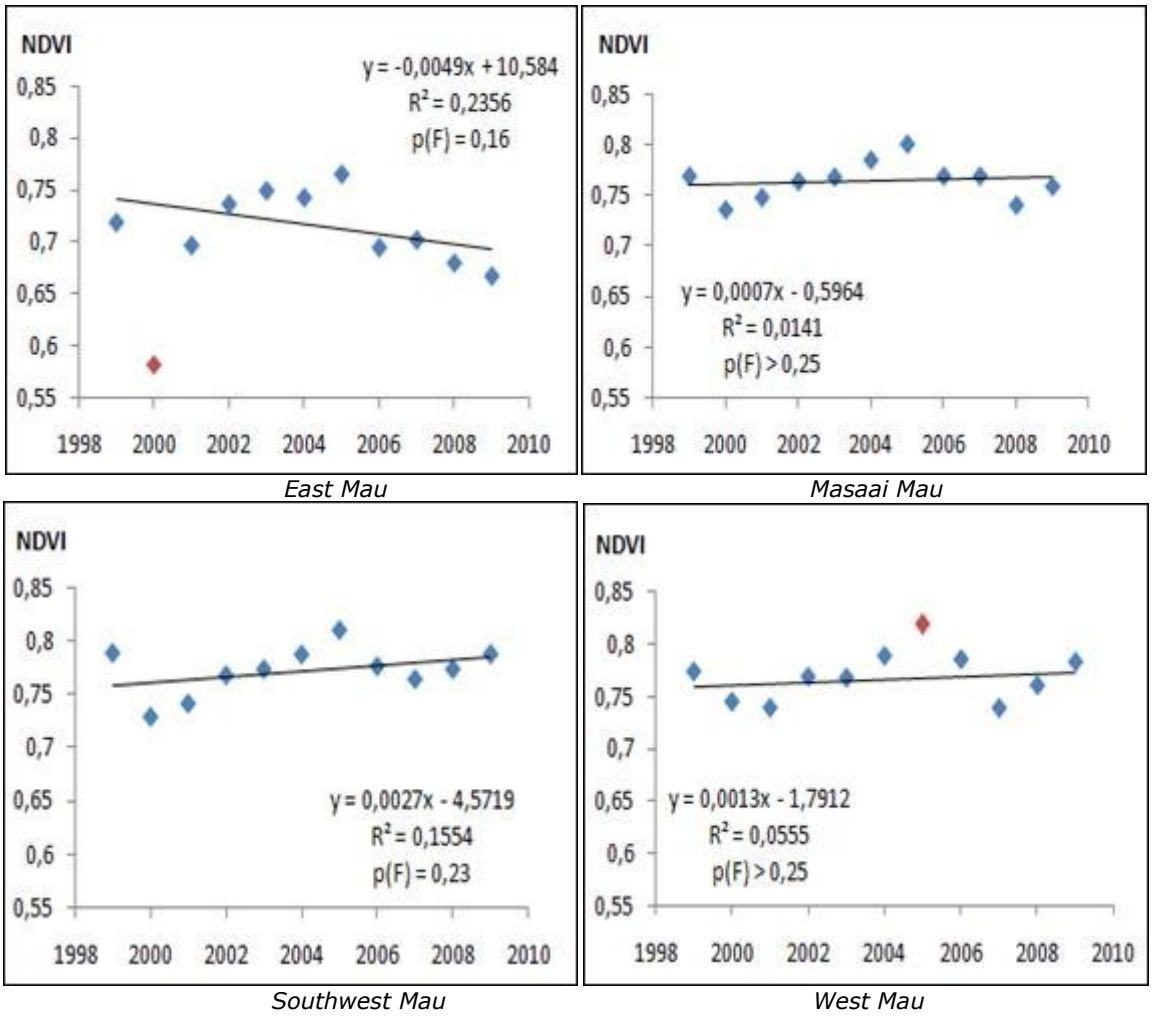
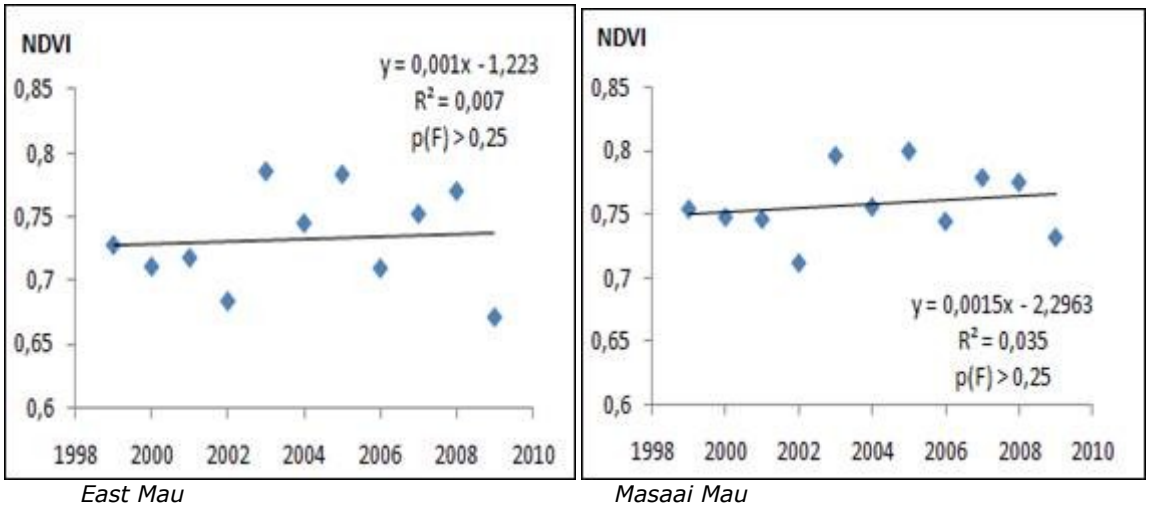
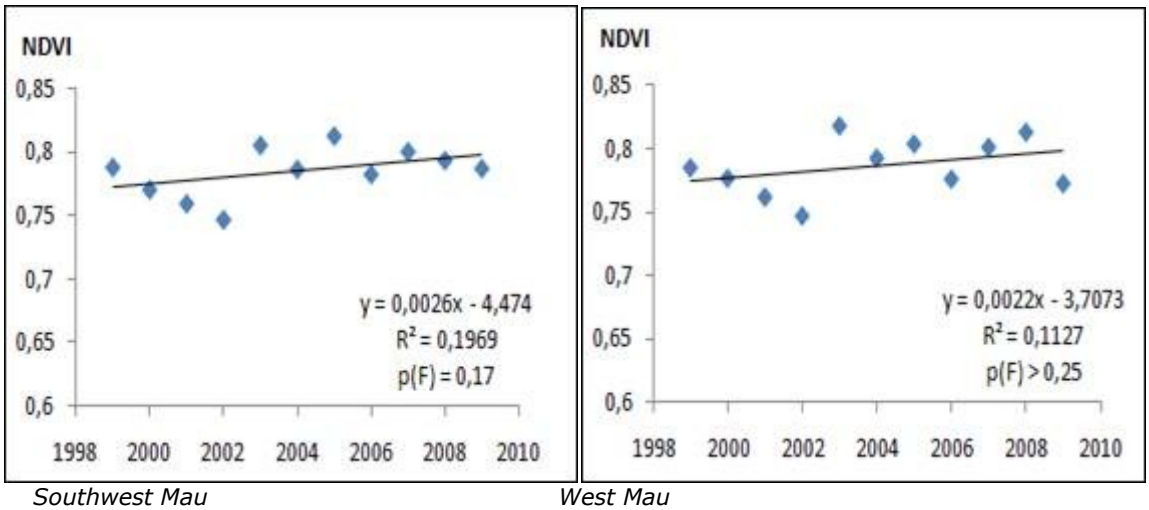


Figure 5. Trend of NDVI values over the study period for the month of JulyNDVI values with |Z-score| > 2 are represented are not taken into account for the regression line (red dots). p(F) is probability of F-test.

In the month of October (figure 6), the scatter plot of Southwest Mau shows a minor correlation for an increase in NDVI values over the study period. This might indicate a delay in the end of the growing season from the late 1990s to 2009.





Southwest Mau *West Mau*

Figure 6. Trend of NDVI values over the study period for the month of October p(F) is probability of F-test.

Considering all scatter plots together, they do not proof any significant trends. Though, it can be noticed that the trend line for March is slightly negative, for July the slope is slightly positive, except for East Mau, and for October there is again a slightly positive trend. This may signify that the growing season has shifted a bit. The July results for East Mau might indicate a slightly vegetation degradation trend. Even though no strong conclusions can be made, they point out for which periods or areas further research would be interesting. More data is needed to confirm the status of the vegetation on the ground.

Discussion

Maasai Mau forest has received the greatest rate of degradation in the last ten years with communities clearing and settling in the forests. The average yearly NDVI does not differ much from West and Southwest Mau, except for the last two years it has become slightly lower. There is a slight negative trend for the NDVI values of July, in the middle of the wet season when vegetation should be least stressed, but this result has to be interpreted carefully.
East Mau was heavily excised taking about 40,000 hectares from the original 65,000 hectares. The remnant forest has a lot of pressure from the forest adjacent community. The dry upland conifer forests are most affected by fires which have been very common in this forest. A section of the bamboo zone in this forest was affected by fires and has not recovered since then. The average yearly NDVI values are clearly lower than for the other forests. A rather slow recovery from drought can be observed when taking into account the trend of all ten daily NDVI values. Though no clear trend can be derived from the seasonal NDVI study. This is a forest that calls for more attention especially because it is a catchment area for L. Nakuru.
Southwest Mau and West Mau forests are on a trend of recovery after forest fires were stopped in 2003. The vegetation conditions vary less over the years and the forest recovers quicker after a dry spell. The fact that these forests are on the leeward side of L. Victoria implies that heavy rainfall enhances vegetation recovery after degradation. This can be confirmed by the presence of the gregarious *N. macrocalyx* that colonises degraded areas very fast. It is in these blocks that there was recent eviction of illegal forest settlers and it is expected that the vegetation will improve in the next years.

Suggestions for further research

Rainfall is very variable in Kenya and has a major impact on the vegetation status, leading to large changes in NDVI from year to year. This makes it quite difficult to identify trends. Therefore it is necessary to obtain rainfall data and examine the relationship between NDVI and rainfall. It may also be interesting to perform an NDVI analysis specifically on those areas where degradation.
Year 2009 was a very dry year all over the country. It is necessary to monitor the forests after the year 2009 to see if they recover after drought. This will confirm the self-recovery process of the forests and may justify which forests need enrichment planting.
Ground truthing should be focused on special cases like East Mau so that remedial action may be taken to save the forest whose role in the Lake Nakuru Ecosystem is very significant.

*For questions related to this topic, please contact Mwangi J Kinyanjui (*mwakinyaa@yahoo.com) or the ENDELEO helpdesk

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