Mount Mulanje Land Cover Time Series Analysis

STTA DRAFT REPORT

Community Partnerships for Sustainable
Resource Management in Malawi

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Acronyms

COMPASS II: Community Partnerships for Natural Resource Management
CBNRM: Community based natural resource management
ETM: Enhanced Thematic Mapper (Satellite imagery)
GIS: Geographic Information Systems
GLCF: Global Land Cover Facility
GPS: Global Positioning System
ISP: Integrated Spatial Planning
LS: Landsat Satellite
MMCT: Mulanje Mountain Conservation Trust
MMS: Multi-spectral scanner
NTF: Non-forest Timber products
NSO: National Statistics Office
UNDRO: United Nations Disaster Relief Operation
TM: Thematic Mapper

Introduction

Located in the Southeast corner of Malawi, Mount Mulanje is a granite massif covering an area of approximately 580 km^2. At 3002 meters, Mchese peak is the highest point south tropical Africa. Gazetted in 1927 as a forest reserve, Mount Mulanje is very rich in botanical bio-diversity. Malawi's natural heritage is in part identified with Mount Mulanje's unique mixed mountain ecosystem. An annotated checklist of Mt. Mulanje spermophytes published by Oxford University Herbaria lists some 138 families, 623 genera, and 1319 species, with a 71 species considered to be endemic to this site. Mulanje cedar (*Widdringtonia whytei* Rendle) is categorized as endangered and has important global conservation status. Mount Mulanje has been designated by the World Wildlife Fund as one of 200 global ecoregions earmarked for biodiversity conservation and has been selected as an Afro-montane Regional Centre of Endemism.

Land resource limitations coupled with population growth and an increasing food security problem contributes to serious ecological, economic and social challenges in Mulanje district. The 1992/93 National Survey of Agriculture indicated that 78% of households in the smallholder sub-sector owned or controlled less than 1 ha of land. Mount Mulanje natural resources are under continual pressure from impoverished local communities who have little economic recourse other than to selectively harvest what they can from the limited forest reserve resources. According to the 1987 national census conducted by the National Statistics Office, there are an estimated 185 persons per square kilometer, totaling an approximate 700,000 people. A large percentage of the local inhabitants rely on the forest resource for fuel, timber for construction, a source of pollen for honey production, medicinal plants, revenue from tourism, and the Mount Mulanje's large watershed that protects nine major rivers and hundreds of smaller stream insuring an adequate supply of surface water.

Major threats that contribute to the general decline in Mount Mulanje bio-diversity and ecosystems health include:

- The high population density within a 5-7 buffer area around Mulanje results in unsustainable resource use that contributes to growing poverty. (Note: Due to the rapidly expanding population in Mulanje and Phalombe districts the boundaries of the Mount

Mulanje Forest reserve has been officially reduced in size five times since being gazetted in 1927).

- General lack of awareness regarding the watersheds role in delivering surface water;
- Incentives for comprehensive conservation practices are lacking;
- Continued encroachment and crop cultivation on the lower slopes ;
- Uncontrolled bush fires due to an incomplete fire break network and insufficient capacity to react; and,
- Persistent invasive alien species.

Deleterious consequences associated with degradation of the fragile escarpment include landslide and floods. A landslide occurred in March 1991 near Mchese, north of Fort Lister in Phalombe district. Substantial damage to housing, crops, schools, bridges and telephone lines was reported. According to the United Nations Disaster Relief Operation (UNDRO) two villages (Mwazale and Wopeliwa) were completely destroyed and 14 other severely affected with estimated 700-1000 local residents were killed and up to 100,000 people affected by this event. Heavy deforestation of the watershed contributed to this disaster. Sound stakeholder-based watershed management practices and community outreach can help to reduce vulnerability to such events in the future.

Government policy allows free access for sustainable harvest and utilization of non-timber products as part of a broad strategy to conserve Mount Mulanje bio-diversity and watershed protection. This incentive forms a broad strategy designed to encourage stakeholder participation in the co-management of the Mulanje's natural resources.   COMPASS II (USAID/Malawi; 2004-2008) encourages stakeholder economic growth through active involvement in income generation activities that comply with community-based natural resources management (CBNRM). Through its efforts COMPASS II creates 'win-win' scenarios where healthy ecosystems are promoted through decentralization of natural resources management and enhancing stakeholder ability to harness non-timber forest products (NTFs) and increasing sales of these products. A strategy to achieve these encompassing cross-cutting goals includes strengthening Non-Governmental Organization (NGO) and Malawian governmental agency capacity to assess the state of Malawi's natural resources. Capacity building involves methods in reliable natural resource inventory and analysis to inform the decision making process. Classified land cover maps are an input to a land use management plan.

Complimentary resource conservation and stakeholder economic development are tied to judicious land resource management. However, historically insufficient knowledge regarding the dynamics and management of Mulanje's indigenous forests, poor public forestry education and limited funding are factors that constrain efforts to promote conservation and co-management initiatives aimed at sustainable environmentally conscious development practices. A solid transparent understanding of current land resources is central to stakeholder driven sustainable land resources management. Understanding stakeholder historical interaction with Mulanje's fragile and finite resources can help planners at the community, district and national levels to make informed decisions regarding the management of finite community land resources and those natural resources earmarked for community-based administration (co-management). Land cover change detection and time series analysis provide valuable insight regarding ecosystem status. The spatial and temporal land cover change analytical results presented in this document represent an estimate of major land cover class conversion and the rate by which it they are changing.

Land cover change can be observed through comparing data from selected historical time steps based on the availability of hard copy maps and remotely sensed imagery (such as aerial photography and satellite imagery). This time-series analysis provides an estimate of the extent, location and the rate by which land cover is changing. Observed change must be corroborated/validated through discussion with stakeholder communities and local officials who have extended history in the area. Using validated results from the time-series analysis planners at every level can evaluate ecosystem 'hotspots' to establish program priorities. Through this process the underlying causes responsible for land cover change can be assessed, monitored and objective-specific action plans proposed.

Visualizing land cover change analysis on a map provides a powerful transparent resource that communicates consistent information to decision makers from the village to the national level. Map products generated through this analysis are designed to engage discussion between stakeholders and local officials regarding how to best approach sustainable co-management action for using finite land resources wisely and protecting fragile eco-systems.

Mount Mulanje Forest Reserve Land Cover Classes

The land cover classes used for this time-series analysis have been adapted from Chapman (1962) and Sambo (2000). There are six ecosystems described in the literature that are defined primarily by elevation (see Table 1.1, below).

For the purposes of this analysis, the high altitude and plateau grassland vegetation types have been collapsed into a single ecosystem category due to phenotypic similarities (i.e., high altitude annuals) that make differentiation based on spectral response difficult. Likewise, Afro-montane and mid-Altitude evergreen forest zones have been combined due to the fact that the flora in these ecosystem categories are difficult to discern based solely on elevation and spectral response. Additional bio-physical factors such as soil type, aspect, slope etc. are required to separate these classes using a probabilistic approach. An additional low shrubs and emergent re-growth class was included to capture the remaining land cover that has been disturbed in the lower montane ecosystem.

Cited Ecosystems:	Time-series classes (reclassification)	Elevation (m)	Vegetation type
High Altitude Zone	High-altitude grass	2400-3000 m	*Aloeachete oreogena, Aloe arborescense, Aloe mawii, Helichrysum whyteanum and Xerophytica splendens*
Plateau Grassland Zone	High-altitude grass	1800-2200m	*Erica johnstonia* and *Morea schimperi* (Mulanje iris) both of which are endemic;
Afro-montane (Evergreen forest zone)	Afro-montane/high to mid-altitude forest	1675-2500m	*Widdringtonia cupressoides, W. whiteyi* (Mulanje cedar), *Olea capensis.*
Mid-Altitude Evergreen forest zone	Afro-montane/high to mid-altitude forest	900 – 1800 m	*Newtonia buchananii, Chrysophllum gorungosum* and *Podocarpus* with a rich understorey;
Lowland semi- evergreen forest zone	Plantation	600 – 950 m	*Pinus patula* and *Eucalyptus spp* dominate. Also, *Khaya anthotheca, Adine microcephele* and *Newtonia buchananii are present*
Closed Canopy miombo woodland zone	Miombo/Low altitude forest	700 – 900 m	Dominated by *Brachystegia* species.
Low Shrub/Re-growth	Disturbed/Shrub/re-growth	600-1000 m	Sparse/disturbed low altitude forest and shrub/woody re-growth.

Table 1.1. Cited ecosystems and reclassified time series zones.

Area of Analysis

For the purposes of this analysis the landscape was divided in two distinct areas (see figure 1.1, below):

1- Mount Mulanje forest reserve – an estimated total area of 56,307 ha.

2- A buffer zone. Based on discussion with project partners a 7km radius buffer area was defined around Mount Mulanje. This area includes stakeholder communities that interact with the Mulanje ecosystems – not including areas outside the borders of Malawi (i.e., Mozambique), the total estimated buffer zone area is 88,322.22 ha.

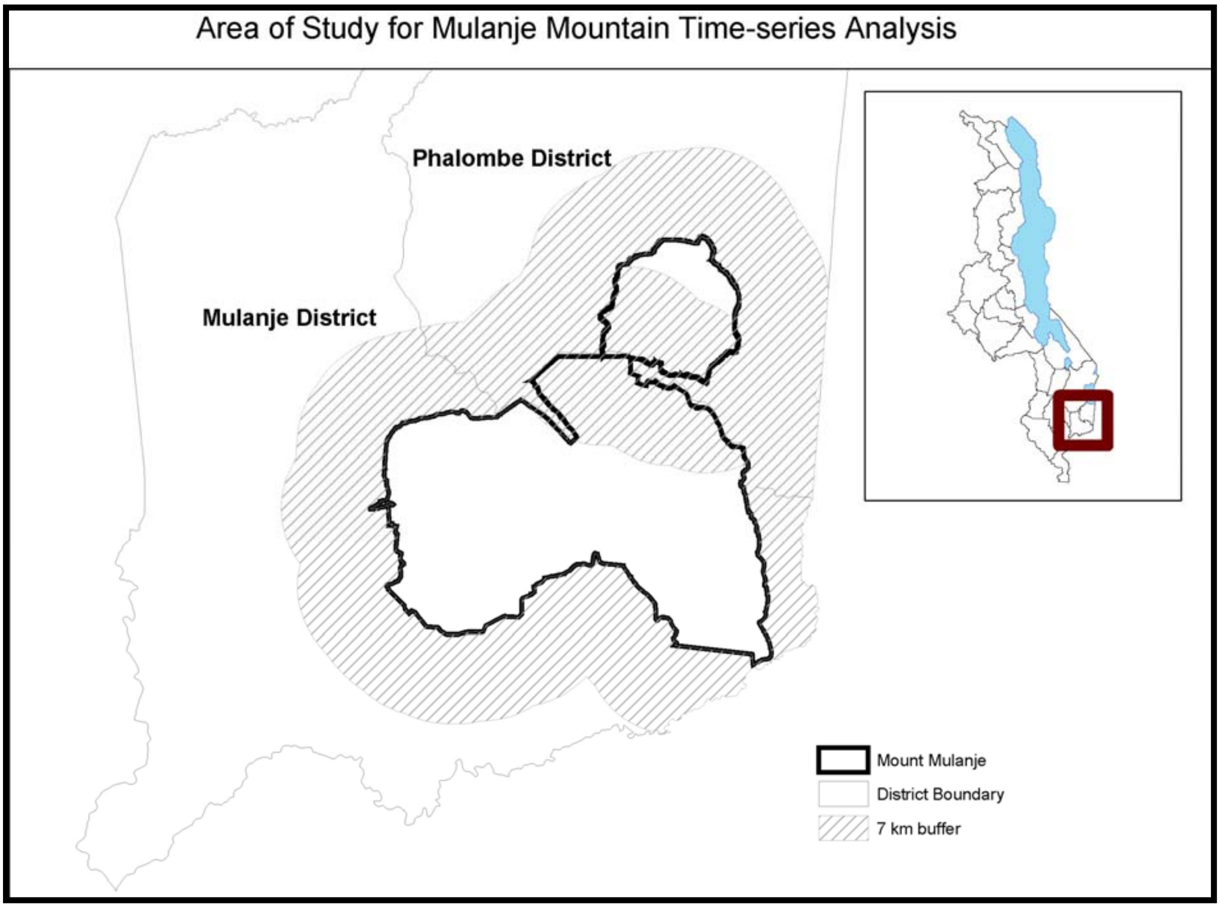

Figure 1.1. Mulanje Mountain Time-Series Analysis Study Area

Methods

Satellite Image Classification

Satellite image classification is the process of deriving land cover data from satellite imagery. All scenes were co-registered (matched) to the 2002 geometrically corrected Landsat Enhanced Thematic Mapper (ETM+) scene. COMPASS II technical specialists design algorithms for automating the process of extracting land cover information from satellite imagery. A supervised classification approach that deploys GPS field surveys to gather ground information was used to ‘’train’ the automated computer classifiers. Hard classifiers (where a discrete decision is made about each pixel) and soft classifiers (where a decision is made about the degree to which a pixel belongs in a class) were used to derive land cover classes described above (table 1.1). Extracted land cover information is subjected to a variety of digital filters to create smooth and contiguous polygons that can be used for management purposes.

Time-Series Analysis

Temporal analysis of land cover change provides insight into the rate, location and extent of land cover change over defined time frame. As stated above, change detection and time-series assessment is based on reliable current and historical spatial data. This analysis made use of certain satellite imagery found in the public domain, much of which can be downloaded cost-free from the University of MD Global Land Cover Facility[1]. Land cover information extracted from historical satellite data are a product of deductive reasoning based on what is currently observed, anecdotal information (usually stakeholder based) and historical research. In the absence of a clear and verifiable record, historical land cover cannot be assessed for ground accuracy. Time-series/change detection analyses are an important method included in the COMPASS II integrated spatial planning (ISP) framework. The ISP framework is designed to help technical specialists and project management to organize spatial technological resources to achieve a specific objective oriented outcome.

Time-Series Analysis Data

Satellite imagery used in this time-series analysis and acquisition dates are shown Table 1 below.

Sensor	**Acquisition Date**	**Resolution (meters)**
Landsat MSS	10/08/1973	80 m multispectral
Landsat TM	07/01/1989	30 m multispectral
ASTER VNIR	09/28/2001	15 m multispectral
ASTER VNIR	10/14/2001	15 m multispectral
Landsat ETM+	05/26/2002	30 m multispectral, 15 m panchromatic

Table 1.1. Satellite imagery used in the Mulanje time-series analysis

[1] http://glcf.umiacs.umd.edu/index.shtml

False color composites were prepared (see annex 1) to enhance visual observation and photo-interpretation. The combination of bands used 2 (visible blue),3 (visible red) and 4 (near infra-red) optimizes detection of vegetation actively producing chlorophyll. Ground data collected in the field in the Mulanje/Phalombe Districts Area (November 2005) was also used for the 2002 supervised classification of the protected area (i.e., training image classifiers).

Land Cover Categories

Protected area:

- Afro-montane/high and mid-altitude forest
- Miombo/low altitude forest
- High Altitude Grassland and Peak Vegetation
- Rock/Outcrop
- Cleared areas
- Disturbed/shrub/re-growth (and sparse low altitude rainforest)
- Evergreen Plantations: Mexican Pine and Eucalyptus
- Shadows/clouds

Buffer area:

- Perennial Tea and macadamia nut plantations
- Bare
- Other/Clouds
- Open miombo/scattered trees and grassland with agriculture

Results

Imagery was collected from sensors on different imaging satellite platforms (see table 1.1) These platforms are configured differently, hence time series results from areas of steep terrain and rock outcrops will be influenced by different shading patterns. Land cover located in steep terrain shows variation this is partly associated with angles of the various sensors resulting in different deep shading patterns. The time of day when the image was acquired and related angle of the sun also results in varying shading patterns in steep terrain. Various image band ratioing techniques were used to 'illuminate' the areas in deep valleys and steep hillsides. However, dark shadows where ground features cannot be discerned are considered no data and are masked out of the analysis (for each scene). Additionally, clouds and cloud shadows are not penetrated by the passive Landsat Satellite sensors and hence are masked out of the analysis as these features represent temporal imaging constraints. The total masked area from forest reserve in each scene was 3516 ha, this allowed each scene to be compared based on what was consistently observed across the three images. The tabular estimates from the Mount Mulanje Forest Reserve time-series analysis are shown in Table 1.2 below.

		Total Observed Masked Land Cover (ha)			Observed Masked Land Cover Change (ha)		
Land Cover Type	Class #	**1973**	**1989**	**2002**	**73-89**	**89-02**	**73-02**
Afromontane/Mid Alt. For	**1**	9292	6140	7928	-3158	1788	-1369
Miombo/Low Alt. For	**2**	14584	11552	12976	-3077	1424	-1653
High grass	**3**	12124	16586	17920	4467	1334	5800
Rock	**4**	2562	4944	2777	2386	-2167	218
Bare soil / no vegetation	**5**	10384	2834	2318	-7458	-516	-7975
Plantation	**6**	851	1337	3292	491	1956	2447
Disturbed/shrub/re-growth	**7**	3032	9403	5585	6349	-3818	2531
Total Masked Area (ha):		**56307**					
Masked shadow area (ha):		**3516**					

Table 1.2. Land cover time series tabular results for Mount Mulanje Forest Reserve.

The results demonstrate general trends regarding distribution of forest cover over 3 ten year plus time steps. Forest change in Mount Mulanje forest reserve is a heterogeneous spatial occurance where forest is cleared and secondary forests become re-established. This pattern is influenced by shifting cultivation practiced by many of the households living within the buffer. Afro-montane/mid altitude forest and Miombo/low altitude forest were subject to a relatively sizeable deforestation event from 1973 to 1989. A slow gradual woody plant successional recovery period was observed from 1989 to 2002. Spatial distribution of this resurgence varies per land cover category. The Afro-montane/mid altitude forest appears to be recovering in the eastern section of the reserve – this is appears to be woody species recovering at mid-high elevations in the Southeastern area. Whereas, pockets of on-going deforestation is observed throughout the duration of the time series assessment.

Land Cover Class		**1**	**2**	**3**	**4**	**5**	**6**	**7**	*1989 total*
Afromontane/mid Alt	**1**	5287	99	58	1	236	18	442	*6141*
Miombo/Low Alt	**2**	168	9525	0	0	1596	0	264	*11553*
High grass	**3**	2357	0	9397	1555	2813	98	367	*16588*
Rock	**4**	37	255	2624	977	1027	0	24	*4944*
Bare land /soil	**5**	8	1165	0	0	1496	0	165	*2835*
Plantation	**6**	0	529	7	3	74	725	0	*1337*
Disturbed/shrub/re-growth	**7**	1433	3008	35	23	3138	5	1763	*9404*
1973 total		*9292*	*14584*	*12124*	*2562*	*10384*	*851*	*3032*	

Table 1.3a. 1973-1989 Cross-tabulation result (Columns 1973, Rows 1989)

During the 1973-89 time step an estimated 2357 ha of Afro-montane/Mid Altitude forest was converted to high grass (indicating removal of tree species) and 1433 ha transitioned to disturbed/shrub or re-growth. This event occurred predominantly in the south and southeastern region of Mount Mulanje (see figure 1.2a and 1.2b). Miombo and Low altitude forest types where also under heavy pressure during the 1973-89 period with 1165 ha converting to bare soil and an estimated 3008 ha changing into the disturbed land cover category. Likewise, this Miombo deforestation event occurred primarily on the eastern border of the forest reserve. By 1989 established plantations (*eucalyptus*) are apparent in the eastern border where Miombo forest had been fragmented due to deforestation.

Land Cover Class		**1**	**2**	**3**	**4**	**5**	**6**	**7**	*2002 total*
Afromontane/mid Alt	**1**	5296	75	975	17	6	15	1545	*7929*
Miombo/Low Alt	**2**	82	9975	3	21	620	119	2158	*12977*
High grass	**3**	430	10	15274	1926	0	0	282	*17922*
Rock	**4**	0	3	202	2490	6	23	49	*2772*
Bare land /soil	**5**	0	201	0	209	1813	9	86	*2318*
Plantation	**6**	69	332	25	13	173	914	1767	*3293*
Disturbed/shrub/re-growth	**7**	263	956	109	270	218	256	3516	*5586*
1989 total		*6141*	*11551*	*16587*	*4944*	*2835*	*1336*	*9402*	*52796*

Table 1.3b 1989-2002 Cross-tabulation result (Columns 1989, Rows 2002).

The overall rate of forest cover loss declined during the 1989-02 time step. An estimated 693 ha of Afro-montane/Mid altitude forest were converted into disturbed/shrub/re-growth class and high grass. Thinning of afro-montane forest appears to be occurring in the western section of the forest reserve (figure1.2a – 2b, figure 1.5a – 5b). Afforestation of mid-altitude woody species is observed in the east and southeast, this region was heavily affected by forest clearing from 1973-89. Between 1989 and 2002 an estimated 1544 ha of disturbed/Shrub/re-growth transitioned to Afro-montane/mid-altitude forest eco-type. This transition back to mid altitude appears to be occurring primarily in the Southeast and Eastern sections of the reserve. Miombo/Low altitude forest cover remains under pressure with nearly 1000 ha being converted to disturbed/shrub/re-growth by during the 1989-2002 time step. Spatial distribution of on-going degradation of miombo/low altitude forest is spatially distributed on all sides of the forest reserve.

There is apparent recovery with over 2000 ha of disturbed/shrubs/re-growth converting to miombo/ low altitude this might be partly associated with unproductive agricultural plots going fallow allowing for woody plant regeneration. However, as population increases the pressure for individual households to identify new areas for crop cultivation within the forest reserve boundaries will increase. Expanding rapid population growth can result in a decrease in fallow period. This could have deleterious impact on the ecosystem's ability to recover. By 2002, plantation species (primarily eucalyptus) have become established throughout the south, southeast and eastern region of the Mount Mulanje forest reserve.

In addition to the forest cover change observed within the boundaries of the forest reserve, change detection/time-series was conducted for the 7 km buffer area that is served by the Mount Mulanje catchment area. The buffer area is heavily influenced by annual agricultural land use. Such patterns are highly variable on annual basis and difficult to analyze effectively with three satellite images with 10+ year intervals. Practical annual vegetation time series analysis utilizes satellite imagery for the same season over several consecutive time steps preferably during the leaf on period when chlorophyll is actively produced. Plant cover that is photosynthesizing is strongly reflected in the species specific wavelengths in near infrared segment of the electromagnetic spectrum making easier to discern between plant species. The imagery used in this analysis was acquired through public domain download. Given the coarse temporal resolution of this time-series analysis, this resource is most appropriate for classifying perennial vegetation where seasonal and annual change is less variable.

Land cover type	Total Observed Area			Observable Change		
	1973	1989	2002	73-89	89-02	73-02
Tea/macadamia/eucalyptus plantations in buffer zone	10450.17	7294.86	7161.6	-3155.3	-133.29	-3288.6

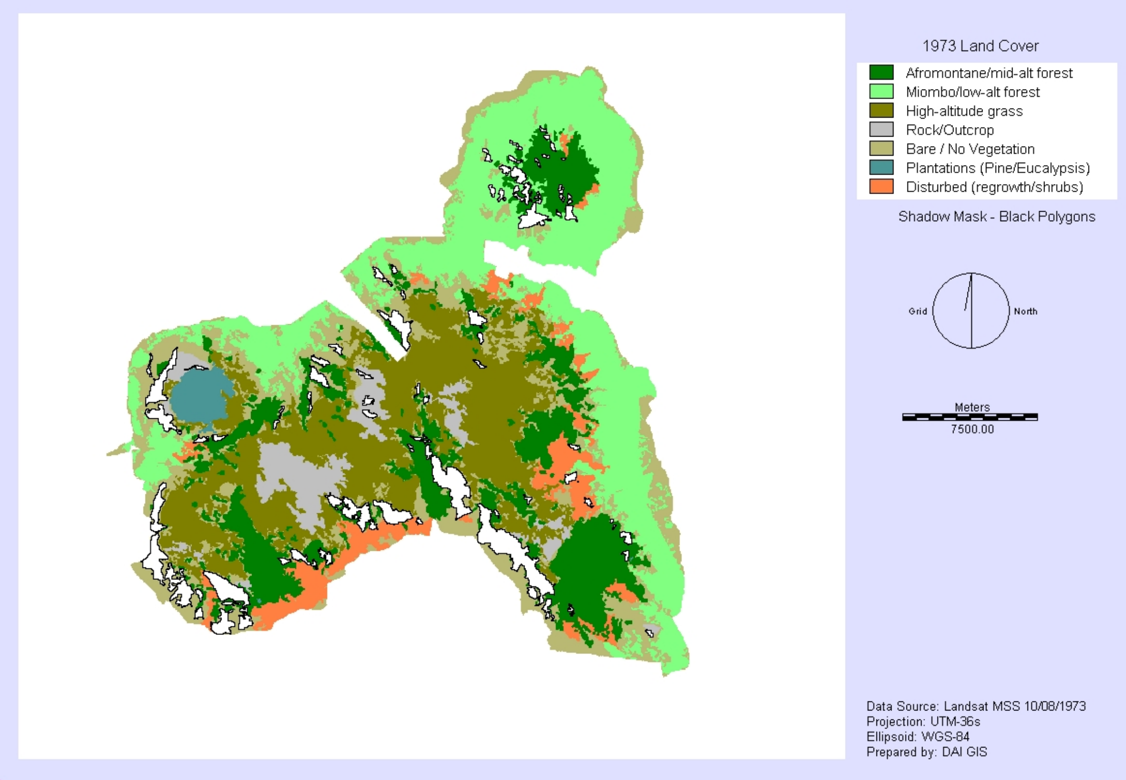

Figure 1.2a. 1973 Estimated Mulanje Forest Reserve Land Cover.

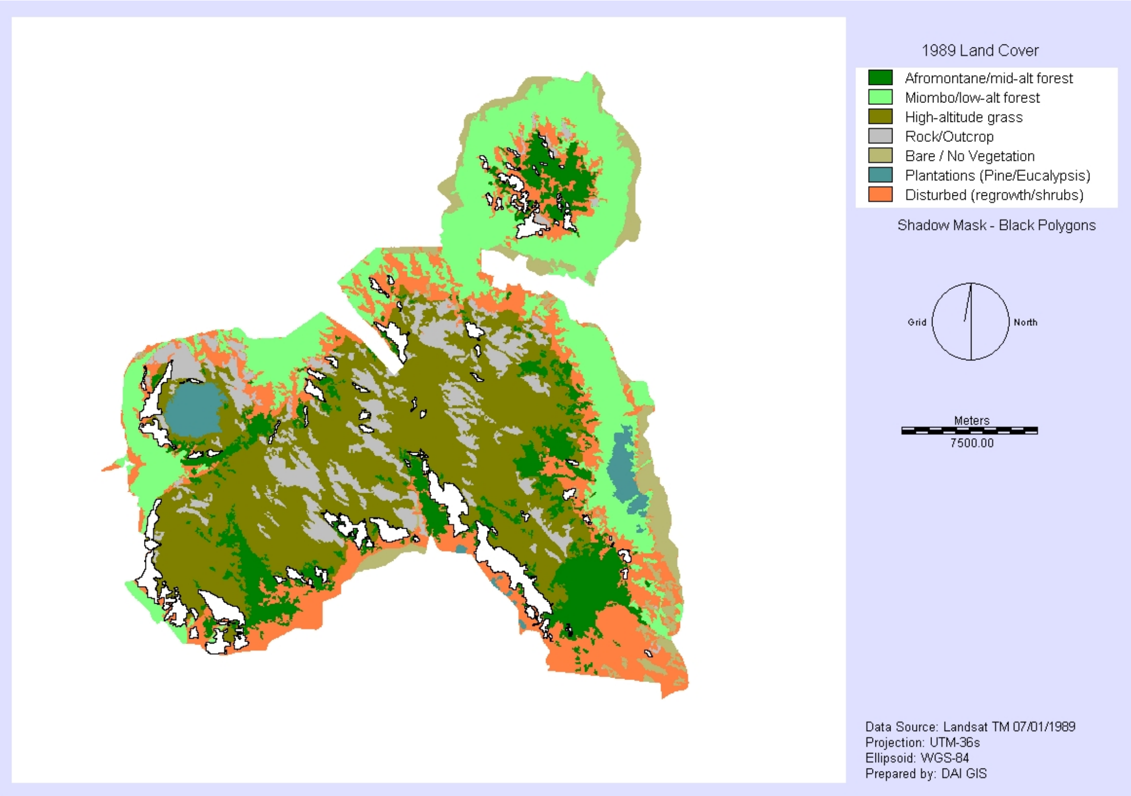

Figure 1.2b. 1989 Estimated Mulanje Forest Reserve Land Cover

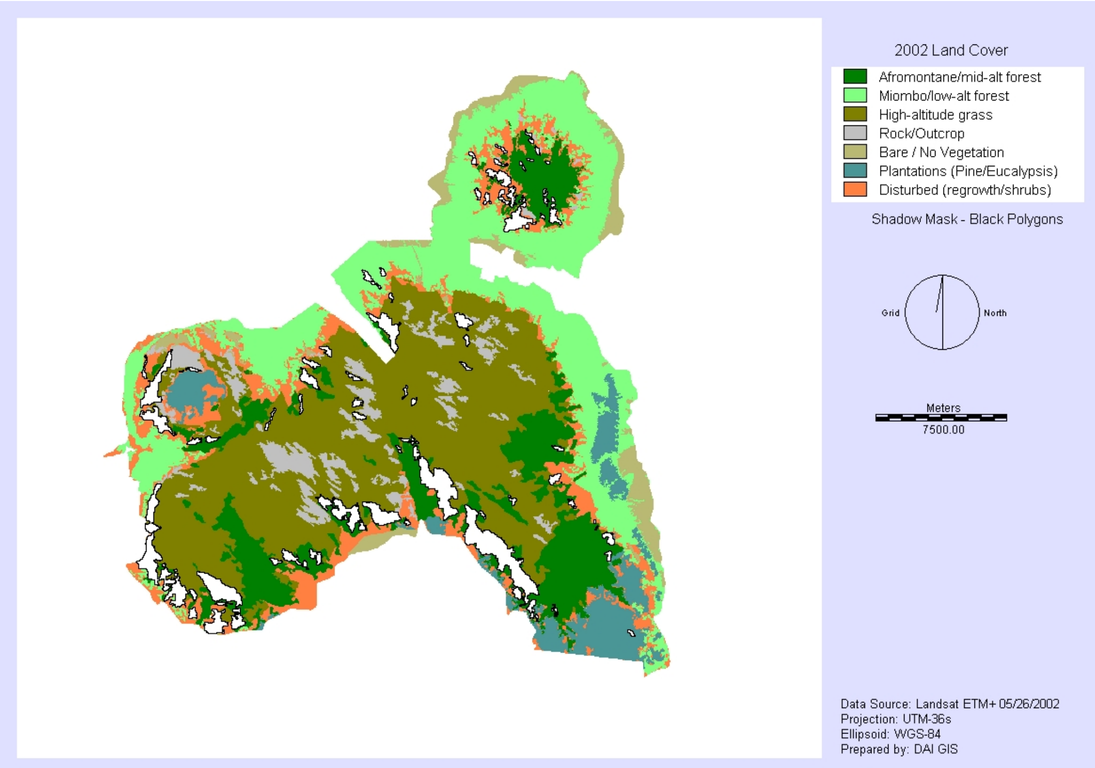

Figure 1.2c. 2002 Estimated Mulanje Forest Reserve Land Cover.

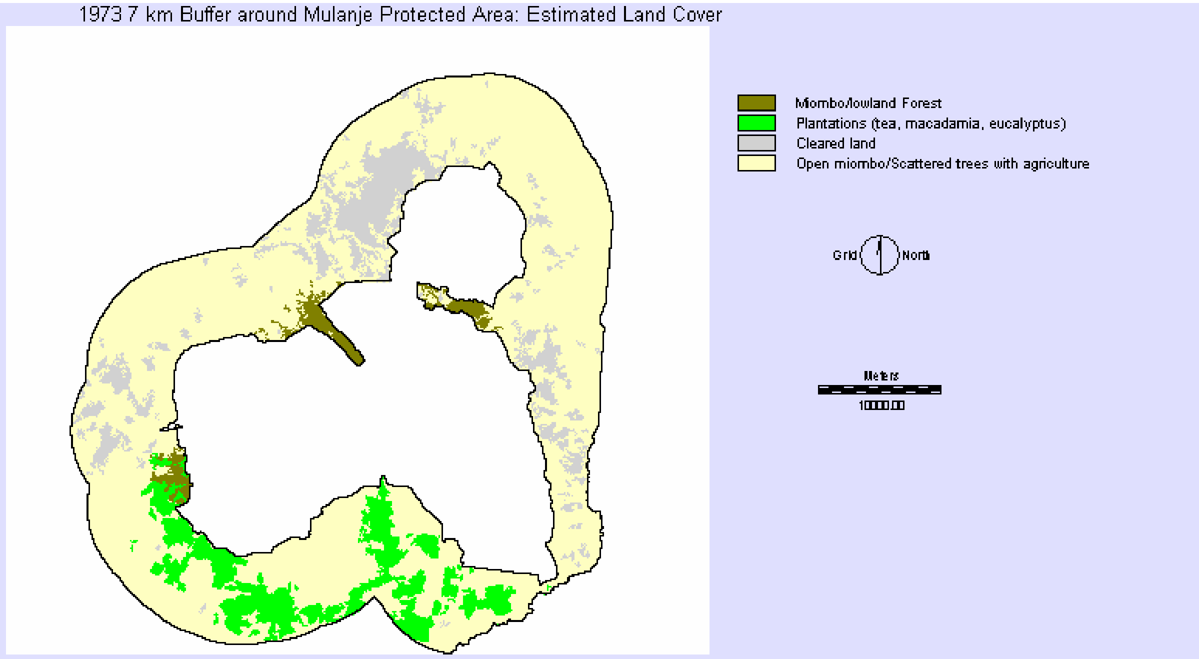

Figure 1.3a. 1973 Estimated Mulanje Forest Reserve buffer area land cover.

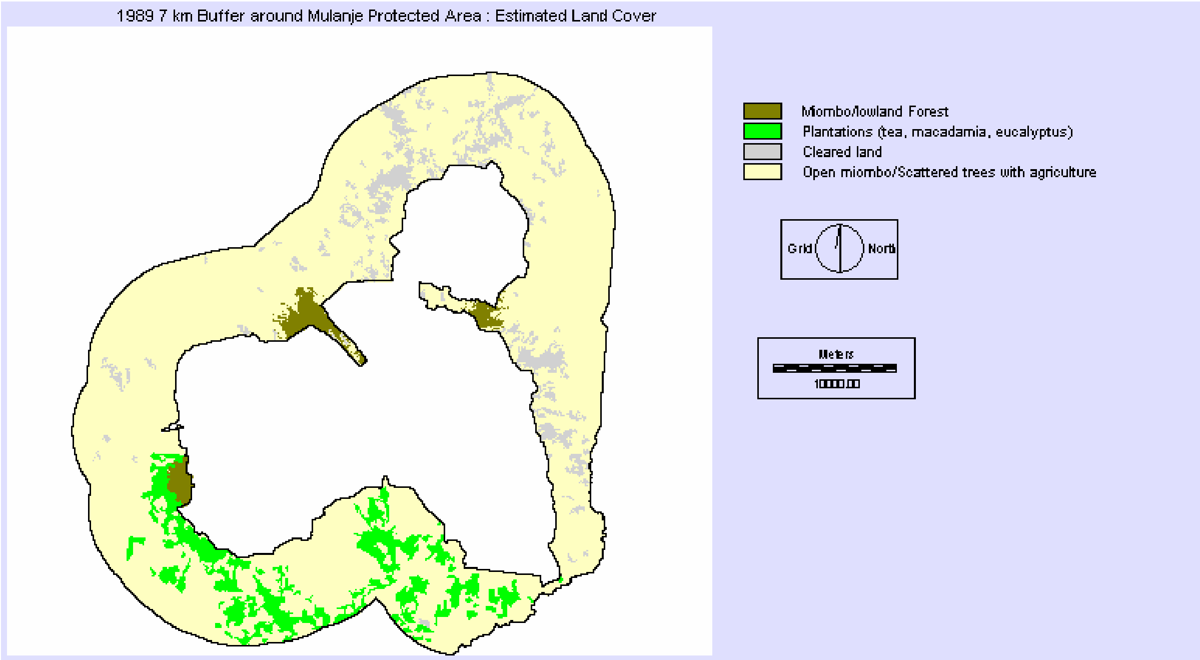

Figure 1.3b. 1989 Estimated Mulanje Forest Reserve buffer area land cover.

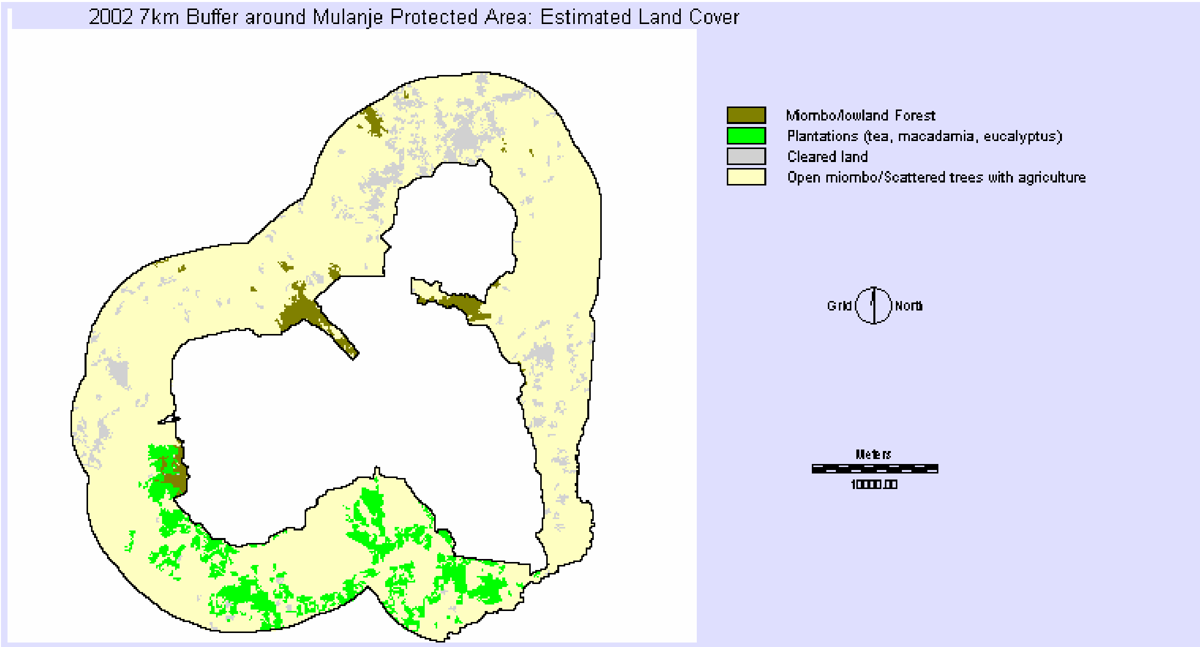

Figure 1.3c. 2002 Estimated Mulanje Forest Reserve buffer area land cover.

Discussion

Malawi forest reserves, national Parks and Wildlife Reserves, and Customary Land forests are afforded full protection or open to regulated grazing or burning. Many forests located on customary land, have no set management plan and are commonly degraded due to bush fires, clearing cultivation land, and felling trees. Dense population associated with the 7 km buffer area around Mount Mulanje forest reserve exerts heavy pressure on local natural resources. Although it is illegal, shifting cultivation is a farming system that is practiced especially in the Mount Mulanje forest reserve's miombo/low altitude eco-zone. Nyondo (2002) describes several primary types of secondary forest re-growth that occurs in Malawi:

- Swidden fallow secondary forests recover primarily through natural processes in woody fallows associated with shifting agriculture. Previously cultivated land is left fallow with the intention of soil recouping lost nutrients for future cultivation. This process appears to occurring in the miombo/low altitude forest zone where expanding population, limited land resources, and food security concerns compel neighboring households engage in shifting cultivation in the protected area. Increasing pressure on the land reduces the time of the fallow and compromises the capacity of the land to recover to the point where the soil can support cultivation.
- Rehabilitated forests where the forest recovery process is augmented through protection from chronic disturbances, site stabilization and active planting to foster the regeneration process. Human response to removal of tree cover in Mount Mulanje forest reserve included replanting of large tracts of eucalyptus in the southeastern and eastern zone.
- Post abandonment secondary forests regenerate primarily through natural processes after having been abandoned by farmers or livestock owners (normally, a function of land becoming unproductive)
- Post extraction secondary forests are a product of natural regeneration after a major clearing of original forest. Assumed regeneration of secondary forests is observed in the higher slopes (1400-1600m) where significant deforestation was observed during the first time-step.
- Post fire secondary forest

These observations need to be field validated in Mount Mulanje natural forest for accuracy.

The mapped results (figures 1.2-1.3) show the spatial distribution of observable land cover change. Plotted time series results provide estimated rates of change over time (see figure 1.4 below). The rapid increase in high altitude grass, an annual vegetation type is in part due to the 1973 image was procured during a drier time of the year as compared to the 1989 and 2002 images.   Mature perennial species tend to demonstrate less fluctuation as they persist year round. This is an example of where mapping annual vegetation cover using coarse time-series temporal resolution yields relatively limited knowledge. An annual vegetation time-series is optimized using imagery representing consecutive years preferably with several images per year that demonstrate seasonal change.

Rock outcrops and shallow/bare soils tend to reflect in a similar wavelength making differention difficult, especially when using the MSS coarse 80 meter resolution during a dry cycle. However, during the rainy season grasses become established on the high altitude

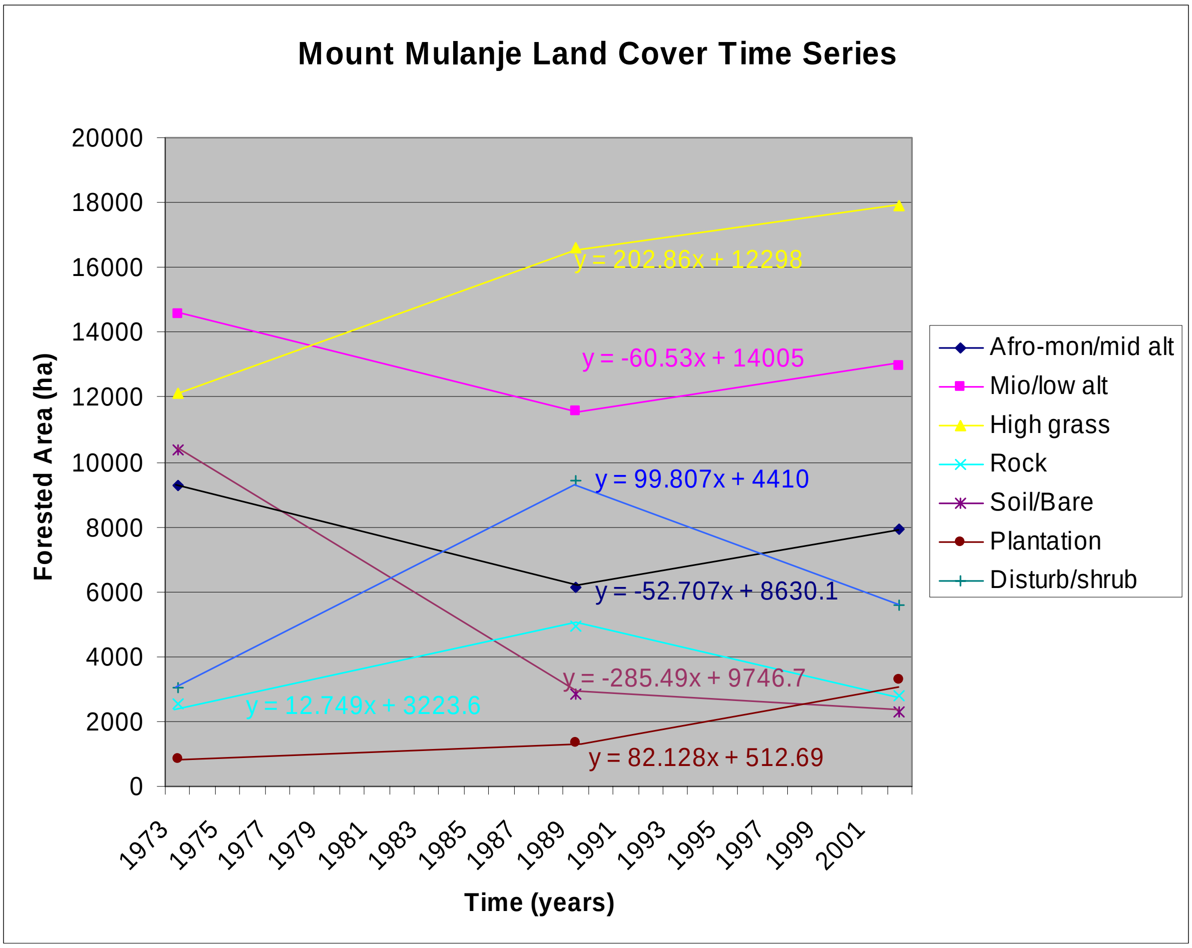

Figure 1.4. Plotted Mulanje Forest Reserve time-series data

shallow soils. The presence/absence of grasses and other annuals at during different seasons affects bare land/soil, high grass and rock area estimates from one time step to the next.

Deforestation rate for miombo/low altitude forest and afro-montane/mid altitude forest was a significant event during the 1973-89 time step. However, observed changes in high altitude perennial vegetation are relatively limited. Forest change at elevations 1700-2300m appear to be occurring near established paths and trails.   Figures 1.5a and 1.5b show location of suspected thinning of afro-montane forest.   Evidence of thinning is observed in several locations, this appears to be associated with selective removal of the forest tracts including Mulanje cedar as it has a high market value that creates incentive for its harvest. However, this observation is not validated and needs to be assessed for accuracy in the field.   Illegally harvested cedar planks are carried down the escarpment by the poacher, a laborious task when considering the steep slopes that must be traversed with a very heavy load. Previously, a timber transport cableway moved logs from the edge of the plateau to the Likhubula Forestry Station. This cableway is no longer operational and planks are carried down manually.   Geographic location tends to provide a natural protection for the Mulanje cedar. This is especially true for those cedar stands that thrive in the deep gorges as these locations provide very challenging access to poachers and provide a natural shield against fire.

The majority of the change observed in the Afro-montane/Mid-altitude forest appears to occur at elevations associated that are dominated by mid-altitude forest types in the South eastern region of Mount Mulanje. Human encroachment on all sides of the mountain was especially important during the Mozambique refugee crisis. The time-series indicate that forest was cleared at elevations up to 1,500m. Persistent population pressure and increasing food security requirements result in on-going forest clearing on lower and mid elevation slopes. In some locations, these cultivated slopes are steep, unstable and characterized by high erosion potential removal of natural vegetation results in accelerated erosion and degradation of the ecosystem. Shifting cultivation practices associated with decreasing fallow tend render soils on the lower slopes unproductive for agriculture. Hence, cultivation spreads throughout the protected as soils nutrients are depleted and previously cultivated fields are abandoned.   Observations indicate that recovery of woody secondary species does occur. However, increasing human pressure for crop cultivation could compromise the ability of the land resource to regenerate.

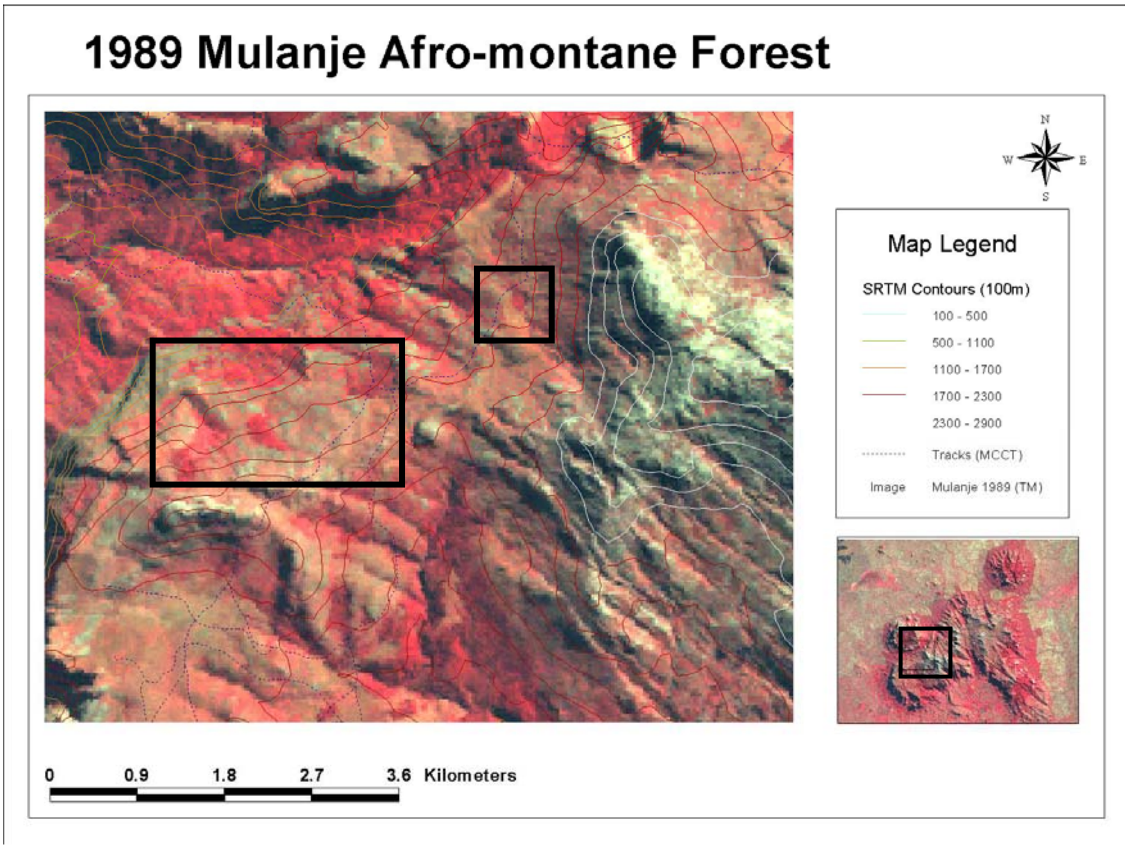

Figure 1.5a. Afro-montane forest plots in 1989 (forest tract in black box).

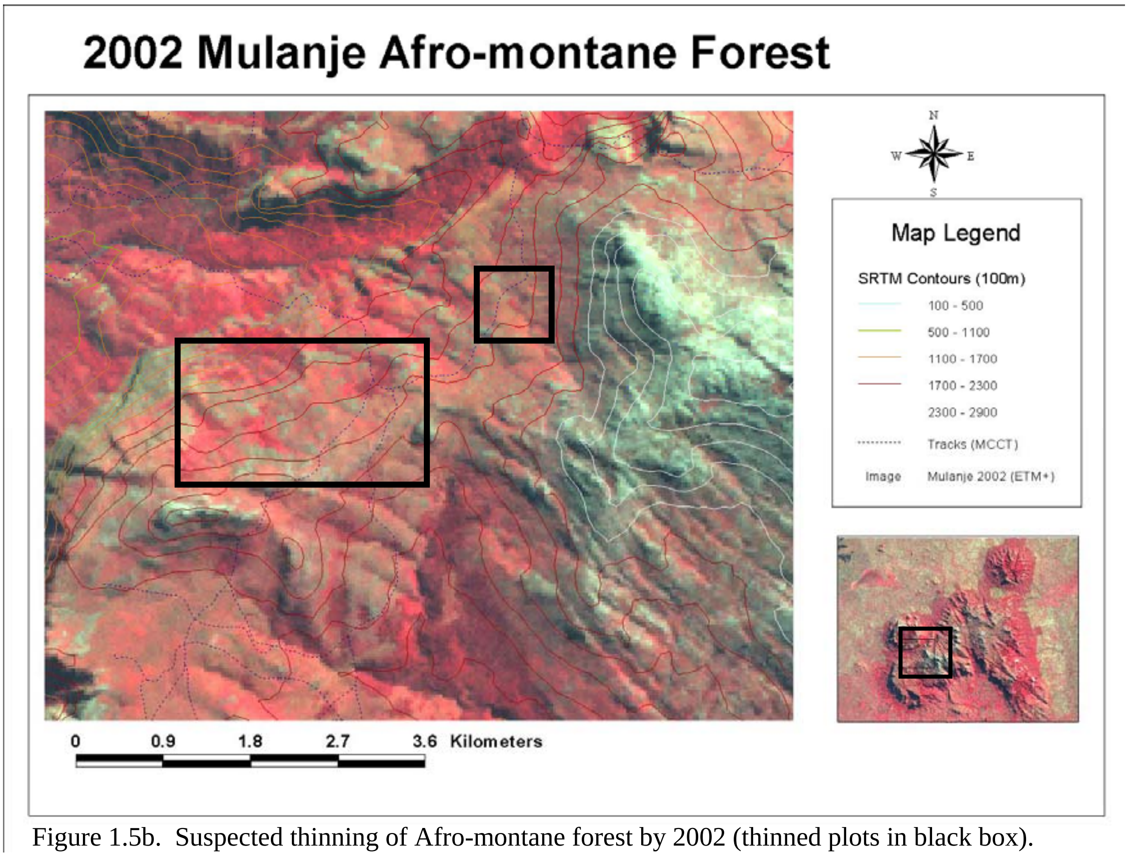

Figure 1.5b. Suspected thinning of Afro-montane forest by 2002 (thinned plots in black box).

Lands cultivated by stakeholders within the boundaries of the forest reserve are not designated customary land therefore little investment is made to keep these illegally cleared lands in agricultural production. In addition, poorly maintained fire breaks and unrestrained fires, many of which are intentionally set to hunt bush meat can reach can result in extensive ecological damage. These un-validated observations may account for part of the forest loss and gain observed in the Mount Mulanje forest reserve time-series.

Perennial vegetation time-series results are consistent with published literature, Bird Life International (http://www.birdlife.org/) reports that human encroachment and consequential deforestation over recent decades has severely impacted Mulanje fragile ecosystems. During the 1980's a significant deforestation event occurred in Chisongeli (SE Mulanje), the largest single block of rainforest zone in Malawi. Large tracts of disturbed forest characterized by shrubs and re-growth are evident in the southern and southeastern (Chisongeli) in the 1989 image (figure 1.4). Clearing low altitude forest for subsistence agriculture in the 1980's was attributed to landless tea estate workers and refugees from Mozambique displaced during the civil war. In an attempt to impede encroachment, the World Bank funded a *Eucalyptus* plantation project in the late 1980s. Plantation *Eucalyptus* was observed growing in the forest reserve southeastern region during in the 1989 imagery. Plantation evergreen area, including *eucalyptus* is detected to a greater extend in the 2002 imagery, this is in part associated with immature trees planted in the late 1980's reaching maturity by 2002. The time series also demonstrates a slow gradual increase for miombo/low altitude and Afro-montane/mid-altitude forest since the significant deforestation events of the 1980's.

The role of Mulanje Forest Reserve Non-government agencies is instrumental in promoting national and international awareness regarding the ecological and human importance of this unique forest reserve. Gradual recovery of low and mid altitude forest in some areas may be a result of increased awareness of the importance of the natural ecosystem's role as a watershed that provides critical surface water for the local population.

Summary:

This spatial analysis of land cover change over a 33 years time frame incorporated a temporal resolution that is relatively coarse (one time-step for every 10+ years). However, results confirm ground observations that reported heavy deforestation in the mid-1980s and efforts to establish *eucalyptus* plantations to stabilize slopes and to provide income. The analysis points to afforestation occurring in areas where heavy deforestation was documented and where apparent action to protect slopes at low to mid-altitude was taken. However, there is continual pressure on all of Mulanje's unique natural resource assets. The economic return for illegally felling a single Mulanje Cedar may be worth the risk for an impoverished household. A rapidly expanding population will require increased crop cultivation land resources which may continue to threaten Mulanje's lower and mid-altitude forested slopes. It appears that the current fallow (over 10+) allows enough time for natural systems to partially recover. Increased demand for finite cultivation land resources may diminish the fallow period and constrain the natural ecosystem capacity to recover. This point illustrates the importance of the COMPASS II, NGO and Government initiatives aimed at expanding non-timber forest product markets and other economic development programs. Co-management of Mount Mulanje forest reserve using a sound CBNRM approach imparts stakeholder ownership of these valuable assets. Ownership implies responsibility to care for and protect these resources to achieve greatest economic benefit.

Continued spatial monitoring of Mulanje forest reserve land cover can help to target activities that foster greater stewardship of forest resources at locations where growing human pressure is evident. These efforts will also help to reduce local population vulnerability to landslides and floods while better assuring a constant supply of surface water. A solid integration of forest resource conservation and economic development can help to insure that Mount Mulanje forest reserve ecosystems will remain intact and functioning for generations to come. Information contained in this report may provide additional resources that can inform government policies aimed at promoting Mount Mulanje forest reserve conservation and environmentally conscious stakeholder economic development.

Recommendations

Discerning Mid-Altitude from Afro-Montane Forest:
Elevation is a primary factor used to distinguish various land cover in the literature cited. However, there are other factors (soils, temperature, aspect, etc) that are important to classifying these ecosystems that are examined in this analysis. For example, the topography of the massif shows extreme diversity with ravines cut into high slopes creating micro-climates protected from fire for important tracts of forest, improved understanding regarding these micro-climates may shed more light on the distribution of the Mulanje Cedar. Using additional information to better refine the physical environment into ecological zones will help to provide better further divide the vegetation types in the land cover classes. A workshop that includes Mount Mulanje forest ecosystems experts can shed important light on distinct forest categories and how they may be best differentiated in a land cover analysis. This will help provide estimates for individual forest ecosystems.

Forest change independent variable analysis and predictive models:
Ground surveys with stakeholder communities can lend insight into the fuel, food security and income requirements for the communities living within the 7km Mulanje Mountain buffer. Such information can be spatially referenced and included as a multiple regression analysis independent variable in an analytical mapping application. This allows the dependent forest cover variable to be evaluated in terms of the independent variables, a preliminary step in predictive modeling that incorporates results from the time-series analysis. This understanding can inform project decision makers regarding project priorities.

On-going time-series monitoring, field validation and training:
The COMPASS II GIS team can benefit from targeted time-series training. This will allow for on-going monitoring of rate and location of land cover change by the local team using new mid-resolution satellite imagery as it becomes available. On-going monitoring serves as a useful internal performance monitoring indicator showing where COMPASS II CBNRM activities are located and the relative impact the project may be having on conserving Mount Mulanje forest reserve bio-diversity. Field validation and accuracy assessment will provide a degree of confidence to which the results can be used in decision support.

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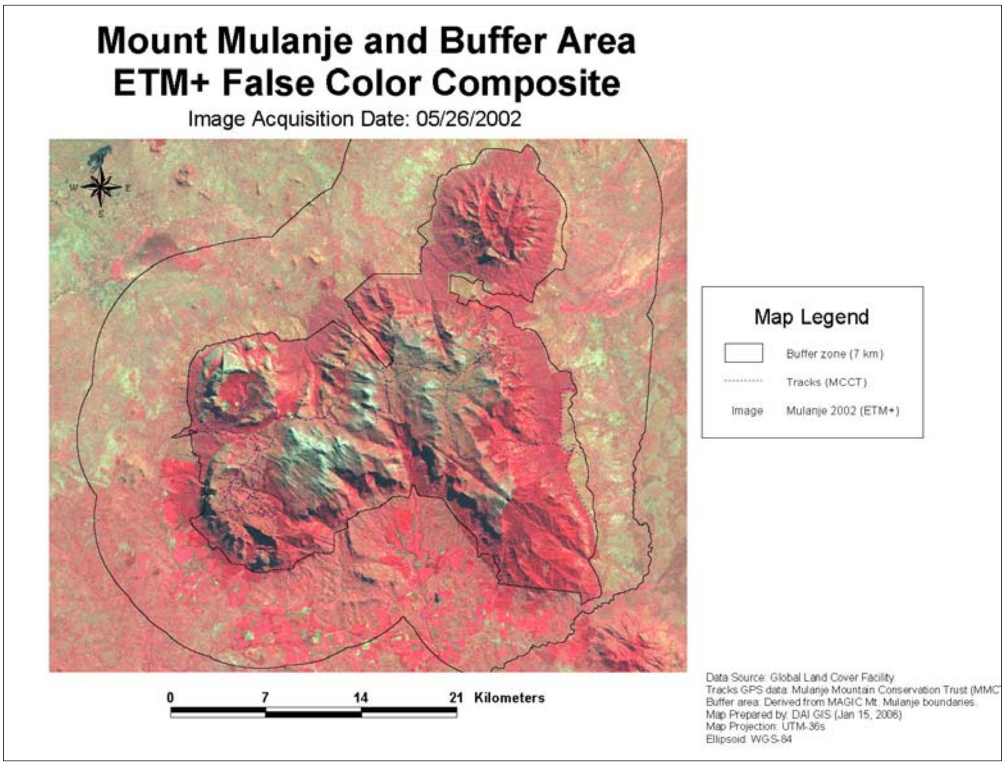
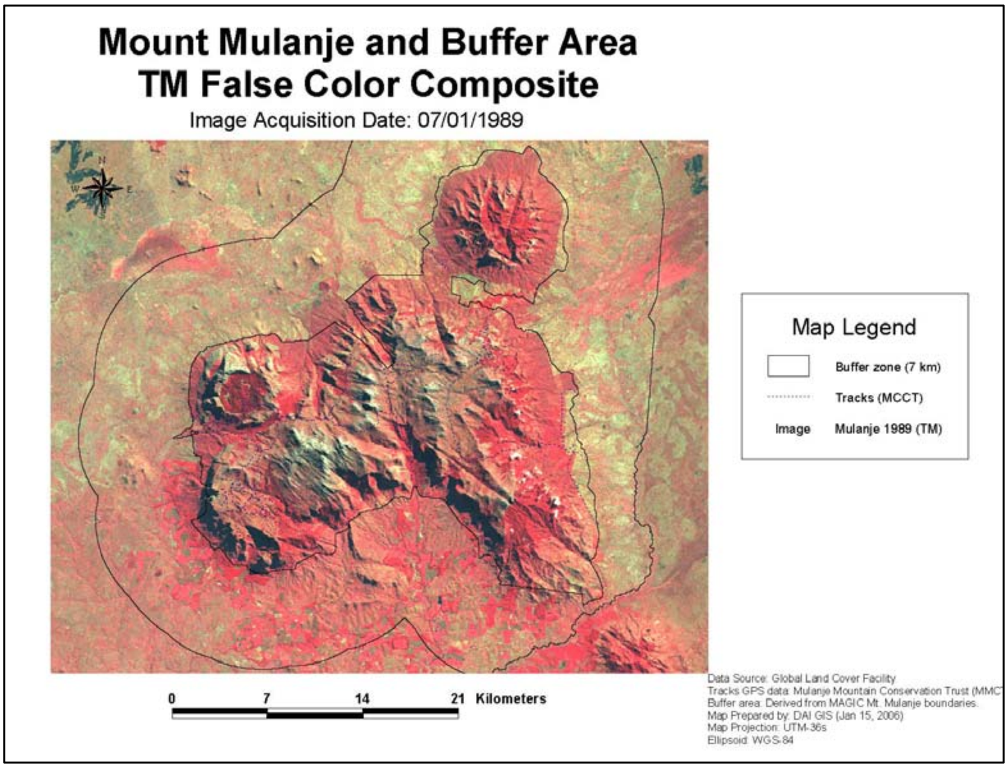
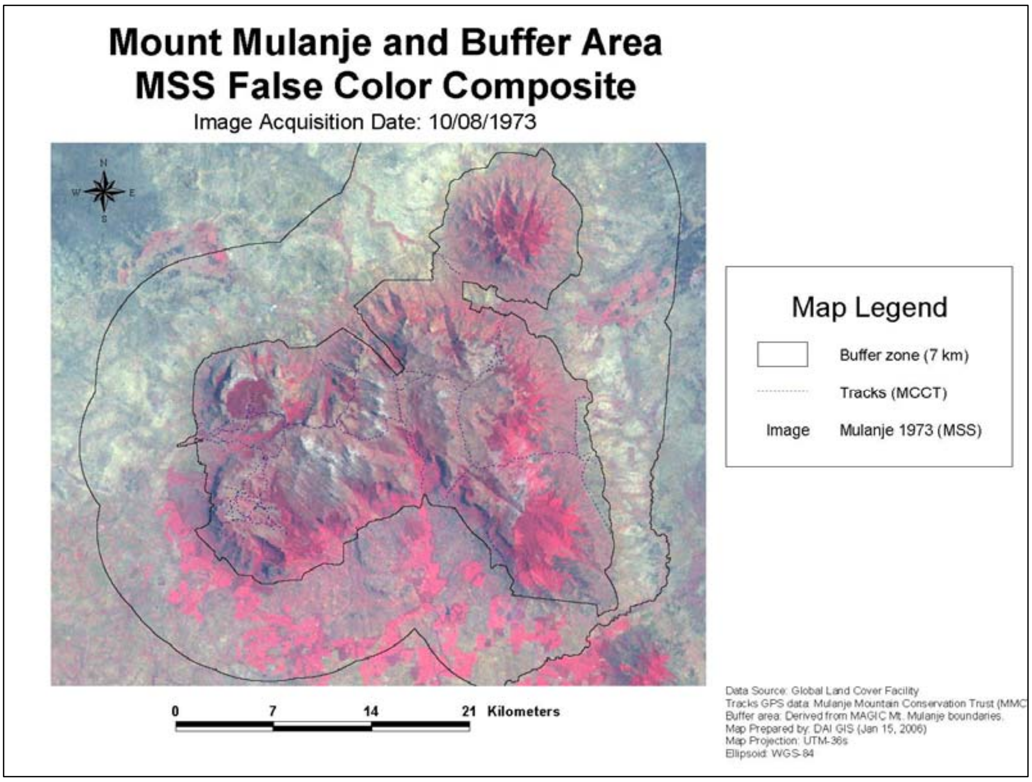
ANNEX 1. MOUNT MULANJE TIME-SERIES FALSE COLOR COMPOSITES






Mount Mulanje and Buffer Area
MSS False Color Composite
Image Acquisition Date: 10/08/1973
Map Legend
Buffer zone (7 km)
Tracks (MCCT)
Image
Mulanje 1973 (MSS)
0
7
14
21
Kilometers
Data Source: Global Land Cover Facility
Tracks GPS data: Mulanje Mountain Conservation Trust (MMC
Buffer area: Derived from MAGIC Mt. Mulanje boundaries.
Map Prepared by: DAI GIS (Jan 15, 2006)
Map Projection: UTM-36s
Ellipsoid: WGS-84

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ANNEX 2. SCOPE OF WORK

COMMUNITY PARTNERSHIPS FOR SUSTAINABLE RESOURCE MANAGEMENT IN MALAŴI (COMPASS II)

Development *Alternatives*, Inc.

Scope of Work	
Position:	Remote Sensing/GIS Mapping Specialist
Expected Duration:	35 days LOE
Proposed Candidate:	Ioana Bouvier
Anticipated Start Date:	October 2005
Purpose of Assignment:	To conduct a land cover and primary forest change analysis for the Mount Mulanje and surrounding area in the Mulanje and Phalombe Districts in Malawi and to provide technical support for the Mulanje ecosystem valuation study.
Deliverable(s):	Brief technical report discussing results of a time-series analysis for a selected area in Malawi. Plan and recommendations for land use change analysis to support the landscape-scale ecosystem health monitoring

Background and Program Context

The purpose of COMPASS II (USAID/Malawi; 2004—2008) is to enhance household revenue from participation in community-based natural resource management (CBNRM) initiatives that generate income as well as provide incentives for sustainable resource use in Malawi. Building on the solid foundation established under NATURE, MAFE, and COMPASS I towards building capacity of the Malawian government and nongovernmental organizations to adopt strategies that ensure long-term economic and environmental sustainability, COMPASS II seeks to accomplish three objectives:

to increase the decentralization of natural resource management,
to enhance rural communities' capacity to sustainably manage their natural resources, and
to increase sales of natural resource-based products by rural households.

Achievement of progress toward these objectives requires a multi-faceted approach toward devolving authority to manage natural resources to field levels, facilitating the acquisition of skills to dispatch that authority responsibly, and profiting from sustainable utilization of those natural resources. The Capacity Building & Public Awareness team is responsible for achieving progress toward the second of these objectives: enhancing rural communities' capacity to sustainably manage their natural resources. One of the foundations of enhancing capacity in natural resources management will be the widespread dissemination of knowledge about natural resources and the various aspects related to their sustainable management by communities.

Knowledge relating to the extent of forest resources and other land use over time can help stakeholders to assess the rate of resource utilization. Stakeholder planning for sustainable land use is supported through an analysis of previous trends and the factors that influence these trends. This information can also be used to inform predictive land cover models that illustrate how policy and subsequent management practices can influence land use.

This assignment will have two main purposes. The first is to establish a rate of forest and general land use change for a selected area in Malawi. This will provide an indicator that helps determine the relative change over time as related to CBNRM activities (including COMPASS I and II and other programs), helping to determine whether they have had an influence on reducing the rate of deforestation. It will also provide the historical land use data needed for the valuation study of the resources of Mulanje Mountain, being carried out by another COMPASS II consultant. A significant amount of coordination is expected between this assignment and the Mulanje Mountain valuation study. The second purpose of this assignment, therefore, is to provide background support on spatial modeling for the valuation study, to ensure that the resulting datasets can be integrated with COMPASS GIS spatial databases and that insofar as possible the analytical work from the valuation study will be usable for other COMPASS activities.

Position Overview and Deliverables

The GIS/Remote Sensing Specialist will work with the COMPASS II Chief of Party and the GIS/IT Specialist as needed to analyze imagery and develop rates of land use change for the Mulanje Mountain area. The land classes covered in the time-series analysis are: primary (dense) forest; natural (high-altitude) grasslands; plantations (pine); and perennial/tea plantations. The work covered by this SOW is limited to the districts of Mulanje/Phalombe. The area of analysis includes the protected Mulanje Mountain area and will correspond to the area of analysis defined in the Mulanje Mountain Valuation Study.

The position requires short-term assistance for a period of approximately 35 person-days LOE, beginning on or about October 10, 2005 and concluding on or about February 28, 2006. The position requires a total number of 12 days based in Malawi and 23 days based in the DAI Office in Bethesda.

The GIS/Remote Sensing Specialist will work primarily with the Chief of Party and the COMPASS GIS/IT Specialist to complete this assignment. The GIS Specialist will coordinate the work with, and report to, the Chief of Party for technical guidance and identification of priorities within this Scope of Work.

The GIS/Remote Sensing Specialist will also work with the COMPASS valuation specialist to provide technical support and input as needed into the spatial predictive modeling work for the valuation study. Technical aspects are expected to be coordinated closely with the valuation specialist in Malawi or in the Bethesda DAI home office and other venues as appropriate.

Deliverables required from the GIS/Remote Sensing Specialist are:

Brief report describing the findings from the time-series analysis in the selected areas and the rate of change from primary forest to a different land cover category. The report will include recommendations for using the forest change analysis to support the COMPASS landscape-scale ecosystem health monitoring and for transferring this analysis to other COMPASS target districts in Malawi.

Maps showing land use change (classes as defined above) in the Mulanje/Phalombe area that corresponds to the area defined in the Mulanje Mountain Valuation Study.
Technical support to the valuation study; this will be incorporated into the deliverables from the COMPASS Valuation Specialist and will not lead to a discrete deliverable from this assignment.

Specific Tasks
As described above, the GIS/Remote Sensing Specialist will identify and analyze imagery to determine the rate of change for the selected area around Mulanje Mountain in the Districts of Mulanje and Phalombe. The Specialist will perform the following specific tasks required to achieve these objectives:
Identify and acquire available remotely sensed data. The specialist will inventory and acquire all available satellite imagery in the public domain and will recommend new satellite image acquisitions when the scenes available do not meet the cloud coverage and temporal requirements.

- Coordinate with the COMPASS II GIS/IT Specialist for field verification and validation of land cover classes included in the analysis
- Determine the primary forest cover change and the other land cover classes defined above over a total of 25-30 years, depending on the available data.
- Coordinate with the COMPASS Valuation Specialist and provide technical support to the spatial analysis aspects of the Mulanje Mountain Valuation study
- Draft, submit to the Chief of Party and COMPASS II team for review, and revise as necessary the brief report, maps and recommendations described above
- Adhere to all USAID and DAI policies, procedures, and regulations that apply to the specific circumstances of the Specialist's engagement under the COMPASS II contract.

PERIOD AND ESTIMATED LEVEL OF EFFORT
The period of performance is October 10, 2004 – February 28 2005, and the estimated LOE is 20 days

Qualifications Required
The GIS/Remote Sensing Specialist should hold an advanced degree in geography, geographic information systems, computer sciences, or similar field, and be thoroughly knowledgeable on methods for estimating land-use change rates using remotely sensed imagery. The ability to write clear, concise technical reports is also required.