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## Drivers and impacts of land-use change in the Maasai Steppe of northern Tanzania: an ecological-social-political analysis

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In this article, we discuss the drivers, causes, and impacts of land-use change in the Maasai Steppe of northern Tanzania. Remote sensing data were used to analyze land-use change, and GIS was used to link-up with wildlife population dynamics and livestock distribution data derived from aerial censuses. Agriculture increased five folds between 1984 and 2000, while human population increased exponentially from 3.3% p.a. in 1988 to 3.4% p.a. in the same period. Wildlife migratory routes declined from 9 in 1964 to 5 in 2000, out of which 3 were seriously threatened for blockage by the extensive cultivation. Recurrent droughts and diseases have contributed to the declining livestock economy over the years due to livestock loss and the unpredictable and erratic rainfall has limited their recovery. To reverse the on-going trends in land use, proper land-use plans should be instituted in parallel with community-based wildlife ventures to maintain long-term ecosystem viability.

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**Keywords:** agriculture; land-use change; drivers of change; semi-arid environment; landscape fragmentation; spatial analysis

### 1. Introduction

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Land-use and land-cover change (LULCC), a central component of global environmental change with direct implications for the Earth's climate, ecology, and human societies, is of great concern to national and international policymakers (Campbell, Lusch, Smucker, and Wangui 2005). Policymakers seek information on the root causes of LULCC from scientists in order that policy may focus not on symptoms, but upon the fundamental processes that require remedial action. However, processes that drive LULCC are complex and require the use of multiple methods of analysis and critical interpretation of social data in order to understand the drivers and impacts of change through time and across spatial scales (Rocheleau 1995; Jiang 2003; Nightingale 2003). Past research in Maasailand has led to development of relative simple conceptual model to help analyze the critical pressure points and thresholds in changing land use and wildlife populations (Sinclair and Arcese 1995; Homewood *et al.* 2001; Serneels and Lambin 2001a). These studies have, however, pointed the need to further understand what are the main determinants shaping livelihoods and

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triggering change? To what extent do external factors such as biophysical and eco-climatic/ agro-ecological factors on the one hand, and infrastructure and policy on the other, shape livelihood choices? To what extent are livelihoods determined by socio-demographic characteristics of the household? What trends do these patterns indicate in terms of land-use change, poverty trajectories, and wildlife conservation?

There are several studies globally related to drivers of land-use change (Burgi and Russell 2001; Lambin *et al.* 2001; Geist and Lambin 2002); however, only a few have tried to link socio-political historical changes to biophysical impacts of land-use change (Reid *et al.* 2000; Stokes, Macallister, Ash, and Gross 2008). A major reason for researching historical land-use change is that by understanding the past we can better understand and anticipate future trajectories (Lambin and Geist 2006). The most significant historical change in land cover has been the expansion of agricultural lands. The past century witnessed over half of the increase in agricultural lands worldwide, and in the developing world, half of the land-cover conversions occurred in just past 50 years (Lambin and Geist 2006). Research on the causes of land-cover change from global to regional levels indicated that the main drivers of change at the global level are population, level of affluence, and level of technology, while the primary drivers at the regional level are rural-to-urban migration, economic growth, changes in lifestyle, and changing economic and political arrangements (Reid *et al.* 2000; Lambin *et al.* 2001). Other causes of change include the role of institutions and influence of local culture (McCusker 2004).

Over the past four decades there has been a notable change in land uses in the Maasai Steppe of northern Tanzania, especially from small-scale subsistence cultivation to extensive large-scale farming (Borner 1985; Mwalyosi 1992; OIKOS 2002). This has resulted into a growing concern about the sustainability of the Maasai Steppe as an ecological system able to support large populations of diverse species of wildlife and livestock (Ecosystems Ltd. 1980; Mwalyosi 1991; Kahurananga and Silkilwasha 1997; TWCM 2000). Some of these changes have been influenced by political factors but the linkages between policies and ecological changes are still poorly understood. Notable land conversions to agriculture by pastoralists in Maasai Steppe are linked partially to issues of land tenure, insecurity, and livelihood needs, particularly, the need of the poor and the most vulnerable families (TNRF 2005; Sachedina 2008 ). These and other factors negatively affect the population of large migratory wildlife as well as the livelihoods of the local Maasai communities who are almost solely dependent on their free ranging livestock both economically and culturally. Many authors have reported that declining mobility of pastoralists leads to environmental degradation and increased poverty (Campbell 1999; Talle 1999; BurnSilver, Worden, and Boone 2008). Overgrazing and land degradation occur to a greater extent when livestock is forced to stay in a restricted area thus exerting persistent heavy grazing pressure, reducing the root stock available and accelerating soil erosion (Boone 2005). Conversely, land degradation from mobile pastoralism is often temporary, allowing sufficient time for resilient vegetation to regenerate during seasons without grazing (Groom 2007). Flexibility and mobility of pastoral livestock are essential to the sustainable utilization of the pastoral rangelands of Tarangire ecosystem but are getting increasingly constrained by the expansion of large-scale commercial and extensive but small-scale cultivation and pastoral settlements necessitated by the expanding human population. Sedentarization of the formerly nomadic pastoralists into villages has been associated with intensification of land use, deterioration, fragmentation and loss of key dry-season grazing areas and watering points (Igoe 2000; Kibebe 2005).

In this study, we adopt an ecological and socio-political approach to analyze the drivers and impacts of land-use change on the Tarangire ecosystem located in the Maasai Steppe of northern Tanzania due to its importance to large migratory wild herbivores and the local



The Tarangire ecosystem hosts the second-largest population of migratory ungulates in East Africa and the largest population of elephants in northern Tanzania (Douglas-Hamilton 1987; Foley 2002). At the onset of the rains the large mammals disperse to areas outside the park (Lamprey 1964) to the Simanjiro plains, an important wet season dispersal and calving range for wildebeest (*Connochaetes taurinus*) and zebra (*Equus burchelli*) (Kahurananga and Silkilwasha 1997). Factors driving these migrations are not fully understood but animals are probably attracted to these areas (Kahurananga and Silkilwasha 1997) because they are richer in minerals (TCP 1998) and forage to satisfy the high energy demands of lactation (McNaughton 1990).

The system is also heavily utilized by Maasai livestock (cattle, sheep, goats and donkeys) of which an estimated one million zebu cattle (Patel, unpublished report) constitute about 90% of the grazing animal biomass (500 kg/km<sup>2</sup>) on the Simanjiro plains in the dry season (Mwalyosi 1992). Like many of the unprotected lands in Tanzania, the Tarangire ecosystem, particularly the Simanjiro plains, are under pressure from expanding cultivation, which increasingly excludes wildlife and livestock (Voeten 1999).

## 2.2. Methods

Analysis of the drivers of land-cover and land-use change requires use of multiple methods and critical interpretation of the data to characterize the drivers and impacts of change through a hierarchy of temporal and spatial scales (Reid *et al.* 2000; Campbell *et al.* 2005). We adopted an ecological and socio-political framework to analyze and evaluate the underlying drivers, causes and impacts of land-use change in the Tarangire ecosystem using historical and contemporary data obtained from archives, remote sensing, interviews, meetings, field work and observations as well as from other research work as outlined below.

### 2.2.1. Classification of satellite imagery

We analyzed land-cover change using two Landsat TM scenes (Path/Row 168/62 and 168/63 of December, 1984) and two corresponding Landsat ETM+ scenes (February, 2000) acquired from the United States Geological Surveys (USGS). The following considerations dictated the choice of the images. First we searched for images matching the timing of the major policy changes and/or events related to land-use changes in the study area over the preceding 15–20 years. Second the images should reflect similar vegetation conditions. The 1984 images were acquired during the short rainy season in December, when rainfall averaged 133 mm. The 2000 images were taken during the short dry season in February, when rainfall averaged 62 mm, well after the short rainy season (October–December) The Normalized Difference Vegetation Index (NDVI) data suggest that both images depict comparable conditions since the NDVI for both was just above zero (Figure A1).

We clipped the study area from the mosaiced and cloud masked pairs of imagery in Erdas Imagine version 8.7 and next performed two unsupervised classifications, with 100 classes for each of the years (Jensen 1996). The unsupervised 2000 image was then subjected to supervised classification while using on the 2000 Africover land-cover map. No land-cover maps were available for 1984 or around this period. Hence, we used the 2000 image characteristics to classify the 1984 image for consistency. Areas of similar characteristics in both images were visually identified, and for these areas the class of the 2000 image was assigned to the 1984 image. Finally the classified images for both 2000 and 1984 were reclassified into 8 and 10 broad land-cover classes, respectively (see Appendix 2 for details).

To map agricultural land-use change between 1984 and 2000, the following three classes for land use were identified: (1) areas with agriculture in 2000 but not in 1984, (2) areas with agriculture in both 1984 and 2000, and (3) areas with agriculture in 1984 but not in 2000. We conducted fieldwork to validate the results of this classification. With the help of Maasai elders knowledgeable about historical land use, we ascertained the presence of agriculture in 1984 and 2000 and assessed the accuracy of the image classification according to Congalton and Green (1999).

### 2.2.2. Drivers of agricultural expansion

We used the Almanac Characterization Tool (ACTS) database (Mud Springs Geographers 2002) to extract spatial rainfall data to define three broad rainfall zones: <500 mm (zone 1), 500–600 mm (zone 2), and >600 mm (zone 3). We tested for differences in the rate of agricultural expansion between 1984 and 2000 by rainfall zones using the Mann–Whitney–Wilcoxon signed rank test in SPSS (SPSS 2005 Version 1).

Long-term monthly rainfall data (1960–2007), collected from one station for each district, obtained from the Tanzanian meteorological department, were analyzed for trends and seasonal and annual variation components using standardized anomalies ( $z = (x_t - \bar{x})/\sigma$ ), where  $x_t$  is the rainfall component in year  $t$ ,  $\bar{x}$  is the mean, and  $\sigma$  is the standard deviation of the rainfall. Rainfall totals falling within the percentiles 0–10, 11–25, 26–40, 41–75, 76–90, 91–95, and 96–100% were classified, respectively, as extreme, severe or moderate, drought years, normal, wet, very wet or extremely wet years (Ogutu, Piepho, Dublin, Bhola, and Reid 2008).

We analyzed distribution in agriculture as a function of distance from protected area boundaries using buffers of 500 m in ArcView GIS v 3.2 to test the hypothesis whether the rate of expansion in agriculture increased with distance away from parks.

### 2.2.3. Impacts of agricultural expansion

We analyzed the impacts of agriculture on the wet season range and migratory routes of wildlife by overlaying (in ArcView GIS v 3.2) maps of the distribution of 1984 and 2000 agriculture with maps of historic (Lamprey 1964) and recent wildlife corridors livestock grazing areas and wet season ranges for the key migratory wildlife species (based on distribution maps derived from various aerial and ground censuses).

### 2.2.4. Ecological time-lines

Ecological time-lines (Stokes *et al.* 2008) were used to summarize major socio-ecological and political events that occurred in Tarangire ecosystem and the larger Maasai Steppe, from the late nineteenth century to the present. The time line was broken down into five major periods: the pre-colonial (before 1880); the colonial (1880–1950), the independence (1960–1970), the post-independence (1970–1990), and the contemporary (2000–2008) periods. Information to develop the time lines was collated from various sources, including literature review, archives, field observations, and informal interviews with long-term residents and experts who have worked in the area. Ideas and views collected from these sources were presented in a workshop; the comments, suggestions, and insights from participants refined the identification, timing, and impacts of major changes and events underlying land-use change.

### 3. Results

#### 3.1. Broad trends in land-use change from remote sensing: agricultural expansion

Agriculture increased five folds from 170 km<sup>2</sup> (17,000 ha) in 1984 to about 881 km<sup>2</sup> (88,100 ha) in 2000 (Table 1). Almost 3% of the total land area was under agriculture in 2000, up from less than 0.6% in 1984. However, agricultural expansion from 1984 to 2000 was not spatially uniform and increased 7.5 times in Monduli district compared to 3.5 times in Simanjiro district over this period (Figure 2a and b). 200

The expansion in agriculture between 1984 and 2000 was statistically significant for the entire study area (Wilcoxon rank test,  $Z = -142.4$ ,  $p < 0.0001$ ) and its constituent districts of Monduli (Wilcoxon rank test,  $Z = 93.7$ ,  $p < 0.0001$ ), and Simanjiro (Wilcoxon rank test,  $Z = 93.6$ ,  $p < 0.0001$ ). Also, mean field size was significantly larger (Wilcoxon rank test,  $Z = 32.2$ ,  $p < 0.0001$ ) in Simanjiro (ca. 4.2 ha) than Monduli (ca. 1.4 ha) in both years. Also, mean field size over the entire study area was about 1.05 ha in 1984 but increased to 1.96 ha in 2000. Land-use changes indicated that about 75% of the area under agriculture in 1984 was abandoned and was not under cultivation by 2000 (Figure 2c and d). Most of the abandonment occurred in Simanjiro (79%), the drier district, compared to Monduli (48%), the wetter district that also experienced a higher increase in the number of people (Table 3). 205 210

#### 3.2. Agricultural expansion in relation to rainfall zones and rainfall patterns

At the district level the relation between agriculture expansion and rainfall was spatially variable (Figure 3). The expansion partly follows the rainfall zones but also mirrors the long-term rainfall trend (Figure 4). Agriculture increased significantly in all rainfall bands (Table 2) but the rate of increase was larger the higher was the rainfall band and was 3, 15, and 30% in the lowest (<500 mm), medium (500–600 mm), and highest (>600 mm) rainfall bands, respectively. In Monduli high increases in agriculture occurred in rainfall bands >600 mm (9%) and 500–600 mm (4.6%) and moderate increases in <500 mm (2%) rainfall band, while in Simanjiro high increases occurred in lower bands of less than 500 mm and moderate increases in the highest rainfall band (>600 mm). Hence agricultural expansion in the study area is not solely determined by rainfall distribution. Other drivers apparently play influential roles as well. 215 220

One of the key drivers of land-use change is climate. The long-term rainfall in Tarangire–Simanjiro ecosystem showed a 3–5 year quasi-periodicity (Figure 4), meaning that there is either a drought or below-average rainfall condition every 3–5 years and implying frequent crop failures. Rainfall was highest during 1962–1970, while the 1971–1977 period showed declining rainfall, with a severe decline evident in rainfall 225

Table 1. Changes in cultivated acreage between 1984 and 2000 in the Tarangire–Simanjiro ecosystem, Monduli and Simanjiro districts.

	Agriculture area (km <sup>2</sup> ) in 1984	Agriculture area (km <sup>2</sup> ) in 2000	Unchanged area (km <sup>2</sup> )	Abandoned area (km <sup>2</sup> )	New fields area (km <sup>2</sup> )
Study area	170	881	42 (25%)	128 (75%)	739 (84%)
Monduli	70	520	21 (30%)	49 (70%)	499 (96%)
Simanjiro	100	362	21 (21%)	79 (79%)	341 (94%)

Note: The changes show areas where agriculture was present in 1984 and 2000, abandoned by 2000, and where new fields were created by 2000.



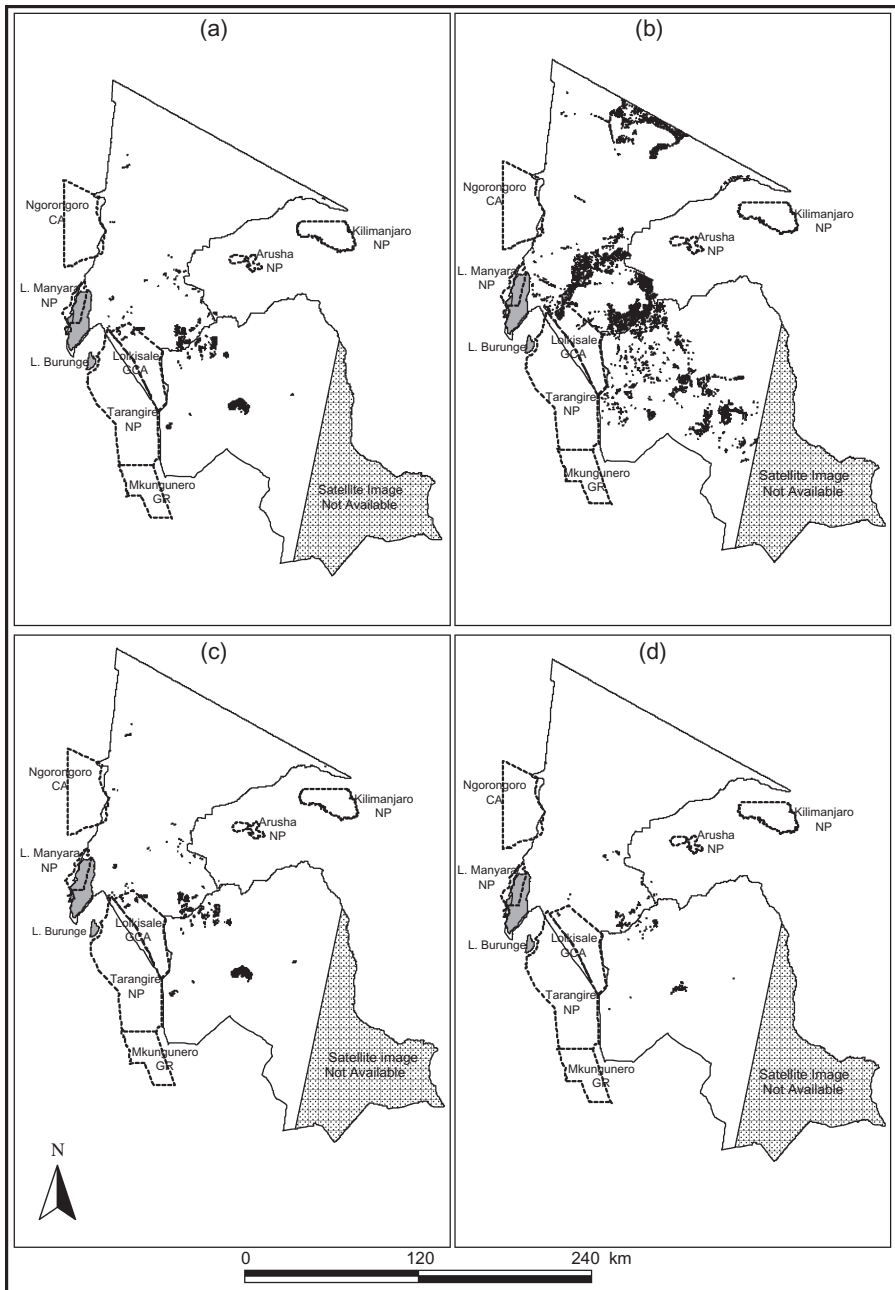


Figure 2. Land-cover changes in the Tarangire–Simaniro ecosystem showing (a) agriculture in 1984, (b) agriculture in 2000, (c) areas where agriculture was present in 1984 but not in 2000, and (d) areas where agriculture was present in both 1984 and 2000.

between 1974 and 1976. After 1976, annual rainfall increased up to 1979. Between 1979 and 2007 the frequency of dry and wet conditions increased significantly compared to the earlier decade. During the study period extreme droughts occurred in 1961, 1965, 1974, 1976, and

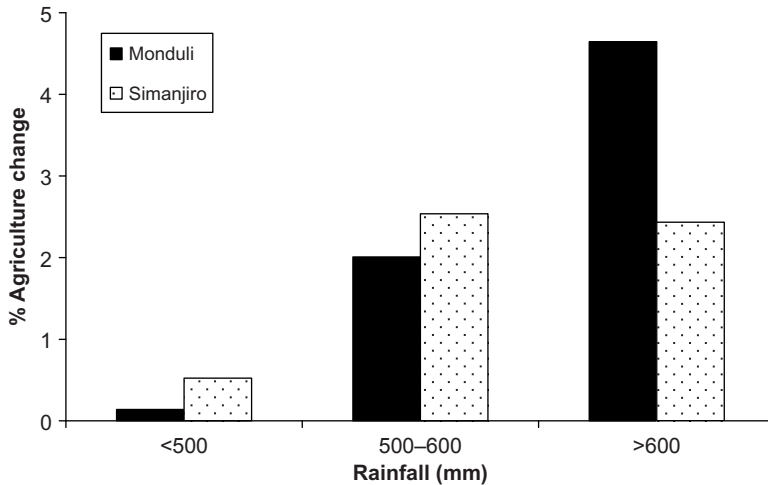


Figure 3. Percentage changes (annual) in cultivated area in relation to low (<500 mm), moderate (500–600 mm), and high (>600 mm) rainfall zones in Monduli and Simanjiro districts between 1984 and 2000.

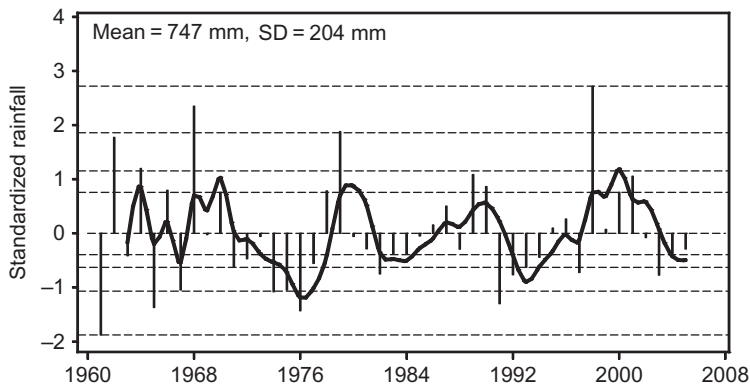


Figure 4. Annual rainfall pattern in Tarangire–Simanjiro. Vertical lines (needles) indicate the standardized values and solid lines are the 3–5 years running means. Dashed horizontal lines are 10, 25, 40, 75, 90, 95, and 100th percentiles.

Table 2. Results of Mann–Whitney *U*-tests comparing changes in areas under cultivation by district and rainfall zones.

District	Rainfall band	1984 vs. 2000
Monduli	<500	-14.2 ( $p < 0.0001^a$ )
	500–600	-6.5 ( $p < 0.0001$ )
	>600	-110.5 ( $p < 0.0001$ )
Simanjiro	<500 <sup>b</sup>	
	500–600	-50.5 ( $p < 0.0001$ )
	>600	-113.6 ( $p < 0.0001$ )

Note the significant relationships between increasing cultivation and rainfall. <sup>a</sup>Probabilities are two-tailed and based on the normal approximation. <sup>b</sup>Absence of agriculture in the portion of Simanjiro in the <500 m rainfall band mapped in 1984 precluded pair wise comparisons.

1991 and severe droughts in 1967, 1975, 1982, 1992, 1993, 1997, and 2003. Moderate droughts were registered in 1963, 1971, 1972, 1977, 1983, 1994, and 2004. Extremely wet years occurred in the study area in 1968 and 1998, while very wet years in 1962 and 1979. Wet years were 1964, 1966, 1978, 1989, 1990, 2000, and 2001. The extensive cultivation in parallel with farm abandonment observed in the Tarangire–Simanjiro area is therefore not surprising; given the increasing climatic variability over the past two-three decades.

### 3.3. *Agricultural expansion in relation to protected areas and its impacts on wildlife migratory corridors*

Tarangire ecosystem boundary defines the spatial extent covered by wildlife migrating from TNP to dispersal and calving areas during the wet season (Figure 1). At about 40 km it is the distance where majority of the wildebeest and zebra concentrate for calving, while 60 km is the maximum distance that majority of the key migratory species can reach. In the 1980s agriculture was limited both in its distribution and in the size of farms. Although there were fields located less than 40 km from protected area boundaries in the ecosystem at times, many of them were smaller in size, averaging 3.4 km<sup>2</sup> (Figure 5a) compared to 2000 when majority of the fields located less than 40 km from protected area boundaries averaged more than 15 km<sup>2</sup> in size (Figure 5c). This is almost a fivefold increase in farm size between 1984 and 2000. Cultivation expanded, both away from and toward protected areas, from about 4% in 1984 (Figure 5b) to more than 7% by 2000 (Figure 5d), corresponding to an increase in the absolute area under cultivation of approximately 725 km<sup>2</sup> between the two periods. Fewer and smaller fields were observed inside Lolkisale GCA in 1984 (Figure 2a), with a few scattered north of TNP and less than 20 km from the park boundary. This changed drastically in 2000 both in the size and location of farms, with increased cultivation inside Lolkisale GCA and toward TNP (Figures 2b and 5c). Extensive cultivation has occurred on the eastern sections of TNP with intensive concentration of farms in the northeast, between Emboreet and Lolkisale (the calving area) toward Makuyuni and LMNP in Esilalei, Mto wa Mbu and Engutoto. This is reflected in the increase of fields in 2000 beyond 60 km as indicated in Figure 5c relative to 1984. Hence contrary to our hypothesis cultivation has expanded both ways, toward and away from protected areas boundary.

Cultivation has taken up the traditional migratory routes particularly on the north and northwest of TNP. Figure 6 shows the spatial extent of agricultural expansion from the 1980s (Figure 6a) to 2000s (Figure 6b). On the eastern side of TNP, the routes toward Lolkisale GCA and Simanjiro plains are threatened with blockage by expanding cultivation. Furthermore, the wet season range for the key migratory species continues to shrink as more of the rangeland is converted to farmland. Accordingly, the densities of wildlife species mapped from aerial surveys (wet season) for the two periods reveal a downward trend (Figure 6). Likewise for the livestock, their grazing land is being taken up by cultivation.

### 3.4. *Historical analysis and synthesis of policies and major events that have impacted land-use changes in Tarangire–Simanjiro ecosystem*

Current land-use changes observed in the Tarangire–Simanjiro ecosystem emanate from a number of historical events, which have disrupted the traditional cultural and social practices of the Maasai pastoralists. Below we review some of the major historical events in the Maasailand over the last century, which are closely associated with the drive for land-use change observed in the study area. For clarity, we organize these major events into the following five periods:

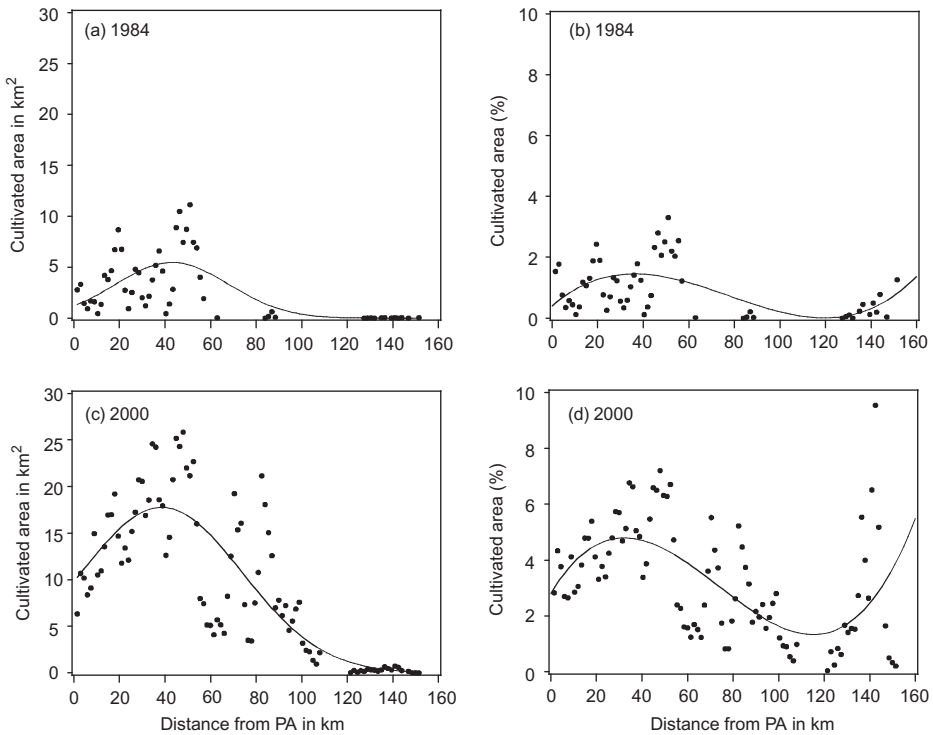


Figure 5. Cultivated area as a function of distance from protected areas boundary in 1984 and 2000; (a and c) absolute cultivated area (in  $\text{km}^2$ ) from the nearest protected area boundary and (b and d) cultivated area as a percent of available area from the nearest protected area boundary.

- (1) *The pre-colonial period: before 1880s.* Between the sixteenth and eighteenth centuries, the Maa-speaking people expanded their influence from Lake Turkana in northern Kenya, southwards throughout the Rift Valley area to modern Tanzania Maasailand replacing other pastoral groups like the Nilotes and Bantu who were also cultivators (Homewood and Rogers 1991). By 1880 the Maasai reached their greatest extent both in terms of numbers and influence. It was not before the turn of the eighteenth century when they were hit by pleuro-pneumonia and small pox diseases that killed many of them. At the same time the outbreak of the rinderpest in cattle and wildlife decimated Maasai livestock at around the beginning of the nineteenth century (Coast 2000). This meant that the main livelihood, that is livestock was gone. With no options for replenishing their depleted stocks, many of them started crop cultivation.
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- (2) *The colonial period: 1880s–1950s.* The nineteenth century had another big influence in terms of changing pastoral way of life as was the colonial period that saw the displacement of Maasai from high potential land for agricultural development by the European farmers/settlers (Homewood and Rogers 1991). This move started in northern Kenya by the British colonialists and moved gradually southwards to German Tanganyika in Tanzania. Many of the game parks were created at the same time through the eviction of pastoralists from key resources such as the dry
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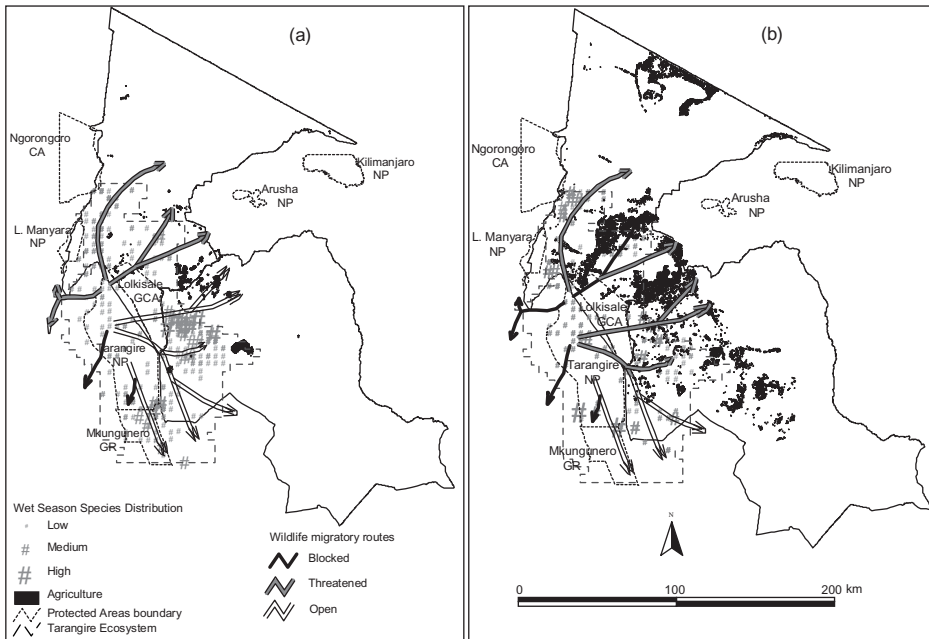


Figure 6. Wet season distribution of migratory wildlife species (a) during 1984–1994 in relation to agriculture in 1984 and (b) during 1997–2004 in relation to agriculture in 2000.

season grazing areas and watering points. Because of the abundant water and pasture in the Tarangire–Simanjiro ecosystem, it had a reputation as one of the best pastoral areas in Tanzania. Many herders who were evicted from the Serengeti National Park in the 1950s relocated to this area (Igoe 2000).

- (3) *Independent period: 1960s–1970s.* Tanzania became independent in 1961 and most of the British colonial administration/legislation was adopted by the new government. In this period rinderpest that had previously killed many wildlife and livestock species was controlled. The control of rinderpest boosted the numbers of wildebeest in the Serengeti ecosystem. This further pushed Maasai to the south, with some moving into Tarangire–Simanjiro area to avoid contact with wildebeest calving areas in the short grass-plains. Such areas are associated with the spread of Malignant Catarrhal Fever (MCF) that affects cattle. Between 1962 and 1963 the worst drought in 50 years hit most parts of the country including Tarangire–Simanjiro area and killed many wildlife and livestock (Lamprey 1963). In 1967 the first president of Tanzania, the late Dr. Julius Nyerere, declared Tanzania a socialist country, through the Arusha Declaration that put a nationalization policy in place (Kikula 1997). Many of the settlers' farms/plantations were nationalized by the government and managed by parastatals like the National Farming Company (NAFCO) and National Ranching Company (NARCO). Agriculture was promoted as the backbone of the national economy. Large-scale farms like the Lolkisale bean farms were established in Tarangire–Simanjiro to produce crops for export as well as for national reserves during droughts and food shortage. Data from the Tanzania National Bureau of Statistics (NBS) indicated a high population increase in the study area in the past 20+ years (Table 3). The growth was due both to natural increase and immigration from nearby

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Table 3. Human population changes in the Tarangire–Simanjiro, Monduli and Simanjiro districts between 1978 and 2002.

	1978	1988	2002	Annual growth rate (%) 1978–1988	Annual growth rate (%) 1988–2002
Study area	145,441	201,357	325,652	3.3	3.4
Monduli	121,784	148,460	184,516	2.0	1.6
Simanjiro	23,657	52,897	141,136	8.0	7.0

Source: Tanzania National Bureau of Statistics, 2007.

Note: The figures show annual percentage population growth rates between 1978–1988 and 1988–2002.

regions of Kilimanjaro and Arusha whose inhabitants were mainly agriculturalists (Igoe 2000). This move continued to displace Maasai pastoralists from their best rangelands into more marginal areas.

- (4) *The post-independent: 1970s–1990s.* In 1970, the Tarangire Game Reserve was upgraded to become Tarangire National Park including the southern portion of approximately one third of the area in the northern Mkungunero. People who were residing in this area had to move to the Simanjiro plains as there were still sufficient pasture and watering points. In the same period the villagization policy (1974) was introduced in the country, as a follow-up of the socialism ideology of 1967. People were forced to live in nucleated villages in order to have access to social services including schools, hospitals, veterinary, and market centers (Kikula 1997). This new policy restricted the movements of pastoralists with their livestock and forced many to settle in village land plots, which were assigned primarily for cultivation, as every villager was supposed to have a plot of land for building a house and producing food for their families. Maasai herders living east of Tarangire began to feel squeezed as commercial seed bean companies and peasants from the slopes of Mount Meru and Kilimanjaro began moving into the area in the early 1980s. By the mid 1980s the movement of commercial interests and peasant farmers into the area had expanded to the villages of Central Simanjiro (Igoe 2000), blocking traditional migratory routes for wildlife (Borner 1985). In 1990s Tanzania, as other countries in the world, was forced to embrace globalization, thus moving away from socialism to a free-market economy in which the social services formerly provided for free by the government ceased (Shivji 1998).

The economic liberalization policies including the Promotion Investment Acts of 1992 were declared – Tanzanite mining at Mererani in Tarangire – Simanjiro was established and attracted many young Maasai men from Tarangire–Simanjiro and neighboring regions (Muir 1994). This resulted in changes in lifestyles as some of the young men became very rich in a short time. Some of them invested back home by buying more livestock to replenish their herds whilst others used the money to open-up new farms for cultivation using modern farm machinery instead of traditional hand-hoe. In parallel with this, many agro-pastoral people moved into Tarangire–Simanjiro as land was seen as plenty for farming (Igoe 2000). The local Maasai decided to lease out their land to these immigrants for fear of losing their land to conservation due to speculations of impending expansion of protected area boundaries like that of TNP (TNRF 2005).

- (5) *The current period: 2000–2008.* The National Land Act (Act no. 4 of 1999) with a follow-up of the Village Land Act (Act no. 5 of 1999) which gave villages more

autonomy over the use of land was promulgated. In the same period a new category of wildlife conservation areas were established in village lands – the Wildlife Management Areas (WMA 2003) (MNRT 1998). Many agro-pastoralists, particularly in Tarangire–Simanjiro have been reluctant to accept the WMA concept because of past painful memories related to establishment of protected areas (i.e. eviction of people), despite the fact that they present a potential pathway for enriching their livelihood options. The new livestock policy was created in the same period following pressure to increase investments in rangelands and advocacy by local NGOs and civil societies to improve the livelihoods of pastoralists in the country (Figure 7).

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#### 4. Discussion and conclusion

In this study we have shown a rapid conversion of rangeland to agriculture in the dispersal areas of TNP. The remote sensing data revealed that the area under agriculture increased from 170 to 881 km<sup>2</sup>, or 10% per year. This increase in cultivated land was due to large-scale farming, such as the cultivation of seed beans in Lolkisale, and small-scale subsistence farming.

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With an overall increase of the area under agriculture, one might expect this to happen particularly in areas further away from the park boundary, as they are typically having fewer infrastructure and more remote from markets. The remote sensing and ground observations revealed the contrary: agriculture evidently expanded both away from and closer to the protected area boundaries.

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We also investigated the contribution of population change as a driver of land-use change. The human population growth rate of the whole area of 3.4% per year was much lower than the annual increase in agricultural area of 10.3% per year. More strikingly, Simanjiro, the district with highest population growth rate (7.4% per year) had a lower rate of agricultural lands (8.0% per year) than Monduli (1.7 and 12.5% per year, respectively). There is no doubt that population increase, driven by natural growth and immigration, have been an important driver of the observed land-use change. Our analysis reveals, however, that population growth alone does not explain all.

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Our analysis of long-term trends of rainfall revealed no evidence to support to hold climate change responsible for the observed land-use change. There was a cyclic pattern of 3–5 years in annual rainfall totals, but not a marked trend over longer periods. Hence, our data does not provide the evidence to support the hypothesis that climate has been a driver for long-term land-use change. Droughts, however, are likely to exert an influence on short-term land-use dynamics. The land-use change described by us was not permanent; a large portion of the land under agriculture in 1980 was abandoned in 2000. This might be attributable to the 3–5 years quasi-periodic oscillation in rainfall, because more than 90% of the farming is rainfall dependent (Kibebe 2005). The recurrent droughts preclude permanent cultivation as a sustainable livelihood option, because crop failure is frequent. Agro-pastoralism, which combines cropping and livestock production and allows falling back on livestock resources in case of drought, might be a more viable livelihood option. It is thus advisable to minimize the land converted to cultivation and instead diversify livelihood options by establishing community conservancies (WMA) to enhance revenue flows from wildlife and wildlife-based tourism both of which are more compatible with pastoral livestock rearing and more resistant to frequent droughts.

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We furthermore have shown that the lands converted to agriculture increasingly block the migration of wildlife. Consequently, the number of routes between TNP and its dispersal areas that have remained open to migratory wildlife has declined from 9 to 5 over the past 25

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Figure 7. Time lines of the major policies and historical events which have shaped land-use change in the Tarangire–Simanjiro ecosystem (Adapted from Stokes *et al.* 2008).

years, and even these 5 remaining routes are threatened to be blocked by the expanding cultivation and settlements around the park (Borner 1985; OIKOS 2002; Gereta, Meing'ataki, Mduma, and Wolanski 2004). Also, the traditional wildebeest calving grounds on the Simanjiro Plains have been taken up by the expanding cultivation (Figure 8).

Above we have argued that there is little evidence for climate change. However, the shrinking wet season range might amplify, similarly to what has been suggested for elsewhere (Serneels and Lambin 2001a; Ogutu *et al.* 2008) the influence of droughts on wildlife and livestock, leading to marked population declines and delayed recovery from droughts due to food insufficiency. It has been suggested that the land-use change adversely impacted



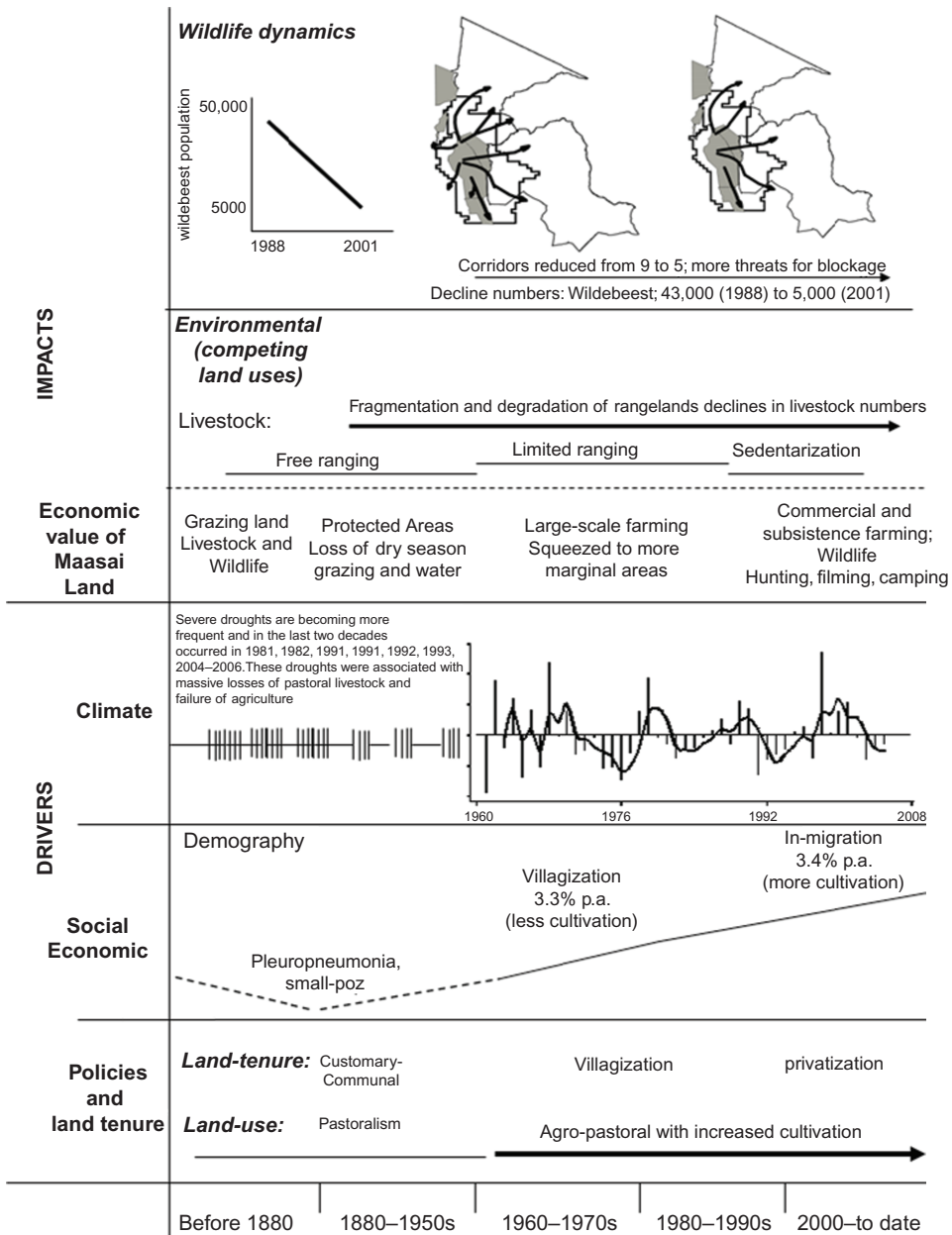


Figure 8. A schematic representation of drivers of change and the associated time lines, their impacts on the environment and livelihoods of agro-pastoralists in the Tarangire ecosystem.

the livelihoods of the agro-pastoralists in Tarangire ecosystem, due to reduced livestock per capita related to the loss of pastoral grazing land (Sachedina 2008).

It has been suggested that other factors such as policy, land tenure and land potential affect land-use change as well (Homewood *et al.* 2001; Campbell *et al.* 2005). The biophysical suitability of land is a strong determinant of the conversion of bush to

agriculture. Changes in land tenure, driven by governmental policies since the colonial era, have played a significant role in land-use change across the Maasai Steppe and particularly in the Tarangire ecosystem. In the pre-colonial period, when the land was communally owned and resources abundant, pastoralists were few and ranged freely, which allowed sustainable use of rangeland resources and co-existence with wildlife (Peterson 1978; Voeten 1999). During the colonial period large-scale plantations excluded pastoralists to some of their previous key grazing lands (Igoe 2000). After independence policies continued encouraging agriculture at the expense of pastoralists (Shivji 1998). The Villagization Policy of 1974, which forced people to live in nucleated villages, further enhanced sedentarization of nomadic pastoralists. The Investments Act of 1992, which encouraged investment in mining in rangelands, further marginalized the people of Tarangire ecosystem. The Land Acts of 1999 that gave villagers more autonomy over land use (Tenga *et al.* 2008) further accelerated sedentarization of the pastoral communities. These changes in land tenure led to rapid population growth, as a result of autochthonous growth and immigration of people from other regions seeking arable land (Mwalyosi 1992; Campbell 1999) and young people attracted by mining (Igoe 2000).

These processes have resulted in the reported land-use change. The blockage or loss of the traditional migratory routes increasingly undermines wildlife conservation in Tarangire ecosystem. Additionally, loss of the wet season dispersal range and widespread poaching of wildlife outside the protected areas threaten the future of wildlife conservation in this ecosystem. Not surprisingly, several studies have linked the declining populations of large mammals in the Tarangire ecosystem (e.g. wildebeest) to the rapidly changing land use, particularly the conversion of rangelands to agriculture and overexploitation of species through hunting and poaching (Galanti, Tosi, Rossi, and Foley 2000; TNRF 2005). Recent aerial surveys in Tarangire ecosystem revealed extreme declines in numbers of the key migratory wildlife species, most notably wildebeest, whose numbers dropped from about 43,000 in 1988 to a mere 5000 in 2001 (TAWIRI 2001). Such drastic declines undoubtedly threaten the future viability of both migratory and resident ungulate species and other species dependent on them.

In this study we have combined an ecological and socio-political approach in an attempt to disentangle the causes of land-cover conversions stemming from historical, political and livelihood needs in the Tarangire ecosystem. This integrated approach included both quantitative and qualitative characterizations of land-use changes and their consequences for the people, wildlife, and livestock in the Tarangire ecosystem. Without such an approach it would not have been possible to comprehend the fundamental driving forces such as policies and land tenure, which are indirect drivers of land-use change. This interdisciplinary approach reveals that agriculture expanded in the past 20+ years and continues to do so.

The results of this study reinforce findings of other studies conducted in East Africa indicating that wildlife habitats inside and outside protected areas are at a high risk of becoming ecological islands able to support a fraction of the previous wildlife populations (Nelson 2007; Ogutu, Piepho, Dublin, Bhola, and Reid 2009). The land transformations currently underway in Tarangire are similar to those observed in Kenya over the last 20 years and portend grave consequences for the future of the local migratory populations and pastoral livelihoods.

Scarcity of land and human population growth are the main drivers of the land-use change, which triggered the degradation of the pastoral livelihoods and the wildlife resources. Any attempt to solve the problems of the dwindling wildlife resources, should therefore address the poverty, which drives this development. Diversification of pastoral livelihoods is commonly propagated as a possible solution. Diversification into agro-

pastoralism, however, exposed pastoral households to crop failure risks emanating from unreliable rainfall and crop damage by wildlife. Diversification to mining improved the livelihood of a few (Sachedina 2008), but the earnings are often invested in livestock herds and expanding cultivation (TNRF 2005), which further accentuates the pressure and loss of the pastoral rangelands. In addition to the environmental risks, the vulnerability of poor pastoral households is heightened by lost access to free social services, such as education and health care (TNRF 2005), due to the change in national policy from *ujamaa* (socialism) to the current *free market economy and privatization policy*. 470 475

The current arrangement of state ownership of wildlife and governmental control of revenue streams generated from wildlife-tourism severely restricts wildlife-related options available to support the income of local people (Sachedina 2008) and diminishes the importance of wildlife conservation in local livelihood and land-use decisions (Tenga *et al.* 2008). Development of community-based tourism is one potential avenue for enhancing the importance of livestock-based wildlife conservation since community lands add a cultural value/element to tourism that is absent from the exclusively protected areas and often have just as much wildlife as do the protected parks and reserves (Kideghesho 2002; Nelson 2007). Policies that encourage development of tourism ventures on community lands would both diversify the tourism industry and encourage benefit sharing with the local people. For this to work successfully local authorities should be empowered to manage wildlife on community lands and establish partnership ventures with private investors. Ultimately, an integrated land-use plan that considers all the different land uses across the landscape as part of a broad development plan would be needed to minimize competition for resources and conflicts as well as sustaining these rangelands. 480 485 490

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## Appendix 1

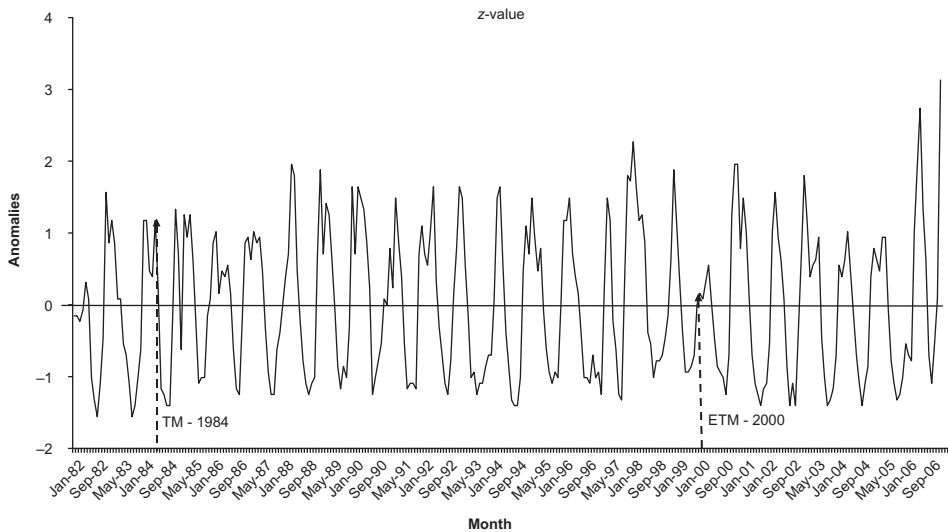


Figure A1. Temporal behavior of NDVI in the study area between 1982 and 2006. Dashed vertical arrows indicate the probable time for the acquisition of the two images.

## Appendix 2

### *Methodology: classification of the images*

All the images were geometrically co-registered with a high accuracy of a root mean square error below the pixel size, using second-order polynomial based ground control points (GCPs). The images were projected from global coordinate system (WGS84) to local coordinate system of UTM projection, based on the 1:50,000 topographic maps of the area.

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After dereferencing the images we masked all areas that had cloud cover in order to have the same corresponding areas for the two images for the year 1984 and year 2000.

The next step was to mosaic or combined the images together and then clip the study area that included both Monduli and Simanjoro districts. The third step was to classify the images using unsupervised classification (Jensen 1996). The images were classified into 100 classes based on the pixel value. In case of year 2000 image, all pixels were given land-cover classes based on Africover vegetation classes done in the same year. The Africover classes were created based on visual interpretation and so a polygon with class A will have many pixels of different classes resulting from unsupervised classification. To go round this we opted to get a minimum of 3 pixel classes within an Africover polygon with majority pixels. The 3 pixel classes were assigned land-cover classes from Africover data. Small and homogenous polygons in colors from Africover database were considered to avoid a big variety in pixels classes within the polygon. The above procedure was repeated several times until the 100 pixel classes were assigned a land-cover class from Africover land-cover data. We could not exactly apply the same method to classify the 1984 mosaic, since no land-cover data or maps were done in the same year or there about which are available to guide in land-cover classes assignment. We therefore decided to use 2000 image characteristics to classify the 1984. Areas in both images with same characteristics were identified and pixels classes within the area in the 1984 image were assigned land-cover class to that 2000 image.

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In both cases the following land-cover classes resulted: water, agriculture, closed trees, open to closed shrubs on temporarily flooded, open shrubs land, open trees, closed shrubs, closed herbaceous vegetation, open to closed herbaceous vegetation on temporarily flooded land, closed trees on temporarily flooded land.

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Then we isolated agriculture in from both mosaics and did change analysis and come up with three scenarios: areas where agriculture was *absent* in 1984 and *present* in year 2000, areas where agriculture was *present* in 1984 and *present* in year 2000, areas where agriculture was *present* in 1984 and *absent* in year 2000. This was followed by field verification of the above scenario. Random points were generated on the image and only 214 sampling points were picked based on their accessibility and scenario for field verification. Only 177 points were located and verified and 82 of 177 matched the scenarios. Field verification was based from the local knowledge from local Maasai elders who know what has been happening in terms of agriculture expansion in the area. The pixels verified, since had  $x-y$  coordinates were used to reclassify the images based on the scenarios.

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