

Full Length Research Paper

Temporal relationship between climate variability, *Prosopis juliflora* invasion and livestock numbers in the drylands of Magadi, Kenya

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A study was conducted to determine the association of climate variability, *Prosopis juliflora* spread, and other vegetation trends with livestock population dynamics in Kajiado County, Kenya. Monthly rainfall, mean monthly temperatures, cattle, sheep and goats populations from January 2000 to December 2014, were analyzed to determine time series trends. Normalized Difference Vegetation Index (NDVI) data derived from moderate resolution imaging spectroradiometer (MODIS) 250 m satellite imageries for 2000 to 2014 were used to determine the temporal dynamics of *P. juliflora* invasion in the study area. Both temperature and rainfall trends showed marked variability over the period under study. The mean monthly temperatures during the long dry season increased erratically from 33°C in 2000 to 37°C in 2014. Moreover, the rainfall during the wettest season was 600 mm in 2000 and 250 mm in 2014. During the study period, divergence from the long term mean rainfall (450 mm) decreased from 585 to 403 mm. At the same time cattle population decreased, sheep and goats populations remained static. *P. juliflora* invasion correlated positively ($r=0.2$; $P<0.05$) with mean monthly temperature and negatively ($r=-0.4$; $P<0.05$) with rainfall and other vegetation cover in drier parts, but not in the higher altitude and wetter parts of the study area. It also correlated negatively with cattle populations ($r=-0.4$; $P<0.05$). In the 1980's, bushlands and woodlands constituted 95 and 5% of the land cover, while in 2008, herbaceous vegetation, shrublands, and open trees together with bare areas constituted 50, 30, and 22%, respectively; out of which 70% had been taken over by *Prosopis* in 2014. This study demonstrated that even though the trends showed that cattle population decreased as climate variability and *Prosopis* invasion increased, there was no significant correlation among the attributes, over the period under study.

Key words: Climate, drylands, livestock, *Prosopis juliflora*, variability vegetation, trends, mesquite.

INTRODUCTION

After introduction to Africa in the 1820s and in Kenya in the 1970's and 1980's (Wahome et al., 2008; Choge and Pasiiecznik, 2006), *Prosopis juliflora* (Sw.) DC (hereafter simply *Prosopis*) and also known as mesquite has been

aggressively invading grazing and farm lands (Tewari et al., 2000; Pasiiecznik et al., 2001; Andersson, 2005). Shiferaw et al. (2004) reported that *Prosopis* is equipped with a number of biological characteristics that can

facilitate its rapid invasion of new areas. Germination is a crucial stage in the life cycle of plants: temperature and drought stress have a dominant role, while higher levels of nutrients increased translocation of sugars to the radicle, improving water uptake capacity through increased osmolarity (El-Sharkawi et al., 1997; Nakano et al., 2004; Leparmarai et al., 2015). Efforts to eradicate *Prosopis* have not succeeded anywhere in the world. Due to its hardiness and versatility, it grows fast in such areas as dry degraded grasslands and wastelands with scanty and erratic rainfall, shifting sand dunes, eroded hills and river beds and saline terrains, and spreads, where virtually no other trees survive (Silva, 1986).

Increased climatic variability trends in the drylands of Africa, associated with frequent and intense droughts, increased proportions of degraded lands that disrupted livelihoods of pastoralists (UNEP/CBD, 2010). Thus, climate change is costly and predictions are that both it and its cost will escalate (Nanyingi et al., 2012). The key costs emanate from livestock deaths and displacement and suffering of human populations (GOK-PDNA, 2012). Despite such costly interventions as free provision of livestock feed and supplements, the dryland communities still suffer enormous livelihood loss (GOK-PDNA, 2012). Climate variability and population increase in the pastoral areas have contributed to the degradation of grazing lands (Kazmi et al., 2010) that has led to changes in vegetation cover and *Prosopis* invasion further aggravating the livelihood challenge. Reports that exist fail to address specific plant species habits towards climate variability (Galvin et al., 2004; IPCC, 2007; Resilience Alliance, 2010; Tennigkeit and Wilkes, 2008; WISP Policy Note No. 04, 2007).

Spread of *Prosopis* was observed since 1994 in Olkiramatian location of Magadi, Kajiado County. The spread was noted to have some effects on indigenous vegetation species and livestock populations (Maundu et al., 2009; Kaur et al., 2012; Getachew et al., 2012; Rettberg et al., 2012). The objective of this study was to evaluate the relationship between *Prosopis* spread patterns, climate variability, vegetation cover trends and livestock population dynamics in the drylands.

MATERIALS AND METHODS

Study area

The study was conducted in Olkiramatian location of Magadi division - Kajiado County. The area is located in South West of Kenya, bordering Tanzania to the south and Narok County to the west. It is situated at altitude of 600 m within latitude/longitude 1°40'S, 36°E, 2°S, 36°15'E (Figure 1), under the inner lowland and

lower midland agro-ecological zones (Jatzold and Schmidt, 1978). It has a bimodal rainfall pattern with an annual total of 460 mm and a mean of 50 mm, mean temperatures of 32°C. The soil texture is very clay, clay and loam, with occasional sand. The clay types are montmorillonitic, kaolinitic and interstratified clay (Kenya Soil Survey, 1997). The landforms are composed of plains, plateaus, low gradient foot slopes, medium gradient hills and occasional high gradient hills (Gregorio and Latham, 2002). The slopes range from flat and wet slopes, gently undulating, rolling and steep slopes. The vegetation is sparse, open bushland, with increasing presence of *Prosopis* (Gregorio and Latham, 2002).

The Olkiramatian plains in Olkiramatian sublocation, receives 400 mm of rainfall annually, average temperatures of 35°C and a vegetation cover of mainly shrubs and bare land with *Prosopis* being the main shrub in the area. The Ngurumani hill slopes in Ngurumani sublocation receive 600 mm of rainfall annually with mean temperatures of 28°C and vegetation dominated by bushland, *Prosopis* and irrigated crop fields.

Data types and sources

Rainfall and temperature data were collected and collated from Makindu and Narok meteorological stations climate data recorded over 30 years (1982-2012); National drought management authority (NDMA) - Kajiado county climate data for 7 years (2007-2013); Magadi soda ash company climate data for 50 years (1964-2013); Kajiado Maasai rural center (Isinya) climate data for 23 years (1981-2014). Olkiramatian climate data (local weather station manned by South rift association of land owners (SORALO) for 5 inconsistent years (2008-2014). The Olkiramatian climate data was used to validate the meteorological stations of Narok and Makindu, Kajiado county (NDMA) climate data Magadi soda ash company climate data and the Kajiado Maasai rural center (Isinya) climate data.

Vegetation and *Prosopis* productivity data, derived from the Terra MODIS (NASA: https://lpdaac.usgs.gov/products/modis_products_table/mod13q1) series vegetation indices Normalized Difference Vegetation Index (NDVI) satellite data (Reeves et al., 2002; Robinson et al., 2008) was used. NDVI data was downloaded from the ENDELEO website (<http://endeleo.vgt.vito.be/>), unzipped and reprojected in ArcGIS (ArcGIS: <http://www.esri.com/software/arcgis/arcgis-for-desktop>). Magadi division and Olkiramatian location vegetation extends were extracted using ArcGIS tools. The vegetation data - NDVI with spatial resolution of 250 m for the period of 14 years (2000 – 2014) and temporal resolution of 30 days (one month) from MODIS satellite images was analysed for vegetation and *Prosopis* trends. Land use, land cover and soil data, field GPS data, and GIS databases from Regional Mapping Center - Kasarani, International Livestock Research Institute (ILRI), Department of Remote Sensing and Resource Surveys (DRSRS), Food and Agriculture Organization (FAO) and Kenya Soil Survey Institutions dealing with spatial data were also used in determining vegetation and *Prosopis* patterns. Participatory mapping of *Prosopis* clusters was done with help of local key informants who composed of three elderly men, one woman and one young man.

Livestock population data were obtained from the annual livestock population collected and collated from Kenya National Bureau of Statistics (2010), Kajiado County livestock offices, Magadi division livestock offices and DRSRS in Nairobi for the period

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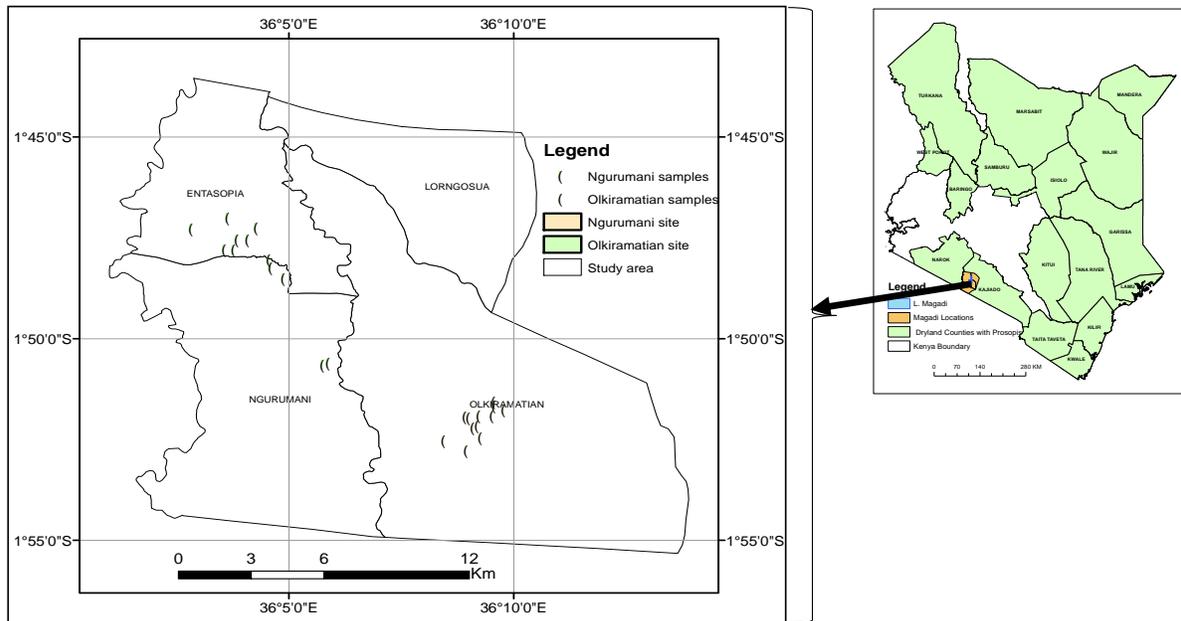


Figure 1. Study area in Magadi of Kajiado County, Kenya.

1980-2013.

GIS and remote sensing methods for estimating vegetation biomass

MODIS satellite derived NDVI images (Jenkerson et al., 2010) were used to establish the spread patterns of *Prosopis*. The NDVI was used to identify the vegetation types which were photosynthetically active during the drought periods. These vegetation types were most likely *Prosopis* plants. Land cover, soil data, GPS data, and GIS databases were used to identify areas with the suitability characteristics for *Prosopis* to thrive.

$$NDVI = (NIR - Red) / (NIR + Red) \tag{1}$$

where NIR (near infra read) and Red are the visible bands of the electromagnetic wavelength (Reeves et al., 2002).

NDVI has been used to indicate the level of photosynthetic activity in a green plant (Grace et al., 2006). It is expressed in values in the range of -1 to +1. Healthy vegetation absorbs most of the visible light that hits it and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light (Grace et al., 2006). It is an indicator of vegetation health status (greenness).

High NDVI values (greater than 0.7) obtained during the dry periods of the year (January to March and June to September) were used to isolate *Prosopis*, which remains green during the dry periods when all other vegetation types have dried up or shed leaves due the dry environmental conditions. Values lower than 0.1 typically correspond to areas with little or no vegetation (rocks, ice, and desert). Moderate values (around 0.2 and 0.3) correspond to shrub and grasslands and high values (0.5 and above) typically correspond to dense vegetation like rainforests (Rahman and Dedieu, 1994; Huete et al., 2002).

The preference of *Prosopis* to saline soils and flood plains was also used to identify *Prosopis* stands in the satellite images. The preference of *Prosopis* to riverine areas; sparse and dense

vegetation areas, woodlands and grasslands was further used to help in delineating *Prosopis* occupied areas.

To establish the disappearance of other plant species, MODIS NDVI images, land use, land cover and soil data, GPS data, participatory mapping of *Prosopis* clusters using community opinion leaders and GIS databases were used. Comparison of climate data trends, *Prosopis*, other vegetation cover and livestock population was done using Excel spreadsheets to establish relationships. This was done using previously developed techniques (Monteith, 1972; Tucker, 1979; Sellers 1985; Roy and Ravan,1996; Gregorio and Latham, 2002; Running, 1986; Jeyaseelan, 2003).Ground GPS data was collected and used to calibrate and validate the presence of *P. juliflora* in the different levels of *Prosopis* invasions of the two landscapes of Olkiramatian plains and Ngurumani hillslopes. The two landscapes of the study area were identified purposefully. Each landscape contained three (3) sites containing sparse (less than 30%) *Prosopis* density, moderate *Prosopis* density of 50 to 70% *Prosopis* and high *Prosopis* density (dense) of greater than 70% *Prosopis*. These were identified with the help of the knowledgeable local informants using participatory mapping and topomaps. GPS points were taken in each site with the help of research assistants. They were used for spatial data overlay analysis, ground truthing and verification using GIS tools.

Data analysis

Climate data (average temperature and total rainfall), livestock population data and vegetation and *Prosopis* productivity datasets for the period 2000 to 2014 were plotted against time to establish trends over the study period.

Correlations analyses were done to determine the longitudinal relationships between trends in rainfall and temperature and livestock population, *Prosopis* and other vegetation cover. Strength and direction of the relationships were tested, while descriptives (standard deviation, mean, range and coefficient of variation (C.V.)) were determined for all variable relationships.

Multiple correlations were done for the monthly and dry season

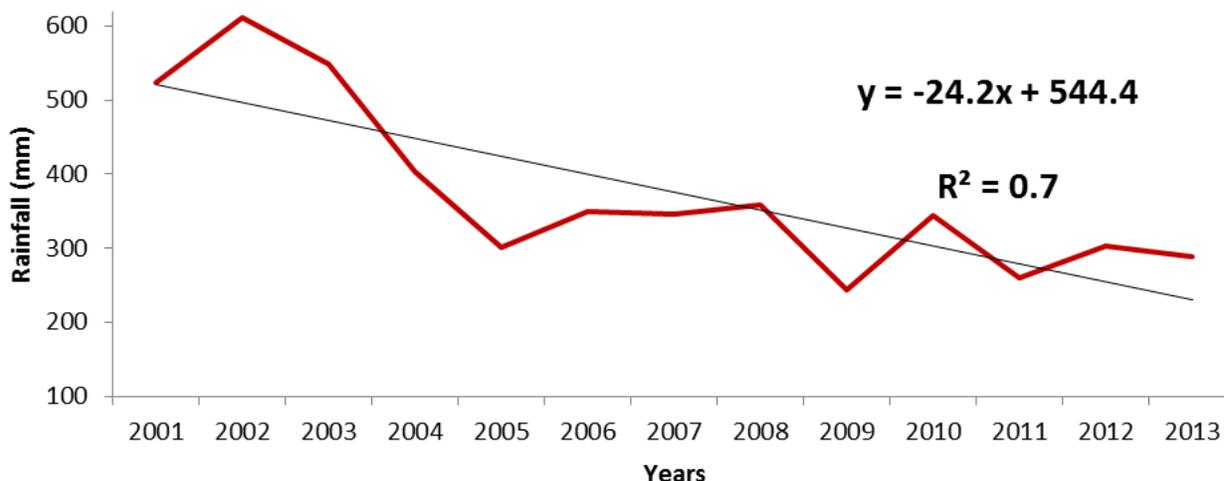


Figure 2. Annual rainfall (mm), trends in Magadi, Kajiado (2001 to 2013) (Magadi Soda Company Meteorological Department, 2014).

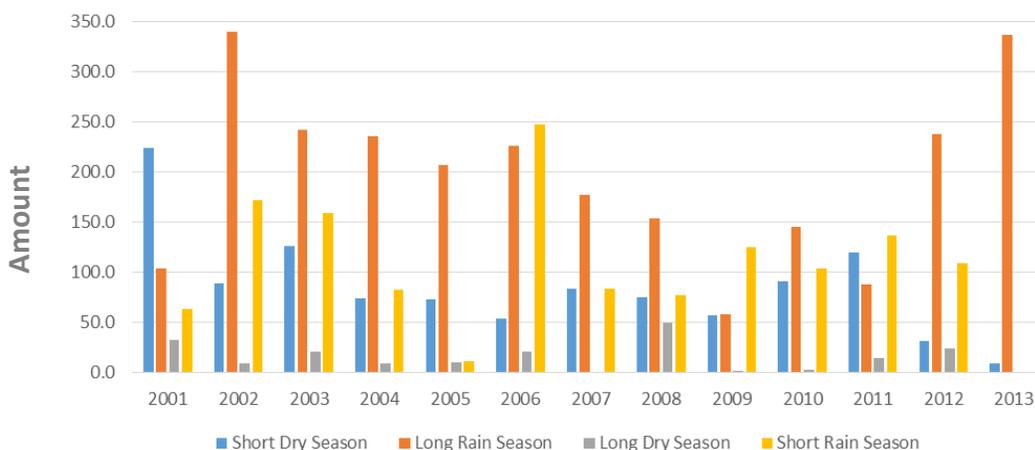


Figure 3. Total seasonal rainfall amounts (mm) in Magadi, Kajiado (2001 to 2013).

time series of the vegetation and *Prosopis* productivity (NDVI) data for the period 2000 to 2014; climate data (monthly rainfall totals and mean temperatures) and livestock populations.

RESULTS AND DISCUSSION

Rainfall and temperature variability in the study area

Long term annual rainfall amounts for Magadi division were plotted against time and a trend developed. It showed that the rainfall amounts were varying and have been on the decline over time and the small R^2 of 0.30 showed there was high rainfall variability (Figure 2).

Seasonal rainfall trends within seasons and within years in Magadi were analysed (Figure 3). The seasons were January to February (short dry season), March to

May (long rain season), June to September (long dry season) and October to December was the short rain season (Agnew et al., 2000). This showed that rainfall variability occurs within the season, from season to season, and even from year to year. A declining trend in the rainfall amounts was observed over the period under study - period of 13 years (Figure 2 and 3). The R^2 values of 0.7 showed there was high rainfall variability during the study period and very low quantities during the short dry season. This has direct implications on the vegetation, livestock and livelihood dynamics.

The results were similar to research done in Eastern Kenya in which it was found that rainfall distribution was very important and rainfall variability was the main limiting factor in biomass production as it causes variation in biomass formation. Infact, the yield of maize stabilized

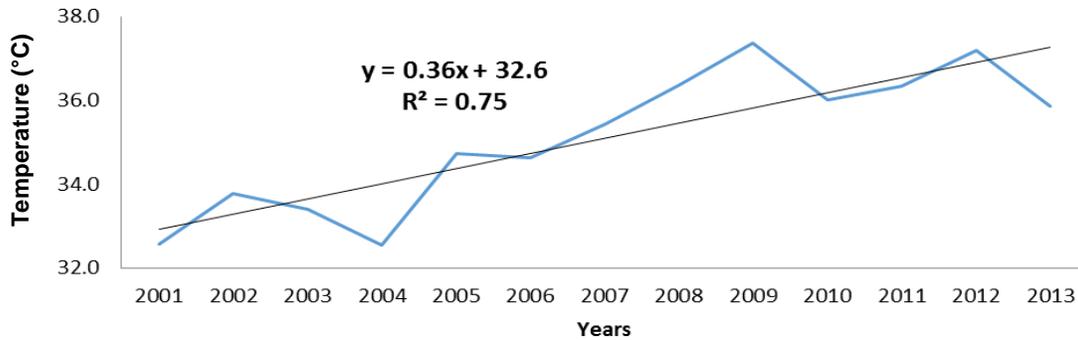


Figure 4. Annual average temperatures in Magadi, Kajiado (2001-2013).

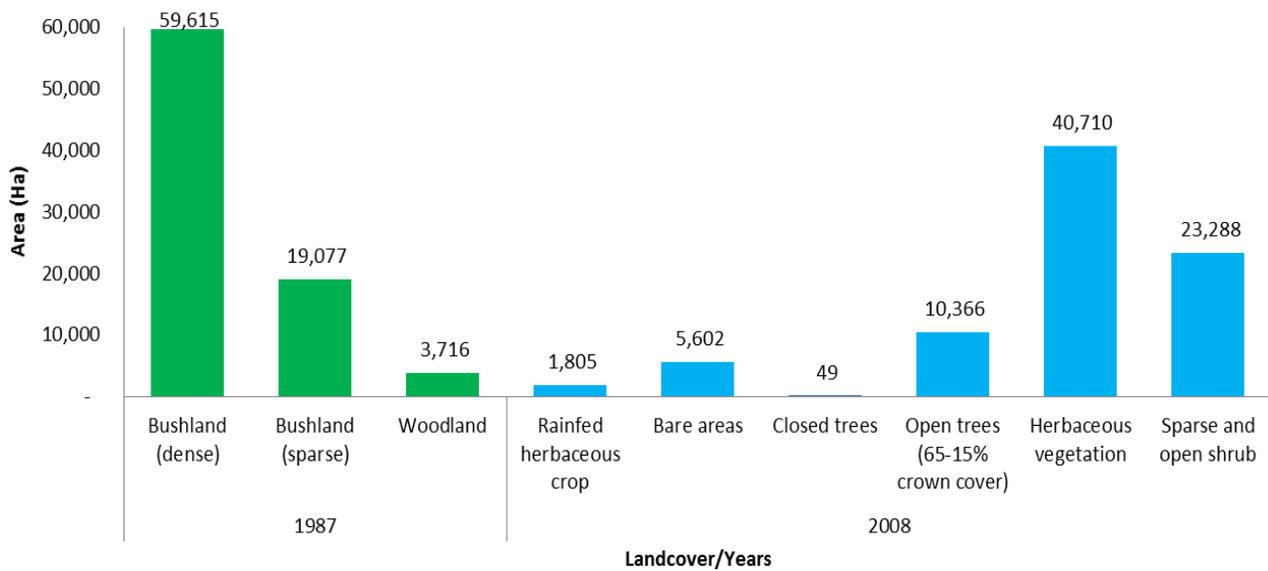


Figure 5. Vegetation cover change over the 20 year period (1987-2008) (Analysis based on FAO Africover Databases)

with even rainfall distribution and increased with increasing rainfall amounts (Kinama et al., 2007).

Droughts are the major climatic conditions which affect vegetation and livelihoods in the ASALs. It was in the dry periods when the effects of water shortages are most apparent. Among the effects was the low vegetation quality and quantity (GOK-PDNA, 2012).

A plot of the annual average temperatures for the period 2001 to 2013 against time (Figure 4) revealed an increase in average temperatures over the study period. A positive relationship between temperature and time ($R^2=0.75$) is an indication of a strong association between temperature and time. Possible effects for the rise of temperatures are the depressed vegetation growth for less drought tolerant plants, dominance of the aridity tolerant plants such as *Prosopis* and high water losses through evapotranspiration (Kinama et al., 2005). Elsewhere, other studies in the ASALs showed that soil evaporation can take upto 50% of seasonal total rainfall (Kinama et al., 2005). Temperature rises have increased

over the years and contributed to global warming.

Land cover changes and in Olkiramatian location

A shift from woodlands and bushlands in the 1980s to shrublands, herbaceous cover and bare lands in the 2000s was evident in land cover change analysis in Olkiramatian location (Figure 5). This could be attributed partly to the declining rainfall amounts, the raise in temperatures and increased human activity (land use). The shrublands, herbaceous cover and bare lands land cover of the 2000's has been taken over by *Prosopis* in 2014 by upto 70% of the landcover (Figure 6).

P. juliflora trends in the floodplains and hillslopes

During the dry seasons, most of the indigenous (native) plants productivity is depressed. *Prosopis* was introduced in Olkiramatian between 1989 and 1994 and it is able to

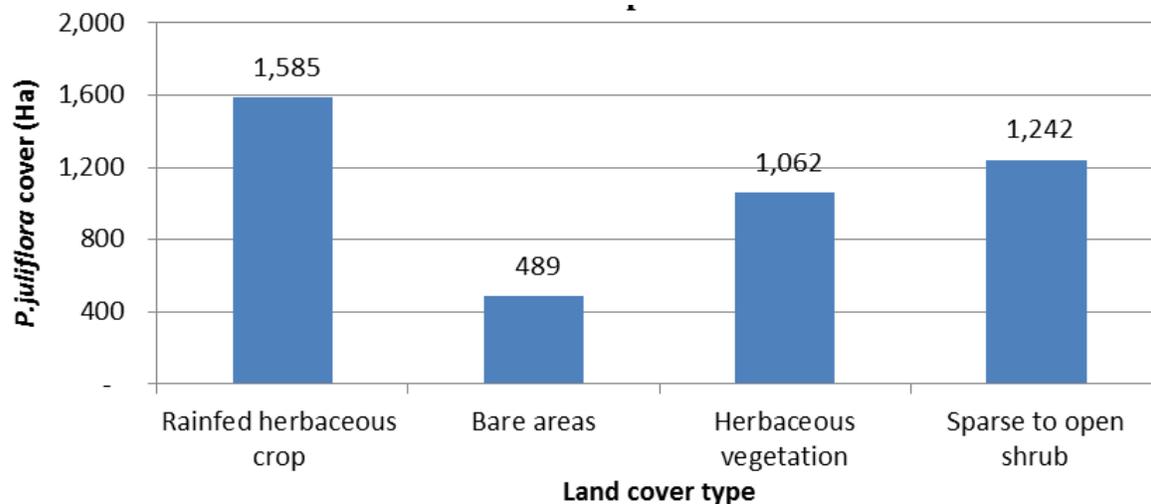


Figure 6. Area (Ha) invaded by *Prosopis* in 2014 (Analysis based on FAO Africover databases, 2008).

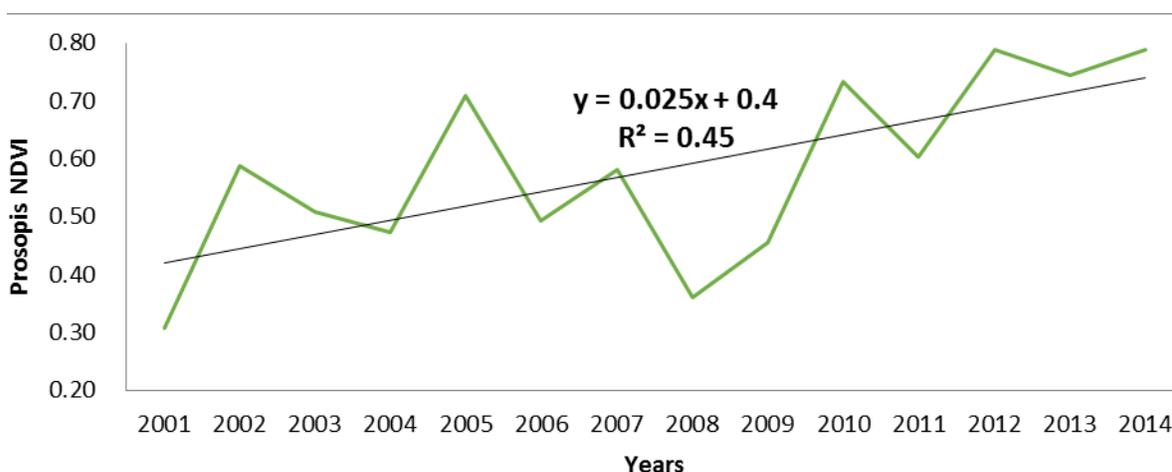


Figure 7. *Prosopis* productivity (NDVI) trends in Olkiramatian (2001-2014) (Author's analysis based on MODIS 250 m data).

tolerate very difficult environments including very arid (hot and dry) areas, very poor soils, saline soils, sandy soils and highly degraded areas (Muturi et al., 2010). It is always green when most of the other vegetation types have either dried up or shed their leaves to cope with drought. The *Prosopis* clusters digitized from the participatory mapping of *Prosopis* locations and the GPS points of the randomly selected field 30x30 m *Prosopis* plots were used to extract *Prosopis* NDVI values from the general vegetation NDVI values in the MODIS 250 m images, using ArcGIS software. *Prosopis* NDVI values were extracted for both the short and long dry seasons. NDVI values declined for the periods between 2006 and 2009, then a steady increase in the NDVI upto 2014 (Figure 7) in Olkiramatian. This could be attributed to the

depressed and highly variable rainfall (Figures 2 and 3) when there was a severe drought in this area. After 2009, the NDVI started to grow at a faster rate. Overall, there was modest increase ($R^2=0.45$) in *Prosopis* productivity during the period under study.

This observation could be further explained by the tolerant behaviour of the *Prosopis* to aridity and saline soils (Yoda et al., 2012). Following its introduction in the early 90s', *Prosopis* was not competitive enough to suppress the other vegetation types until the 2006 to 2009 droughts. After 2009, *Prosopis* was more dominant and competitive owing to its superior adaptive capacity to arid conditions (Pasiiecznik et al., 2004). The annual rainfall amounts were declining during the entire monitoring period from 585 to 403 mm (Figure 2).

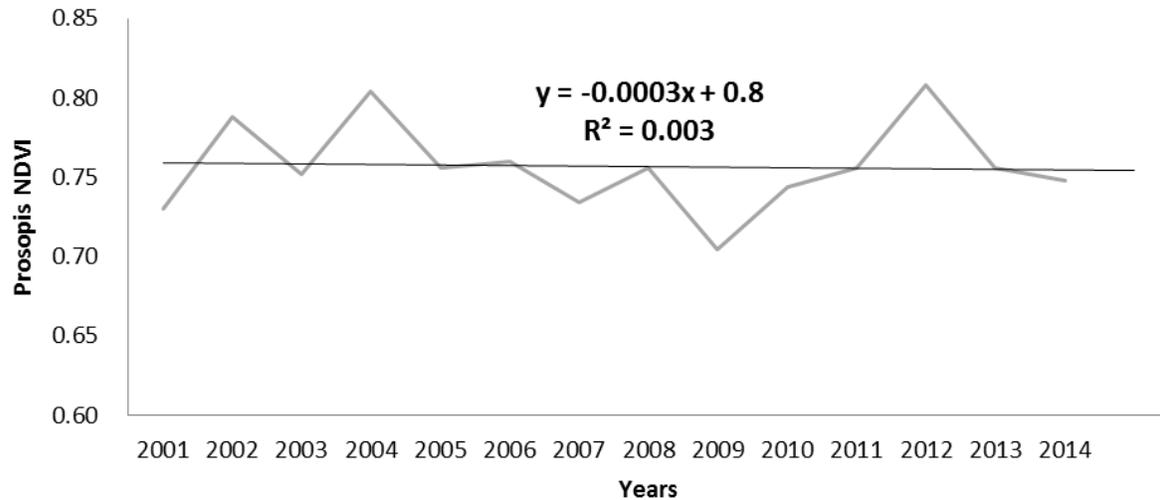


Figure 8. Prosopis productivity (NDVI) trends in Ngurumani (2001-2014) (Author's analysis based on MODIS 250 m data).

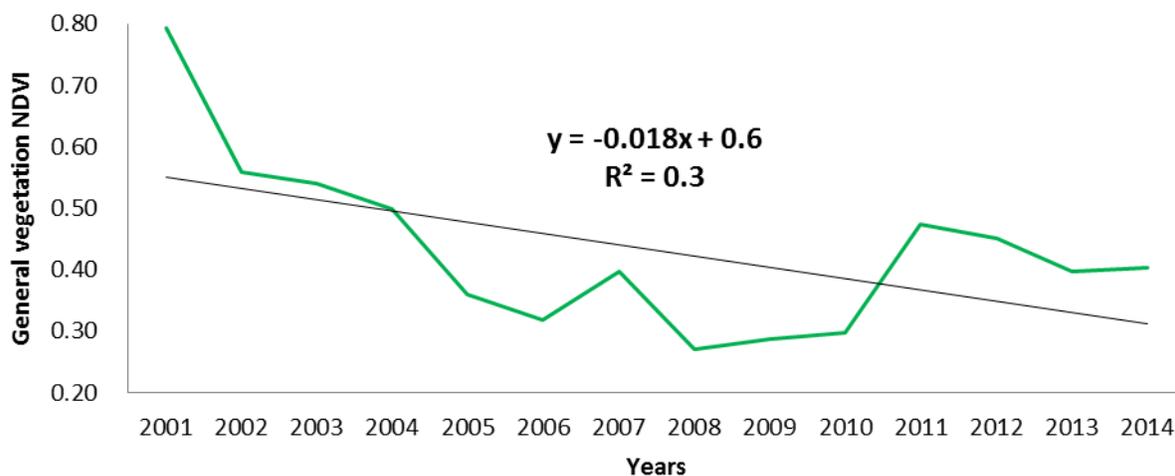


Figure 9. General vegetation NDVI trends in Olkiramatian plains (2001-2014) (Author's analysis based on MODIS 250 m data).

The low value ($R^2=0.003$) suggested that there was less fluctuation of *Prosopis* trends but there was high values in *Prosopis* NDVI in Ngurumani (Figure 8). Ngurumani hill slopes, the traditional dry season grazing area of the local Maasai community, receives moderately higher rainfall amounts than the Olkiramatian plains (Agnew et al., 2000). It has numerous natural springs flowing throughout the year and in the late 1990s, 'much of its woodlands and bushlands were opened up for irrigated agriculture (Agnew et al., 2000). The combination of the opened spaces, saline soils, Ewaso Ngiro riverine ecosystem and the severe droughts of the late 2000s' encouraged *Prosopis* colonization. Although *Prosopis* was colonizing the area at a faster rate, it had not reached the stage where it could competitively suppress the other vegetation types. This was due to the

availability of relatively adequate water sources to enable other plants to compete favorably. The high NDVI values (greater than 0.75, Figure 8) was an indication that there were favorable conditions for *Prosopis* to thrive, notably good supply of water.

Other vegetation trends

NDVI values for the other vegetation for the period 2000 to 2014 were plotted against time (years) – (Figures 9 and 10) in the floodplains of Olkiramatian sublocation and the hillslopes of the Ngurumani and Entasopia sublocations in Magadi Subcounty.

The NDVI values in the Olkiramatian plains declined in that period (Figure 9), while there was little change (less

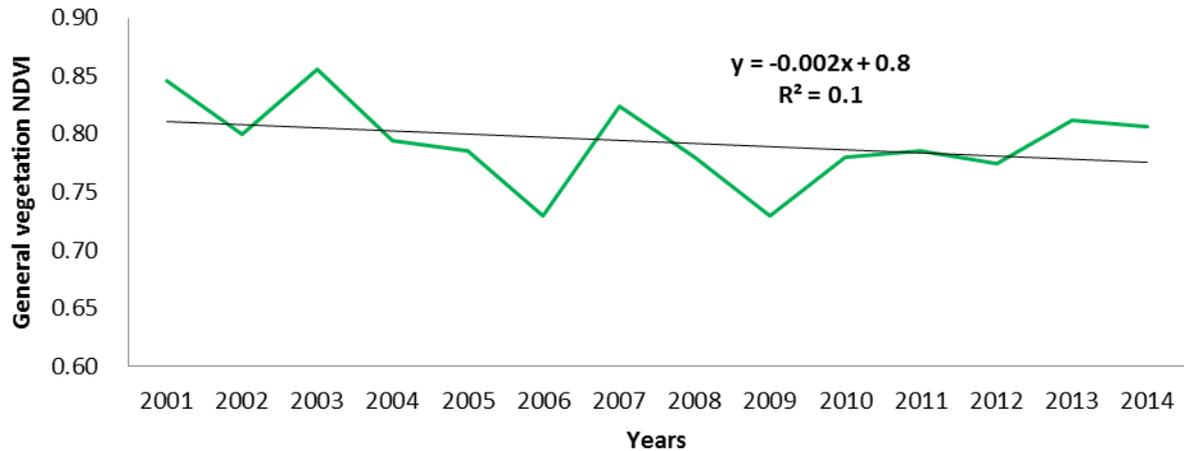


Figure 10. General vegetation NDVI trends in Ngurumani hill slopes (2001-2014) (Author's analysis based on MODIS 250 m data).

fluctuations) to the NDVI values for the Ngurumani hillslopes (Figure 10) for the same period. This could be attributed to the lower rainfall amounts in the Olkiramatian plains (Figure 2) and the higher rainfall amounts and the numerous natural springs in the Ngurumani hill slopes (Agnew et al., 2000). It could also be as a result of the competitive advantage of the drought resistance plants e.g. *Prosopis* in the water stressed plains as opposed to the hillslopes.

There was an observed decline in the NDVI values upto the period between 2006 and 2009, then a steady increase in the NDVI upto 2014 (Figure 9). This could be attributed to the depressed rainfall upto 2009 when there was a severe drought in Olkiramatian. After 2009, the NDVI grew at a slower rate. The overall NDVI trends of the general vegetation are in the decline, in line with the depressed rainfall amounts. In Ngurumani, other vegetation NDVI trends have little fluctuations due to the higher moisture levels in Ngurumani (Figure 10). This mirrors the landcover change trends, where the cover changed from woodlands and bushlands in early 1980's to open trees, herbaceous vegetation, shrublands and bear lands in 2000's (Figure 8).

Vegetation plays a keep role in regulating the atmospheric dynamics and also ensures the survival of both the humans and animals. Monitoring vegetation productivity is important in assessing threats to environment and to ensure feed and food sustainability to humans and animals. Ali et al. (2013) estimated vegetation productivity using normalized difference vegetation index (NDVI). It is an indicator of photosynthetic activity in a living plant. It has been used as an indicator (proxy) for vegetation vigour and vitality (Reeves et al., 2002).

Droughts are the major climatic conditions which affect vegetation and livelihoods in the ASALs. It is in the dry periods in Magadi when the effects of water and forage

shortages are most apparent. Among the effects is the low vegetation quality and quantity. Vegetation productivity during the dry seasons is one of the most limiting factors to pastoral livelihood sustainability in the ASALs (Kazmi et al., 2010). Dry season vegetation and *Prosopis* productivity was established due to the significance of the dry seasons to the pastoral communities and the green *Prosopis* all year round (Kazmi et al., 2010). It has a direct consequence to pastoral livestock production systems. It is therefore important to understand the vegetation dynamics during these critical periods (Patel et al., 2012) as it informs decision making for interventions (FAO, 2007). It is also during the dry seasons when *Prosopis* has superior competitive capacities for survival in these areas (Kazmi et al., 2010). It is the period when it is easy to isolate *Prosopis* from the other plants due to its greenness when all the other plants have either shed leaves or dried up.

Vegetation productivity during the dry seasons is one of the most limiting factors to pastoral livelihood sustainability in the ASALs (Agnew et al., 2000). It has a direct consequence to pastoral livestock production systems. It is therefore important to understand the vegetation dynamics during these critical periods as it informs decision making for interventions.

Comparisons of *Prosopis* and other vegetation productivity trends

There were few fluctuations, similar trends and higher values in the NDVI values in the Ngurumani *Prosopis* and other vegetation in both the short and long dry seasons (Figures 11 and 12). This was because of the higher water endowment in Ngurumani hill slopes for most of the time during the year.

In the Olkiramatian *Prosopis*, the situation was different.

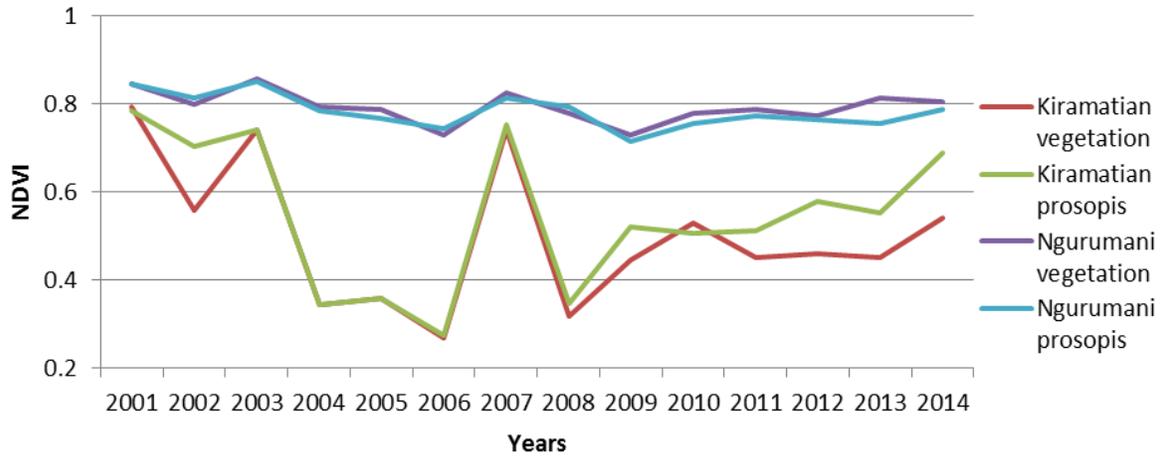


Figure 11. NDVI comparisons during the short dry season (2001-2014) (Analysis based on MODIS 250 m data from Endeleo website (<http://endeleo.vgt.vito.be/>)).

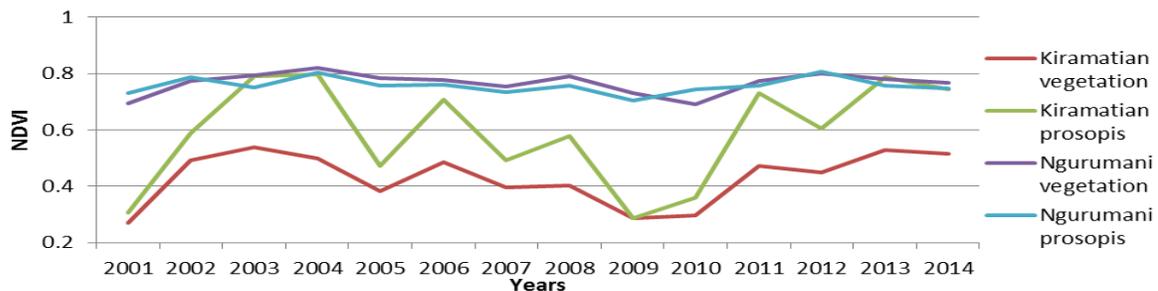


Figure 12. NDVI comparisons during the long dry season (2001-2014) (Analysis based on MODIS 250 m data from Endeleo website (<http://endeleo.vgt.vito.be/>)).

The superior competitive advantage of *Prosopis* was evident in the steady increase of NDVI values from year 2008 in both the short and long dry seasons, after a period of similar pattern to that of the other vegetation types (Figures 11 and 12). However, the *Prosopis* NDVI increase in Olkiramatian was most prominent during long dry period, when it was consistently higher than that of the other vegetation and it marched the trends in the water endowed Ngurumani *Prosopis* in 2003 and 2004 (Figure 12). Reasons for these patterns could be due to *Prosopis* superior competitive coping capacities during the dry seasons (de Bie et al., 2011).

Livestock population trends in Magadi

There was little change ($R^2=0.1$) in the population trends of goats and sheep (shoats) from 2001 to 2013 (Figure 13). However, there was significant change (decrease) in the cattle numbers ($R^2=0.6$) during the same period and the population numbers were decreasing (Figure 13). This could be explained partly by the disappearance of the grasslands (GOK- PDNA 2012) and the appearance

of the *Prosopis*, among other shrubs, replacing the former grasslands. Goats and sheep are generally browsers, feeding mainly on shrubs. The shoats were also known to browse on *Prosopis* (Koech et al., 2010). Cattle mainly feed on grasses, which was on the decline. The opening up and alienation of the Ngurumani dry season grazing areas for irrigated agriculture (Agnew et al., 2000) has also contributed to the decrease of the cattle population.

Relationships between rainfall, temperature, *Prosopis*, other vegetation and livestock trends

Correlation analysis was done to determine the relationship between climate variability, *Prosopis* spread, vegetation change and livestock population dynamics and it was found that the correlations were significant at the 0.05 confidence level (Table 1). Correlation coefficients for *Prosopis* spread against rainfall were -0.4 in Olkiramatian and coefficients for *Prosopis* spread against temperature were 0.3 in Ngurumani and Correlation coefficient for *Prosopis* spread against cattle

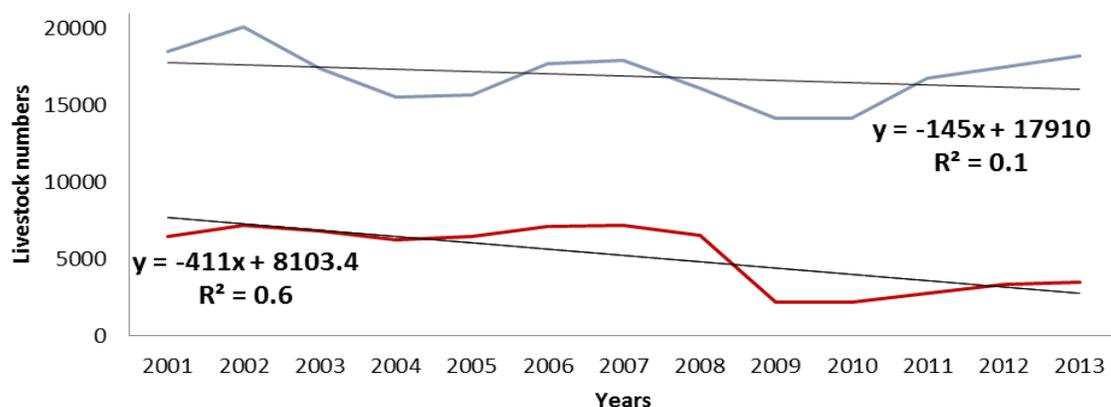


Figure 13. Livestock population trends in Olkiramatian location (2001-2013) (Agadi Division Livestock Office, 2014).

Table 1. Correlations between rainfall, temperature, *Prosopis*, other vegetation and livestock populations.

| Correlation | Rainfall totals | Average Temperature | Kiramatian vegetation | Kiramatian <i>Prosopis</i> | Ngurumani vegetation | Ngurumani <i>Prosopis</i> | Cattle | Shoats |
|----------------------------|-----------------|---------------------|-----------------------|----------------------------|----------------------|---------------------------|----------|----------|
| Rainfall totals | 1 | -0.169* | 0.360** | -0.367** | 0.385** | 0.227** | 0.093 | 0.158 |
| | | 0.039 | 0.000 | 0.000 | .000 | 0.005 | 0.256 | 0.052 |
| | | 151 | 151 | 151 | 151 | 151 | 151 | 151 |
| Average temperature | - | 1 | -0.219** | 0.228** | -0.375** | -0.343** | -0.523** | -0.319** |
| | | | 0.007 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | 151 | 151 | 151 | 151 | 151 | 151 |
| Kiramatian vegetation | - | - | 1 | 0.992** | 0.620** | 0.602** | 0.073 | 0.244** |
| | | | | 0.000 | 0.000 | 0.000 | 0.376 | 0.003 |
| | | | | 151 | 151 | 151 | 151 | 151 |
| Kiramatian <i>Prosopis</i> | - | - | - | 1 | 0.611** | 0.597** | -0.364 | 0.241** |
| | | | | | 0.000 | 0.000 | 0.400 | 0.003 |
| | | | | | 151 | 151 | 151 | 151 |
| Ngurumani vegetation | - | - | - | - | 1 | 0.734** | 0.251** | 0.314** |
| | | | | | | 0.000 | 0.002 | 0.000 |
| | | | | | | 151 | 151 | 151 |
| Ngurumani <i>Prosopis</i> | - | - | - | - | - | 1 | 0.337** | 0.330** |
| | | | | | | | 0.000 | 0.000 |
| | | | | | | | 151 | 151 |
| Cattle | - | - | - | - | - | - | 1 | 0.559** |
| | | | | | | | | 0.000 |
| | | | | | | | | 151 |
| Shoats | - | - | - | - | - | - | - | 1 |

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

was -0.4 (Table 1). Although the correlation coefficients were low for *Prosopis*, these values could be higher if the period of study was divided into two (from 2001 to 2008 and 2009 to 2014). In the first period (from 2001 to 2008), *Prosopis* biomass was declining and the second period (2009 to 2014) *Prosopis* biomass was on the increase.

CONCLUSION AND RECOMMENDATIONS

The study revealed decreasing and variable rainfall amounts and patterns; and an increase in mean annual temperatures in the study area. The vegetation cover was noted to decline especially during the long dry seasons when livestock feed supply was limited and *Prosopis* cover was increasing during the same period. The cattle populations were also on the decline over the 13 year study period while the sheep and goats populations remained largely unchanged.

These trends could be attributed partly to climate variability. With climatic variability expected to continue, it was recommended that viable *Prosopis* utilization options be explored to take advantage of its adaptability to climate variability. Options for the control of the aggressive spread of *Prosopis* need to be explored. Among the viable options include control through utilization as animal feeds, human food and source of carbon credits, fuel and high quality hard wood timber (Zimmermann et al., 1991; Choge and Pasiecznik, 2006; Wahome et al., 2008).

Conflict of Interests

The authors have not declared any conflict of interests.

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