PASTORALIST CULTURAL RESPONSES TO CLIMATE VARIATIONS POTENTIALLY CONTRIBUTING TO DROUGHT CONDITIONS ON THE HORN OF AFRICA

Russell F. Schimmer, Ph.D.-J.D. Student
Dept. of Natural Resources and the Environment
University of Connecticut
Storrs CT, 06269
Roland A. Geerken, Director of Geomatics
SIAS-Global
New Haven, CT 06511
Yancey A. Orr, Ph.D. Student
School of Anthropology
University of Arizona
Tucson, AZ 85721
russell.schimmer@uconn.edu
rgeerken@siasglobal.com
yorr@email.arizona.edu

ABSTRACT

During the period from 2007 through 2010, pastoralists in the semiarid region of Northern Kenya and southwestern Somalia reported progressively severe drought conditions. Locals complained of diminishing water resources and some groups came into conflict while competing to sustain economically vital livestock herds. To understand the relationship among precipitation, environmental stress, and cultural responses in the region, we analyzed climate records over ten-, twenty-, and sixty-year spans. Remarkably, years of below-average rainfall (RF) do not highly correlate as catalysts to recorded drought events. Even more surprisingly, in some cases vegetation vigor recorded by NDVI (the Normalized Difference Vegetation Index) was negatively related to precipitation increases, which is an indication that resource management is a key factor to maintaining environmental integrity. The absence of a consistent one-to-one relationship between RF and drought, in addition to the importance of livestock grazing and herd sizes on vegetation health and water resources in the region, suggests that the number and management of livestock in Northern Kenya are determinants influencing environmental vulnerability. We argue that traditional resource management practices, as cultural responses to multi-year climate cycles, can contribute to the frequency and severity of drought events. The most important responses that set the conditions for drought occurrences likely take place during average RF periods and above-average RF years when environmental conditions are suitable for increasing herd sizes.

Keywords: climate, NDVI, pastoralists, livestock, Kenya, drought, vulnerability, cultural adaptation

INTRODUCTION

During the period 2007–2010, pastoralists in the region of Northern Kenya and southwestern Somalia (Figure 1) reported progressively severe drought conditions. Neighboring tribes, e.g., Pokot, Borana, and Turkana, complained of diminishing water resources and some groups came into conflict while competing to sustain economically vital livestock herds. Locals named unpredictable seasonal rains and decreased rainfall (RF) as reasons contributing to these stressful environmental conditions.

Among many pastoralists of this region, the number of livestock owned by an individual, household, or community is a sign of wealth, as well as an investment that yields returns. The necessity to sustain herds and any opportunity to increase herds maintains considerable priority for a family's unity and survival (Henriksen, 1974). Thus, traditional cultural responses promote propagating livestock herds whenever environmental conditions are suitable (McCabe, 2004). However, these anthropogenic responses to short-term climatic oscillations can contribute to environmental stress and subsequent losses of livestock and exacerbate social tensions and regional instability. This phenomenon can be described as a cyclical Tragedy of the Commons (Hardin, 1968).

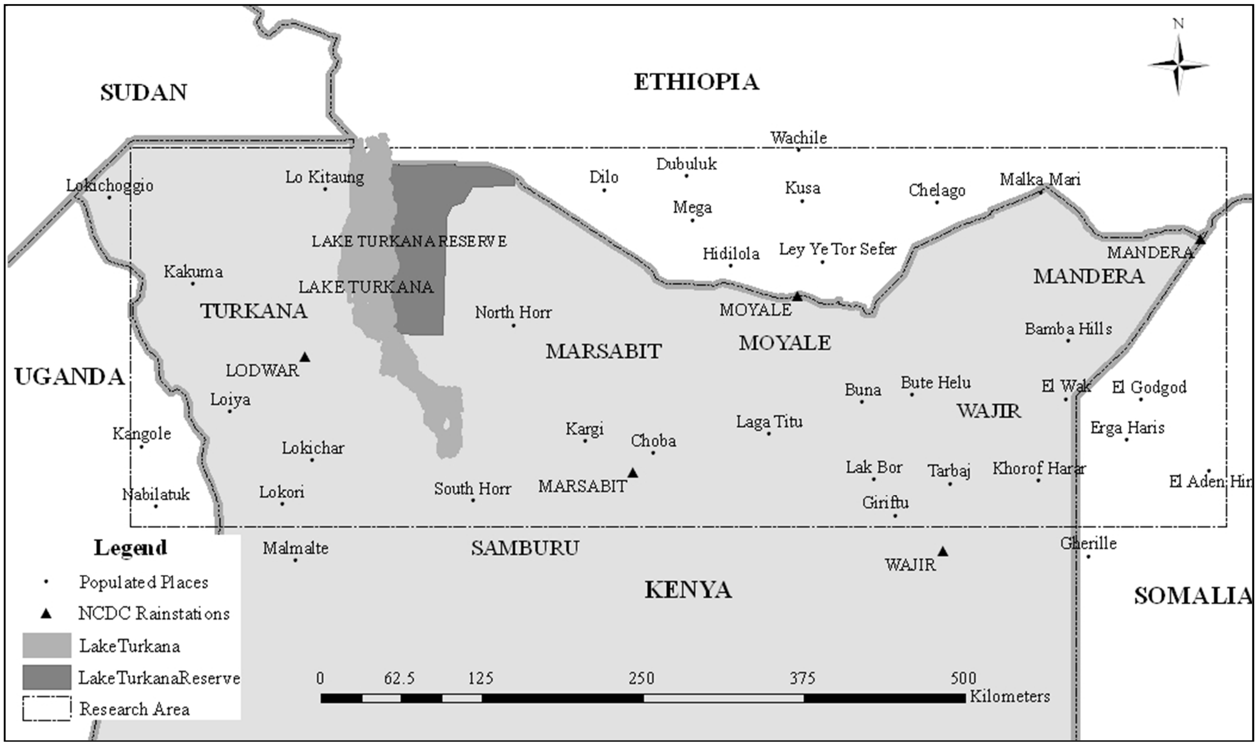

Figure 1. Research Area.

We examined two RF-measuring products and two vegetation-monitoring products to analyze intra- and inter-annual trends of RF correlations to recorded drought events and vegetation responses over a sixty-year period in the study region. For examining the sixty-year (1948–2007) RF record, we used rain station-based estimates from a product prepared by the GPCC (Global Precipitation Climatology Centre). For the ten-year (2001–2010) RF record, we used RF estimates from a satellite product, the Meteosat Rainfall Estimates (RFE). In addition, we examined NDVI (Normalized Difference Vegetation Index) estimates for the region. We used AVHRR (Advanced Very High Resolution Radiometer) NDVI data to analyze vegetation responses to GPCC estimates for a twenty-five year period, 1982–2006, and MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI data to analyze vegetation responses to RFE for the ten-year period, 2001–2010. An expected correlation response of NDVI to RF is conformity; i.e., in an equilibrium system, one expects NDVI to increase with increased RF. By combining RF and NDVI analyses with cultural responses and historical records, researchers can study human interactions with environmental change thus qualify and quantify contributing factors to events such as drought. We further categorized drought events based on these data and determined that the most recent drought event (2007–2010) cannot be attributed to climate alone. We suggest that normative cultural responses contributed to the duration and severity of this prolonged drought event.

METHODS AND MATERIALS

Research Area

We studied an area that covered the five major districts of Northern Kenya, viz., Turkana, Marsabit, Moyale, Wajir, and Mandera (Figure 1). This is a particularly fragile environment inhabited primarily by agriculturalist and pastoralist groups. It is a region that experienced a prolonged drought from 2007 to 2010. The research area covers an area of ~255,000 km^2. The climate is classified as semiarid and the predominant biome is semiarid desert. The dominant land cover types are Northern Acacia-Commiphora bushlands and thickets in the western districts; Masai-Xeric grasslands and shrublands in the central districts; Somali Acacia-Commiphora bushlands and thickets in the eastern districts; and East African Montane Forests sporadic throughout but mostly in the west. Lake Turkana and the Lake Turkana Reserve are dominant features in the northwest.

Rainfall (RF) Data

For Africa, several products are available that differ in spatial resolution, temporal resolution, and temporal coverage. We examined two available products, DWD's (Deutscher Wetterdienst) GPCC estimates and EUMETSAT's (European Organisation for the Exploitation of Meteorological Satellites) Meteosat RFE. A third product, NASA's (National Aeronautics and Space Administration) TRMM (Tropical Rainfall Measuring Mission), also provides RF data for the region but we do not include those findings in this report, primarily because TRMM pixel sizes are over six times larger than RFE and temporally cover about the same period (TRMM 1998–2010 and RFE 2001–2010).

Temporal coverage of the GPCC data set starts in January 1901,[*] making it particularly suitable for monitoring long-term precipitation variations and trends. Due to its coarse temporal (monthly) and spatial resolution (0.5^o – 2.5^o), the data are less suited for local studies but rather for regional, including large watershed or basin analyses. For this study, we used GPCC's version 004 product produced at the 0.5^o resolution, or pixel area of ~ 3080 km^2, and covering the period from 1901 to 2007. The data set is a reanalyses product based on interpolation of measurements from station data. Temporal coverage for the RFE daily product we used in this study starts in January 2001.[**] RFE data are available in different temporal intervals, e.g., daily and decadal, and spatial resolutions. The daily product we used for this research has a spatial resolution of ~120 km^2 pixel area.

Although many satellite climate monitoring products use station data for calibrating satellite acquired precipitation amounts, a main disadvantage to these precipitation products is that, unlike reliable station records, these products provide information about "precipitable water" in the atmosphere. These estimates may not be synonymous with the actual precipitation reaching the ground. Thus, the mean RF values reported here should not be considered as actual ground level accumulations but representative of these accumulations. We calculated an "annual RF mean" on daily or monthly records comprising a calendar year and a multi-year period we calculated from the average of annual means for that period. We use the term "RF period" to describe a temporal unit either longer than a year or traversing parts of two subsequent years thus distinguishing a period from a calendar year.

NDVI

In addition to RF, we examined two NDVI estimates for the region captured by multispectral satellite instruments, NASA's MODIS-Vegetation and National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR). Since 1982, NOAA's AVHRR (GIMMS data set—semi-monthly compositing) has captured daily spectral data suitable for NDVI in the visible (0.58–0.68 μ) and near infrared (0.725–1.10 μ) ranges of the electromagnetic spectrum with global coverage in an 8 km spatial resolution (64 km^2 pixel size).[***] NASA's Terra missions include the MODIS instrument, which collects NDVI data globally on a one-to-two day basis at a 250 m spatial resolution (0.0625 km^2 pixel size).[****] Intra- and inter-annual changes in NDVI prove a reliable monitor for plant growth (vigor), vegetation cover, and biomass production from multispectral satellite data produced in nearly cloud-free weekly and bi-weekly composites. The principle behind NDVI is that chlorophyll causes considerable absorption of incoming sunlight visual light in the red-light region of the electromagnetic spectrum, whereas a plant's spongy mesophyll leaf structure creates considerable reflectance in the near-infrared region of the spectrum (Tucker, 1979; Jackson et al., 1983; Tucker et al., 1991). As a result, vigorously growing healthy vegetation has low red-light reflectance and high near-infrared reflectance hence high NDVI values. The algorithm produces output values in the range of -1.0 to 1.0. Increasing positive NDVI values indicate increasing amounts of green vegetation. NDVI values near zero and decreasing negative values indicate non-vegetated features such as barren surfaces (rock and soil), water, snow, ice, and clouds.

[*] http://kunden.dwd.de/GPCC/Visualizer
[**] http://earlywarning.usgs.gov/fews/africa/web/dwndailyrfe.php
[***] http://phenology.cr.usgs.gov/ndvi_avhrr.php
[****] http://modis.gsfc.nasa.gov/about/

FINDINGS

The GPCC Sixty-Year Rainfall Record (1948–2007)

Although the GPCC, 0.5^{O}, RF data set covers the period 1901–2007, we chose a sixty-year period (1948–2007) for the purpose of this study as a statistically suitable sample both honoring the Central Limit Theory and within the life-span of an individual. The GPCC 107-year mean RF is 560 mm and the sixty-year mean is 559 mm, essentially equal. Thus, mean RF during the 20th century and first decade of the 21st century is nearly unchanged.

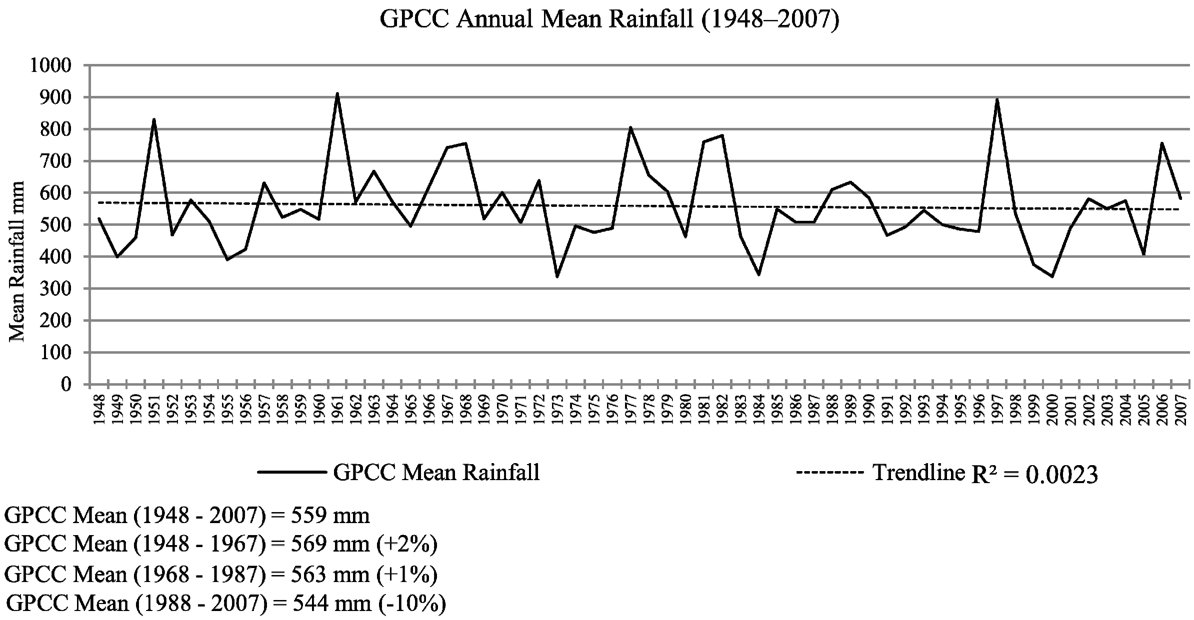

Figure 2. GPCC Annual Mean Rainfall (1948–2007).

A time series trend analysis of the GPCC estimates for the period 1948–2007 results in a negative fitted trend equation, Yt = 569.492 - 0.357768*t, with mean absolute percentage error (MAPE) 18.3%. Although this is a mild negative trend, the most recent twenty years (1988–2007) have a mean RF decrease of 10% (544 mm) from the sixty-year mean (559 mm). In addition, the data are not normally distributed, p-value < 0.005 at 95% C.I., and contain three mild outliers for the above-average RF years 1951, 1961, and 1997.

In the districts of Northern Kenya from 1948 to 2007, United Nations agencies and their sources have recorded twenty-five years as experiencing drought events () (UNDP, 2004) and the period from 2007 to 2010 as essentially a period of continuous drought (see generally UNICEF Humanitarian Action Reports, Kenya). Thus, we further divided the RF data among three twenty-year periods because time series patterns of droughts revealed clustering in three twenty-year periods, 1948–1967, 1968–1987, and 1988–2007 (Table 2). Furthermore, each of these periods contains at least one year with RF ≥ 40% of the sixty-year mean (1951, 1961, 1977, 1982, and 1997), of which three are mild outliers (1961, 1981, and 1997). Although not statistical outliers, mean RF for the years 1973 and 2000 were ≤ -40% of the sixty-year mean. According to the Oceanic Niño Index,* 1951 and 1997 were weak El Niño years, 1997 a strong El Niño year, 2000 a weak La Niña year and 2007 a moderate La Niña year.

Table 1. Recorded Historical Drought Events

Recorded Drought Events in Northern Kenya				
1952	1953	1954	1955	1960
1961	1972	1973	1974	1975
1977	1980	1981	1983	1984
1991	1992	1994	1995	1996
1999	2000	2004	2005	2007
Sources: UNDP and UNICEF				

* http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ens

Deriving Annual RF Percentages from the Sixty-year Mean and the 5% and 10% Thresholds

In order to better analyze the rainfall data, we calculated annual means as percentages of the sixty-year mean. In addition, we processed the data into two sets of thresholds, 5% and 10%, based on these mean RF percentages. For the 5% threshold, we consider the range -4.99% to 4.99% typifies an average RF year and, for the 10% threshold, the range -9.99% to 9.99% typifies an average RF year. Using these thresholds, we analyzed correlating patterns between annual RF estimates and recorded drought events (Table 3).

Table 2. GPCC Sixty-year and Twenty-year Annual Mean Rainfall Estimates

Rainfall estimates in mm	1948–2007	1948–1967	1968–1987	1988–2007
Mean	559	569 (+2%)	563 (+1%)	544 (-10%)
Max.	911	911	804	892
Min.	337	391	337	338
StDv.	130	136	135	125
Frequency ≥ 5% (+)	19	6	8	5
Frequency ≥ 5% (–)	30	10	11	9
Reported Droughts	25	6	9	10
Frequency of Droughts	1 drought per 2.4 years	1 drought per 3.3 years	1 drought per 2.2 years	1 drought per 2 years

We found that historical drought events correlated with 64% of the ≤ -10% threshold years but only with 8% of the ≤ -5% threshold years. Moreover, drought events correlated with 16% of the ≥ +10% threshold years. From these findings, we determined that an average rainfall year, i.e., an annual mean rainfall that alone could not explain the onset of a drought, is in the range of -9.99% to 9.99%. Other notable observations include: (1) the frequency of below-average RF years is 32% higher than above-average RF years, but the magnitude of above-average RF years is 41% greater than below-average RF years; and (2) the frequency and upper range, or magnitude, of positive RF years in the ≥ ± 25% ≤ ranges are higher than for negative RF years.

Table 3. Drought Categories and GPCC Estimates, 5%, 10%, and 25% Thresholds of Annual % of 60-Year Mean

Threshold	Frequency in years	Drought Category-1	Drought Category-2	Drought Category-3	Drought Category-4
≥-+25% ≤ +63%	9		1	1	1
≥-+10%	15			1	
≥ +5%	19				
-4.99% – +4.99%	11			2	1
≤ -5%	30			1	1
≤ -10%	22	5			5
≤ -25% ≥ -40%	7	1			5

Determining the Drought Categories

As we discussed in the previous section, we determined that the range -9.99% to 9.99% describes an average rainfall year in Northern Kenya. Using this baseline and examining the groupings and frequency of recorded drought events, we created four categories by which to group droughts (Table 3). The twenty-five droughts recorded during the sixty-year period result in an average of one drought per 2.4 years, but the frequency of droughts in the last twenty years of the record has increased to one drought per two years.

A Category-1 drought is a correlated same-year response of a recorded drought event to a below-average RF year but not directly preceded either by a recorded drought event, or by a below-average RF year. A Category-2 drought is a recorded drought event responding to a ≥ 2-year period of consecutive below-average RF years but not directly preceded by a recorded drought event. A Category-3 drought is a recorded drought event occurring during an average or above-average RF year but not directly preceded by either a Category-1, -2, or -4 recorded drought event, or below-average RF year. A Category-4 drought is not otherwise categorized hence we define it as a confluence of the other three categories within a multi-year period.

Note that the frequency of below-average RF years falling in the adjusted ≤ -5% category is ~37% greater than for the adjusted ≥ +5% category and contributes to 64% of the twenty-five recorded droughts during the sixty years but, of these twenty-five droughts, only two are attributed to the ≥ -5% < -10% range. In addition, all Category-1 (direct response) droughts we attribute to below-average RF years in the ≥ -10% range. Finally, Category-4 (the confluence category) corresponds to the greatest number of recorded droughts (thirteen events) distributed throughout the threshold ranges but with a high frequency in the ≤ -10% range. Thus, we attribute 24% of the recorded drought to sudden decreases in RF with a magnitude ≤ -10% and the remaining 76% of droughts to a confluence of factors and multi-year responses.

AVHRR NDVI Correlations with GPCC Recorded Long Rains (LR) and Short Rains (SR)

Northern Kenya traditionally receives two RFs per year, the long rains (LR) and the short rains (SR). LR occur during the first half of the year and SR during the second half. We conducted a twenty-five year (1982–2006) correlation analysis of AVHRR NDVI responses to GPCC RF during these LR and SR periods and found that the dominant NDVI triggering LR come between January and April and the triggering SR between September and December but are most dominant in October. Essentially, this comprises one period from September through April. However, November and December rains are sporadic. Over the sixty-year study period, LR have a mean of 297 mm with a standard deviation of 83 mm; SR have a mean of 227 mm and standard deviation of 106 mm (Table 4).

We tested the two populations, LR and SR, for normal distribution of the means and equal variances. For the two populations, LR are very well distributed (p-value = 0.707, 95% C.I.) with one mild outlier for 1981. However, the short rains are not evenly distributed (p-value < 0.005, 95% C.I.) and the data are skewed toward the negative values but with mild positive outliers in 1997, 1961, and 2006. In addition, the two populations have statistically equal variances (Levene's test statistic = 0.10 and p-value = 0.747, 95% C.I.).

Table 4. GPCC LR and SR Estimates

Category	LR (January–June) in mm	SR (July–December) in mm
60-year Mean (1948–2007)	297	227
60-year StDv. (1948–2007)	83	106
60-year Max. (1948–2007)	547	683
60-year Min. (1948–2007)	103	102
20-year Mean (1948–1967)	298	237
20-year StDv (1948–1967)	62	109
20-year Mean (1968–1987)	314	207
20-year StDv (1968–1987)	102	77
20-year Mean (1988–2007)	278	236
20-year StDv (1988–2007)	81	130

We conducted similar tests for the twenty-year sample periods, three periods per population. We conducted one sample T-tests for each twenty-year period, LR and SR, based on each population's mean. At a 95% C.I., we found no statistically significant observations. In addition, we tested equal variances among the three periods for each population using an F-test for the LR samples and Levene's test for the SR samples. At a 95% C.I., the six tests, three combinations per population, resulted in no statistically significant observations.

During the three twenty-year periods, both LR and SR fluctuate one distinction might have relevance for understanding the increase of recorded drought events during the 1988–2007 period, namely, the contributing factor to the 10% decrease in mean annual RF from the sixty-year mean is entirely attributed to LR—a 7% decrease from the 1948–1967 period and an 11% decrease from the 1968–1987 period with relatively no change in SR means for all three periods (Table 4). Although SR decreased 13% from the 1948–1967 period to the 1968–1987 period, SR increased 13% during the 1988–2007 period. Thus, the smallest difference in mean RF between LR and SR occurred during the 1988–2007 period.

No discernable pattern emerges that links SR estimates immediately preceding a recorded drought event in the following year other than the occurrences of Category-1 and -3 droughts, which have the highest tendencies of describing these events and, in the period 1979–1998, a series of five Category-1 events succeeded each other. In certain cases, especially for Category-3 droughts, we looked to the preceding year's SR (October–December) as a contributor to the following year's recorded drought event but found no correlation.

Finally, RF variations affect agricultural cycles. Although the standard deviations for both LR and SR vary considerably during the three twenty-year periods, these variations remain statistically insignificant. Still, the highest result (130 mm) occurs during the SR 1988–2007 period, 23% higher than the sixty-year standard deviation for the short rains. In a fragile environment, this variation potentially has contributed to the increased number of recorded droughts during this period.

Insofar as AVHRR NDVI responses to GPCC RF, we calculated the correlation coefficients for both LR and SR for the period 1982–2006 using Pearson's correlation coefficient.* We expect NDVI responses to conform to RF; i.e., more rain should cause a positive vegetation response as measured in NDVI. During consecutive years of non-drought events, correlations between NDVI and LR are consistently high (> 0.7) and punctuated by single badly correlated years (< 0.5), e.g., the period 1985–1990. Furthermore, all first years following a drought event result in a high correlation ranging from > 0.6 to > 0.9.

One reason for these patterns might be an indication that reduced livestock herds are placing less stress on recovering vegetation, which is rebounding to increasing water availability (Schimmer, 2009). But in subsequent years, as livestock herds replenish, more stress is placed on vegetation and its response to rainfall becomes less correlated. Thus, after the first or second years of intensified breeding to replenish herd populations following a drought, vegetation begins to respond less well to RF until an equilibrium is reached.

Table 5. GPCC-AVHRR Correlations NDVI Responses to LR and SR

Year (drought year shaded)	GPCC-AVHR Correlation 1st Half (1982–2006)	GPCC-AVHR Correlation 2nd Half (1982–2006)
1982	0.89	0.67
1983	0.95	-0.13
1984	0.37	0.45
1985	0.65	-0.43
1986	0.48	0.10
1987	-0.93	0.82
1988	0.77	0.02
1989	0.90	-0.13
1990	0.96	0.51
1991	0.85	0.57
1992	0.38	0.38
1993	0.93	0.27
1994	0.04	0.34
1995	0.94	0.60
1996	-0.19	0.38
1997	0.74	0.71
1998	0.92	0.19
1999	0.76	0.32
2000	0.33	0.29
2001	0.91	-0.17
2002	-0.29	0.14
2003	0.01	0.02
2004	0.71	0.01
2005	-0.98	0.19
2006	0.91	-0.25

Furthermore, in all but one set of two consecutive drought events, NDVI responses to consecutive annual decreases in LR means correlate well (> 0.7) for the first year and not well (< 0.4) for the second year (Table 5). The one outlier in this pattern occurs in the mid-1990s during a period of multiple consecutive drought events. However, 1991 and 1992 fit the pattern; 1993 was not a reported drought year; 1994 and 1995 reverse the pattern; and 1995 and 1996 fit the pattern.

One fundamental question is whether this equilibrium is sustainable during periods of decreased RF. The data appears to suggest that sustainability is less disruptive to vegetation responses to RF in the first year of LR during a multi-year drought but highly disruptive during the second and, sometimes, third. In addition to human and livestock resource extraction, this pattern is likely influenced by a decreasing amount of water resources banked in the environment for which vegetation, livestock, and humans compete.

Whereas NDVI responses to LR reveal a number of patterns, we did not observe any similar patterns of NDVI responses to SR. None of the correlation coefficients for the same drought events is > 0.6 and the majority (82%) is < 0.5. Thus, NDVI responses do not correlate well with SR during drought events. Moreover, we did not observe consistency between LR and SR responses for the same or consecutive years. Compared to non-drought years during the period 1982–2006, LR remain consistently highly correlated with NDVI, either negatively or positively. In sixteen of the twenty-five

* Pearson's correlation coefficient calculates values between -1 and +1 where 0 equals no correlation, a negative value indicates an inverse correlation and a positive value indicates conformity; a resulting p-value less than α means that the null hypothesis is rejected thus the correlation is not zero.

years analyzed (67%), LR correlated with NDVI at > |0.7|. Conversely, in only five years (21%) over the same period, SR correlated at > |0.6|. This finding further suggests that LR in confluence with human responses to these rain periods have a greater influence on triggering drought events than do SR.

To understand if biomass changes in the study area are purely climate driven or if humans contribute to vegetation growth – positive or negative - requires an integrated analysis of vegetation and climate parameters (Evans and Geerken, 2004). We only consider rainfall as the forcing climatic variable; temperature, as is typical for these climates, shows only minor inter-annual variations without a significant influence on green biomass. In a first analysis, we calculated the NDVImax trends between 1982 and 2006 resulting in a mixed picture of positive and negative trends showing different spatial distribution patterns for the summer NDVImax and the winter NDVImax (Figure 3).

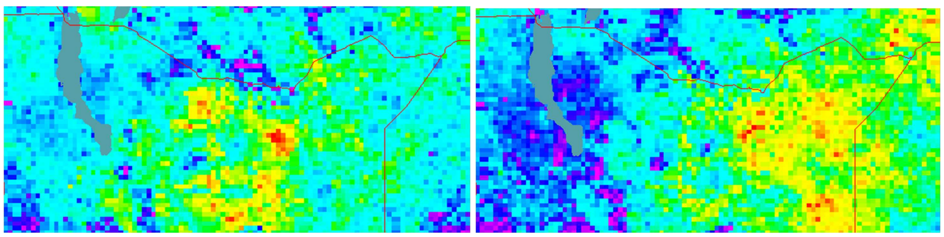

Figure 3. NDVImax trends for summer peak (left) and winter peak (right). Red areas show improvements of up to 0.018 (NDVI) per year, purple areas NDVI losses of up to 0.0085 per year. Areas shown in cyan do not show any significant changes.

To learn about the driving forces – climate or human - triggering the trends in figure 3, we analyzed the development of rainfall over the same period. The integrated NDVI-rainfall analysis shows areas that are very well correlated to a distinct rainfall period but also some poorly correlated pixels. The latter include floodplains that are more dependent on river discharge; other poorly correlated pixels may have vegetation and land cover that is severely degraded, i.e., not responding to rainfall as expected. In addition, some deeper-rooting vegetation covers do not depend as much on seasonal rainfall.

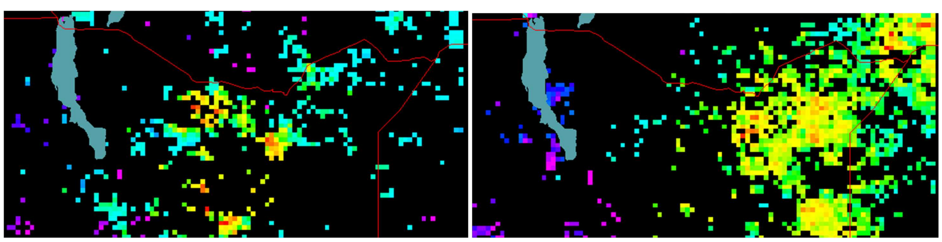

Figure 4. Trend of residuals (change of responsiveness of NDVI to rainfall) for the summer NDVImax (left) and the winter NDVImax (right). Green, yellow to red colors indicate an increasingly better responsiveness; dark bluish to purple colors stand for increasingly worse responsiveness.

To find evidence of potential human influences on biomass development, we analyzed temporal changes in the NDVI response to rainfall. Changes in the responsiveness of biomass show in the trends of the residuals that are calculated between the statistically predicted and the measured NDVI. Statistical NDVI predictions are based on the best correlating rainfall period as explained above. In figure 4, we see vast areas in the study region's eastern part where the NDVI shows an increasing (green, yellow to red) responsiveness to rainfall (up to 0.018 NDVI response per year, red colors), meaning a total increase in NDVI over a twenty-five year period of 0.45. Areas displayed in dark blue and purple respond increasingly worse to rainfall with maximum losses of 0.009 per year accumulating to a total twenty-five-year loss in NDVI of 0.225.

For the trends of the residuals, indicating human influences on biomass development, we applied strict thresholds showing only trends that are significant at a 0.9 level and with a correlation coefficient between NDVImax and rainfall that is better than 0.5. As shown in figure 3, much larger areas are actually under degradation (blue and purple); human activities may be a driving force contributing to this trend. However, potential human influence does not show in this analysis because the NDVImax-rainfall correlation in these areas is poor (black) with a correlation coefficient less than 0.5 (Figure 4). In future studies, additional information including vegetation type might provide further evidence to prove a human contribution to vegetation degradation.

The RFE Ten-Year Record

For processing and analyzing the RFE data, we used many of the same methods as for the GPCC data (Table 6, Figure 5). Because the period is much shorter, we further checked RFE correlation with GPCC data for the ten-year period. The RFE data are normally distributed with a mild outlier of above-average rainfall in 2006 and a mild positive trend for the decade. We tested the two data sets for equal variance and found them to be normal, Levene's Test p-value = 0.379. In addition, the Pearson's Correlation statistic for RFE and GPCC is 0.943 (p-value 0.001) hence the two data sets are highly correlated. Based on yearly percentages of the ten-year mean and the 10% threshold, the RFE record contains three below-average RF years, 2001 (-30%), 2005 (-34%), and 2009 (-21%), and two above-average RF years, 2002 (20%) and 2006 (60%). The remaining five years fall within the -9.99 – +9.99 threshold range of average RF.

Table 6. Meteosat RFE mean RF estimates

Year	Annual Mean RF (mm)	% 60-year Mean	5% Threshold	10% Threshold
2001	231	-30	-30	-30
2002	394	20	20	20
2003	339	3	0	0
2004	334	2	0	0
2005	215	-34	-34	-34
2006	525	60	60	60
2007	297	-9	-9	0
2008	349	6	6	0
2009	260	-21	-21	-21
2010	337	3	0	0
Avg.	328			
StDv.	89			
GPCC v. RFE (2001-2007) Corel. Coef.				0.94

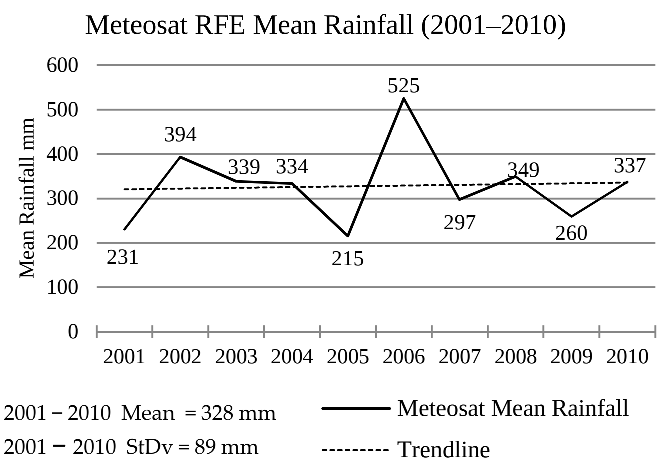

Figure 5. Meteosat RFE mean RF estimates (2001–2010).

MODIS NDVI Responses to Meteosat RF, 2001-2010

A time series trend analysis of the Meteosat annual mean RF data for the period 2001–2010 results in a mild positive fitted trend equation, Yt = 319.267 + 1.60606*t, with MAPE 19.85%. A time series trend analysis of the MODIS NDVI data set over the same period results in a much stronger negative fitted trend equation, Yt = 4662.73 - 20.5333*t, with MAPE 8.0%. A Pearson's Correlation of the two data sets results in a 0.837 correlation statistic (p-value = 0.003). Thus the data conform well but for two inverse relations for the years 2003 and 2008 (

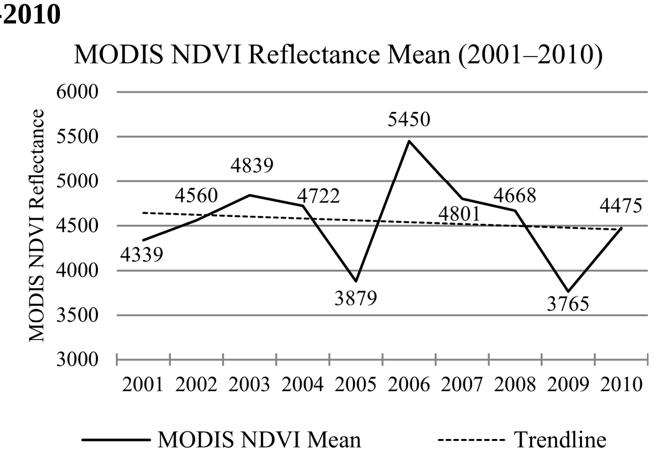

Figure 6. MODIS NDVI reflectance (2001–2010).

Figure 6). However, time series trendlines for the two data sets reveal opposite trends—mean RF increased while mean NDVI decreased. Thus, some factor other than RF is causing NDVI to decrease although annual NDVI responses to RF conform well.

PASTORALIST CULTURAL VALUES IN NORTHERN KENYA

Pastoral societies across Africa hold livestock as the major source of wealth within their communities. This wealth is both material and symbolic and has been referred to as the East African "cattle complex" (Herskovits, 1926). Both forms of wealth increase with the size of one's herd. Livestock are used within market economies in addition to religious and ceremonial activities. Larger livestock numbers allows for greater social networks, which are built on the reciprocal giving and receiving of livestock between men. A larger herd provides more security against the effects of livestock raiding. Because there is little access to other forms of investment in the region, livestock also form a currency from which interest accumulates in the form of calves and a source from which things can be bought and sold (Henriksen, 1974; McCabe, 2004; Jones, 1984).

Theoretical debate has considered how to conceptualize such an ecological and social system that continuously tax the limits of environmental resources. The most striking fact for social and environmental scientists to explain is that the regulation method for herd sizes most often comes in the form of population collapse. This collapse is the result of degraded environmental conditions from overgrazing, a decrease in precipitation, or disease as well as the combination of the three (Henriksen, 1974). As is seen in the history of drought and famine, precipitation of 10% below average can result in decimated herds (see the recorded droughts of 1972, 1980 and 1983). These factors create an ecological system that exists at disequilibrium rather than a stable population size that linearly adjusts to external inputs such as RF and vegetation over an extended period of time (McCabe, 2004).

DISCUSSION

A Narrative of Climate, NDVI, and Cultural Responses, 2001–2010

In the last ten years, the average RF in Northern Kenya was approximately 10% less than the GPCC sixty-year mean. Such a decrease in precipitation has likely contributed to the increasing number of droughts experienced in this region. However, this trend does not satisfactorily explain whether climate alone caused all the recorded drought events during this period, especially considering population increases in the region over the same sixty-years. Conversely, the categorical paradigms we use to base these observed patterns in the sixty-year record provide a better starting point to our analysis for qualifying the causal elements of the most recent prolonged drought period, 2007–2010.

We suggest that following 2005, a below-average RF year, a cultural response to the abundance of RF in 2006 contributed more to the drought period of 2007–2010 than the below-average year in 2009; i.e., below-average RF in 2009 exacerbated an existing drought but it cannot explain the instigation nor wholly contribute to the severity of the drought period 2007–2010. In this analysis, we use the last ten years of the GPCC record (1998–2007) in combination with the RFE record (2001–2010) to analyze RF and the MODIS record (2001–2010) to analyze NDVI.

Following three years of below-average RF years (2002–2004) and two recorded droughts (1999–2000), a nearly three year recovery period (2002–2004) ensued. Average and above-average RF allowed livestock herds to replenish while vegetation and water resources recovered. The NDVI data recorded this process, which is especially evident in the inverse correlation between RF (decrease) and NDVI (increase) in 2003. In 2004, a Category-3 drought disrupts this trend, which annual mean RF (neither LR nor SR) cannot explain. The drought continues as a Category-4 in 2005 (GPCC -27%, Meteosat -34%). But the abnormally copious RF (GPCC +35%, Meteosat +60%) the following year likely stimulated an increase in livestock numbers as NDVI rebounded to well above the ten-year average (+20%). But a Category-3 drought is again recorded in 2007 although GPCC reports an average year and Meteosat reports a below-average year (-9%), but not exceeding the adjusted ≥ 10% threshold.

According to the records, this drought persists at different levels of severity for the following three years (2008–2010) as a Category-4 drought; 2009 is the only below-average RF year (Meteosat -21%) and the other two, 2008 and 2010, are average RF years. Similar to 2003, NDVI responds inversely to RF in 2008; i.e., NDVI decreased in spite of an increase in RF. Moreover, although NDVI results show good positive correlations to annual mean RF fluctuations except in two key years, 2003 and 2008, the ten-year NDVI trend is strongly negative thus not conforming to the slightly positive trend of increasing RF for the decade.

In summary, three important observations suggest that factors other than climate contributed to the two drought periods of the last decade: (1) a poor correlation with the onset of recorded drought events or periods and below-average RF years; (2) an inverse correlation between RF and NDVI for two years, of which one preceded a drought year not explained by below-average RF for that year; and (3) an inverse correlation between a slight positive trend in RF and a strong negative trend in NDVI for the decade.

We provide two analyses, either (1) local communities are over responding to positive RF periods in ways not sustainable during negative RF periods, or (2) local communties' necessary demands on environmental services and resource availability can only be sustained during the normal and positive RF years. Historically drought events occur in sets of two to four consecutive years. Thus, the recent increasing frequency of drought events is best described as fewer years between drought events rather than more consecutive years of drought. Population increase perhaps contributes to the recent increase in drought frequency over the last twenty years. However, we are more interested in the highs not lows because cultural responses to high RF periods appear to contribute to the onset and severity of droughts.

Garrett Hardin (Hardin, 1968) describes the tragedy of the commons as resulting from imbalances between resource extraction and resource availability. A point can come in pastoralist communities sharing common resources when the desire for social stability inspires herdsmen, as rational beings, to maximize their individual gains by increasing utility through expanding herd sizes. Hardin argues that eventually the cumulative of this competition will lead to a destruction of the environment on which they rely to maintain their gains but that this occurs less often in societies organized by private property.

However, converting traditional community property into private or regulated property is neither a popular nor functional approach among these pastoralist groups (Lusigi, 1984; de Haan, 1994). Educational or management approaches must embrace the structure of livelihood systems among the cultural groups of these fragile environments (Young, 2009). John McPeak (McPeak, 2005) argues that the record of failure in pastoral development in Northern Kenya may be partially due to a faulty conceptual foundation; he suggests that facilitating herd accumulation may offer more promise than discouraging it.

CONCLUSION

In addition to human management of water quality and quantity, a number of natural variables affect water resources. As a water resource, the amount of RF is important. When and where rain falls, and how the environment consumes, reacts, and distributes the water resource are fundamental to ensuring the sustainable availability of the resource and sustaining vegetation health. For example, varying utilities of water use and conservation by different plant species can attribute to both negative and positive latent responses in NDVI (Celis, De Pauw, and Geerken, 2007). In addition, the level and consistency of water resources contributed by watersheds in adjacent regions, the capacity and recharging of groundwater, and the loss of water due to surface runoff and inadequate catchments can further contribute to the depletion of water during a period of decreased RF. Finally, intense agricultural activities, especially wet farming, will increase NDVI in spite of periodical diminished precipitation so long as water resources are available to maintain production (Celis, De Pauw, and Geerken, 2007). Conversely, overgrazing in open ranges during periods of increased precipitation can inhibit positive NDVI responses.

Thus, as important to understanding what climate factors trigger droughts is knowing what occurs during the periods between droughts that are not recorded in the climate record. Primarily, how are resources being extracted and managed and how do positive climate events, e.g., above-average RF years, contribute to cultural responses that potentially lead to negative feedback loops of environmental stress during average RF periods, and subsequently contribute to the severity of below-average RF periods. We suggest that cultural responses to climate occurring during the average to above-average RF periods contribute to environments that are more fragile during periods of decreased RF.

REFERENCES

Baldyga, T. J., Miller, S. N., Driese, K. L., and Gichaba, C. M., 2008. Assessing land cover change in Kenya's Mau Forest region using reomtely sensed data, *African Journal of Ecology , 46* (1): 46-54.

Celis, D., De Pauw, E., and Geerken, R., 2007. *Assessment of Land cover and land use in Central and West Africa and North Africa: Part 2. Hot Spots of Land Cover Change and Drought Vulnerability*. Aleppo, Syria: International Center for Agricultural Research in Dry Areas (ICARDA).

Gulliver, P., 1951. A preliminary survey of the Turkana, *Communications from the School of African Studies, New Series* (26).

de Haan, C., 1994. An Overview of the World Bank's Involvement in Pastoral Development, *Pastoral Development Network, #31b*. London: Overseas Development Institute.

Evans, J., and Geerken, R., 2004. Descrimination between climate and human induced dry-land degradation in *Journal of Arid Environments, 57*: 535-554.

Hardin, G., 1968. The Tragedy of the Commons. *Science , 162*: 1243-1248.

Hastenrather, S., Polzin, D., and Mutai, C., 2006. Diagnosing the 2005 Drought in Equatorial East Africa, *Journal of Climate , 20*: 4628-4637.

Henriksen, G., 1974. *Problems of Development in Turkana.* Bergen: University of Bergen Press.

Herskovits, M., 1926. The Cattle Complex in East Africa. *American Anthropologist , 8* (2).

Ingold, T. 1988. *Hunters, Pastoralists and Ranchers: Reindeer Economics and their Transformations.* Cambridge: Cambridge University Press.

Jackson, R. D., Slater, P. N., and Pinter, P. J., 1983. Discrimination of growth and water stress in wheat by various vegetation indices through clear and turbid atmospheres, *Remote Sensing of the Environment , 15*: 187-208.

Jones, D. K., 1984. *Shepherds of the Desert.* London: Elm Tree Books.

Lusigi, W., 1984. *Integrated Resources Assessment and Management Plan for Western Marsabit District, Northern Kenya.* Nairobi: UNSESCO.

McCabe, T., 2004. *Cattle Brings Us to Our Enemies; Turkana, Ecology, Politics, and Raiding in a Disequilibrium System.* Ann Arbor: University of Michigan Press.

McPeak, J., 2005. Individual and Collective Rationality in Pastoral Production: Evidence from Northern Kenya. *Human Ecology , 33* (2): 171-197.

Orindi, V. A., Nyong, A., and Herrero, M., 2007. Pastoral Livelihood Adaptation to Drought and Instititutional Interventions in Kenya. *Human Development Report 2007/2008* .

Schimmer, R., 2009. Satellite Evidence of Large Scale Environmental Change Caused by Violence in Darfur Since 2003, *Environment and Conflict in Arrica: Reflections on Darfur*. M. Leroy (Ed.), Addis Ababa, Ethiopia: University for Peace, Africa Programme.

Tarekegn, B., 2009. Pastoralism and Adaptation to Climate Change, *Environment and Conflict in Arrica: Reflections on Darfur*. M. Leroy (Ed.), Addis Ababa, Ethiopia: University for Peace, Africa Programme.

Tucker, C. J., 1979. Red and photographic infrared linear combinations for monitoring vegetation, *Remote Sensing of the Environment , 8*: 127-150.

Tucker, C. J., Newcomb, W. W., Los, S. O., and Prince, S. D., 1991. Mean and inter-year variation of growing-season normalized difference vegetation index for the Sahel 1981-1989, *International Journal of Remote Sensing , 12*: 1113-1115.

UNDP, 2004. *Kenya Natural Disaster Profile.* United Nations Development Program.

Watson, D. J., and Binsbergen, J. v., 2008. Livestock Market Access and Opportunities in Turkana, *International Livestock Research Institute Research Report 3*.

Young, H., 2009. Pastoralism, Power and Choice, *Environment and Conflict in Arrica: Reflections on Darfur*. M. Leroy (Ed.), Addis Ababa, Ethiopia: University for Peace, Africa Programme.