# ESTABLISHMENT AND EVALUATION OF A LIVESTOCK EARLY WARNING SYSTEM FOR LAIKIPIA, KENYA

A Thesis

by

ZOLA RYAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2004

Major Subject: Rangeland Ecology and Management

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Approved as to style and content by:

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## ABSTRACT

Establishment and Evaluation of a Livestock Early Warning

System for Laikipia, Kenya. (May 2004)

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A new zone was added to the existing Livestock Early Warning System (LEWS), which is a subproject of the USAID Global Livestock Collaborative Research Support Program. LEWS uses the PHYGROW model and satellite imagery of weather and vegetation to estimate the availability of forage to livestock and wildlife. Drought advisories are then distributed to governments, development organizations, and pastoralists via the Internet, satellite radios, and written reports.

The Laikipia zone was established in 2001 to provide drought early warning for the arid pastoral rangelands of the Ewaso Ngiro ecosystem in the Laikipia and southern Samburu Districts, Kenya. Field verification of PHYGROW estimates of standing crop was conducted in 2002. In addition, research was conducted to determine the ability of the warning system to provide significant advance notice of emerging drought conditions.

Results of this study indicate that LEWS is capable of providing accurate estimates of forage availability on East African rangelands. There is also evidence that the use of LEWS advisories could accelerate drought response by pastoralists as much as three to seven weeks.

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# CHAPTER I

# INTRODUCTION

## Literature Review

In recent years, the chance of drought occurring in parts of East Africa has increased to as often as one in three years (LEWS 1999a). Glantz (1987) noted that drought is an integral, recurring part of the African climate and can no longer be ignored in development planning. Even in times of 'normal' rainfall, weather patterns in East Africa are highly variable (LEWS 1999a). This variability and high probability of drought has critical implications for pastoralists.

Pastoralists may face greater risks from droughts than do other members of the agricultural sector for several reasons. First, pastoralists occupy the driest areas of the arid and semi-arid lands of East Africa. These lands are more apt to experience drought conditions than the more productive lands where crops are grown (ASARECA 2000). Second, this process is becoming more and more the case as marginalization of pastoralists takes place. In efforts to increase food production, many of the more mesic lands that have traditionally been grazing lands have been converted to farmland. Pastoralists are restricted to only the driest and least productive areas. Even when crops fail and the fields are returned to pasture, the land has often been seriously degraded and

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is no longer as beneficial for livestock production as it once was (Horowitz and Little 1987, Webb and Coppock 1997). As marginalization occurs, traditional coping mechanisms are interrupted. Areas that were once designated as grazing reserves for times of drought are called upon more and more frequently and traditional migration routes must be altered (Webb and Coppock 1997, Vosti and Reardon 1997).

Another challenge facing pastoralists in times of drought is deteriorating purchasing power. As a drought progresses, pastoralists need to sell animals in order to purchase food grains. Livestock prices quickly plummet while grain prices rise sharply. If the drought continues, people may be forced to sell reproductive animals, which represent current and future assets of the pastoralist (Watts 1987, Toulmin 1988, Vosti and Reardon 1997). When drought breaks, pastoralists usually face greater obstacles to recovery than farmers. Livestock populations are depleted due to high mortality. The scarcity of animals drives the price up as pastoralists seek to restock their herds with limited cash reserves. In addition, recovery time is limited by the reproductive rates of the animals (Toulmin 1988), which are delayed up to eighteen months under post-drought conditions. Families experiencing total loss are forced into alternative lifestyles where cultural norms of community restocking of family herds break down.

Numerous authors have stressed that early detection of onset of drought and continuous monitoring of forage and weather are the first step in preventing famine. Mewaee (1982) attributed the famine in Ethiopia in the early 1980s to the lack of warning systems, claiming that the situation was discovered after the critical response time had passed. Cohen and Lewis (1987), drawing on experiences from the 1984-85 drought in Kenya, emphasized the necessity of building capacities related to tracking systems, crisis identification, and famine response. They pointed out that sufficient lead time is needed to arrange for resources to respond to a developing crisis and that close monitoring is important so that the appropriate amount of resources will be devoted to the intervention. McAlpin (1987) studied famine relief policy in India to determine lessons for Africa. She concluded that early intervention was important to drought management and that although drought emerges over time rather than being a sudden crisis, the first signs should produce action. Vosti and Reardon (1997) claimed that famine early warning systems and emergency relief systems must be made more sensitive if household food security is to be attained.

Early warning is not simply a means to rapid delivery of relief aid. Famine prevention activities are distributed along a continuum from relief to development. It is generally believed that while relief is necessary in times of emergency, more resources must be devoted to development in order to achieve true food security. Development workers, government authorities, researchers, and farmers have emphasized the need for development activities to promote self-reliance and self-sufficiency as opposed to dependency (Bethell 1995, Green 1995, Thrupp 1996, World Bank 1994, and World Bank 2001). EWS advisories are capable of empowering farmers and pastoralists by providing critical information they can use to make management decisions that allow for developing environmental conditions and prepare for severe events.

Despite general agreement that early warning is essential to food security and drought management, and despite the level of risk pastoralists face from severe weather events, few warning systems have been developed for extensive livestock management. The vast majority of early warning systems monitor indicators of human nutrition, market prices, or crop productivity (Anderson 1982, Frere and Saran 1982, FEWS NET 2000, and ASARECA 2000). The USAID sponsored Famine Early Warning System Network (FEWS NET) collects and distributes data on rainfall, vegetation greenness (NDVI), crop growth, crop production, food prices, market supply, school attendance, household income, population, employment, human growth, and malnutrition (FEWS 2000). The Intergovernmental Authority on Development (IGAD) is in the process of establishing a Regional Integrated Information System (RIIS). The goals of RIIS are enhancement of sustainable production and timely dissemination of information. Potential outputs of the system are planting success, crop progress, and predicted crop/pasture conditions (USGS 1999).

One exception is the early warning system developed by the Arid Lands Program and Drought Preparedness, Intervention and Recovery Programme of Kenya. These two programs were recently integrated into one organization, the Arid Lands Resource Management Program. The warning system was specifically developed for the ten most arid districts of the country, which are inhabited primarily by pastoralists (FAO 2000). Monitoring indicators used by the Kenyan EWS include precipitation, mean watering distance, water ponding, livestock condition, animal disease incidence, livestock sales, livestock mortality, human nutrition, household migration, and meat prices (LEWS

1999b). Many of these indicators deal specifically with issues facing pastoralists as opposed to those involved in crop production.

The focus of this discussion of early warning systems is not meant to cast a negative light on existing systems. These systems are essential to developing food security in East Africa and each has been designed to monitor important indicators of the status of the food system. Nutrition monitoring identifies social groups in the greatest need of relief or who are being bypassed by relief measures (Anderson 1982). Market prices and crop production have a direct bearing on food security. The point to be made in this discussion is that these systems should be complemented by systems which address indicators of livestock well-being, and especially by systems with predictive capabilities for livestock condition and the forage base (LEWS 1999a).

The Livestock Early Warning System (LEWS) being developed as a sub-project of the Global Livestock Collaborative Research Support Program (GL-CRSP) aims to predict the nutritional status of free-ranging livestock from NIRS fecal profiling, and forage supply from weather and soil hydrological characteristics (LEWS 1999a). The technologies and methodologies used in LEWS are expected to provide information at least six to eight weeks earlier than current monitoring systems (LEWS 1999b).

Many current early warning systems measure indicators such as human malnutrition, crop and livestock prices, and animal deaths. The response of these indicators is only observable after severe conditions have developed and little time is allowed for preparation and mitigation (LEWS 1999a, Anderson 1982). The earliest indicators of rangeland productivity are the initiating conditions, particularly precipitation and temperature. Scientists currently have the ability through remote sensing technology to attain reasonably accurate, spatially explicit estimates of weather conditions. Current early warning systems, such as FEWS NET and ALRMP are making use of these data.

The strength of the LEWS system is that it not only observes the initiating conditions of rangeland production, but uses scientifically based biophysical modeling to predict the effects of those initiating conditions on forage production and animal well being. Guggenheim and Ojha (1982) argue that computer-based models using mathematical algorithms are the best way to predict famine conditions since they allow for simultaneous consideration of complex mechanisms, combinatorial, and multiplier effects. The LEWS program was initially designed to provide at least six to eight weeks advanced notice compared to existing warning systems (LEWS 1999b). In reality, LEWS currently provides reports with 12-week forage projections. These projections are updated every ten days. This is a significant advantage given the weight placed on early detection in famine prevention literature.

There are a variety of reasons to establish an EWS for use by a non-governmental organization. Scott (1987) emphasized the ability of NGOs to develop, implement, and evaluate experimental developments with greater ease than governments. This advantage includes greater opportunity for direct interaction with the pastoralists who might use the innovations. The means of these interactions are often farmer associations, service cooperatives, or village level organizations that work with

NGO staff. Along these same lines, Curtis et al. (1988) stressed that research and development should be carried out in close contact with the supposed benefactors.

Another justification for developing early warning systems for use by NGOs comes from a discussion by Cohen and Lewis (1987). From a financial standpoint, information systems need to be multi-purpose in nature. Development of technologies and infrastructures which are useful only during periods of crisis and remain nearly idle are of little benefit when conditions are "normal." Instead, early warning system technology should serve some purpose in day to day management and when there are indications of impending crisis, the appropriate decision makers can be informed. The LEWS technologies are well suited for day to day use by an NGO wishing to monitor its forage base for livestock and wildlife within their area of influence. Automation of the system will make it conducive to use by other researchers and land managers who already have a full complement of commitments and duties.

## Objectives

This project was conducted to achieve two principal objectives.

1. Evaluate the ability of a prototype early warning system for grazinglands to predict forage conditions to a suitable level of accuracy and be used by non-governmental organizations (NGOs) as a key outreach instrument with pastoral communities.
2. Evaluate the ability of LEWS to provide significant advance warning of drought conditions to pastoralists.

## General Research Approach

This project was conducted in the Laikipia District of Kenya, based out of the Mpala Research Centre (MRC). The first phase of the project was a preliminary phase which involved establishing the early warning system. The technological tools of LEWS were put into place and stabilized. The second phase of the project was the research phase. Field verification was conducted to test the accuracy of forage estimates and two case studies were conducted to determine the ability of LEWS to provide advance warning of drought compared to traditional mechanisms.

### Phase 1: System Establishment

Tools used by the GL-CRSP Livestock Early Warning System project were put in place for the Mpala Research Centre, establishing the MRC as a new node in the LEWS communication and monitoring network. The MRC was considered a highly desirable partner in the LEWS system because of its stability, established working relationships with local farmers and pastoralists, ownership and research involving domestic livestock, collection of historical data, and status as a non-governmental organization. These characteristics placed Mpala Research Center in a prime position to monitor changes in the forage base and animal health and communicate those changes to the pastoral community on a sustainable basis.

*Modeling Forage Production*

The first task in establishing the EWS was to identify the major plant communities in Laikipia District based on existing vegetation maps, scientific literature, soil surveys, and the expertise of MRC staff. Monitoring points for the warning system were established using the following criteria:

1. Representation of the range of plant communities in the area.
2. Convenience of location to MRC staff for purposes of monitoring.
3. Adequate spatial representation of the Ewaso Ngiro Ecosystem, the area of interest to MRC.
4. MRC staff recommendations.

Co-kriging, a geo-statistical technique used by LEWS to extrapolate information from monitored points to non-monitored areas, requires a minimum of thirty monitoring points, scattered across a target landscape (Webster and Oliver 1992). Mean grid size is based on 8x8 km NDVI satellite data (Agbu and James 1994).

PHYGROW, a biophysical model of forage production, is used to estimate forage availability at each monitoring point. For each point, a parameter file was constructed containing information in four components: a) soil hydrological characteristics, b) plant growth characteristics, c) herbivore stocking rates and grazing preferences, and d) weather conditions.

Soil parameters were developed from soil survey data (Ahn and Geiger 1987). Each plant community was described according to the initial standing crop and percent maximum expression of the plant species present. Percent maximum expression was measured as percent basal area of grasses, percent frequency of forbs in a 5x5 cm frame, and effective canopy cover for shrubs and trees. Plant parameters describing the growth characteristics of those species were acquired from existing model values generated by LEWS teams in East Africa, the ECOCROP database (FAO 1996), and published literature. Herbivore stocking rates were set or estimated from data collected in interviews with pastoralists, ranchers, and game biologists in the study area.

One vital task was to designate grazer preferences for each of the plant species at various stages of growth. Preference designations include preferred, desirable, undesirable, non-consumed, emergency and toxic (Quirk and Stuth 1995). Livestock preferences are available from existing model values generated by LEWS teams. Wild herbivores, however, have not been considered in existing LEWS zones. For this reason, livestock and wildlife experts were asked to estimate the appropriate preference designation for each wildlife species grazing a particular plant species at various growth phases (rapid growth, declining growth, quiescence, death) for current year's and woody growth.

Both historical and current weather data are necessary. The WxGen statistical software (Nicks et al. 1990) was used to generate a statistically correct population of historical weather using historical coefficients from nearby World Meteorological Organization stations, which are geographically adjusted using surface weather data in the Almanac Characterization Tool (ACT) developed by Corbett et al. (1999). Current weather data are attained from NOAA Rainfall Estimate (RFE) data (NOAA Climate Prediction Center 2001).

PHYGROW parameter files were developed using the data described above and entered into the automated modeling system housed at the Center for Natural Resource Information Technology (CNRIT) at Texas A&M University. The automated system accesses updated weather information and performs model simulations every ten days. The model outputs are posted on the Internet in the form of a collection of graphs and data files showing percent deviation of total forage available from the long term mean and the percentile ranking of the current year's forage production among the previous twenty-five years (http://cnrit.tamu.edu/aflews).

In addition, the automated system accesses NASA normalized difference vegetation index (NDVI) data (http://edcw2ks21.cr.usgs.gov/adds/). NDVI is a vegetation greenness index, which is used along with NOAA RFE data to extrapolate the forage production estimates from LEWS monitoring points across the landscape. This is done using co-kriging geostatistical methods.

## Phase 2: Evaluation

### *Field Verification*

A field verification study was conducted to test the ability of the early warning system to accurately predict standing crop at each of the monitoring points. At each monitoring point, standing crop was measured and compared to the PHYGROW estimate of standing crop for that point on the sampling date.

*Pastoralist Perceptions of Drought*

One key characteristic of a drought early warning system is the ability to detect the emergence of drought and warn the community before community members make critical decisions in reaction to drought using traditional indicators. In order to gauge the ability of the LEWS to provide advance warning of drought, experiences from the severe drought of 2000 were examined with two pastoral communities in Laikipia.

Members of each community were asked to recall the 2000 drought, and then answer a few questions about their perception and reaction to the event. The questions asked were:

1. When did you first begin to be concerned that a drought may have been developing?
2. When were you first convinced that a drought was emerging and some mitigating action would need to be taken?
3. When did you first decide to take some action to limit losses from the drought?
4. What were the indicators that accompanied each of these levels of drought perception?

The remainder of this document provides a detailed analysis of each phase of the research program.

# CHAPTER II

# SYSTEM ESTABLISHMENT

## Introduction

A new monitoring zone of the USAID Global Livestock Collaborative Research Support Program's (GL-CRSP) Livestock Early Warning System (LEWS) was established in Laikipia and southern Samburu Districts, Kenya in 2001. The Mpala Research Center (MRC) and the associated Laikipia Wildlife Forum (LWF) provided assistance and valuable input on local attitudes, grazing practices, barriers to drought mitigation, and conservation needs and efforts within the District. An effort was made in the establishment process to design the zone and the early warning system to complement and assist research efforts of MRC and outreach activities of LWF.

The Laikipia Wildlife Forum aims to conserve or restore healthy ecosystem function within the watershed of the Ewaso Ngiro River, throughout Laikipia and southern Samburu Districts. Mpala Research Center serves as the primary provider of scientific information relevant to this effort, and expressed great interest in the insight that the early warning system could provide into livestock and wildlife migrations, weather patterns, and plant biomass within the Ewaso Ngiro Ecosystem. For the expressed needs of these NGOs, the extent of the Laikipia zone was determined by the boundaries of the Ewaso Ngiro watershed.

# Methods

## Extent of Zone

The Laikipia zone covers 8,060 $km^2$, stretching from Ol Pejeta Ranch (0.088° N , 36.823 ° E) in the south, to Wamba Town, Samburu District (1.070° N, 37.113° E) in the north. The zone extends beyond Rumuruti Town (0.683° N, 36.433° E) in the west and to the edge of the Mukogodo Forest (0.247° N, 37.269° E) in the east. The extent of the zone was determined by the boundaries of the Ewaso Ngiro Ecosystem, in keeping with the objectives of the Laikipia Wildlife Forum.

## Location of Sampling Points

Thirty monitoring points were established within the arid and semiarid rangelands of the Ewaso Ngiro Ecosystem. Due to the distribution of land ownership within the zone, these thirty monitoring points were divided equally between privately owned commercial ranches and communal grazing lands. The locations of the points were selected using several criteria.

1. Each point was established at a location subjectively determined to be representative for the dominant vegetation in the area.
2. Each point was established in an area that could be accessed with relative ease and was secure from conflict threats.
3. No two monitoring points were placed within the same 8 x 8 km grid cell of the NOAA NDVI image.

**Establishing Sampling Frame**

A special sampling frame was designed specifically for use in characterizing the plant communities within the study region for the early warning system to allow direct input from field measurements to the PHYGROW model. This frame was designed to allow determination of spatial or quadrant frequency of forbs, basal cover of grasses, and effective canopy cover of trees/shrubs concurrently at five individual sampling points. Due to the vast area covered by each zone of the early warning system, each monitoring point must be characterized as quickly and efficiently as possible.

The sampling frame consists of five, 0.25 $cm^2$ quadrats for measuring forb frequency and five point sample pins for measuring grass cover. A small mirror with a sample point drawn on the surface was aligned with each of the pins for measuring effective woody species cover. The frame and mirror are shown in Figures 1 and 2.

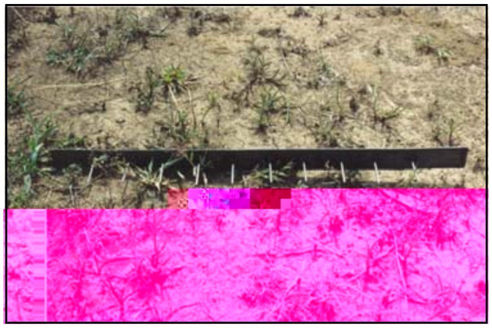

Figure 1. Sampling frame.

Figure 2. Sampling mirror.

**Vegetation Characterization Protocol**

For each of thirty monitoring points, the composition of the dominant vegetative community was determined as follows: percent frequency of forbs, percent basal cover of grasses, and percent true canopy cover of woody species were measured along a 200 meter transect. These variables were measured using the specially designed sample frame and mirror described above. The sampling frame was placed on the ground at 100 stations (separated by 2 meter intervals) along the transect. Measurements were taken in each of the five forb quadrats and each of the five grass/shrub points, resulting in a sample size of 500 for each variable.

**Soil Characterization Protocol**

The Laikipia Soil Survey (Ahn and Geiger 1987) was used to obtain profile descriptions for the soils of each monitoring point. The percent sand, silt, and clay from the survey data were entered into the Soil Textural Triangle Hydraulic Properties

Calculator (Saxton et al. 1986) to obtain the wilting point, field capacity, saturation point, saturated hydraulic conductivity, and bulk density of each soil horizon. Dry bulk density was estimated by adding 0.05 g $cm^{-3}$ to the bulk density value. The NRCS soil runoff curve numbers were determined using the NRCS soil runoff curves (NRCS 1986), based upon land use and overall hydrologic condition. Surface water storage, slope, and the percentage of rock within each horizon were determined by field observation.

**Grazing Rules Characterization Protocol**

Livestock stocking rates for each monitoring point were determined through interviews with livestock managers. On private ranches, the ranch owner or manager was interviewed. When a monitoring point was established in an area grazed communally by pastoralists, a group of elders or a representative appointed by the community was interviewed. When a group of elders participated in the interview, the group was asked to come to a consensus on each question.

After the location of a monitoring point had been selected, the livestock manager(s) was asked the following questions.

1. What species of livestock graze in this area?
2. What times of the year is this area typically used for livestock grazing?
3. During the normal grazing period for this site, how many cattle, sheep, and/or goats are present during a normal year?
4. What is the least number of cattle, sheep, and/or goats that would be present during the normal grazing period? In other words, if there were a severe

shortage of forage at the monitoring point, how many animals would remain in the area?

5. What is the greatest number of cattle, sheep, and/or goats that would be in the area during the normal grazing period? In other words, in the best forage year, how many animals would be in the area?
6. How many cattle, sheep, and/or goats are in the area during the rest of the year (not the normal grazing period)?
7. How far do the herds generally travel while grazing in the area of the monitoring point? For example, how far do they go from the *boma* in one day?

The responses to these questions were used to establish the normal grazing period, the typical grazing radius for the herd, maximum herd size, and minimum herd size for each monitoring point.

Wildlife stocking rates were set according to wildlife survey values, average herd size, and rancher or pastoralist testimony about migration patterns on their land.

**Weather Characterization Protocol**

*Precipitation*

Dr. Nick Georgiadis, Director of the Mpala Research Center provided historical precipitation data from several weather stations located throughout the Laikipia zone. From this data a climatically similar weather record was selected for each monitoring point. The annual and monthly means and standard deviations of precipitation were calculated for each of the selected data sets.

*Temperature*

The Almanac Characterization Tool (Corbett et al. 1999) was used to identify World Meteorological Organization (WMO) weather stations in areas with similar temperature regimes for each monitoring point. The annual and monthly means and standard deviations of minimum and maximum temperatures for these weather stations were extracted from a database of statistics from WMO stations.

*Generation of Climate Profiles*

The long-term statistics for precipitation distribution from the Laikipia weather stations were combined with the long term statistics for temperature from the WMO stations to produce complete climate profiles. A modified version of the WXGEN statistical weather generator software (Sharpley and Williams 1990, LEWS 1999a) was then used to generate a statistically correct weather history for each monitoring point. The generated weather record covered the synthetic years 1972 through 1997.

**Parameterizing the PHYGROW Model**

The soil, vegetation, grazer, and weather data that were gathered were compiled to create a parameter file for each monitoring point. Each parameter file contains four sections addressing (1) soils, (2) plants, (3) grazers, and (4) weather.

Two virtual horizons are added to the soil profile derived from published soil surveys. These horizons contribute to the hydrologic function of the soil at the evaporative surface and at the deep drainage level. The first virtual layer is referred to as the evaporative layer because it allows the model to capture the gain and loss of water to the soil through vapor exchange at the soil surface. It is given a depth of 0.5 cm, shares the soil hydraulic attributes of the first true soil horizon, and is designated as the surface horizon of the soil.

The second virtual layer is referred to as the image layer (Saxton et al. 1984) and is placed at the bottom of the soil profile. The image layer captures the deep water drainage and storage functions, which are essential to the maintenance of trees and deep rooted shrubs on a site. The depth of the image layer is determined by the maximum rooting depth of the tree species in the plant community and should provide sufficient water capacity to sustain the woody plant population over the 25-year base simulations.

The PHYGROW model requires a full complement of parameters describing plant growth. These parameters are listed in Appendix A. These values were obtained from a database constructed by LEWS team members, wherever possible. For plant species not found in the database, values were obtained from the ECOCROP database (FAO 1996), Missouri Botanical Garden's Tropicos database (Internet site, http://mobot.mobot.org/W3T/Search/vast.html), the HortiPlex database (Internet site, http://hortiplex.gardenweb.com/plants/), published literature, and expert opinion. In some cases, data for a plant species were lacking and values for similar species were applied. For example the grass-like species *Commelina diffosa* and *Commelina africana* have very similar growth characteristics. They grow on similar sites and share many morphological characteristics. The LEWS database contained values for *C. diffosa*, but none for *C. africana*. Therefore, the values of the former species were used for the latter as well.

The forb frequency, grass basal cover, and effective canopy cover of woody species were entered into the parameter file as *Percent Maximum Expression*, a measurement of the abundance of each species relative to its genetic potential to fully occupy the site.

The PHYGROW model requires users to complete a matrix, designating the preferences of each individual herbivore species for the current year's growth and woody portions of each plant species in the community at various stages of growth. LEWS staff have constructed a database of preference values for cattle, sheep, and goats in East Africa based on expert opinion and published diet studies (Stewart and Stewart 1970, Rodgers 1976, and Hansen et al. 1985). Where possible, values were drawn from this database. Wildlife preferences, and livestock preferences for plant species not included in the database, were derived from a search of relevant literature, interviews with wildlife experts, and interviews with elders of the pastoral communities. Preferences were assigned to the rapid growth period, declining growth period, quiescence and dead phonologic stages for each herbivore and plant species in the model.

**Tuning the PHYGROW Model**

Once the initial parameter files were created, they were entered into the PHYGROW model. Usually a certain amount of tuning was required in order to stabilize the simulations. This tuning generally involved making adjustments to soil depth, rockiness, and hydraulic conductivity; adjusting plant growth parameters such as leaf area index and leaf turnover; or adjusting the stocking rate rules to more accurately reflect grazing patterns.

Adjustments to soil parameters are justifiable under the assumption that soil survey data for a soil type will not perfectly describe every soil attribute at the data collection site in a landscape. Also, the Soil Textural Triangle Hydraulic Properties Calculator (Saxton et al. 1986) was developed for estimating that hydraulic characteristics of temperate soils and may not provide accurate estimates for tropical soils.

Adjustments to plant growth parameters can be justified under the assumptions that there can be multiple ecotypes within a plant species and expression of genetic potential is affected by environmental factors. Adjustment of plant growth parameters were particularly important where attributes of one species had been applied to a similar species due to lack of available data.

The initial grazer stocking rules were often based on rough estimates of grazing radius and minimum and maximum forage availability to initiate stocking or destocking. These numbers were adjusted after an initial simulation run of the PHYGROW model to better reflect the actual grazing patterns described by land managers.

**Characteristics of Modeled Forage**

Four basic plant community types were characterized for model simulation. These were *Acacia drepanolobium* bush, mixed *Acacia* bush, *Euclea – Croton* bush, and native *Pennisetum* grasslands. The *Pennisetum* grasslands were the most productive sites. These sites were located on high plateaus with Black Cotton vertisols. There were virtually no shrubs on these grasslands. The vegetation was dominated by *Pennisetum mezianum, Pennisetum stramineum, Themeda triandra,* and *Cymbopogon pospichilii*. Peak production averaged 3262 kg $ha^{-1}$.

The *Acacia drepanolobium* bush sites were located on Black Cotton vertisols and were the second most productive sites. Peak understory production averaged 3070 kg $ha^{-1}$, and the understory consisted primarily of the perennial grasses *Pennisetum mezianum, Themeda triandra, Cymbopogon pospichilii,* and *Pennisetum stramineum*.

The *Euclea – Croton* bush sites were located on moderately productive clay loam or sandy clay loam soils. The community is dominated by *Euclea* sp. and *Croton dichrogamous*, with the herbaceous layer being dominated by *Themeda triandra*. These sites were generally grazed and browsed quite heavily. Average peak herbaceous production was 1270 kg $ha^{-1}$.

The mixed *Acacia* bush was the most widespread plant community, and there is great variability among sites. However, these sites can be characterized by the nutrient poor sandy red soils on which they are found and by a dominant shrub layer made up of two or three *Acacia* species. Commonly the dominant *Acacia* species are *A. etbaica, A. mellifera, A. nilotica,* or *A. tortilis*. *Acacia brevispica, Euphorbia* sp., and *Grewia* *atenax* are often significant components of the shrub layer as well. *Cynodon dactylon* and *Digitaria milanjiana* are the dominant grass species. Average herbaceous production for mixed *Acacia* bush sites was 1182 kg ha$^{-1}$.

A table containing the name of each monitoring point, the plant species present and the maximum expression value for each species is provided in Appendix A.

**Allocation of Monitoring Points by Land Ownership**

Thirty monitoring points were established within the Ewaso Ngiro watershed. Fifteen of the monitoring points were located on ten private commercial ranches. Ten of the monitoring points were established on Maasai or Samburu group ranches. The remaining six monitoring points were established within government settlement schemes where low productivity has prevented actual settlement from occurring. These rangelands are utilized heavily by a number of pastoral groups. The division of monitoring points between land ownership types is shown in Table 1. Figure 3 shows the distribution of the monitoring points within the Ewaso Ngiro ecosystem.

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**Table 1. Land ownership of monitoring points.**

| Private Ranch | Group Ranch | Settlement Scheme |
|---|---|---|
| Borana | Il Polei | Baraka |
| El Karama | Koija | Moundu ni Meri |
| Kisima | Kurikuri | Nagum |
| Mpala | Luoniek | Narok |
| Mugie | Morupusi | P and D |
| Ngorare | Musul | |
| Ol Jogi | Tiemamut | |
| Ol Maisor | Silanko Nanyuki | |
| Ol Pejeta | Nkaroni | |
| Segera | Lengarde | |

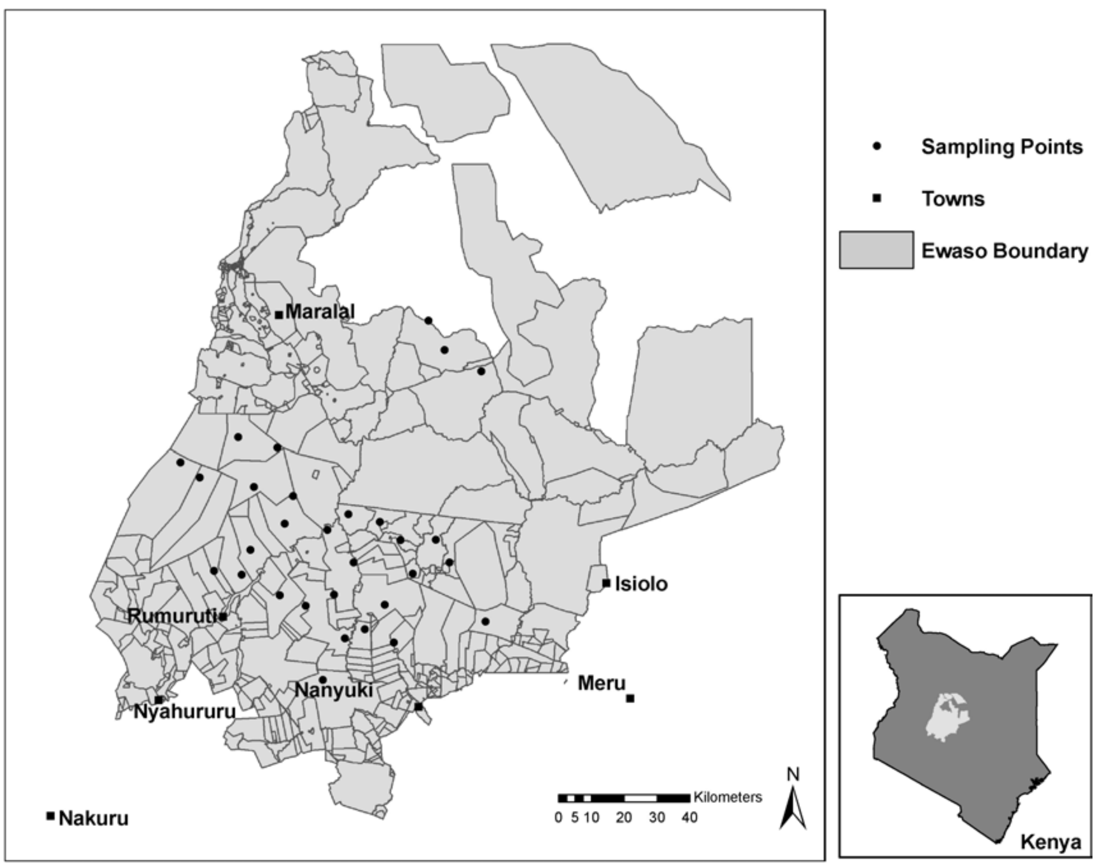



**Figure 3. Location of monitoring points in the Ewaso Ngiro ecosystem.**

## Summary

The Laikipia monitoring zone was established in order to expand the spatial coverage of LEWS, but also with the intent of assisting Mpala Research Centre and the Laikipia Wildlife Forum in their research, development, and conservation efforts. The Ewaso Ngiro Ecosystem boundaries determined the spatial extent of the Laikipia zone, in order to achieve these goals. In addition, the thirty monitoring points were distributed within the zone according to variations in vegetation and land ownership.

Data were collected in four areas: soils, plants, grazers, and weather. Tools such as the Soil Textural Triangle Hydraulic Properties Calculator (Saxton et al. 1986) and the modified WXGEN statistical weather generator (Sharpley and Williams 1990, LEWS 1999a) were used to process the collected data, generating model parameters for which data were unavailable. Parameter files were then constructed for each of the thirty Laikipia monitoring points. The forage availability estimates from the PHYGROW model simulations using these parameter files will serve as the basis of all LEWS drought advisories.

# CHAPTER III

# OUTPUT FROM THE AFLEWS ANALYSIS PORTAL

## Introduction

Following stabilization of the PHYGROW parameter files, each file was entered into the African Livestock Early Warning System (AFLEWS) automated analysis system. This system automatically updates each file every ten days with the most recent weather data from EROS, runs the updated file in the PHYGROW model, performs analyses of the outputs from PHYGROW, and posts the results to the AFLEWS Analysis Portal, located online at https://cnrit.tamu.edu/aflews. In addition to the PHYGROW results, the AFLEWS Analysis Portal contains NOAA Normalized Difference Vegetation Index (NDVI) data and maps of forage availability.

The automated Analysis System and Portal is essential to the rapid construction and delivery of early warning products to the end users. Gathering data, running the PHYGROW model, and constructing reports by hand would require many hours of labor and would severely delay the delivery of the products. In addition, the limited communications infrastructure of East Africa presents challenges to the timely delivery of information. Where Internet connections are available, the use of this tool greatly increases the speed of communication. Without the AFLEWS Analysis Portal, LEWS reports would reach end users after the critical time for decision making had passed.

It should be mentioned that many areas in East Africa are still without Internet access. In Kenya, Internet access is primarily limited to large towns and cities. In

Nairobi, Internet cafes are readily available and most government offices, universities, and NGOs in the capital have full access to the World Wide Web and email services. In Laikipia District, email services are available through a server located in the town of Nanyuki. Connections outside Nanyuki itself however are too slow to accommodate use of the World Wide Web. At this point in time, use of email within Laikipia is largely limited to private ranchers and NGOs, who can afford computers and service fees and who have some computer literacy. The remote, undeveloped nature of southern Samburu District has precluded the introduction of any Internet services in that area, with the possible exception of Maralal Town.

Due to these constraints, LEWS bulletins are delivered to these remote areas through digital satellite radios, using WorldSpace Foundation's AfriStar satellite broadcasts. Two organizations, RANET and Arid Lands Information Network (ALIN), have partnered with LEWS to broadcast regional and country bulletins and forage maps. The bulletins and forage maps are prepared using the information on the AFLEWS Analysis Portal and are viewed using a web browser. Computers, printers, and satellite radios have been placed with organizations in the Laikipia zone which regularly interact with the pastoral communities and ranchers. These organizations download and print the LEWS bulletins, deliver the hard copies to livestock owners, and assist in interpretation of the warning information.

# Methods

## Data Analysis

After the parameter file for each monitoring point had been stabilized, it was entered into the AFLEWS automated system. Each file contained the parameters describing soils, plants, and grazers as well as weather data for the years 1972 through 1997. The file is run through PHYGROW and results are posted on the AFLEWS Analysis Portal every ten days. The tasks involved in this process are described below.

### *Current Weather Data*

Current weather data for each monitoring point are obtained from the Africa Weather site located at http://cnrit.tamu.edu/rsg/rainfall/rainfall.cgi. This site allows the user to query the NOAA Rainfall Estimate (RFE) satellite image, using the geographic coordinates of the monitoring point, to obtain weather data from 1 January 1998 to the present. The results are provided in a text file format, containing daily values for minimum temperature, maximum temperature, precipitation, and solar radiation. The parameter file is updated every ten days with the most recent weather data.

### *Automated PHYGROW Simulations*

Each parameter file, with the most recent weather data, is automatically loaded into the PHYGROW model for simulation. The following outputs from each simulation are saved as text files:

- Total forage available by grazer species (kg $ha^{-1}$).

- Leaf growth (kg $ha^{-1}$ $day^{-1}$) by plant species.
- Green standing crop (kg $ha^{-1}$) by plant species.
- Current year's forage standing crop (kg $ha^{-1}$) by plant species.
- Woody standing crop (kg $ha^{-1}$) by plant species.

*Analysis of PHYGROW Outputs*

Three graphs are created from the data for each PHYGROW output listed above. The three graphs show (1) the actual amount in kg $ha^{-1}$ of total available forage for each herbivore (or kg $ha^{-1}$ $day^{-1}$ for leaf growth), (2) the percent deviation in total available forage from the long-term mean for the same Julian day of the year for each herbivore, and (3) the percentile ranking of the total available forage for the Julian day among the historical years by herbivore. The PHYGROW outputs for the synthetic years 1972 to 1997 provide the baseline data for long-term comparisons. The data from each graph are also saved and made available on the AFLEWS Analysis Portal as text files.

*Determining Warning Status*

A warning status is assigned to each monitoring point based upon the percent deviation of total forage available for a given herbivore on the analysis date. There are seven possible designations, ranging from Above Normal to Disaster (Table 2).

**Table 2. Designation of warning status.**

| Warning Status | Percent Deviation |
|---|---|
| Above Normal | >20 |
| Normal | 0 to 20 |
| Watch | -20 to 0 |
| Warn | -20 to -40 |
| Alert | -40 to -60 |
| Emergency | -60 to -80 |
| Disaster | < -80 |

*Normalized Difference Vegetation Index*

Every ten days, the automated system accesses the Africa Data Dissemination Service website at http://edcsnw4.cr.usgs.gov/adds/adds.html and downloads the latest Normalized Difference Vegetation Index (NDVI) images. NDVI is an index of vegetation greenness. The products used in LEWS are provided by the National Oceanographic and Atmospheric Association (NOAA) and have a resolution of 8 x 8 km. Two images are acquired: (1) actual NDVI and (2) percent deviation of NDVI from the long-term mean. The automated system calculates the percentile ranking of NDVI among years.

*ARIMA Model Projections of Forage Availability*

The ARIMA Model is used to project forage availability, within a 95% confidence interval, during the 90 day period following the analysis date (Box et al. 1994). The results are presented within the Analysis Portal in two forms. First, a graph is constructed showing the actual forage available at the monitoring point over the past twelve months and the projected forage availability over the coming three months. Second, a set of four tables is constructed. Each table shows the projected amount of forage and warning status of all the monitoring points in the zone in 0, 30, 60, or 90 days.

*Forage Availability Maps*

Two sets of forage availability maps are constructed by extrapolation of the data from all the monitoring points. The method used is a geostatistical technique called co-kriging (Isaaks and Srivastava 1992). Co-kriging uses the covariance of two variables with changing distance to estimate the value of the less intensively sampled variable. In this case forage availability, for which only thirty point based values are available, is estimated from NDVI, for which there is a continuous set of values across the landscape at an 8 x 8 km resolution.

Two types of forage availability maps are constructed. The first shows the amount of forage available (kg $ha^{-1}$) while the second shows the percent deviation of forage available from the long-term average. These maps are constructed for the entire region covered by the early warning system and for each individual monitoring zone.

Currently, the co-kriging analysis is not an automated function. Every ten days, LEWS staff members enter the NDVI and forage values into the GS+ software, select the best statistical model (the model with the greatest regression coefficient and least residual sums of squares) to capture the covariance between the two variables, and then construct the maps using ArcView. The final maps are then uploaded to the AFLEWS Analysis Portal.

**Reporting**

*Zonal Summary*

A zonal summary table is constructed to provide an overview of each monitoring zone. The table contains the warning status, forage amount, percent deviation of forage, forage trend, percentile ranking of forage, NDVI, percent deviation of NDVI, NDVI trend, and percentile ranking of NDVI for each monitoring point within the zone (Table 3). The forage and NDVI trends are small image files (.gif) showing the last 20 days of the forage and NDVI deviation graphs.

*Projection Charts*

Four projection charts are constructed. They provide the warning status, percent deviation of forage one year previous, current forage deviation, and projected forage deviation in 30, 60, and 90 days. Each chart focuses on one of the following; the analysis date, 30 days post analysis, 60 days post analysis, or 90 days post analysis. On each chart the warning status given is for the focus date, and the monitoring points are arranged in the table from worst- to best-case scenario (Table 4).

**Table 3. Zonal summary table for the Laikipia monitoring zone from 10 December 2002.**

| Kenya: Laikipia Zone (Dec, 10, 2002) | | | | Forage Available | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Actual | | Deviation | | % |
| District | Location | Local Name | Site ID | Status | Value (kg/ha) | Value | Trend | Rank |
| LAIKIPIA | CENTRAL | Baraka | KE-LA-BAR-01 | Warn | 1331 | -21.0 | | 32.0 |
| LAIKIPIA | CENTRAL | Borana | KE-LA-BOR-01 | Watch | 3237 | -14.9 | | 36.0 |
| LAIKIPIA | CENTRAL | El Karama | KE-LA-KAR-01 | Watch | 1530 | -10.9 | | 40.0 |
| LAIKIPIA | MUKOGONDO | Il Polei | KE-LA-POL-01 | Warn | 762 | -32.5 | | 4.0 |
| LAIKIPIA | RUMURUTI | Kisima | KE-LA-KIS-01 | Warn | 1444 | -38.1 | | 36.0 |
| LAIKIPIA | NG'ARUA | Kisima | KE-LA-KIS-02 | Warn | 1863 | -21.8 | | 44.0 |
| LAIKIPIA | MUKOGONDO | Koija | KE-LA-KOI-01 | Watch | 781 | -7.3 | | 60.0 |
| LAIKIPIA | MUKOGONDO | Kurikuri | KE-LA-KUR-01 | Alert | 805 | -42.5 | | 4.0 |
| LAIKIPIA | NG'ARUA | Luoniek | KE-LA-LUO-01 | Warn | 804 | -30.0 | | 24.0 |
| LAIKIPIA | MUKOGONDO | Morupusi | KE-LA-MOR-01 | Alert | 911 | -40.2 | | 4.0 |
| LAIKIPIA | RUMURUTI | Moundu ni | KE-LA-MOU-01 | Warn | 944 | -35.0 | | 0.0 |
| LAIKIPIA | RUMURUTI | Mpala | KE-LA-MPA-01 | Warn | 756 | -28.9 | | 4.0 |
| LAIKIPIA | MUKOGONDO | Mpala | KE-LA-MPA-02 | Warn | 562 | -33.8 | | 0.0 |
| LAIKIPIA | CENTRAL | Mpala | KE-LA-MPA-03 | Warn | 1401 | -27.9 | | 12.0 |
| LAIKIPIA | NG'ARUA | Mugie | KE-LA-MUG-01 | Warn | 1706 | -30.3 | | 16.0 |
| LAIKIPIA | NG'ARUA | Mugie | KE-LA-MUG-02 | Warn | 802 | -34.7 | | 28.0 |
| LAIKIPIA | MUKOGONDO | Musul | KE-LA-MUS-01 | Warn | 782 | -33.0 | | 4.0 |
| LAIKIPIA | NG'ARUA | Nagum | KE-LA-NAG-01 | Watch | 1373 | -17.3 | | 24.0 |
| LAIKIPIA | RUMURUTI | Narok | KE-LA-NAR-01 | Warn | 1335 | -34.5 | | 0.0 |
| LAIKIPIA | RUMURUTI | Ngorare | KE-LA-NGO-01 | Warn | 2052 | -20.4 | | 36.0 |
| LAIKIPIA | CENTRAL | Ol Jogi | KE-LA-JOG-01 | Watch | 1040 | -15.1 | | 40.0 |
| LAIKIPIA | RUMURUTI | Ol Maisor | KE-LA-MAI-01 | Alert | 798 | -51.4 | | 24.0 |
| LAIKIPIA | CENTRAL | Ol Pejeta | KE-LA-PEJ-01 | Emergency | 1398 | -65.2 | | 24.0 |
| LAIKIPIA | NG'ARUA | P and D | KE-LA-PAD-01 | Warn | 527 | -26.3 | | 32.0 |
| LAIKIPIA | CENTRAL | Segera | KE-LA-SEG-01 | Watch | 1633 | -16.3 | | 40.0 |
| LAIKIPIA | CENTRAL | Segera | KE-LA-SEG-02 | Watch | 1239 | -15.4 | | 60.0 |
| LAIKIPIA | MUKOGONDO | Tiemamut | KE-LA-TIE-01 | Normal | 857 | 0.8 | | 44.0 |
| SAMBURU | WAMBA | Wamba | KE-LA-WAM-01 | Above Normal | 713 | 27.1 | | 76.0 |
| SAMBURU | WAMBA | Wamba | KE-LA-WAM-02 | Warn | 736 | -23.7 | | 40.0 |
| SAMBURU | WAMBA | Wamba | KE-LA-WAM-03 | Emergency | 6 | -99.0 | | 8.0 |

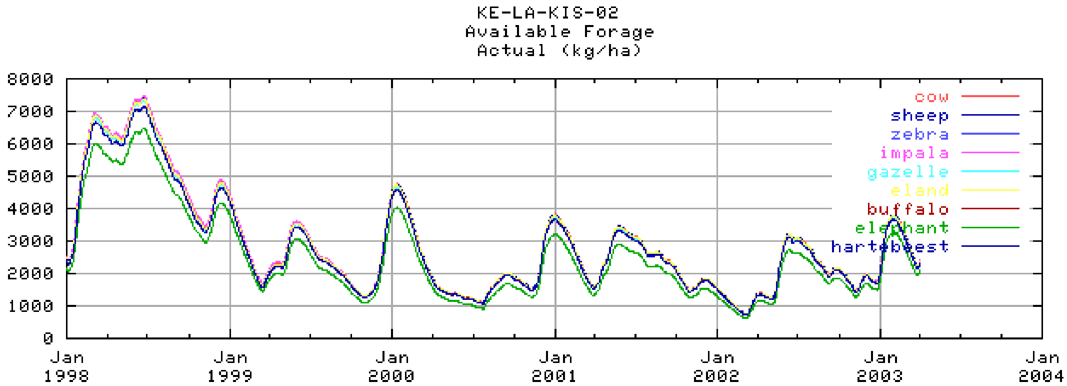
**Table 4. Projection chart for 10 December 2002, highlighting expected conditions in 90 days.**

| Kenya: Laikipia Zone Projection Summary (Dec dekad 1, 2002) | | | | Forage Available | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Status | Deviation (%) | | Projected Deviation (%) | | |
| District | Location | Local Name | Site ID | | Today | 12 Mths Ago | 30 Days | 60 Days | 90 Days |
| SAMBURU | WAMBA | Wamba | KE-LA-WAM-03 | Emergency | -98.99 | 58.56 | -100.00 | -100.00 | -100.00 |
| LAIKIPIA | CENTRAL | Ol Pejeta | KE-LA-PEJ-01 | Emergency | -65.19 | -44.41 | -71.10 | -85.97 | -91.52 |
| LAIKIPIA | RUMURUTI | Ol Maisor | KE-LA-MAI-01 | Emergency | -51.43 | -22.90 | -59.52 | -79.05 | -87.27 |
| LAIKIPIA | RUMURUTI | Kisima | KE-LA-KIS-01 | Emergency | -38.07 | -18.48 | -47.86 | -66.24 | -79.02 |
| LAIKIPIA | NG'ARUA | Luoniek | KE-LA-LUO-01 | Emergency | -30.04 | 24.17 | -34.19 | -54.94 | -75.51 |
| LAIKIPIA | NG'ARUA | Mugie | KE-LA-MUG-02 | Emergency | -34.73 | -11.07 | -44.09 | -59.57 | -74.79 |
| LAIKIPIA | CENTRAL | Segera | KE-LA-SEG-02 | Emergency | -15.38 | -15.36 | -40.28 | -65.17 | -72.77 |
| LAIKIPIA | NG'ARUA | P and D | KE-LA-PAD-01 | Emergency | -26.34 | -23.49 | -35.62 | -54.99 | -72.58 |
| LAIKIPIA | NG'ARUA | Kisima | KE-LA-KIS-02 | Alert | -21.84 | -30.89 | -31.77 | -48.05 | -57.71 |
| LAIKIPIA | NG'ARUA | Mugie | KE-LA-MUG-01 | Alert | -30.31 | -20.63 | -30.21 | -32.41 | -40.47 |
| SAMBURU | WAMBA | Wamba | KE-LA-WAM-02 | Warn | -23.67 | 13.46 | -14.36 | -13.78 | -33.01 |
| LAIKIPIA | RUMURUTI | Narok | KE-LA-NAR-01 | Warn | -34.53 | -26.01 | -32.79 | -29.91 | -31.94 |
| LAIKIPIA | MUKOGONDO | Koija | KE-LA-KOI-01 | Warn | -7.32 | -0.55 | -11.84 | -17.59 | -31.83 |
| LAIKIPIA | MUKOGONDO | Kurikuri | KE-LA-KUR-01 | Warn | -42.54 | -50.02 | -37.55 | -33.91 | -31.69 |
| LAIKIPIA | MUKOGONDO | Mpala | KE-LA-MPA-02 | Warn | -33.82 | -34.25 | -32.83 | -31.97 | -31.13 |
| LAIKIPIA | RUMURUTI | Moundu ni | KE-LA-MOU-01 | Warn | -34.96 | -18.06 | -31.73 | -30.84 | -31.03 |
| LAIKIPIA | NG'ARUA | Nagum | KE-LA-NAG-01 | Warn | -17.29 | -10.47 | -16.40 | -22.78 | -30.98 |
| LAIKIPIA | MUKOGONDO | Morupusi | KE-LA-MOR-01 | Warn | -40.17 | -40.91 | -34.17 | -29.78 | -28.28 |
| LAIKIPIA | RUMURUTI | Mpala | KE-LA-MPA-01 | Warn | -28.86 | -22.17 | -29.10 | -27.42 | -27.48 |
| LAIKIPIA | MUKOGONDO | Musul | KE-LA-MUS-01 | Warn | -32.99 | -28.98 | -28.47 | -27.08 | -27.31 |
| LAIKIPIA | CENTRAL | Mpala | KE-LA-MPA-03 | Watch | -27.95 | -32.64 | -22.16 | -18.91 | -18.05 |
| LAIKIPIA | CENTRAL | Segera | KE-LA-SEG-01 | Watch | -16.32 | -19.72 | -7.83 | -4.46 | -17.72 |
| LAIKIPIA | MUKOGONDO | Il Polei | KE-LA-POL-01 | Watch | -32.47 | -46.70 | -26.38 | -20.27 | -16.91 |
| LAIKIPIA | RUMURUTI | Ngorare | KE-LA-NGO-01 | Watch | -20.43 | -24.18 | -12.56 | -10.62 | -12.41 |
| LAIKIPIA | CENTRAL | Baraka | KE-LA-BAR-01 | Watch | -21.04 | -18.60 | -10.06 | -5.59 | -11.08 |
| LAIKIPIA | CENTRAL | Ol Jogi | KE-LA-JOG-01 | Watch | -15.09 | -41.96 | -4.07 | 1.14 | -0.71 |
| LAIKIPIA | MUKOGONDO | Tiemamut | KE-LA-TIE-01 | Normal | 0.75 | 8.98 | 9.77 | 11.22 | 1.01 |
| LAIKIPIA | CENTRAL | El Karama | KE-LA-KAR-01 | Normal | -10.92 | -16.27 | -1.31 | 5.81 | 4.71 |
| LAIKIPIA | CENTRAL | Borana | KE-LA-BOR-01 | Normal | -14.88 | -48.84 | -2.96 | 8.91 | 12.32 |
| SAMBURU | WAMBA | Wamba | KE-LA-WAM-01 | Normal | 27.08 | 27.00 | 20.65 | 18.74 | 18.52 |

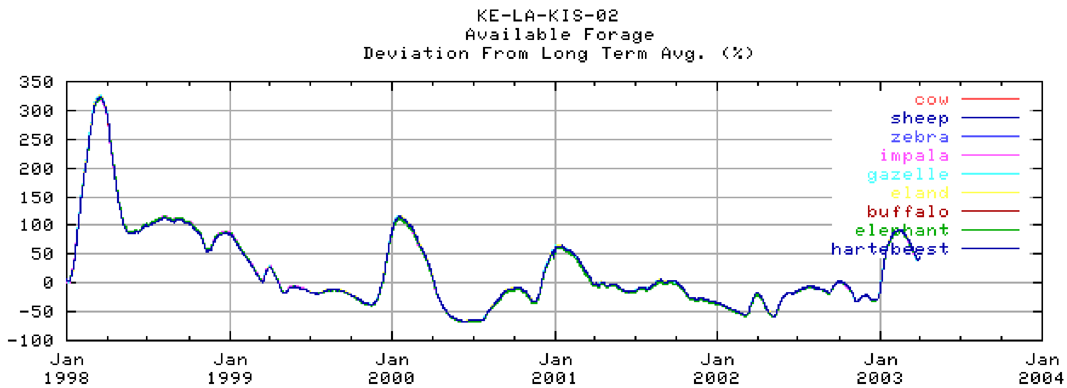
*Point Specific Data*

A complete set of point specific data is available for each monitoring point. These data are available as graphs and text files containing the daily values. The data set includes the following variables; 1) forage available, 2) daily growth rate, 3) total green standing crop, 4) NDVI, 5) standing crop of current year's growth, and 6) woody standing crop. For each variable the amount, percent deviation, and percentile rankings are provided. In addition, the data set includes the projected forage deviation for the site.

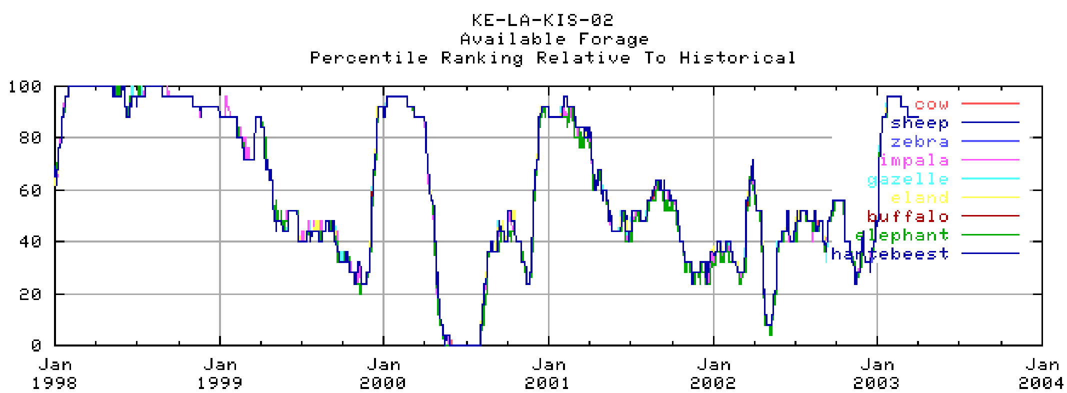
Figure 4 shows three of the graphs available for a single monitoring point. The selected site is KE-LA-KIS-02, which is located on Kisima Ranch in Northern Laikipia. The complete set of graphs can be found in Appendix B.




(a)




(b)




(c)

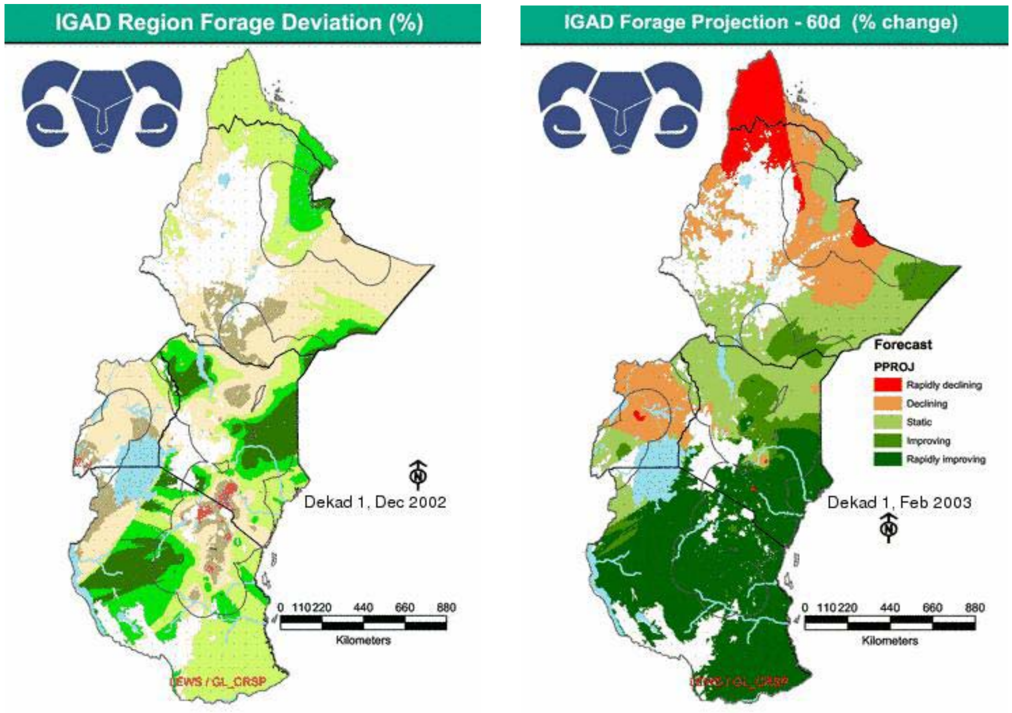
**Figure 4. Forage availability graphs showing (a) actual forage available (kg ha$^{-1}$), (b) percent deviation of forage available from the long term average, and (c) percentile ranking of forage available by animal kind.**

*Maps*

Maps are created at the regional (Fig. 5), country (Fig. 6), and zonal (Fig. 7) scales and display the spatial distribution of amount of forage available or the percent deviation of forage availability. New maps are posted for each new dekad, while all previously created maps remain available for viewing. This allows the progress of wetting and drying systems to be followed through time. In addition, a 60-day projection map is posted to show the expected spatial distribution of forage.

*Monthly Situation Reports*

Each month a situation report is compiled for each country in the IGAD region (Eritrea, Ethiopia, Kenya, Uganda, and Tanzania) and posted on the AFLEWS Analysis Portal. These reports contain the forage maps and projections for each zone within the country, along with a brief narrative explanation of the overall situation. The reports are created in .pdf format.




**(a)** **(b)**

**Figure 5. Regional forage map. (a) 10 December 2002 map showing percent deviation from long term average. (b) Projection map showing expected percent deviation in 60 days.**

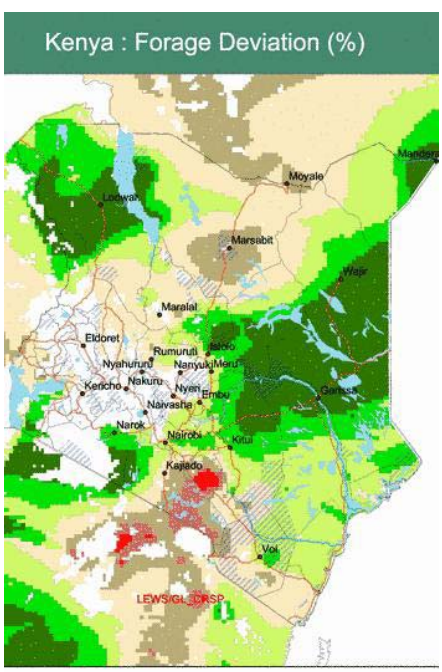



**Figure 6. Forage deviation map for Kenya, 10 December 2002.**

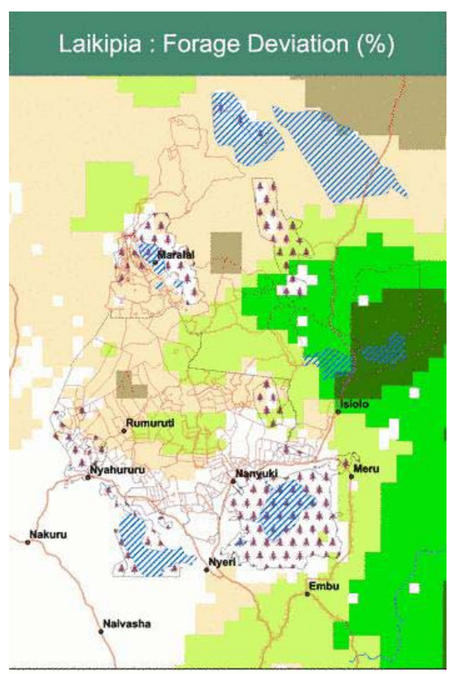



**Figure 7. Forage deviation map for Laikipia zone, 10 December 2002.**

## Results

### Year 2000

In the year 2000, much of East Africa was struck with a severe drought. According to USAID Office of U.S. Foreign Disaster Assistance (2001), the drought was the worst in Kenya in 60 years. By November 2000, food assistance was being provided to 3.2 million Kenyans. Pastoralists were severely affected. Estimates of livestock losses vary. Cattle herds are estimated to have decreased by 30 to 40 percent. Estimates for the decrease in herds of small stock range from 20 to 29.5 percent. Camel herds reportedly decreased by 18 percent in Northern Kenya (Aklilu and Wekesa 2001 and OFDA 2001).

The trough of the drought in Laikipia District occurred in July 2000. Figure 8 shows the mean departure from the daily long term average forage availability for cattle for the thirty monitoring points in the Laikipia zone. Using this indicator, 8 July 2000 can be identified as the worst point of the drought. On that day, the monitoring point showing the greatest negative deviation from average forage conditions was the Il Polei point (KE-LA-POL-01) at -84%, while the monitoring point showing the smallest deviation from average was the Northern Wamba point (KE-LA-WAM-03) at -9%. This is somewhat deceiving, as shown below.

Figure 9 shows the mean amount of forage available for cattle in kg $ha^{-1}$. Using this indicator, 26 July 2000 is identified as the peak of the drought. On that date, the PHYGROW estimate for forage available at the Northern Wamba point was only 346 kg $ha^{-1}$, making it the second lowest forage availability in the zone. This is a much different picture from that provided in Figure 8, where the same point appears to be the least affected of the monitoring points within the zone. This discrepancy can be explained by chronically poor forage conditions at the Northern Wamba point. Due to a sparse understory and high stocking rates, this monitoring point never achieves high forage availability.

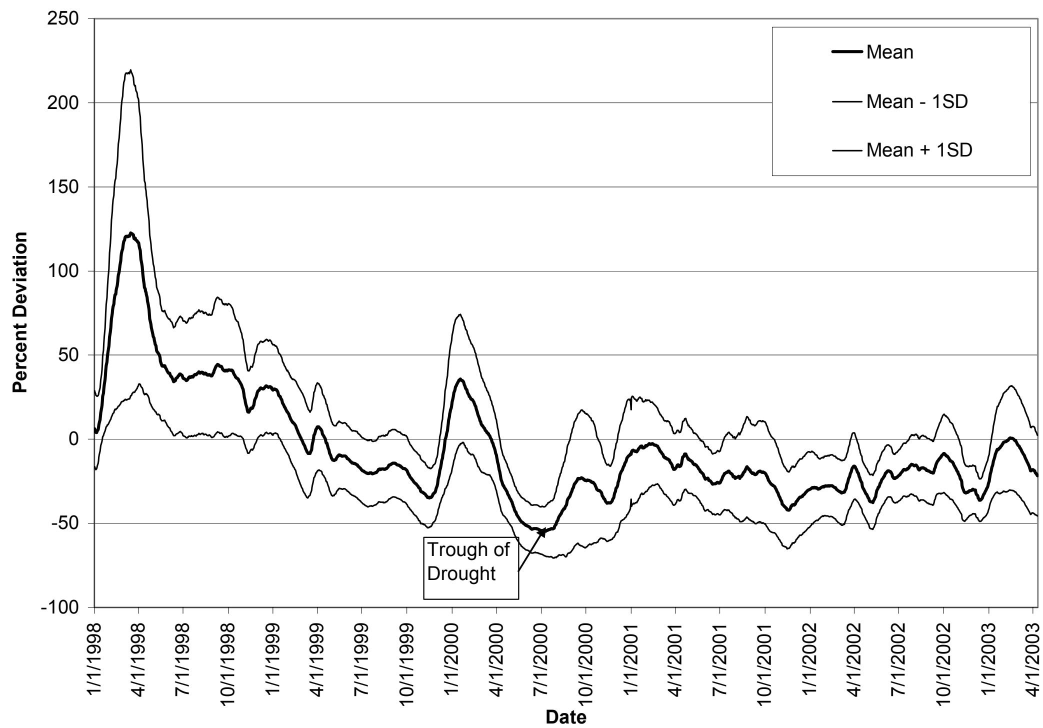



**Figure 8. Daily mean and standard deviation of percent deviation of forage available to cattle from the long-term average for the Laikipia zone. n=30.**

When using the mean forage availability in kg $ha^{-1}$, the Il Polei point remains the most affected point with 179 kg $ha^{-1}$ of forage available for cattle. However, according to this indicator, the Eastern Mugie monitoring point (KE-LA-MUG-01) had the greatest forage availability at the peak of the drought, with 1424 kg $ha^{-1}$.

These three monitoring points - Il Polei, Northern Wamba, and Eastern Mugie – will be used throughout the remainder of this chapter to illustrate changing forage conditions in the Laikipia zone during 2001 and 2002. In addition, the Baraka monitoring point (KE-LA-BAR-01) will be used because as seen in Figure 10, forage conditions at this point, both in terms of percent deviation and actual forage available, closely follow the averages for the zone. The total forage available and percent deviation graphs for each of the four monitoring points are shown in Appendix C. For ease of discussion, Figure 11 shows the kg $ha^{-1}$ of forage available to cattle at each of the four points. Likewise, Figure 12 shows the percent deviation of cattle forage at the four locations.

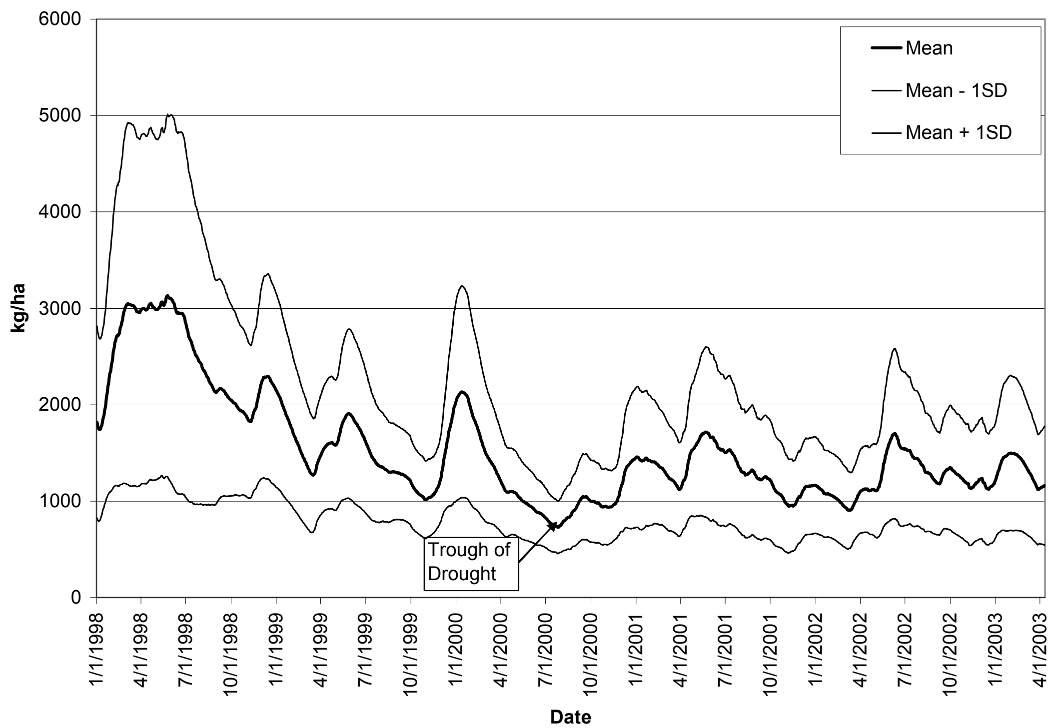
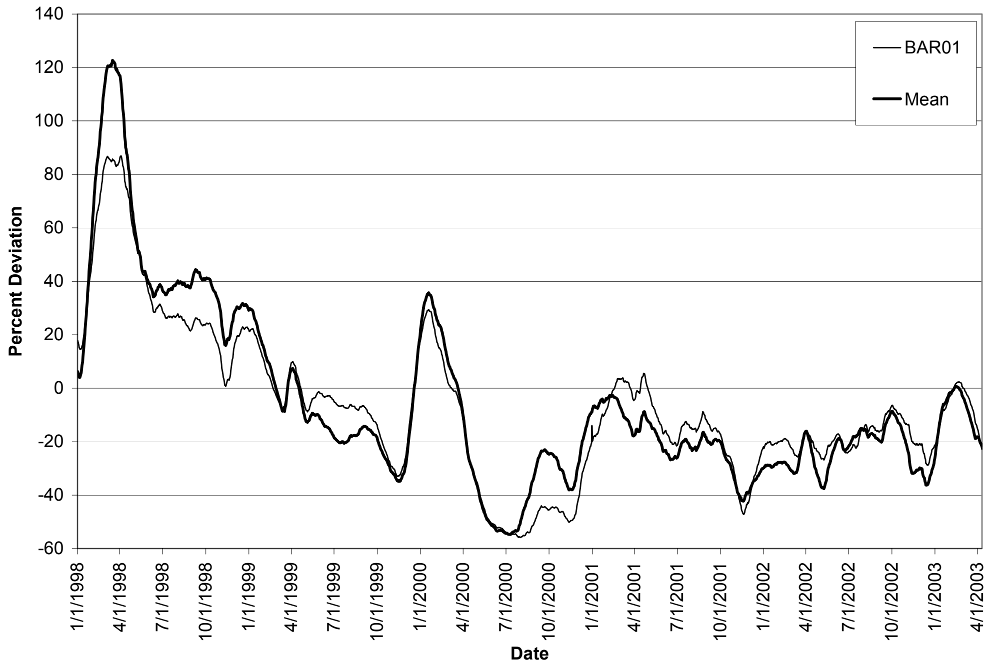
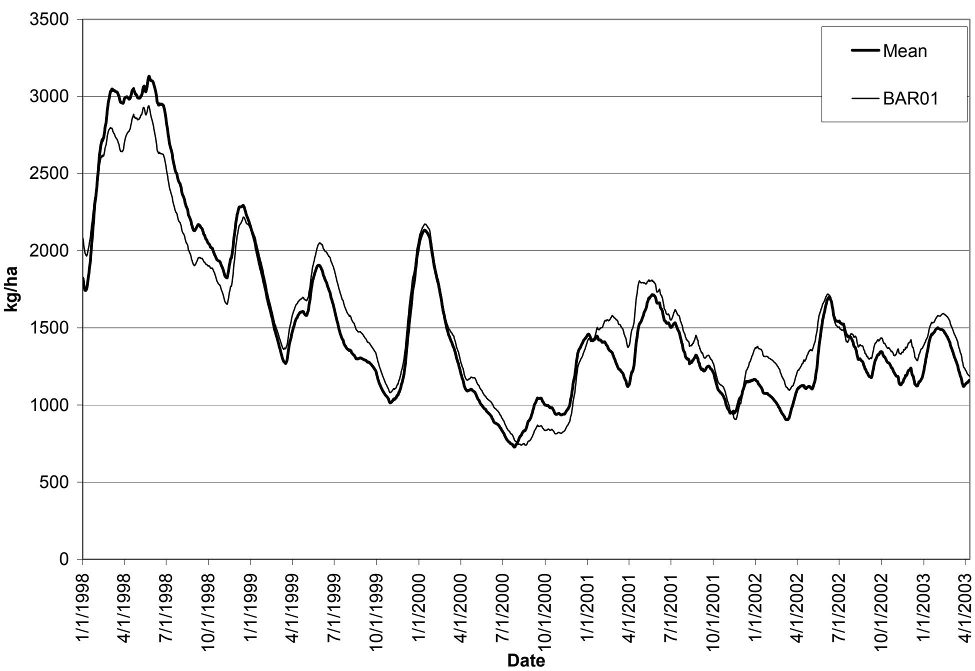



**Figure 9. Daily mean and standard deviation of forage available to cattle (kg $ha^{-1}$) for the Laikipia zone. n=30.**




**(a)**




**(b)**

**Figure 10. Comparison of forage conditions at Baraka monitoring point and average conditions within the zone in terms of (a) percent deviation from long-term average and (b) actual forage available in kg ha$^{-1}$.**

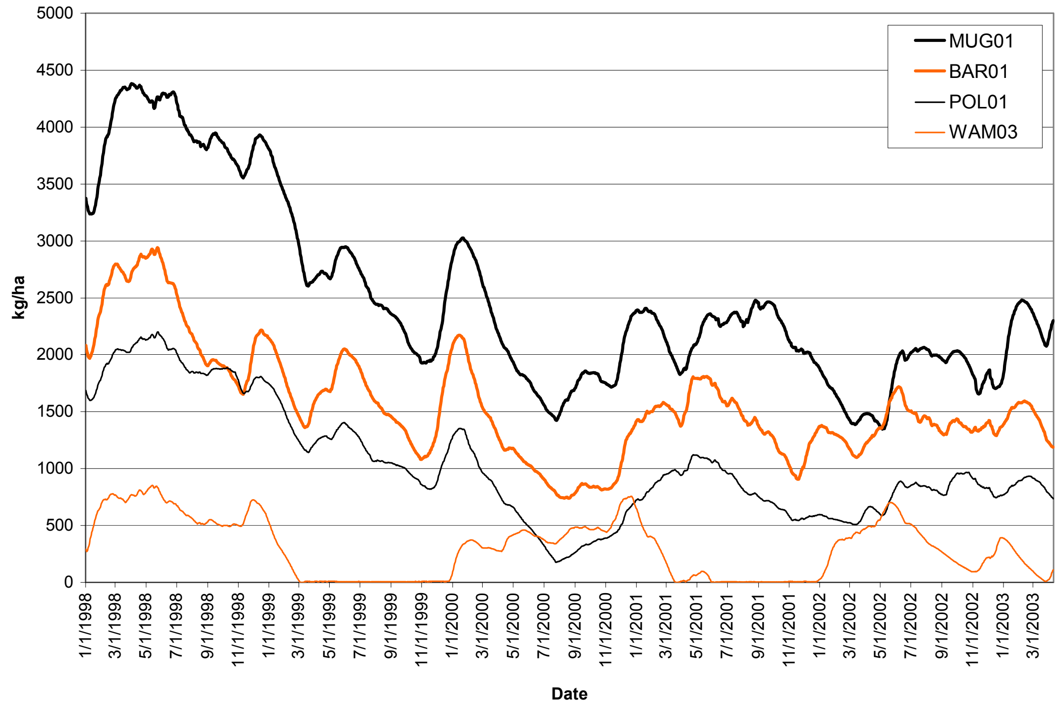



**Figure 11. Total forage available to cattle (kg $ha^{-1}$) at four monitoring points.**

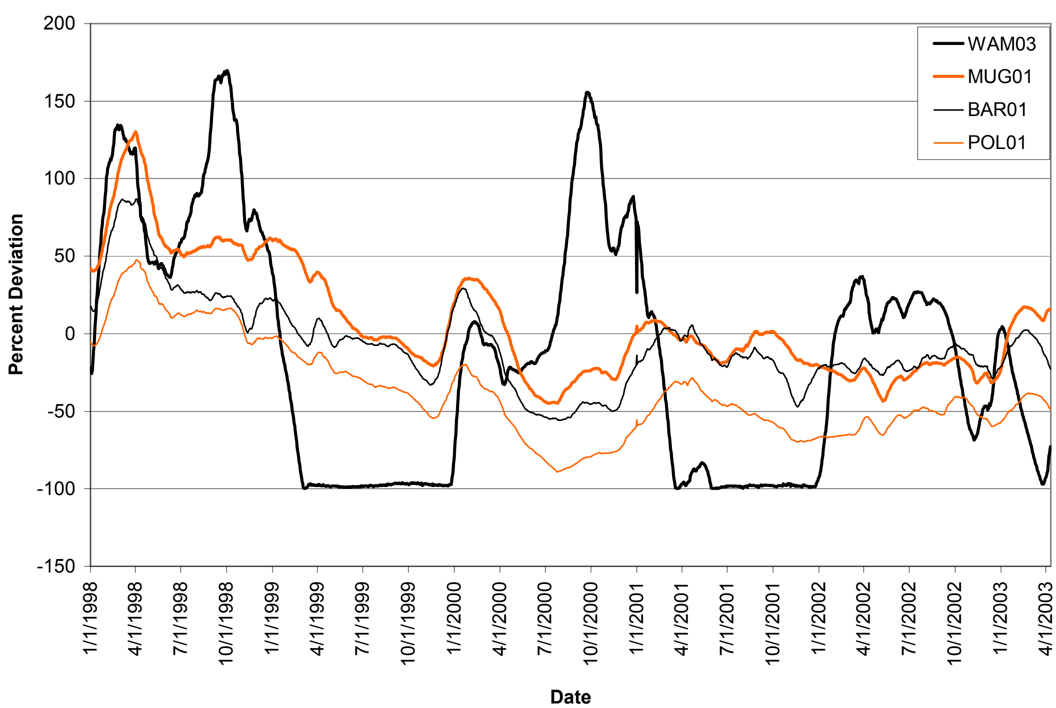



**Figure 12. Percent deviation of forage available to cattle from the long-term average at four**

**Year 2001**

The 2000-2001 short rains provided some relief to the area, although true recovery did not occur. The mean forage availability for the thirty Laikipia monitoring points reached 1459 kg $ha^{-1}$ ( $\pm$ 731 kg $ha^{-1}$) on 2 January 2001, before falling again (Fig. 9). On that date, the forage availability for the four points of interest were 633 kg $ha^{-1}$ at Northern Wamba, 729 kg $ha^{-1}$ at Il Polei, 1426 kg $ha^{-1}$ at Baraka, and 2395 kg $ha^{-1}$ at Eastern Mugie. However, examination of Figure 11 reveals that the timing of peak response to the short rains varied greatly by monitoring point. In Northern Wamba, peak forage production occurred around 21 December 2000, while peak response at Il Polei did not occur until 18 March 2001. Forage availability following the short rains ranged from 31% below normal at Il Polei to 89% above normal at Northern Wamba (Fig. 12).

The 2001 long rains did little to improve the drought situation in Laikipia. At the Northern Wamba point, forage availability had fallen precipitously between December and March. Following the long rains, the PHYGROW estimate of forage available to cattle at Northern Wamba is only 97 kg $ha^{-1}$ on 11 May 2001, 83% below normal. Peak response to the long rains occurred around 23 April 2001 at the Il Polei monitoring point and 21 May 2001 at Baraka. At the Eastern Mugie monitoring point, however, forage availability continued to build until peaking at 2479 kg $ha^{-1}$ around 26 August 2001.

Following the poor to moderate response to the long rains, forage availability fell steeply. On 19 November 2001, at the end of the dry season, the mean percent deviation for the thirty Laikipia monitoring points was 42% below average ( $\pm$ 23%). For the four points of interest in this discussion deviation values on that date were -98% at Northern Wamba, -70% at Il Polei, -47% at Baraka, and -17% at Eastern Mugie.

**Year 2002**

The 2001-2002 short rains resulted in little improvement in forage availability. Forage availability decreased throughout the normal short rain season at the Eastern Mugie monitoring point. Forage availability at Baraka improved to 21% below normal with 1379 kg $ha^{-1}$ available on 4 January 2002. Forage availability at Il Polei increased to 67% below normal on 31 December 2001, and to 11% above normal (378 kg $ha^{-1)}$ on 14 February 2002 at Northern Wamba.

At peak response to the long rains of 2002, the mean for the thirty Laikipia points was 1701 kg $ha^{-1}$ ( $\pm$ 882 kg $ha^{-1}$) of forage, or 19% below normal ( $\pm$ 15%). At that time, percent deviation of forage availability from the long-term average at the four points of interest ranged from 52% below normal at Il Polei, to 18% above normal at Northern Wamba.

Table 5 summarizes the changes in forage availability from the peak of the drought in 2000 through the years 2001 and 2002.

**Table 5. Forage availability at peak wet and dry periods.**

| | 7/8/2000 | | 1/2/2001 | | 5/21/2001 | |
|---|---|---|---|---|---|---|
| | % | kg/ha | % | kg/ha | % | kg/ha |
| Mean | -55 | 783 | -7 | 1459 | -19 | 1717 |
| Median | -55 | 721 | -19 | 1310 | -16 | 1572 |
| Standard Deviation | 15 | 293 | 32 | 731 | 19 | 880 |
| MUG01 | -45 | 1503 | 1 | 2395 | -10 | 2344 |
| BAR01 | -55 | 859 | -19 | 1426 | -12 | 1809 |
| POL01 | -84 | 274 | -59 | 729 | -40 | 1091 |
| WAM03 | -9 | 349 | 71 | 633 | -88 | 72 |

| | 11/19/2001 | | 12/29/2001 | | 6/10/2002 | |
|---|---|---|---|---|---|---|
| | % | kg/ha | % | kg/ha | % | kg/ha |
| Mean | -42 | 962 | -30 | 1166 | -19 | 1701 |
| Median | -44 | 846 | -30 | 1182 | -22 | 1375 |
| Standard Deviation | 23 | 465 | 23 | 501 | 15 | 882 |
| MUG01 | -17 | 2030 | -20 | 1895 | -28 | 2017 |
| BAR01 | -47 | 908 | -23 | 1361 | -17 | 1710 |
| POL01 | -70 | 545 | -67 | 596 | -52 | 891 |
| WAM03 | -98 | 6 | -95 | 20 | 18 | 608 |

## Discussion

These results illustrate two important points. First, no one measure of forage availability is adequate for analyzing drought. Second, forage conditions vary greatly among locations at both large and small scales.

The results from the four points discussed, particularly for Northern Wamba, illustrate the need for more than one measure of forage availability. Taken alone, percent deviation of forage availability would have indicated that Northern Wamba was the monitoring point least affected by the drought. When the actual amount of forage available is considered, however, it becomes evident that forage conditions at that location were quite poor. Taken together, the two measures provide insight not only into the current conditions at the site, but also into the likely long term situation. In this case, they indicate that forage conditions at Northern Wamba are chronically poor.

The results from the four locations also indicate that the variation in forage conditions among sites is such that expressing drought information in terms of the mean for the zone is probably insufficient. These variations exist in the timing and severity of forage response. Peak forage response to the short rains of 2000 – 2001 was separated by three months and 58 percentage points (Figs. 11 and 12) at these four points.

This variability illustrates the necessity of providing point specific information to end users of LEWS. While expressing forage conditions in terms of zonal averages may be sufficient when communicating with national governments and international organizations, it is inappropriate at the local level. Pastoralists and local development workers need the site specific information provided through the AFLEWS Analysis Portal in order to understand the spatial distribution of forage in the zone.

## Summary

The automation of data analysis and reporting through the AFLEWS analysis system and AFLEWS Analysis Portal significantly enhances the ability of LEWS to deliver drought warning in a timely manner.  The Portal makes available information on current forage conditions, projected conditions, and the spatial distribution of forage. The variety of drought indicators, (i.e. forage amount, departure from long term means, and NDVI information) provides a clearer picture of both short and long term forage conditions.

# CHAPTER IV

# FIELD VERIFICATION

## Introduction

If drought warnings and management suggestions are to be issued based on PHYGROW results, then the model and the methodology used in establishing monitoring points must first be shown to provide accurate information on forage availability. This is done by performing ground truthing or field verification to compare actual standing crop values to the estimates produced by the model. There are many elements that could introduce error into the model and decrease the accuracy of model predictions. For example, the model itself might contain mathematical or logical errors, or may oversimplify the complexities of ecosystem functions and processes. Alternatively, there might be inaccuracies in the data that is initially input into the model.

The PHYGROW model relies on the input of a large amount of information in four main categories: soil hydrology, plant growth, herbivore demand, and weather. In East Africa, access to much of this information is extremely limited. Due to this lack of data, the following list of assumptions were made when populating the PHYGROW model with parameter values.

1. The Soil Textural Triangle Hydraulic Properties Calculator (Saxton et al. 1986) calculated accurate hydraulic properties for the soil at the monitoring

points from average textural values of soils mapped at 1:250,000 (Ahn and Geiger 1987).

2. Bulk density and field capacity values given for vertisols of the Ethiopian highlands (Woldeab 1988 and Kamara and Haque 1988) were accurate for the Black Cotton vertisols of Laikipia.
3. Biological literature, the ECOCROP database (FAO 1996), and experts provided reasonable biological values for plant growth attributes.
4. When no values were available for a species, values for similar species could be substituted and adjusted given observations of morphological and phonological characteristics.
5. Human recollections of grazing patterns and stocking rates for both livestock and wildlife were accurate, as were their written and verbal accounts of dietary preferences.
6. Satellite weather data provided accurate information about precipitation and temperature at the monitoring points.

## Methods

The comparative yield method was used to determine standing crop of herbaceous species at each of the thirty monitoring points within the Laikipia zone. Prior to visiting the monitoring points, photoguides were constructed to aid in visual estimation of standing crop. Separate guides were provided for the high productivity Black Cotton soils and the low productivity red sandy soils. For each photoguide, five reference quadrats (0.5 $m^2$) were selected which represented the range of productivity for the site. These reference quadrats were scored one (minimal standing crop) through five (maximal standing crop). The plots were then photographed and the vegetation clipped at the soil surface. The plant material was dried and weighed. New reference quadrats were selected until the relationship between score and standing crop approached an $r^2$ value of 1 using simple linear regression. Photoguides were prepared showing each reference quadrat, its score, and the standing crop in kg $ha^{-1}$.

At each monitoring point, fifty plots, placed along five, 50 m transects, were scored for standing crop, using the photoguides for reference. Fifteen of these plots were then clipped to ground level, and the vegetation dried and weighed in order to determine the relationship between the scores and weights. Using linear regression, the weight of each of the fifty scored plots was computed. The mean standing crop and standard error of prediction was compared to the PHYGROW estimate of standing crop for the sampling date.

**Results**

Fifteen of the fifty scored plots at each monitoring point were clipped and weighed. Regression analysis was then conducted for each monitoring point with standing crop regressed on the scores. The thirty $r^2$ values for the comparative yield analyses are shown in Table 6.

The PHYGROW model estimate of standing crop fell within the standard error of the mean clipped weight for 21 of the 30 monitoring points. Upon examination of

Figure 13, MUS01 and MUG01 are easily identified as statistical outliers. A regression analysis which included these two data points had an $r^2$ value equal to .92 and a standard error of 255 kg $ha^{-1}$ (Fig. 14). When the two outliers were excluded from the regression, the regression coefficient increased to .99 with a standard error of 94 kg $ha^{-1}$ (Fig. 15).

**Table 6. $R^2$ values for comparative yield analysis.**

| Site | R2 | Site | R2 |
|---|---|---|---|
| KE-LA-BAR-01 | 0.65 | KE-LA-MUG-01 | 0.78 |
| KE-LA-BOR-01 | 0.72 | KE-LA-MUG-02 | 0.78 |
| KE-LA-JOG-01 | 0.91 | KE-LA-MUS-01 | 0.78 |
| KE-LA-KAR-01 | 0.51 | KE-LA-NAG-01 | 0.77 |
| KE-LA-KIS-01 | 0.76 | KE-LA-NAR-01 | 0.85 |
| KE-LA-KIS-02 | 0.65 | KE-LA-NGO-01 | 0.28 |
| KE-LA-KOI-01 | 0.84 | KE-LA-PAD-01 | 0.61 |
| KE-LA-KUR-01 | 0.57 | KE-LA-PEJ-01 | 0.4 |
| KE-LA-LUO-01 | 0.49 | KE-LA-POL-01 | 0.53 |
| KE-LA-MAI-01 | 0.74 | KE-LA-SEG-01 | 0.41 |
| KE-LA-MOR-01 | 0.94 | KE-LA-SEG-02 | 0.73 |
| KE-LA-MOU-01 | 0.7 | KE-LA-TIE-01 | 0.74 |
| KE-LA-MPA-01 | 0.89 | KE-LA-WAM-01 | 0.85 |
| KE-LA-MPA-02 | 0.82 | KE-LA-WAM-02 | 0.9 |
| KE-LA-MPA-03 | 0.84 | KE-LA-WAM-03 | 0.92 |
| | | MEAN | 0.71 |

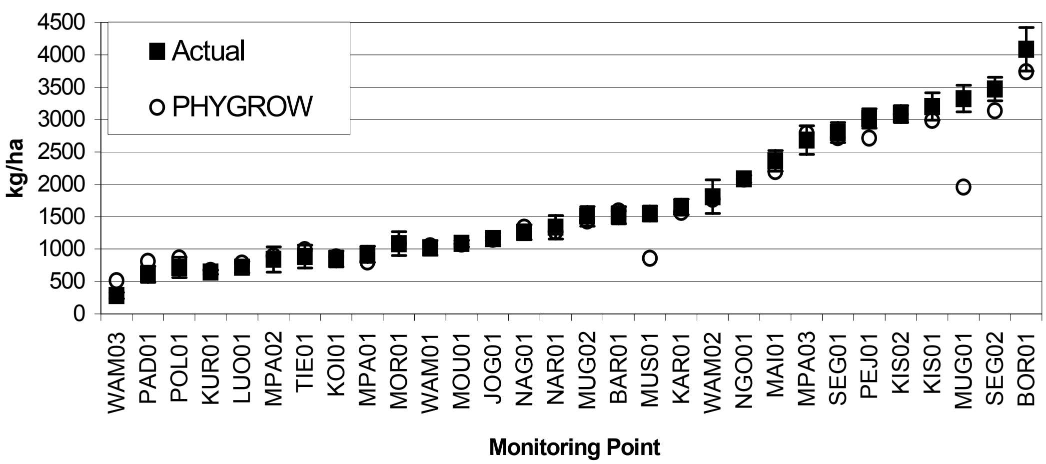



**Figure 13. Comparison of the PHYGROW estimate of standing crop to the actual clipped standing crop at each monitoring point.**

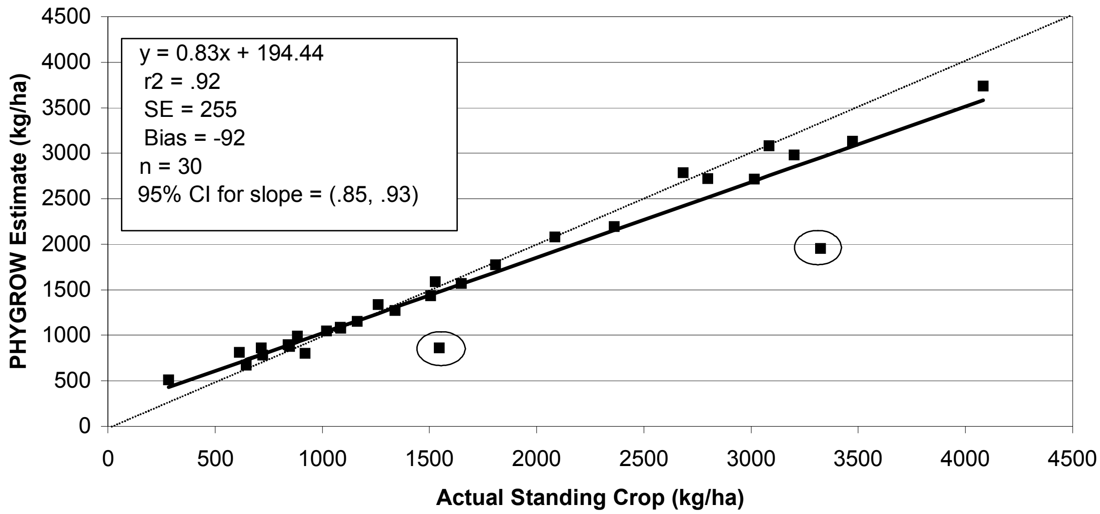



**Figure 14. Regression of PHYGROW standing crop estimate on actual standing crop. All thirty monitoring points included.**

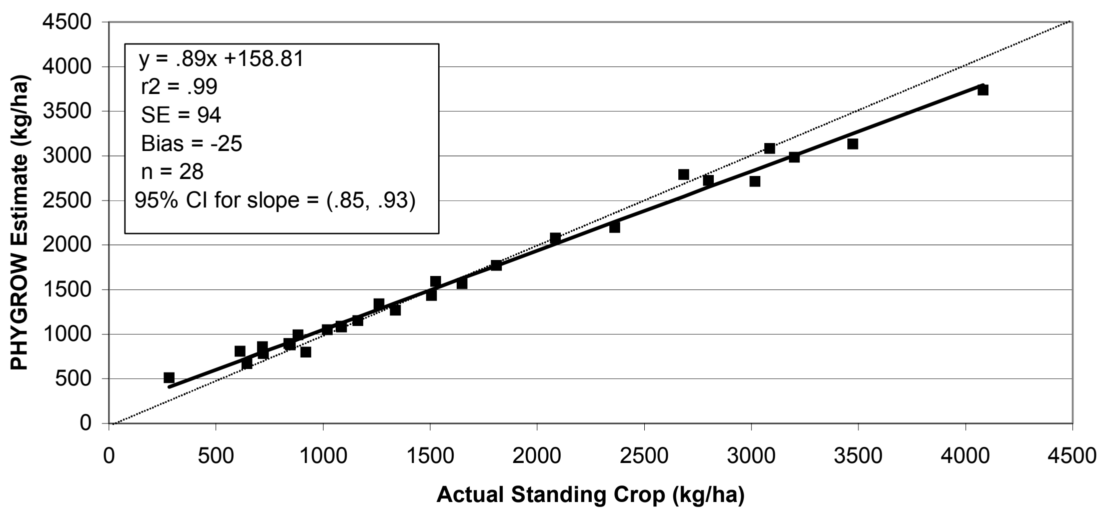



**Figure 15. Regression of PHYGROW standing crop estimate on actual standing crop. Two outliers removed.**

## Discussion and Conclusions

Overall, PHYGROW produced accurate estimates of standing crop for the thirty monitoring points in Laikipia. The accuracy was sufficient to provide useful information for formulation of drought advisories.

The source or sources of inaccuracy in the monitoring points KE-LA-MUS-01 and KE-LA-MUG-01 remain uncertain. It seems likely that some of the original assumptions made in the modeling process do not hold true in all situations. For instance, soil survey data may not accurately describe the soil at the monitoring point, or the stocking rules may not accurately represent herbivory at the point. Determining which of the assumptions is false at any one monitoring point is nearly impossible. There is also a chance that plant productivity at these monitoring points is strongly influenced by some ecosystem process that is not included in the PHYGROW model equations. For example, PHYGROW does not factor in the effect of water run on, so a monitoring point located in a depression in the landscape might absorb more water than fell on the site as precipitation, and this would not be reflected in the PHYGROW model. A third possible explanation of these outliers is that error occurred in weighing the clipped forage samples.

The ability to accurately predict the amount of forage available on East African rangelands should improve dramatically as new and better biological and ecological data become available. More intensive soil survey data and laboratory analysis of the hydraulic characteristics of those soils will assist in the simulation of water movement at each monitoring point. There is a great need for research into the growth attributes of rangeland plants, as historically crop species have been given priority. Resolution and access of satellite imagery is improving at a dramatic rate. Improved accuracy and higher resolution weather data will improve the ability to estimate forage production across a landscape.

In the future, field verification of the PHYGROW standing crop estimates should be conducted on multiple sampling dates throughout the year. This would build a more robust data set and allow researchers to more thoroughly analyze the ability of the early warning system to accurately track seasonal fluctuations in forage availability across a wide variety of landscapes.

# CHAPTER V

# DETECTING DROUGHT EMERGENCE

## Introduction

Livestock owners pass through a decision making process related to drought response that involves several key stages. The process begins with the initial detection of a drought threat. This is followed by a planning phase in which assets are counted, options are weighed, and an action plan is developed. Next, a decision is made to implement the action plan and some mitigation strategy is enacted.

If a Livestock Early Warning System is to be effective, it must offer some improvement in this process over existing traditional drought detection and response systems. This could be process acceleration and/or process expansion. Process acceleration would mean that the implementation stage of the process – but potentially initial detection and planning as well - is achieved earlier. Process expansion would mean that more time is spent in the planning phase, so that, initial detection and planning would occur earlier, but implementation may occur at the same time.

Process acceleration is particularly desirable as it results in earlier drought response; animals are moved to better pasture earlier, supplemental feed is introduced earlier, or animals are sold sooner in higher body condition. The main advantage to process expansion is that more time is available to fully investigate alternative strategies, make necessary leasing arrangements, or locate supplemental feed. A combination of process acceleration and process expansion would be the ideal outcome of a Livestock Early Warning System.

## Methods

Representatives from two pastoral communities in Laikipia District were interviewed to learn when they detected and responded to the drought of 2000. Each representative group was asked to identify the approximate dates when (1) individuals first began to experience some concern that a drought might be developing, (2) the community began to discuss the drought and possible mitigation strategies, and (3) the community took action in response to the drought. Community members attending the meeting were asked to select the dekad (10-day period) during which the majority felt the perception or response had taken place. In addition, information was gathered on the indicators that accompanied these decisions and the sorts of actions taken.

The two participating communities were from the Tukasoma Pastoralist Project and the Kurikuri Group Ranch. Tukasoma is made up of pastoralists living in the area surrounding the Baraka monitoring point, KE-LA-BAR-01, and the Kurikuri Group Ranch is made up of pastoralists living in the area around the Kurikuri monitoring point, KE-LA-KUR-01 (Fig. 16). These communities were selected for the interviews primarily because of their relationships with development workers who could serve as translators.

For each pastoral community, the responses were compared to the dekads during which the drought advisory status issued by the Livestock Early Warning System would have reached WATCH, WARN, and ALERT levels. Although LEWS was not yet in place in Laikipia during the 2000 drought, PHYGROW results can be obtained for that time period by running the model with weather data from that year.

Within LEWS, advisory status is determined according to the percent deviation of current forage availability from the long term mean. When the percent deviation drops below 0%, a drought WATCH is established, while the WARN level is achieved at –20%, and an ALERT is issued at –40% (Table 7). In general, it is recommended that during the WATCH phase, pastoralists should pay close attention to developing climatic and forage conditions and inventory their resources. During the WARN stage, livestock owners should formulate plans of action. This can include determining migration routes, making any necessary leasing or access arrangements or obtaining permission to cross properties, considering livestock sales, and identifying possible sources of supplemental feeds. When an ALERT is issued, the livestock owners should implement the action plan developed during the WARN phase.


**Figure 16. Location of participating communities within Laikipia District.**

**Table 7. Levels of warning status.**

| Warning Status | Percent Deviation |
|---|---|
| Above Normal | >20 |
| Normal | 0 to 20 |
| Watch | -20 to 0 |
| Warn | -20 to -40 |
| Alert | -40 to -60 |
| Emergency | -60 to -80 |
| Disaster | < -80 |

**Community Descriptions**

Several characteristics make the Baraka community unique in Laikipia. First, members of the community are squatters on lands that are owned by absentee landowners. The area was established as a government settlement scheme, but the land buyers were farmers who abandoned their parcels when they discovered that the area was non-arable. This places the residents of Baraka in a more precarious position than communities within group ranches or where individuals hold title to the land. Second, the members of the Tukasoma Pastoralist Project in Baraka are mainly from the Turkana tribe, but some are also from the Kalenjin and Maasai tribes. The diversity of the group is unique, but it should also be noted that most of the community members – the Turkanas and Kalenjins – are living outside their traditional tribal lands. Third, while some members of the Baraka community are true pastoralists, many would be better described as agropastoralists. In addition to herding livestock, they grow maize and beans in small plots. Finally, the Tukasoma Pastoralist Project is unique among the communities in this study in that they were the only people to proactively seek inclusion in the Livestock Early Warning System. Word of LEWS reached the group and they approached me to request that a monitoring point be established in their area.

The Kurikuri community is much more typical of the communities in the zone. Kurikuri Group Ranch is located among a cluster of Maasai group ranches in the Northeastern portion of Laikipia District. Pastoralism is the primary means of securing a livelihood for community members. All residents of the group ranch are members of the Maasai tribe. OSILIGI, a community based organization, has been working on community development and advocacy issues in the Kurikuri community for several years. Staff of OSILIGI are members of the local group ranches who have obtained some level of post-secondary education and now work to better the economic and social plight of their communities. The staff of OSILIGI agreed to assist in the establishment and dissemination of the early warning system in the Maasai group ranches.

## Results

### Baraka

At the Baraka monitoring point, community members stated that they first began to experience concern that a drought might develop during the first dekad of January. LEWS would have issued a WATCH advisory during the first dekad of April. However, a WARN would have been issued by the third dekad in April, while community members stated that they did not begin to discuss potential actions until the second dekad in May. An ALERT would have been issued in the second dekad of May. Community members stated that wild fruit storage began in the second dekad of May and herd migration began during the first dekad of June. Figure 17 contains a graph showing the progression of the drought and the timing of LEWS advisories relative to the three stages of pastoral decision-making

### Kurikuri

At the Kurikuri monitoring point, LEWS would have issued a WATCH during the first dekad of February. Community members stated that they first began to experience concern during the second dekad of April. WARN status had been achieved by the first dekad of April. Community members became aware that some action would need to be taken during the second dekad of May. An ALERT would have been issued during the second dekad of May and community members reported that herd migration began during the first dekad in July. This information is presented graphically in Figure 18.

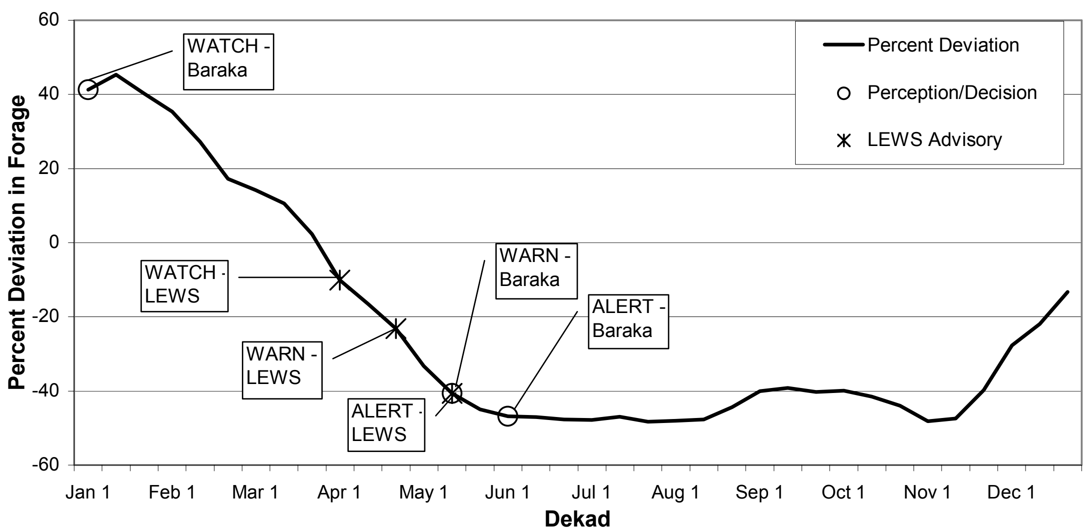



**Figure 17. Progression of 2000 drought at Baraka monitoring point. Circles represent each of three levels of pastoralists' perception and reaction to drought – initial concern, drought recognition, and implementation of coping strategies. Asterisks represent when LEWS would have elevated the advisory status to Watch, Warn, and Alert.**

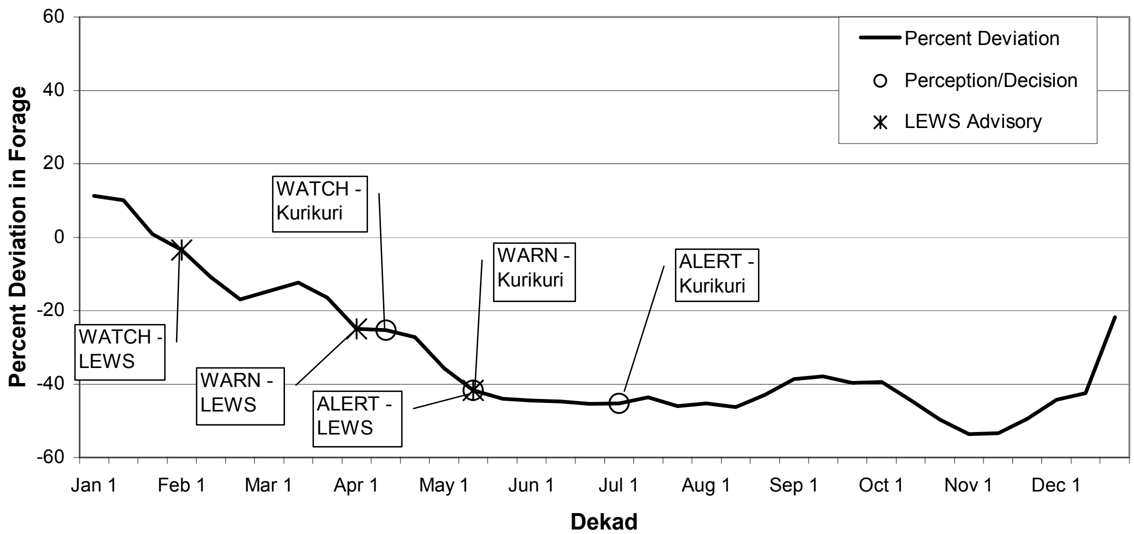



**Figure 18. Progression of 2000 drought at Kurikuri monitoring point. Circles represent each of three levels of pastoralists' perception and reaction to drought – initial concern, drought recognition, and implementation of coping strategies. Asterisks represent when LEWS would have elevated the advisory status to Watch, Warn, and Alert.**

## Discussion

These results can be discussed in light of the two means of early warning improvement mentioned in the introduction to this chapter – process acceleration and process expansion. Process acceleration means entering all stages of the process earlier, especially the ALERT or implementation stage (Table 8). In these two case studies, a WARN status would have been assigned 20 – 40 days prior to the time when community members reported realizing that drought conditions were likely and that action would have to be taken. More importantly, the ALERT stage was reached 20 – 50 days prior to the beginning of herd migrations. This information can be found in the Lead Time columns of Tables 9 and 10. Therefore, process acceleration would have been achieved if the early warning system had been in place.

Process expansion occurs when more time is spent in the planning stage of the decision making process. This did not occur in either case study. The planning stage for LEWS was equal to the planning stage of the community at Kurikuri and 10 days shorter than the community planning stage at Baraka (Tables 9 and 10).

In particular, it is interesting to note that for both communities, the dekad in which ALERT status was achieved coincides with the dekad in which the community began to discuss possible actions.

**Table 8. Stages of the drought decision making process.**

| Stage | Warning Status | Pastoral Decision | Associated Activities |
|---|---|---|---|
| I | WATCH | Initial Concern | Track weather conditions<br>Track forage conditions<br>Resource inventory |
| II | WARN | Planning | Formulate action plan<br>Determine migration route<br>Make lease/access arrangements<br>Consider livestock sales<br>Locate supplemental feed |
| III | ALERT | Implementation | Implement action plan |

**Table 9. Timing of the decision making process at Baraka. Lead time refers to the number of days advance warning provided by LEWS advisories as compared to community decisions. A negative number indicates that the community entered the designated stage earlier than LEWS reports.**

| | Duration | | |
|---|---|---|---|
| Stage | LEWS (days) | Community (days) | Lead Time (days) |
| I | 20 | 130 | -90 |
| II | 20 | 20 | 20 |
| III | NA | NA | 20 |
| Total | 40 | 150 | NA |

**Table 10. Timing of the decision making process at Kurikuri. Lead time refers to the number of days advance warning provided by LEWS advisories as compared to community decisions. A negative number indicates that the community entered the designated stage earlier than LEWS reports.**

| | Duration | | |
|---|---|---|---|
| Stage | LEWS (days) | Community (days) | Lead Time (days) |
| I | 60 | 30 | 70 |
| II | 40 | 50 | 40 |
| III | NA | NA | 50 |
| Total | 100 | 80 | NA |

## Summary

Evidence from these two case studies indicates that the Livestock Early Warning System has the potential to significantly accelerate the detection and response to drought on East African rangelands. If the system had been in place during the 2000 drought, and pastoralists had chosen to follow the recommendations given for each advisory level, they would have been able to take mitigating action 3 to 7 weeks earlier than actually occurred.

From this data, the Early Warning System does not appear to extend the amount of time that would be spent in developing an action plan. In both communities the amount of time spent in the Warning stage was equal to or slightly less than the period of time between first realizing action would be necessary and taking action. More case studies should be conducted in order to determine if this pattern of process acceleration versus process extension is consistent.

# CHAPTER VI

# SUMMARY AND SUGGESTIONS FOR FUTURE RESEARCH

## Introduction

Drought is a frequent threat to agricultural production in East Africa. A variety of early warning systems have been developed to help cope with this threat, but the majority of those systems are based on crop production or human nutrition. The void of early warning systems for livestock production may be filled, at least in part, by the Livestock Early Warning System (LEWS) being developed through USAID's Global Livestock CRSP. Research conducted in the Laikipia zone indicates that LEWS can be a multifunctional system, capable of reaching a variety of audiences in innovative ways with accurate drought information. Researchers and pastoral communities, however, still face challenges. These challenges include technical issues within the system itself, barriers to effectively communicating forage reports to pastoral communities, and the difficulty of providing viable options for communities to cope with drought. These challenges will be discussed in detail later in this chapter and suggestions will be given for future research topics to address these challenges.

## Vision for a Successful Livestock Early Warning System

It is good to begin by envisioning what a successful LEWS would look like. The success of LEWS will depend on (1) accurate input data, (2) accurate and timely simulation of forage conditions, (3) involvement and commitment from governments, agencies, and individuals at all levels, (4) effective communication of drought information to all of those entities, and (5) successful implementation of drought mitigation plans as a result of receiving that information.

The first two items in the list above – accurate input data and accurate, timely results – need little explanation. Both are essential to the success of LEWS. Soil, plant, grazer, and weather data are entered into the PHYGROW model and the simulation is run to determine forage conditions. NDVI data and the point-based PHYGROW estimates of forage availability are then used to estimate forage conditions across the landscape.

For LEWS to be successful, these results must reach all the interested parties, in a format that is accessible and useful. These interested parties include international research and development groups, national governments, local government officials, community-based organizations (CBO), and pastoral communities. LEWS is attempting to deliver drought information to each of these groups in a variety of ways. First, all results are posted on an Internet site (http://cnrit.tamu.edu/aflews). Selected portions of that site are then broadcast over the Africa Learning Channel on the WorldSpace satellite radio. Satellite radios and computers have been placed in remote pastoral areas which lack access to the Internet. Staff of the NGO, CBO, or government offices where the radios are placed are then trained in the use of the radio and interpretation of LEWS reports. These trained collaborators carry hard copies of the reports to their local pastoral communities and explain the contents. In addition, LEWS sends formal monthly reports containing an overview of regional forage conditions to various government offices, such as agriculture ministries, and to development and research organizations working in the region.

LEWS results must be reported at varying levels of technical expertise and regional interest. Given the high rate of illiteracy and the smaller spatial scale of interest in pastoral communities, a ranking system supplemented with forage maps may be sufficient. This is the purpose of the Above Normal, Normal, Watch, Warn, Alert, Emergency, and Severe status labels. Each status level has an associated suggested response. For example, if an area is in the Warn stage, LEWS suggests that they begin making plans and arrangements for livestock sales, movements, or supplemental feed. Ideally, in the future these reports will be delivered in the local language.

More technical audiences, such extension and development workers, receive more detailed reports. These contain graphs, maps, and written summaries of forage distribution. Scientific audiences may access complete sets of graphs, data files, and series of maps from the Internet site.

The final component of a successful early warning system would be the implementation of effective drought mitigation techniques as a result of LEWS reports. This will be the true measure of the success of the system. The vision of a successful LEWS includes community level drought response plans in place before a drought emerges. These plans would include specific steps to be taken at each level of drought warning. An example might be that when forage conditions in a community reach the Watch stage, a *baraza*, or meeting of community elders, will be held to discuss the community's options if conditions worsen. At the Warn stage, leasing or grazing access arrangements will be made in preparation for herd migrations and local NGOs will assist the community in locating sources of water and/or supplemental feed. At the Alert stage, the community will begin herd movements and the water and feed will be delivered.

If pastoral communities are to implement effective mitigation strategies, they will need assistance. Government and development personnel will need to be informed of the drought situation, provide timely information to livestock owners, and assist them in identifying viable options.

## LEWS Successes in Laikipia

### Ability to Customize LEWS for Multiple Use

A review of drought and early warning related literature revealed that several authors felt NGOs and CBOs should be involved in the development of early warning systems. This is due to their familiarity with pastoral communities and because the financial resources available to these organizations help to ensure the sustainability of the system (Scott 1987 and Curtis et al. 1988). In addition, Cohen and Lewis (1987) suggest that information systems, such as LEWS, need to be multifunctional in order to justify the use of limited resources for the day-to-day operation of the system. With these things in mind, the Laikipia Zone of LEWS was specifically developed to serve the drought early warning purposes of the LEWS project, and to meet the needs of Mpala Research Centre (MRC) and the Laikipia Wildlife Forum (LWF) in Laikipia.

The Laikipia monitoring zone successfully meets those criteria. The establishment of the zone was beneficial to LEWS. One goal of the LEWS project is to monitor forage conditions in all of the pastoral regions of East Africa. The Laikipia zone had not yet been included in that coverage. The thirty monitoring points within the zone also improved the spatial distribution of points throughout the East African region, which allowed LEWS to perform more robust geospatial analyses for the creation of regional forage maps.

In order to meet the needs of MRC and LWF, the Laikipia zone was specifically designed to cover the Ewaso Ngiro watershed. This is the geographic area of interest for these two organizations. Wildlife were included along with livestock as grazers within the PHYGROW model simulations for the Laikipia points. This is to assist MRC and LWF in monitoring forage availability for wildlife, identifying possible points of human/wildlife conflict, and studies of wildlife migrations.

LEWS also placed a satellite radio at MRC. This was a mutually beneficial arrangement. MRC downloads LEWS advisories from the WorldSpace broadcasts and distributes them to surrounding ranches and communities. In addition, MRC is able to access other sources of climate and development information that are broadcast via the satellite. The experience in the Laikipia zone of LEWS indicates that it is possible to establish LEWS as a multipurpose system.

**Automation of Analysis**

The automation of the data analysis process was an important success for all of LEWS, not just the Laikipia zone. Once the initial parameter file for a new monitoring point has been created and stabilized, the automated system automatically updates the file with current weather data, runs the model simulation, creates graphs and tables of the results, and posts them to the Internet every ten days. This saves LEWS staff countless hours of labor and ensures the timely delivery of drought advisories to end users.

**Delivery via WorldSpace Satellite Radio**

The Laikipia monitoring zone was the pilot site for the placement of satellite radios in 2001. Currently, there are four radio setups placed within the zone. These locations are the Wamba Community Development Program in Wamba, OSILIGI in Dol Dol, Mugie Ranch near Suguta Marmar, and Mpala Research Centre. Additional radios have since been placed in other zones. The placement and use of satellite radios is significant because it allows LEWS to overcome the difficulty of disseminating drought advisories to remote areas in a timely fashion. In addition to allowing pastoral communities without Internet access to receive LEWS reports, the radios also provide access to programs containing news, health, weather, agricultural, and development information.

**Multiple Products for Multiple Audiences**

Another area in which LEWS has experienced success is in the development of multiple reporting techniques for the various end users of LEWS products. At the village level, cooperating NGO, CBO, or government officials disseminate drought advisories in the form of color coded maps and verbal explanations of the current warning status (i.e. Watch, Warn, Alert, etc.). Development organizations and government offices can download written reports containing graphs, maps, and situation summaries either from the Internet or satellite radio. Scientific and technical audiences, such as other drought researchers are able to access complete sets of graphs, data files, and map series from the Internet site.

**Accuracy of Standing Crop Estimates**

Research from Laikipia indicates that the PHYGROW model is capable of providing reasonable estimates of standing crop. This was tested using the comparative yield method; clipping and weighing the standing crop at thirty monitoring points and comparing those weights to the PHYGROW estimates of standing crop. The regression analysis for the thirty points had an $r^2$ value of .92 and a standard error of 255 kg $ha^{-1}$ (see Chapter IV). The ability of PHYGROW to accurately simulate forage conditions at a monitoring point is essential, since this estimate is the basis of the entire system.

### Ability to Accelerate Drought Detection and Response

Two case studies from Laikipia indicate that LEWS is capable of accelerating drought detection and response as compared to traditional systems. Two communities were asked to recount the timing of three levels of drought detection and response – initial concern, drought recognition and planning, and implementation of coping strategies. The period of interest was the severe drought that occurred during the year 2000. The timing of their decisions was then compared to the timing of LEWS advisories at the Warn, Watch, and Alert stages.

The results of these two case studies showed that the Alert stage was achieved 3 to 7 weeks prior to the communities' drought response (herd migration). This suggests that drought management decisions based on LEWS advisories could significantly improve the timing of response to drought.

## Challenges Facing LEWS

### Challenges to the System Proper

One of the biggest challenges to the Livestock Early Warning System is the scarcity of data on soils, plant communities and weather in East Africa. This shortage of information forces us to use estimated and substituted values in many cases. For this reason, the PHYGROW model simulations for the Laikipia zone are based on the following assumptions.

It was assumed that the Soil Textural Triangle Hydraulic Properties Calculator (Saxton et al. 1986) calculated accurate hydraulic properties for the soil at the monitoring points from average textural values of soils mapped at 1:250,000 (Ahn and Geiger 1987). Also, it was assumed that bulk density and field capacity values given for vertisols of the Ethiopian highlands (Woldeab 1988 and Kamara and Haque 1988) were accurate for the Black Cotton vertisols of Laikipia.

It was assumed that biological literature, the ECOCROP database (FAO 1996), and experts provided reasonable biological values for plant growth attributes. When no values were available for a species, it was assumed that values for similar species could be substituted and adjusted given observations of morphology and phenology.

Human recollections of grazing patterns and stocking rates for both livestock and wildlife were assumed to be accurate. Written and verbal accounts of dietary preferences were assumed to be accurate.

It was assumed that satellite weather data provided accurate information about precipitation and temperature at the monitoring points.

Faulty assumptions become a source of error in the system. As more research data comes available in the future, the PHYGROW model will become less dependent on these assumptions. This can only improve the accuracy of LEWS.

A second challenge to the early warning system itself is the development of accurate and timely projections of forage conditions beyond real time analysis. Currently LEWS staff are using the ARIMA model (Box et al. 1994) to generate 90 day projections. Further testing is necessary to determine the accuracy of these projections.

Finally, on a regional scale more monitoring points with a better spatial distribution are needed in some areas of East Africa to improve the accuracy and robustness of forage mapping techniques.

**Challenges to Communication**

One major challenge to LEWS is getting reports to communities in a reliable manner. The current network of WorldSpace satellite radios and government or development workers has the potential to be effective. This system however relies heavily on a strong commitment from those who must actually deliver the reports to pastoralists to do so in a reliable and timely fashion. It remains to be seen whether this will occur consistently over the long term.

Another challenge to communication of LEWS results is the high illiteracy rate of pastoral populations and the language barrier. Currently, all LEWS reports are written in English. In order to improve the acceptance and understanding of LEWS advisories, these reports need to be translated at least to Kiswahili, and possibly to tribal languages such as Maa and Turkana as well.

In many cases, further training is needed for the personnel delivering the reports to the communities to assist them in fully understanding the implications of the information contained in LEWS reports. They need training in how to effectively communicate this information and on how to assist the community in identifying viable options in drought situations.

**Challenges to Implementation**

According to a discussion held with staff members of the community based organization, OSILIGI, in Laikipia District, it may take four to eight years for the Laikipiak Maasai to accept the LEWS advisories as accurate and useful. The Maasai consider drought to operate on a four-year cycle. Therefore, they will probably need to observe the operation of LEWS through one or two of these cycles before they determine whether or not to trust the advisories. If this concept holds true for most of the East African communities involved in the LEWS program, then it will be impossible to truly determine the impact of the program before those four to eight years have passed.

Another aspect of this challenge is that LEWS reports must be reliably accurate during this time, even though the system is young and still in the development stages. A single gross error in a LEWS report could set back or ruin the chances of community acceptance. Pastoralists will not implement drought mitigation strategies based on a system they do not trust or believe to be accurate.

Finally, one very large challenge to implementation of mitigation strategies is the lack of viable solutions. There are economic, political, and cultural barriers to be overcome. Marketing of livestock in remote areas is difficult. Often the “middle men” who purchase livestock from the producer and transport the animals for slaughter and sale in economic centers take much of the profit. In Kenya, Nairobi is the primary market for meat. Many people believe this market is already saturated, causing lower prices and further diminishing the profit to pastoralists. The export market represents the greatest potential for improved profitability. However, disease and carcass quality issues preclude most animals from entering this market.

In addition to marketing struggles, some pastoral tribes have cultural norms that prevent them from fully exploiting marketing opportunities that may exist. These cultural norms vary from tribe to tribe and clan to clan.

Often, when discussing drought in pastoral systems, forage availability is considered the limiting factor. This is in fact the indicator LEWS uses to monitor drought conditions. In some areas, however, lack of livestock water limits use of grazing lands even when forage remains available. One challenge for the LEWS project is to find a means of incorporating stock water into the monitoring scheme. However, monitoring of water availability alone will not be enough. Means of improving water distribution and availability need to be identified in order to increase opportunities for communities to respond positively to drought. In areas where forage is indeed the limiting factor, access to, and storage of, supplemental feeds need to be worked out.

When considering what constitutes viable mitigation strategies, development workers will need to consider that a viable option for one community may not be viable for another. The varying economic, cultural, and infrastructural situations of these pastoral communities must be accounted for. This makes a strong argument for community level drought plans, designed to take advantage of the specific opportunities available to that community.

## Suggestions for Future Research

### Research Questions Specific to LEWS

There are several research topics the LEWS project should pursue in the future in order to ensure the accuracy of drought reports being disseminated and improve the usefulness of the system. First, further verification or ground truthing of LEWS forage availability estimates should be conducted. In this study, the PHYGROW estimates of standing crop at each of the thirty Laikipia zone monitoring points were verified on a single sampling date. Each of the thirty points were clipped once between early May and mid-July 2002. While the results of this study reflect positively on the accuracy of the PHYGROW estimates, further research should be conducted. Ideally, the comparative yield method should be used to verify the PHYGROW model estimates of standing crop during the short rains, short dry season, long rains, and long dry season. Also, this verification should be repeated over a period of 2 to 4 years, in order to ensure the PHYGROW simulations are tracking not only seasonal variation in forage conditions, but also annual variations. In addition, this verification process needs to be conducted in all zones of the early warning system, not just in Laikipia.

During this study, ten NDVI grids, which did not contain monitoring points, were randomly selected in order to conduct verification of the forage maps created using the cokriging technique. Unfortunately, a large number of those samples were lost in transit or storage, making it impossible to perform a meaningful analysis. This portion of the study should be repeated and expanded to cover seasonal variation, annual variation, and the regional scale of LEWS coverage.

Further research is needed to determine the ability of the early warning system to provide significant lead-time in detecting and responding to drought over traditional warning systems. LEWS staff in the various monitoring zones is currently carrying out studies along these lines. Researchers should investigate the capability of LEWS to achieve either process expansion or process acceleration as described in Chapter V.

Finally, it would be helpful to identify a means of monitoring the availability of livestock water. This ability would improve the usefulness of LEWS in areas where water is depleted before forage resources in drought situations.

**General Research Questions**

There are some research questions which would be beneficial to the success of the Livestock Early Warning System, but which researchers outside the program are likely better suited to answer. First, while the research presented here indicates that PHYGROW is capable of providing reasonable estimates of forage availability given the assumptions made in the data input process, the importance of more abundant and accurate input data remains undiminished. LEWS would benefit from (1) research into the plant growth characteristics of East African range plants, (2) improved soil maps and understanding of tropical and subtropical soil hydrology, (3) improved knowledge of livestock and wildlife diet preferences, and (4) improved weather data. Improved weather data could come through better distribution of weather stations in the remote pastoral regions of East Africa. It seems more likely, however, that increased knowledge of weather patterns will come through the continual process of improved satellite imagery.

The most essential research questions, those that may most improve the ability of governments and communities to mitigate the effects of drought, fall under the heading of viable solutions. How can domestic livestock markets be improved to increase profitability? Researchers and development workers need to determine how to encourage more timely sales of livestock to maximize returns to sellers. The problem of access to export markets needs to be addressed, from the economic standpoint and through research into disease control and improved meat quality. Pastoralists need access to supplemental feeds, water, grazing leases, and grazing reserves. These are the questions that must be answered to make LEWS a truly successful system.

## Summary

The USAID Global Livestock CRSP Livestock Early Warning System has the potential to meet the urgent need for drought warning in the pastoral livestock systems of Eastern Africa. The evidence from research conducted in the Laikipia zone of LEWS indicates that forage availability can be monitored using the PHYGROW model. Reports containing this information are successfully being posted on the Internet and broadcast on WorldSpace satellite radios. Two case studies carried out in Laikipia also indicate that LEWS is capable of alerting pastoral communities to emerging drought conditions earlier than the community detects those conditions using traditional methods.

This should allow pastoralists to respond earlier and utilize coping mechanisms more effectively.

Further research is necessary as LEWS continues to develop to ensure the accuracy of the extrapolation and projection techniques. Possible improvements to the system include adding a stock water monitoring component.

The eventual success of the early warning system, however, will rely not only on the accuracy of the drought advisories produced, but also on the management decisions made as a result of receiving the advisories. This will require commitment from governments, researchers, development workers, and pastoral communities to seek workable solutions to the many challenges facing effective drought mitigation.

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# APPENDIX A

## PLANT GROWTH ATTRIBUTES USED IN PHYGROW

Leaf Area Index

Dry Matter to Radiation Conversion Ratio (g dry matter/megajoule radiation)

Suppression Temperature (°C)

Base Temperature (°C)

Leaf Turnover (%)

Heat Units to Seed Set

Heat Units to Maturity

Maximum Rooting Depth (cm)

Maximum Canopy Height (cm)

Maximum Above Ground Biomass at Maximum Expression (kg/ha)

Leaf to Above Ground Biomass Ratio

Stem Area Index

Leaf Water Storage Capacity (g $H_2O$/ g dry matter)

Stem Water Storage Capacity (g $H_2O$/ g dry matter)

Fraction of Water Transferred From Leaf to Stem

Stem Turnover Rate (%)

Cold Unit Accumulation to Freeze Leaf Damage

Leaf Green to Dead Rate (%)

Leaf Green to Dead Rate During Dormancy (%)

Canopy Base Diameter (cm)

Canopy Crown Diameter (cm)

Height at Canopy Start (cm)

Height at Beginning of Canopy Curvature (cm)

Maximum Leaf Litter Decomposition Rate (% of leaf litter standing crop)

Maximum Stem Litter Decomposition Rate (% stem litter standing crop)

Leaf Litter Water Storage Capacity (g $H_2o$/ g dry matter)

Stem Litter Water Storage Capacity (g $H_2o$/ g dry matter)

Contribution to Range Site Hydraulic Condition

Minimum Required Day Length to Grow (hours)

# APPENDIX B

# GRAPHS GENERATED BY THE AFLEWS AUTOMATED ANALYSIS SYSTEM

Every ten days, the AFLEWS Automated Analysis System updates the parameter files for each monitoring point with the most recent NOAA RFE weather data. The system then runs the files through a PHYGROW simulation, analyzes the results, and generates graphs. These graphs are then posted on the AFLEWS Analysis Portal, online at http://cnrit.tamu.edu/aflews. This appendix contains a complete set of graphs constructed for the monitoring point named KE-LA-KIS-02, which is located on Kisima Ranch in Northern Laikipia. The graphs were posted on 10 March 2003.

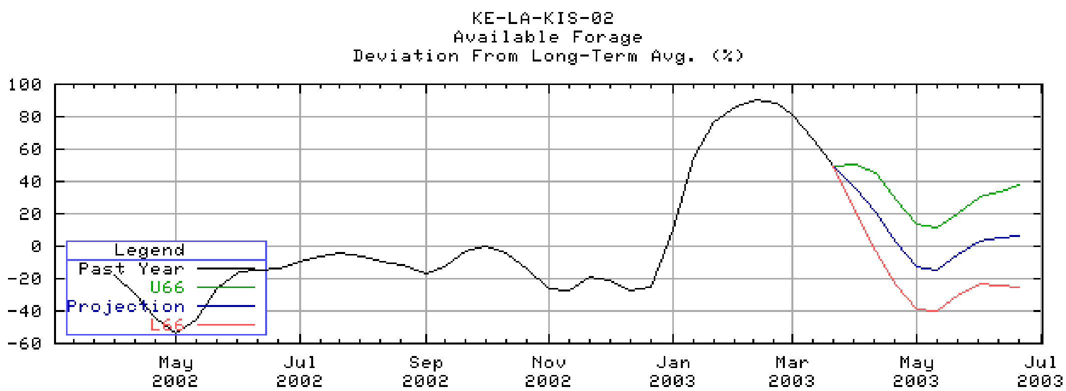
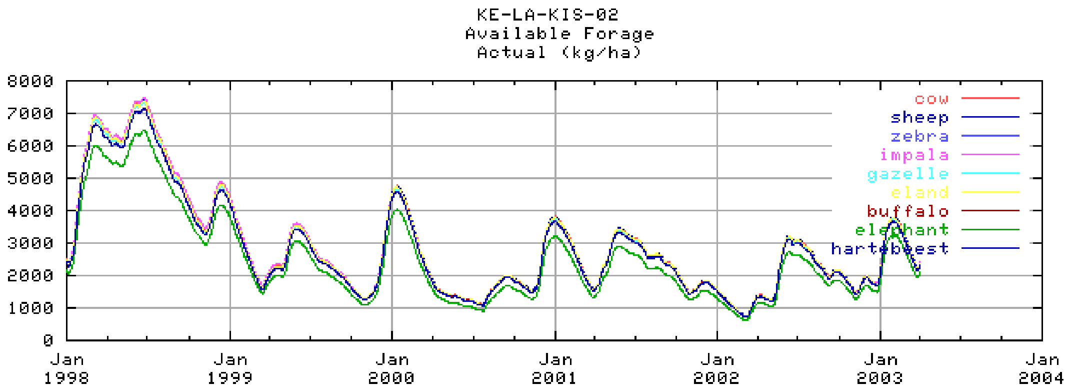
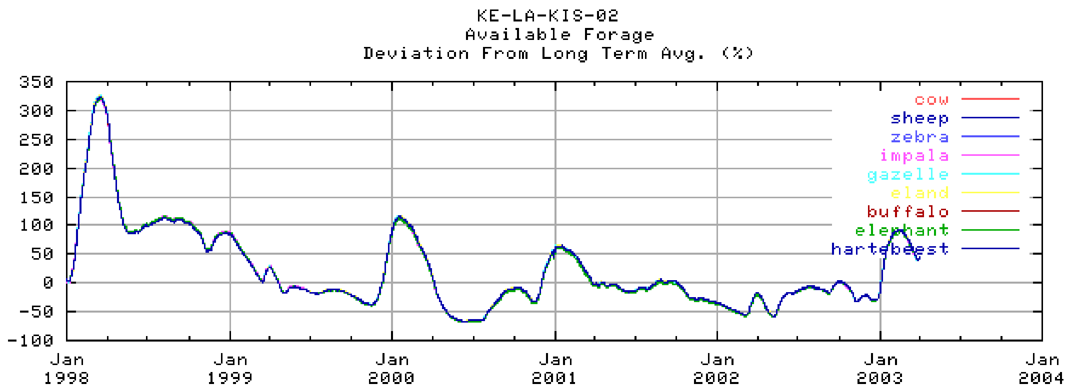


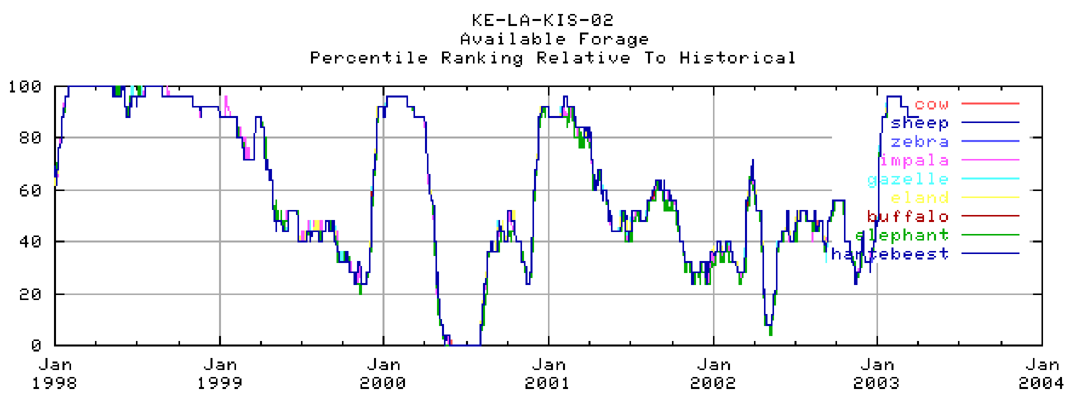

**Figure B-1. Graph of projected percent deviation of total forage available for the 90 day period following 1 April 2003. Lines labeled U66 and L66 represent the upper and lower limits of a 66 percent confidence interval.**




(a)

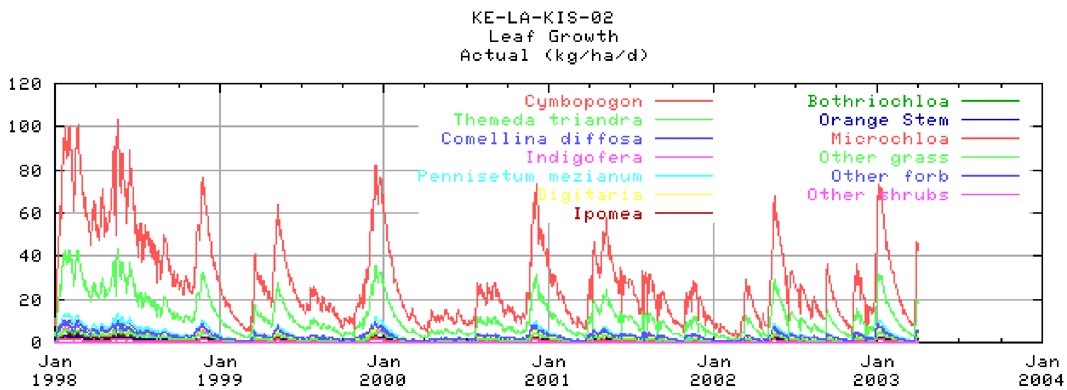



(b)

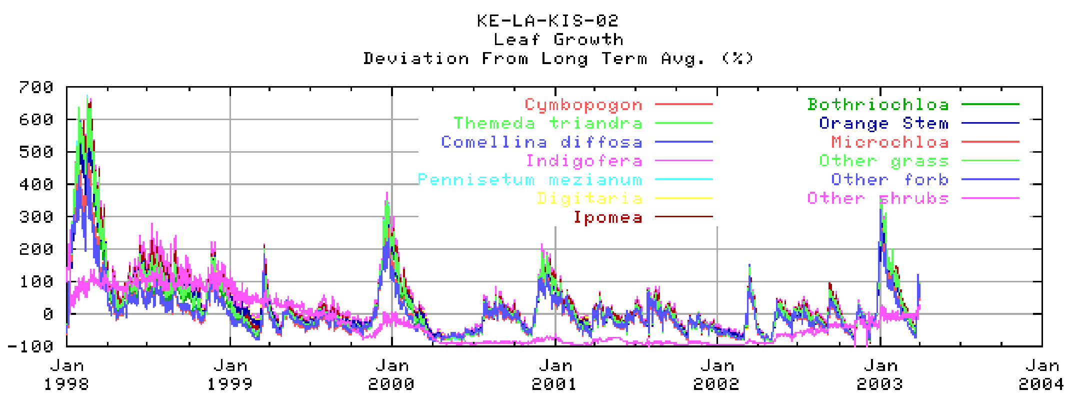



(c)

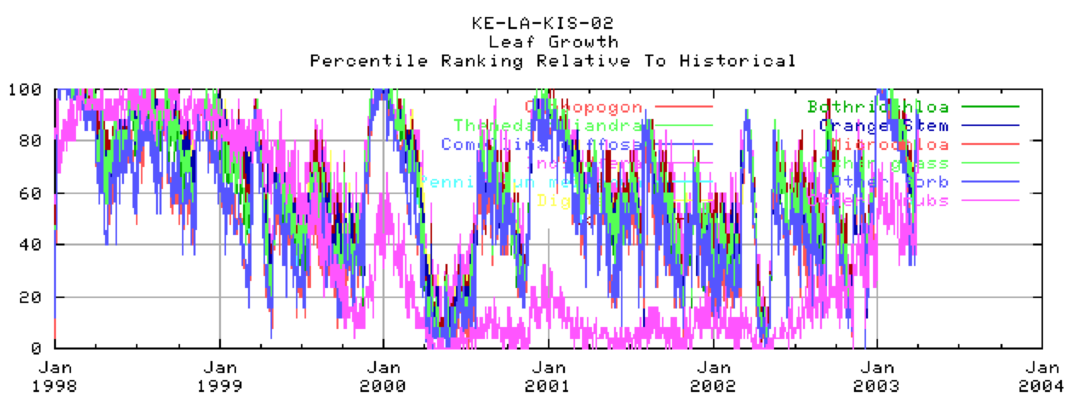
**Figure B-2. Forage availability graphs showing (a) actual forage available (kg ha$^{-1}$), (b) percent deviation of forage available from the long term average, and (c) percentile ranking of forage available by animal kind.**




(a)

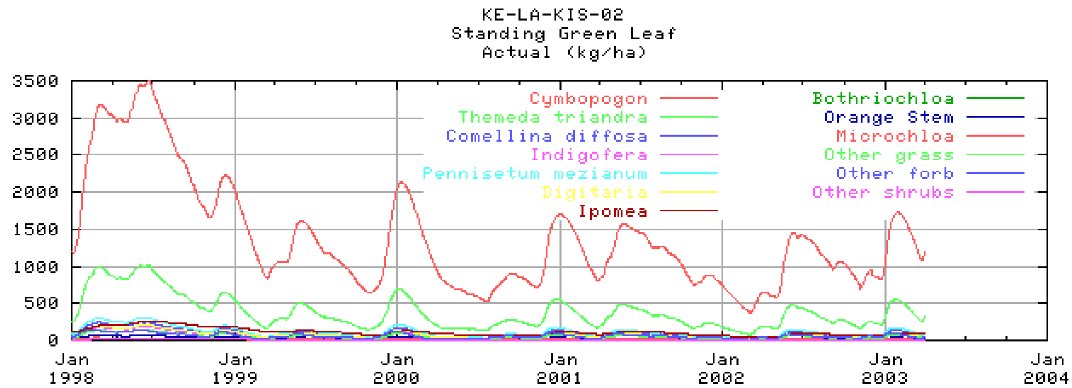



(b)

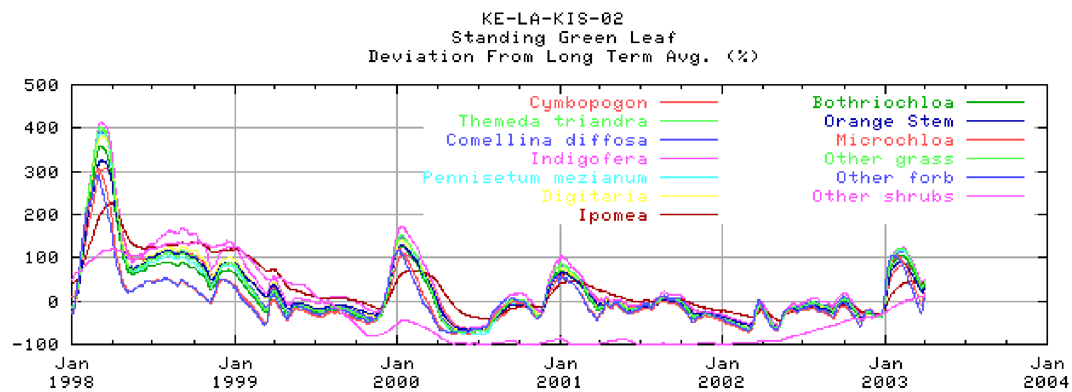



(c)

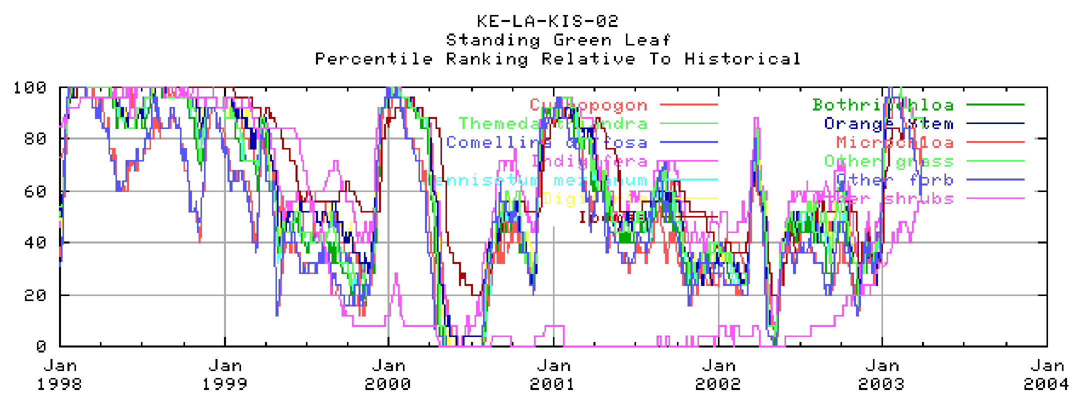
**Figure B-3. Daily growth rate graphs showing (a) actual growth rate (kg $ha^{-1}$ $day^{-1}$), (b) percent deviation of growth rate from the long term average, and (c) percentile ranking of growth rate by plant species.**




(a)

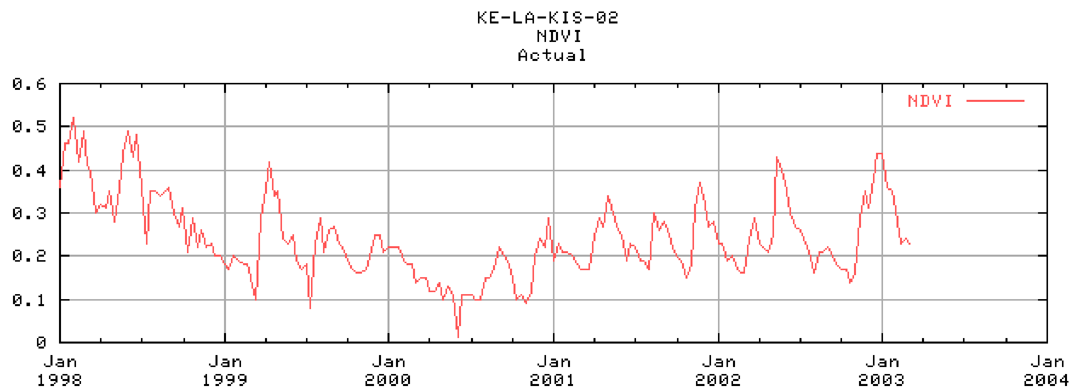



(b)

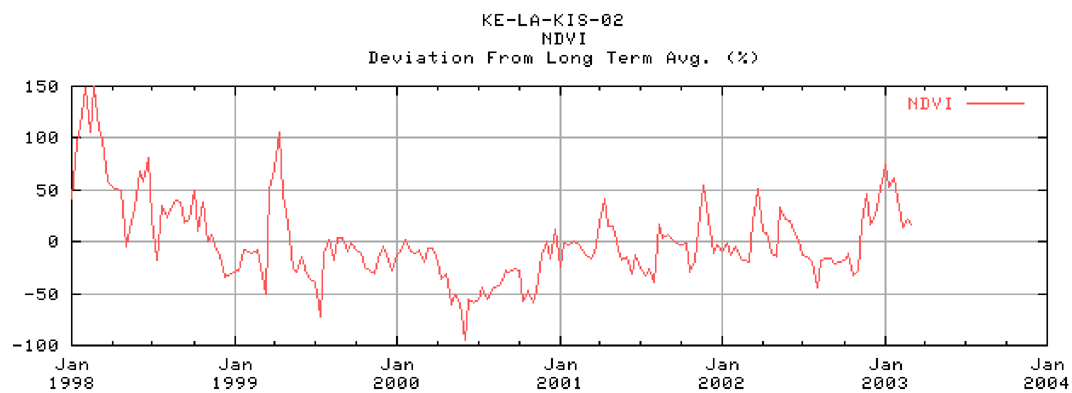



(c)

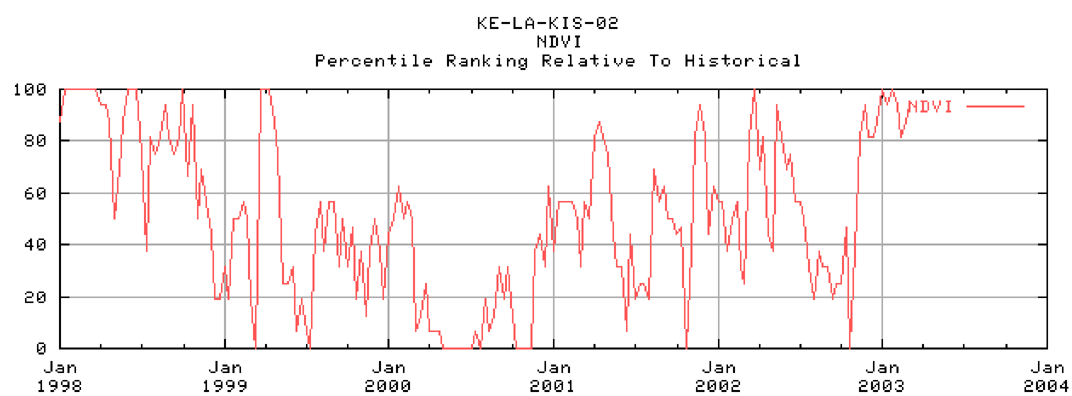
**Figure B-4. Green standing crop graphs showing (a) actual live standing crop (kg ha$^{-1}$), (b) percent deviation of green standing crop from the long term average, and (c) percentile ranking of green standing crop by plant species.**




**(a)**

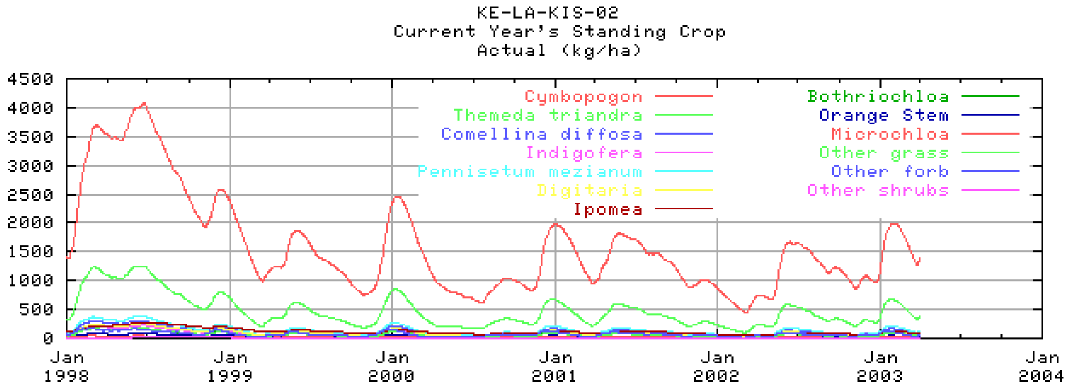



**(b)**

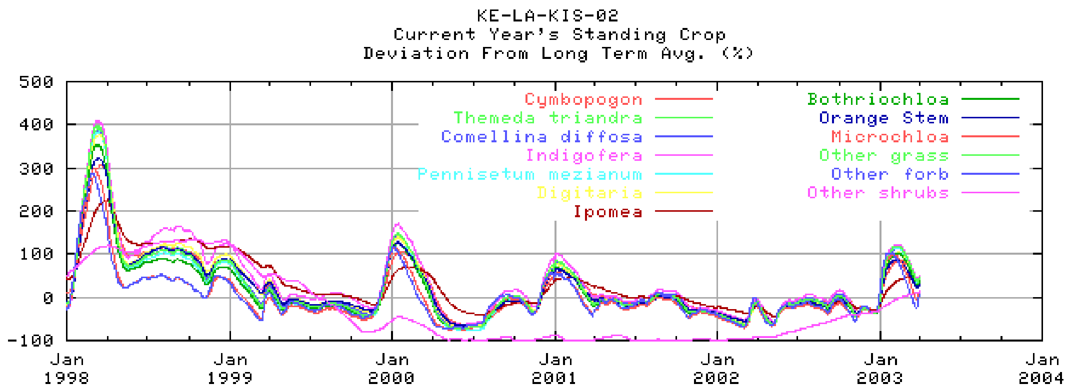



**(c)**

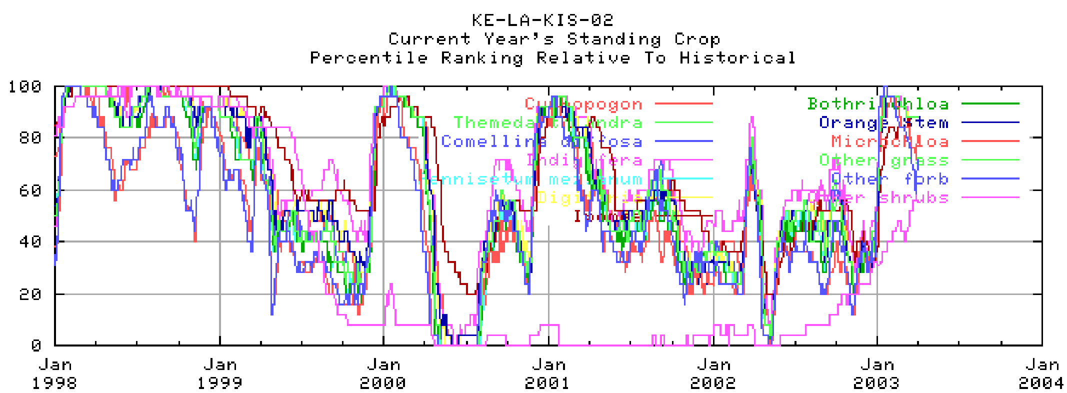
**Figure B-5. Normalized Difference Vegetation Index graphs showing (a) actual NDVI, (b) percent deviation of NDVI from long term average, and (c) percentile ranking of NDVI.**




(a)

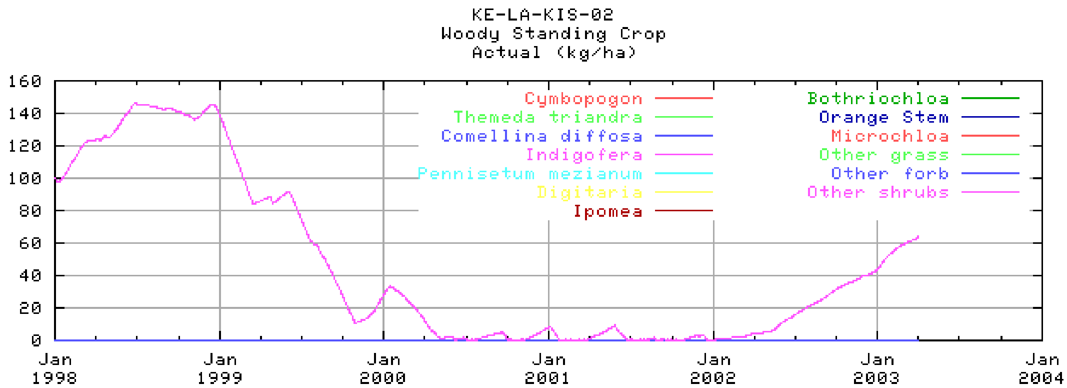



(b)

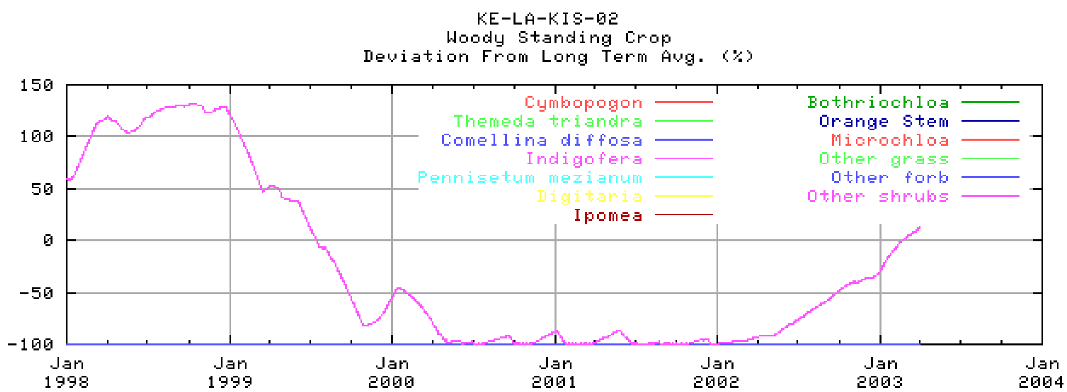



(c)

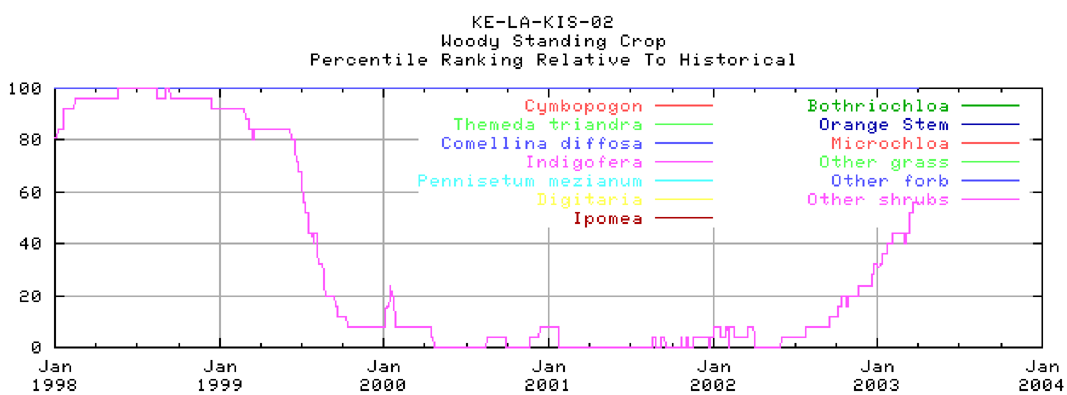
**Figure B-6. Current year's growth standing crop graphs showing (a) actual standing crop of current year's growth (kg ha$^{-1}$), (b) percent deviation of current year's standing crop from the long term average, and (c) percentile ranking of current year's growth standing crop by plant species.**




(a)




(b)

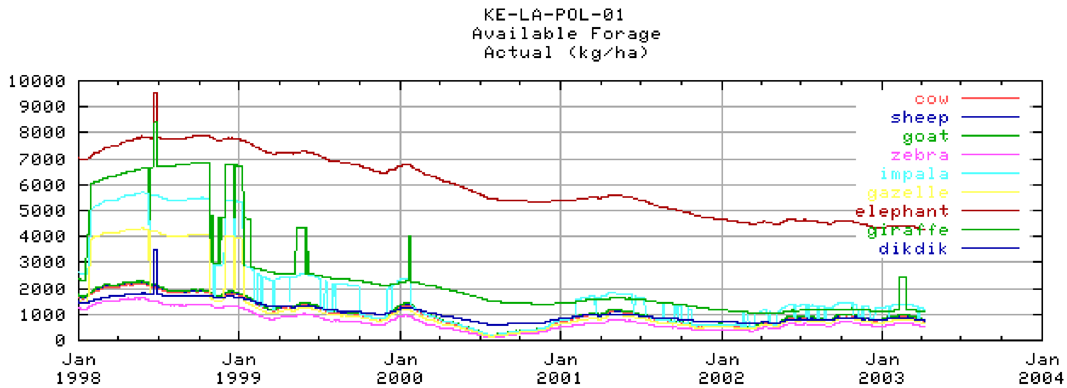



(c)

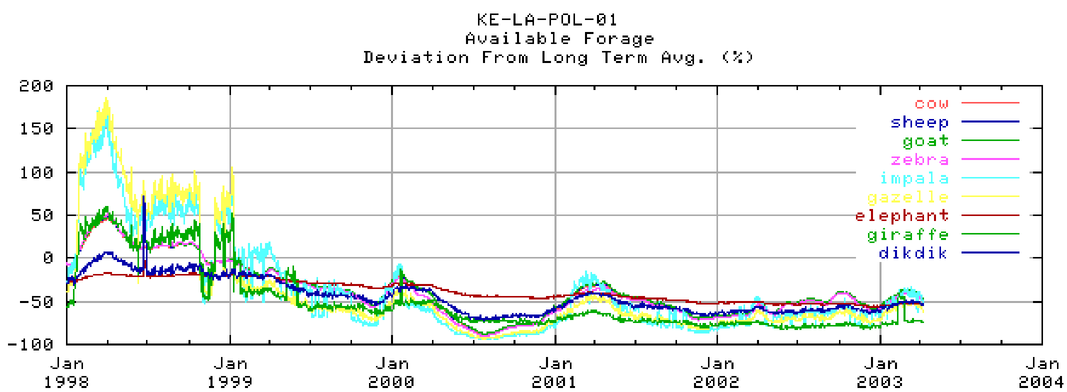
**Figure B-7. Woody standing crop graphs showing (a) actual woody standing crop (kg ha$^{-1}$), (b) percent deviation of woody standing crop from the long term average, and (c) percentile ranking of woody standing crop by plant species.**

# APPENDIX C

## FORAGE CONDITIONS AT FOUR MONITORING POINTS

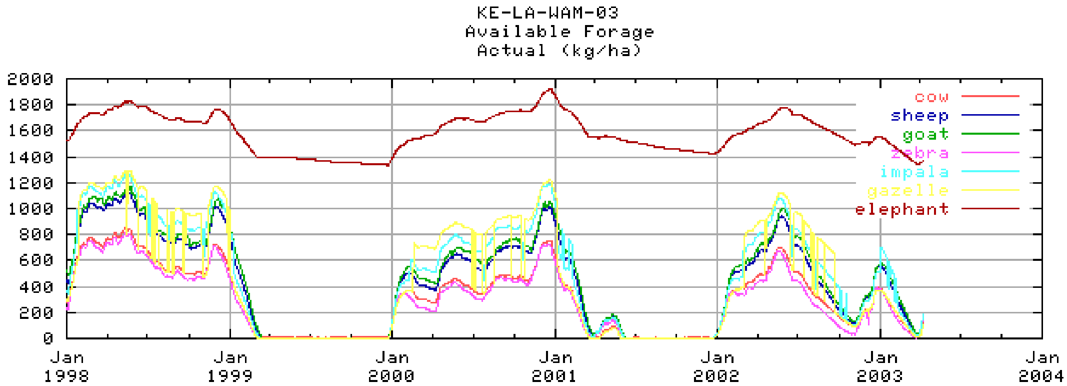



**(a)**

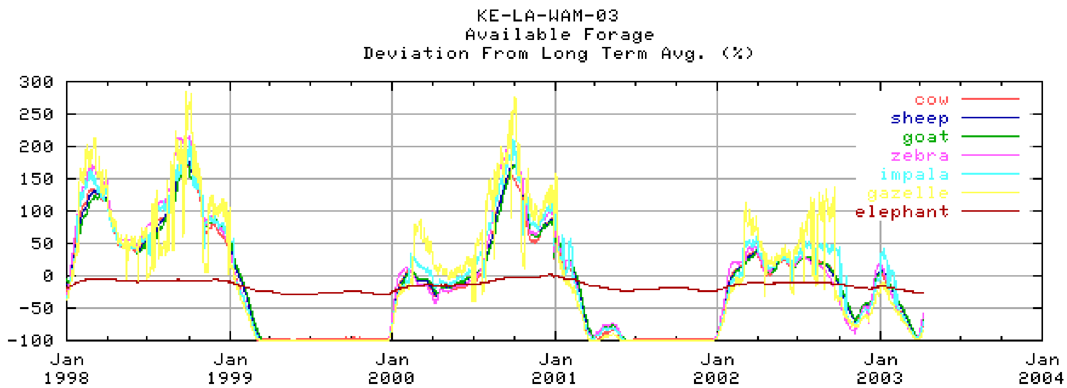



**(b)**

**Figure C-1. Forage availability at the Il Polei monitoring point. (a) Total forage available (kg $ha^{-1}$) and (b) Percent deviation from long-term average.**

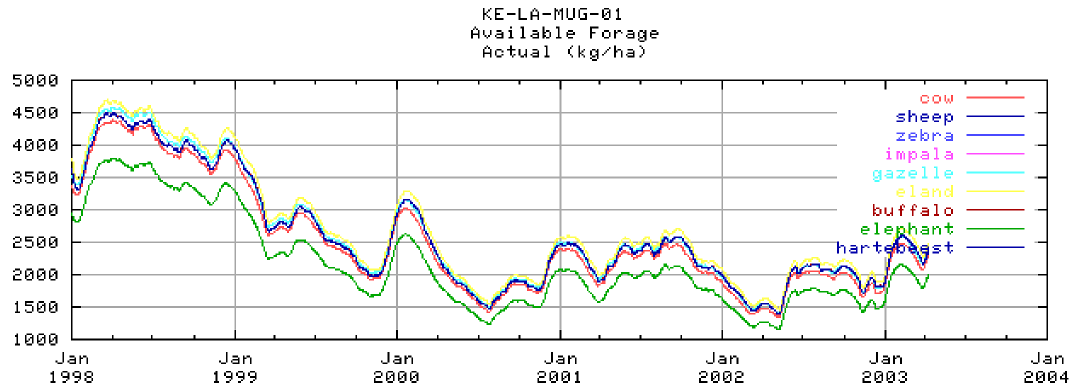



(a)

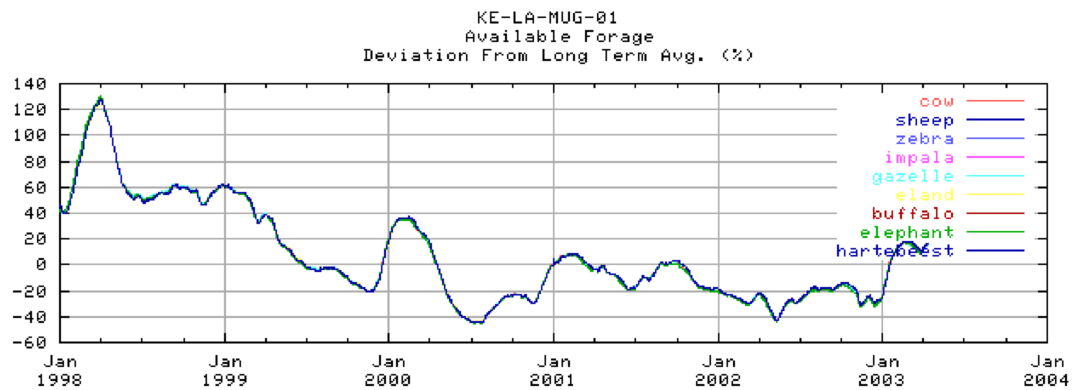



(b)

**Figure C-2. Forage availability at the Northern Wamba monitoring point. (a) Total forage available (kg $ha^{-1}$) and (b) Percent deviation from long-term average.**

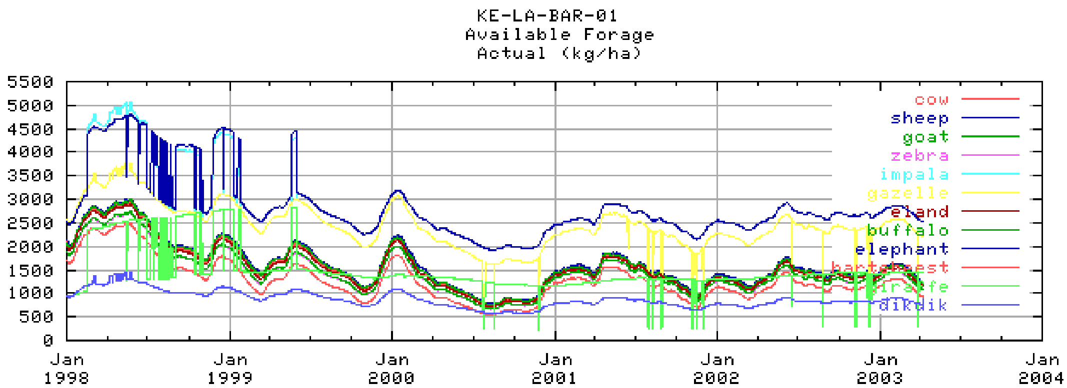



(a)

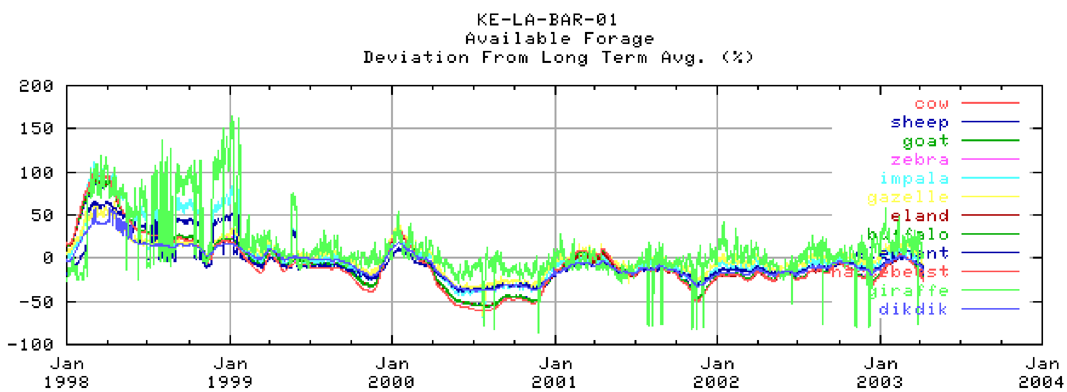



(b)

**Figure C-3. Forage availability at the Eastern Mugie monitoring point. (a) Total forage available (kg ha$^{-1}$) and (b) Percent deviation from long-term average.**




(a)




(b)

**Figure C-4. Forage availability at the Baraka monitoring point. (a) Total forage available (kg $ha^{-1}$) and (b) Percent deviation from long-term average.**

# APPENDIX D

# COMPOSITION OF PLANT COMMUNITIES AT MONITORING POINTS IN THE LAIKIPIA ZONE

**Table D. Species composition.**

| ID Number | Location | Species S = Shrub G = Grass F = Forb | Percent Maximum Expression* |
|---|---|---|---|
| KE-LA-BAR-01 | Baraka | Acacia nilotica (S) | 8.4 |
| | | Acacia drepanolobium (S) | 2.2 |
| | | Lantana trimera (S) | 1.8 |
| | | Balanites aegyptica (S) | 1 |
| | | Cynodon spp. (G) | 6 |
| | | Eragrostis tenuifolia (G) | 5 |
| | | Sporobolus sp. (G) | 3.4 |
| | | Pennisetum stramineum (G) | 2.4 |
| | | Bothriochloa insculpta (G) | 1.8 |
| | | Other grasses (G) | 3.4 |
| | | Indigofera sp. (F) | 3 |
| | | Hibiscus spp. (F) | 1 |
| | | Other forbs (F) | 4 |
| KE-LA-BOR-01 | Borana | Acacia drepanolobium (S) | 3.8 |
| | | Pennisetum stramineum (G) | 21 |
| | | Commelina africana (G) | 9.8 |
| | | Digitaria milanjiana (G) | 4 |
| | | Brachiaria lachnantha (G) | 2.2 |
| | | Themeda triandra (G) | 2 |
| | | Eragrostis tenuifolia (G) | 1.4 |
| | | Other grasses (G) | 1.6 |
| | | Indigofera sp. (F) | 4 |
| | | Portulaca spp. (F) | 1 |
| | | Other forbs (F) | 1.8 |

**Table D. Continued**

| ID Number | Location | Species | S = Shrub<br>G = Grass<br>F = Forb | Percent Maximum Expression* |
|---|---|---|---|---|
| KE-LA-JOG-01 | Ol Jogi | Acacia etbaica | (S) | 15.6 |
| | | Acacia drepanolobium | (S) | 4.4 |
| | | Acacia mellifera | (S) | 1.4 |
| | | Other shrubs | (S) | 0.8 |
| | | Digitaria milanjiana | (G) | 16.6 |
| | | Pennisetum stramineum | (G) | 2.8 |
| | | Themeda triandra | (G) | 1.8 |
| | | Pennisetum mezianum | (G) | 1.8 |
| | | Harpachne schimperi | (G) | 1.4 |
| | | Microchloa kunthii | (G) | 1.2 |
| | | Other grasses | (G) | 1.8 |
| | | Indigofera sp. | (F) | 7.2 |
| | | Other forbs | (F) | 9.2 |
| KE-LA-KAR-01 | El Karama | Acacia drepanolobium | (S) | 16.4 |
| | | Acacia seyal | (S) | 4.6 |
| | | Croton dichogamous | (S) | 2 |
| | | Barleria sp. | (S) | 2 |
| | | Acacia gerardii | (S) | 0.9 |
| | | Other shrubs | (S) | 1.4 |
| | | Cynodon spp. | (G) | 14.6 |
| | | Eragrostis tenuifolia | (G) | 3.4 |
| | | Aristida sp. | (G) | 3 |
| | | Commelina diffosa | (G) | 1.8 |
| | | Harpachne schimperi | (G) | 0.5 |
| | | Commelina africana | (G) | 1 |
| | | Digitaria milanjiana | (G) | 1 |
| | | Other grass | (G) | 3 |
| | | Aspilia sp. | (F) | 13.4 |
| | | Galium sp. | (F) | 4 |
| | | Indigofera sp. | (F) | 3.8 |
| | | Ipomea sp. | (F) | 2 |
| | | Other forbs | (F) | 4.6 |

**Table D. Continued**

| ID Number | Location | Species | S = Shrub<br>G = Grass<br>F = Forb | Percent Maximum Expression* |
|---|---|---|---|---|
| KE-LA-KIS-01 | Southern Kisima | Acacia drepanolobium (S) | | 6.8 |
| | | Cymbopogon pospischilii (G) | | 5.6 |
| | | Enneapogon sp. (G) | | 4.4 |
| | | Themeda triandra (G) | | 3 |
| | | Pennisetum mezianum (G) | | 2.6 |
| | | Pennisetum stramineum (G) | | 2 |
| | | Digitaria milanjiana (G) | | 2 |
| | | Setaria phleoides (G) | | 1.2 |
| | | Other grasses (G) | | 4 |
| | | Aspilia sp. (F) | | 6.6 |
| | | Monsonia sp. (F) | | 2.4 |
| | | Monechma sp. (F) | | 1.8 |
| | | Hibiscus spp. (F) | | 1.4 |
| | | Indigofera sp. (F) | | 1.2 |
| | | Other forbs (F) | | 9.2 |
| KE-LA-KIS-02 | Northern Kisima | Other shrubs (S) | | 1 |
| | | Cymbopogon pospischilii (G) | | 21.2 |
| | | Themeda triandra (G) | | 8.6 |
| | | Commelina diffosa (G) | | 4.8 |
| | | Pennisetum mezianum (G) | | 2.8 |
| | | Digitaria milanjiana (G) | | 2 |
| | | Bothriochloa insculpta (G) | | 1.4 |
| | | Microchloa kunthii (G) | | 1.2 |
| | | Other grasses (G) | | 1.4 |
| | | Indigofera sp. (F) | | 3.2 |
| | | Ipomea sp. (F) | | 1.6 |
| | | Unknown forb (F) | | 1.4 |
| | | Other forbs (F) | | 3.4 |

**Table D. Continued**

| ID Number | Location | Species S = Shrub G = Grass F = Forb | Percent Maximum Expression* |
|---|---|---|---|
| KE-LA-KOI-01 | Koija | Acacia mellifera (S) | 5.2 |
| | | Acacia etbaica (S) | 1.2 |
| | | Cadaba farinose (S) | 1 |
| | | Other shrubs (S) | 1.2 |
| | | Pennisetum stramineum (G) | 5.8 |
| | | Microchloa kunthii (G) | 1.8 |
| | | Commelina diffosa (G) | 1.4 |
| | | Other grasses (G) | 2.2 |
| | | Portulaca spp. (F) | 3.4 |
| | | Sansevieria sp. (F) | 1.8 |
| | | Ipomea sp. (F) | 1.2 |
| | | Aloe sp. (F) | 1.2 |
| | | Indigofera sp. (F) | 1.2 |
| | | Other forbs (F) | 4 |
| KE-LA-KUR-01 | Kurikuri | Acacia lahai (S) | 1 |
| | | Other shrubs (S) | 3.6 |
| | | Cynodon spp. (G) | 4.8 |
| | | Aristida sp. (G) | 2 |
| | | Microchloa kunthii (G) | 2 |
| | | Digitaria milanjiana (G) | 1.4 |
| | | Eragrostis tenuifolia (G) | 1.4 |
| | | Other grasses (G) | 2.4 |
| | | Helichrysium sp. (F) | 6.6 |
| | | Hibiscus spp. (F) | 4.4 |
| | | Gomphocarpus sp. (F) | 2.4 |
| | | Indigofera sp. (F) | 1.8 |
| | | Other forbs (F) | 2.8 |

**Table D. Continued**

| ID Number | Location | Species S = Shrub G = Grass F = Forb | Percent Maximum Expression* |
|---|---|---|---|
| KE-LA-LUO-01 | Luoniek | Euclea divinorum (S) | 21.8 |
| | | Croton dichogamous (S) | 5 |
| | | Psidia sp. (S) | 5 |
| | | Rhus natalensis (S) | 2.2 |
| | | Lantana trimera (S) | 2.2 |
| | | Grewia tenax (S) | 2.2 |
| | | Acacia gerardii (S) | 2 |
| | | Other shrubs (S) | 0.8 |
| | | Enteropogon sp. (G) | 2.2 |
| | | Eragrostis tenuifolia (G) | 1.4 |
| | | Microchloa kunthii (G) | 1.4 |
| | | Panicum sp. (G) | 1.2 |
| | | Themeda triandra (G) | 1.2 |
| | | Other grasses (G) | 3.8 |
| | | Monechma sp. (F) | 9.4 |
| | | Rhinacanthus ndorensis (F) | 4.6 |
| | | Oxalis latifolia (F) | 2.4 |
| | | Hibiscus spp. (F) | 2.2 |
| | | Other forbs (F) | 10 |
| KE-LA-MAI-01 | Ol Maisor | Acacia nilotica (S) | 6 |
| | | Acacia xanthophloea (S) | 3 |
| | | Scutia sp. (S) | 1.4 |
| | | Sida sp. (S) | 1.2 |
| | | Other shrubs (S) | 1.2 |
| | | Themeda triandra (G) | 17.2 |
| | | Cymbopogon pospischilii (G) | 12.8 |
| | | Microchloa kunthii (G) | 3.6 |
| | | Pennisetum mezianum (G) | 1.8 |
| | | Sporobolus sp. (G) | 1.2 |
| | | Other grasses (G) | 3.8 |
| | | Monsonia sp. (F) | 9.8 |
| | | Dischoriste radicans (F) | 8 |
| | | Justicia sp. (F) | 2.2 |
| | | Indigofera sp. (F) | 1 |
| | | Other forbs (F) | 3.4 |

**Table D. Continued**

| ID Number | Location | Species S = Shrub G = Grass F = Forb | Percent Maximum Expression* |
|---|---|---|---|
| KE-LA-MOR-01 | Morupusi | Acacia tortilis (S) | 10 |
| | | Acacia nilotica (S) | 5.2 |
| | | Ipomea hildebrandtii (S) | 4 |
| | | Barleria sp. (S) | 1 |
| | | Acacia etbaica (S) | 0.4 |
| | | Pennisetum stramineum (G) | 3.2 |
| | | Cynodon spp. (G) | 2.8 |
| | | Commelina africana (G) | 1.2 |
| | | Eragrostis tenuifolia (G) | 1 |
| | | Other grasses (G) | 1.4 |
| | | Justicia sp. (F) | 4.2 |
| | | Indigofera sp. (F) | 2.2 |
| | | Solanum incanum (F) | 1.6 |
| | | Portulaca spp. (F) | 1.2 |
| | | Hibiscus spp. (F) | 1.2 |
| | | Other forbs (F) | 1.6 |
| KE-LA-MOU-01 | Moundu-ni-meri | Carissa edulis (S) | 6.2 |
| | | Acacia gerardii (S) | 4.6 |
| | | Sida sp. (S) | 1.2 |
| | | Other shrubs (S) | 0.2 |
| | | Themeda triandra (G) | 7.1 |
| | | Microchloa kunthii (G) | 2.5 |
| | | Eragrostis tenuifolia (G) | 1.1 |
| | | Tragus sp. (G) | 1 |
| | | Bothriochloa insculpta (G) | 0.9 |
| | | Harpachne schimperi (G) | 0.6 |
| | | Aristida sp. (G) | 0.6 |
| | | Sporobolus sp. (G) | 0.5 |
| | | Bracharia lachnatha (G) | 0.5 |
| | | Setaria pallide-fusca (G) | 0.4 |
| | | Eragrostis racemosa (G) | 0.4 |
| | | Other grasses (G) | 0.5 |
| | | Ocimum sp. (F) | 2.2 |
| | | Indigofera sp. (F) | 1.8 |
| | | Rhinacanthus ndorensis (F) | 0.6 |
| | | Aspilia sp. (F) | 0.6 |
| | | Hypoxis obtuse (F) | 0.6 |
| | | Craterostigma sp. (F) | 0.6 |
| | | Monsonia sp. (F) | 0.5 |
| | | Dischoriste radicans (F) | 0.4 |
| | | Other forbs (F) | 1.5 |

**Table D. Continued**

| ID Number | Location | Species S = Shrub G = Grass F = Forb | Percent Maximum Expression* |
|---|---|---|---|
| KE-LA-MPA-01 | Northern Mpala | Acacia mellifera (S) | 18 |
| | | Acacia etbaica (S) | 5.6 |
| | | Boscia sp. (S) | 3 |
| | | Acacia brevispica (S) | 2.2 |
| | | Grewia tenax (S) | 1.8 |
| | | Barleria sp. (S) | 0.6 |
| | | Other shrubs (S) | 1 |
| | | Cynodon spp. (G) | 1.6 |
| | | Commelina diffosa (G) | 1.8 |
| | | Sporobolus sp. (G) | 0.7 |
| | | Enteropogon sp. (G) | 0.6 |
| | | Cyperus sp. (G) | 0.5 |
| | | Pennisetum stramineum (G) | 0.4 |
| | | Other grasses (G) | 0.8 |
| | | Aerva lanata (F) | 0.4 |
| | | Other forbs (F) | 1.6 |
| KE-LA-MPA-02 | Central Mpala | Acacia etbaica (S) | 29 |
| | | Acacia mellifera (S) | 5.4 |
| | | Acacia brevispica (S) | 1 |
| | | Digitaria milanjiana (G) | 1.8 |
| | | Microchloa kunthii (G) | 1 |
| | | Brachiaria lachnantha (G) | 0.4 |
| | | Other grasses (G) | 1.8 |
| | | Indigofera sp. (F) | 1.3 |
| | | Oxygonum sinuatum (F) | 0.6 |
| | | Sarcostemma sp. (F) | 0.6 |
| | | Rhinacanthus ndorensis (F) | 0.5 |
| | | Other forbs (F) | 1.4 |

**Table D. Continued**

| ID Number | Location | Species S = Shrub G = Grass F = Forb | Percent Maximum Expression* |
|---|---|---|---|
| KE-LA-MPA-03 | South Mpala | Acacia drepanolobium (S) | 8.2 |
| | | Other shrubs (S) | 0.8 |
| | | Commelina Africana (G) | 5.1 |
| | | Brachiaria lachnantha (G) | 4.3 |
| | | Pennisetum mezianum (G) | 2.4 |
| | | Setaria phleoides (G) | 2.2 |
| | | Eragrostis tenuifolia (G) | 1.3 |
| | | Themeda triandra (G) | 1.2 |
| | | Tragus sp. (G) | 0.5 |
| | | Cynodon spp. (G) | 0.5 |
| | | Bothriochloa insculpta (G) | 0.5 |
| | | Other grasses (G) | 0.3 |
| | | Dischoriste radicans (F) | 2.1 |
| | | Aeva lanata (F) | 1.8 |
| | | Indigofera sp. (F) | 1.7 |
| | | Oxygonum sinuatum (F) | 0.9 |
| | | Leucas sp. (F) | 0.8 |
| | | Aspilia sp. (F) | 0.6 |
| | | Helichrysium sp. (F) | 0.5 |
| | | Other forbs (F) | 1.7 |
| KE-LA-MUG-01 | Eastern Mugie | Pennisetum mezianum (G) | 22.2 |
| | | Commelina Africana (G) | 7.2 |
| | | Enneapogon sp. (G) | 1.4 |
| | | Pennisetum stramineum (G) | 1 |
| | | Other grasses (G) | 2 |
| | | Dischoriste radicans (F) | 2.4 |
| | | Other forbs (F) | 0.6 |

**Table D. Continued**

| ID Number | Location | Species | S = Shrub<br>G = Grass<br>F = Forb | Percent Maximum Expression* |
|---|---|---|---|---|
| KE-LA-MUG-02 | Western Mugie | Acacia nilotica (S) | | 12.8 |
| | | Barleria sp. (S) | | 1.4 |
| | | Lantana trimera (S) | | 1.2 |
| | | Other shrubs (S) | | 0.8 |
| | | Themeda triandra (G) | | 13.4 |
| | | Pennisetum stramineum (G) | | 4.4 |
| | | Bothriochloa insculpta (G) | | 4 |
| | | Digitaria milanjiana (G) | | 3.8 |
| | | Pennisetum mezianum (G) | | 3 |
| | | Cynodon spp. (G) | | 2 |
| | | Aristida sp. (G) | | 1 |
| | | Other grasses (G) | | 2.6 |
| | | Indigofera sp. (F) | | 4.2 |
| | | Anthericum cooperi (F) | | 2.8 |
| | | Felicia sp. (F) | | 2.4 |
| | | Ipomea sp. (F) | | 1.2 |
| | | Craterostigma pumilum (F) | | 1 |
| | | Other forbs (F) | | 4.6 |
| KE-LA-MUS-01 | Musul | Acacia etbaica (S) | | 9 |
| | | Lycium sp. (S) | | 1.4 |
| | | Cynodon spp. (G) | | 2.8 |
| | | Microchloa kunthii (G) | | 2.2 |
| | | Eragrostis tenuifolia (G) | | 2 |
| | | Pennisetum mezianum (G) | | 1.6 |
| | | Other grasses (G) | | 1.2 |
| | | Tribulus sp. (F) | | 4 |
| | | Justicia sp. (F) | | 1.4 |
| | | Indigofera sp. (F) | | 1 |
| | | Other forbs (F) | | 1.4 |

**Table D. Continued**

| ID Number | Location | Species S = Shrub G = Grass F = Forb | Percent Maximum Expression* |
|---|---|---|---|
| KE-LA-NAG-01 | Nagum | Acacia gerardii (S) | 4.2 |
| | | Croton dichogamous (S) | 1.9 |
| | | Euclea divinorum (S) | 1.5 |
| | | Barleria sp. (S) | 0.4 |
| | | Other shrubs (S) | 0.6 |
| | | Themeda triandra (G) | 7.6 |
| | | Cynodon spp. (G) | 6.1 |
| | | Eragrostis tenuifolia (G) | 2.9 |
| | | Microchloa kunthii (G) | 1.1 |
| | | Cymbopogon pospischilii (G) | 1.1 |
| | | Pennisetum mezianum (G) | 0.8 |
| | | Eragrostis racemosa (G) | 0.6 |
| | | Tragus sp. (G) | 0.5 |
| | | Pennisetum stramineum (G) | 0.4 |
| | | Heteropogon contortus (G) | 0.4 |
| | | Other grasses (G) | 1 |
| | | Indigofera sp. (F) | 2.5 |
| | | Monechma sp. (F) | 1.8 |
| | | Ipomea sp. (F) | 1.4 |
| | | Pentanisia sp. (F) | 1 |
| | | Solanum incanum (F) | 0.5 |
| | | Other forbs (F) | 3.3 |
| KE-LA-NAR-01 | Narok | Acacia xanthophloea (S) | 2.4 |
| | | Scutia sp. (S) | 0.9 |
| | | Psidia sp. (S) | 0.5 |
| | | Other shrubs (S) | 0.7 |
| | | Themeda triandra (G) | 3.9 |
| | | Microchloa kunthii (G) | 2.2 |
| | | Eragrostis tenuifolia (G) | 2 |
| | | Enteropogon sp. (G) | 1.9 |
| | | Bothriochloa insculpta (G) | 1.4 |
| | | Aristida sp. (G) | 0.6 |
| | | Tragus sp. (G) | 0.6 |
| | | Harpachne schimperi (G) | 0.5 |
| | | Other grasses (G) | 1.3 |
| | | Indigofera sp. (F) | 1.6 |
| | | Ocimum sp. (F) | 1.4 |
| | | Aspilia sp. (F) | 1.1 |
| | | Justicia sp. (F) | 0.5 |
| | | Other forbs (F) | 3.4 |

**Table D. Continued**

| ID Number | Location | Species S = Shrub G = Grass F = Forb | Percent Maximum Expression* |
|---|---|---|---|
| KE-LA-NGO-01 | Ngorare | Acacia drepanolobium (S) | 7.6 |
| | | Lantana trimera (S) | 1 |
| | | Other shrubs (S) | 0.8 |
| | | Themeda triandra (G) | 11.6 |
| | | Setaria phleoides (G) | 10.4 |
| | | Pennisetum stramineum (G) | 5 |
| | | Pennisetum mezianum (G) | 1.6 |
| | | Bothriochloa insculpta (G) | 1.4 |
| | | Brachiaria lachnantha (G) | 1 |
| | | Other grasses (G) | 1.8 |
| | | Aspilia sp. (F) | 3.2 |
| | | Indigofera sp. (F) | 1.6 |
| | | Rhinacanthus ndorensis (F) | 1.4 |
| | | Oxygonum sinuatum (F) | 1 |
| | | Other forbs (F) | 2.6 |
| KE-LA-PAD-01 | P and D | Barleria sp. (S) | 2.4 |
| | | Acacia nilotica (S) | 2.2 |
| | | Themeda triandra (G) | 7.4 |
| | | Microchloa kunthii (G) | 5.6 |
| | | Eragrostis tenuifolia (G) | 2.4 |
| | | Pennisetum mezianum (G) | 2 |
| | | Cynodon spp. (G) | 1.8 |
| | | Pennisetum stramineum (G) | 1.2 |
| | | Digitaria milanjiana (G) | 1 |
| | | Cymbopogon pospischilii (G) | 1 |
| | | Other grasses (G) | 1.4 |
| | | Monsonia sp. (F) | 1.6 |
| | | Indigofera sp. (F) | 2 |
| | | Other forbs (F) | 5.8 |

**Table D. Continued**

| ID Number | Location | Species | S = Shrub<br>G = Grass<br>F = Forb | Percent Maximum Expression* |
|---|---|---|---|---|
| KE-LA-PEJ-01 | Ol Pejeta | Acacia drepanolobium (S) | | 6.9 |
| | | Cynodon spp. (G) | | 17.3 |
| | | Pennisetum mezianum (G) | | 11.8 |
| | | Pennisetum stramineum(G) | | 7.8 |
| | | Themeda triandra (G) | | 6.7 |
| | | Other grasses (G) | | 0.4 |
| | | Dischoriste radicans (F) | | 2 |
| | | Indigofera sp. (F) | | 1.4 |
| | | Other forbs (F) | | 2.9 |
| KE-LA-POL-01 | Il Polei | Acacia mellifera (S) | | 12 |
| | | Acacia etbaica (S) | | 8 |
| | | Barleria sp. (S) | | 2.2 |
| | | Lycium sp. (S) | | 1.8 |
| | | Cynodon spp. (G) | | 6 |
| | | Microchloa kunthii (G) | | 2.4 |
| | | Digitaria milanjiana (G) | | 1 |
| | | Other grasses (G) | | 2.6 |
| | | Hibiscus spp. (F) | | 4 |
| | | Portulaca spp. (F) | | 2.8 |
| | | Chenopodium sp. (F) | | 1.8 |
| | | Indigofera sp. (F) | | 1 |
| | | Other forbs (F) | | 2.6 |

**Table D. Continued**

| ID Number | Location | Species S = Shrub G = Grass F = Forb | Percent Maximum Expression* |
|---|---|---|---|
| KE-LA-SEG-01 | Southern Segera | Acacia drepanolobium (S) | 13 |
| | | Euclea divinorum (S) | 8.8 |
| | | Carissa edulis (S) | 4 |
| | | Acacia tortilis (S) | 3.2 |
| | | Rhus natalensis (S) | 1 |
| | | Grewia tenax (S) | 1 |
| | | Pennisetum stramineum (G) | 10.8 |
| | | Pennisetum mezianum (G) | 6.4 |
| | | Cynodon spp. (G) | 4.8 |
| | | Commelina africana (G) | 1.4 |
| | | Brachiaria lachnantha (G) | 1.2 |
| | | Themeda triandra (G) | 1.2 |
| | | Other grasses (G) | 3 |
| | | Indigofera sp. (F) | 6 |
| | | Mollugo nudicaulis (F) | 4 |
| | | Rhinacanthus ndorensis (F) | 3.4 |
| | | Portulaca spp. (F) | 2.6 |
| | | Asparagus sp. (F) | 2.6 |
| | | Helichrysium sp. (F) | 2.4 |
| | | Other forbs (F) | 9 |
| KE-LA-SEG-02 | Northern Segera | Acacia drepanolobium (S) | 9 |
| | | Rhynchonsia sp. (S) | 1.4 |
| | | Themeda triandra (G) | 9.8 |
| | | Pennisetum stramineum (G) | 8.8 |
| | | Digitaria milanjiana (G) | 7.4 |
| | | Brachiaria lachnantha (G) | 6.2 |
| | | Pennisetum mezianum (G) | 3.4 |
| | | Commelina africana (G) | 2 |
| | | Commelina diffosa (G) | 1.2 |
| | | Setaria phleoides (G) | 1.2 |
| | | Cyperus sp. (G) | 1 |
| | | Other grasses (G) | 0.6 |
| | | Dischoriste radicans (F) | 11 |
| | | Aspilia sp. (F) | 5.4 |
| | | Leucas sp. (F) | 2.2 |
| | | Indigofera sp. (F) | 2 |
| | | Rhinacanthus ndorensis (F) | 1 |
| | | Other forbs (F) | 2.2 |

**Table D. Continued**

| ID Number | Location | Species | S = Shrub<br>G = Grass<br>F = Forb | Percent Maximum Expression* |
|---|---|---|---|---|
| KE-LA-TIE-01 | Tiemamut | Acacia nilotica | (S) | 5.8 |
| | | Acacia etbaica | (S) | 1.4 |
| | | Eragrostis tenuifolia | (G) | 2.8 |
| | | Cyperus sp. | (G) | 2.8 |
| | | Cynodon spp. | (G) | 2.2 |
| | | Digitaria milanjiana | (G) | 1.4 |
| | | Pennisetum mezianum | (G) | 1.2 |
| | | Other grasses | (G) | 1.2 |
| | | Indigofera sp. | (F) | 2.6 |
| | | Tribulus sp. | (F) | 2.4 |
| | | Solanum incanum | (F) | 1 |
| | | Other forbs | (F) | 2 |
| KE-LA-WAM-01 | Southern Wamba | Acacia etbaica | (S) | 4.8 |
| | | Other shrubs | (S) | 1 |
| | | Aristida sp. | (G) | 1 |
| | | Other grasses | (G) | 2 |
| | | Tribulus sp. | (F) | 6.3 |
| | | Oxygonum sinuatum | (F) | 6.3 |
| | | Bidens pilosa | (F) | 4 |
| | | Hibiscus spp. | (F) | 2.4 |
| | | Solanum incanum | (F) | 1.6 |
| | | Other forb | (F) | 2.2 |
| KE-LA-WAM-02 | Central Wamba | Ipomea hildebrandtii | (S) | 2.7 |
| | | Acacia lahai | (S) | 4.6 |
| | | Barleria sp. | (S) | 0.3 |
| | | Brachiaria lachnantha | (G) | 4.2 |
| | | Microchloa kunthii | (G) | 2.2 |
| | | Cynodon spp. | (G) | 2 |
| | | Bothriochloa insculpta | (G) | 1.3 |
| | | Other grasses | (G) | 1.1 |
| | | Tribulus sp. | (F) | 4.6 |
| | | Oxygonum sinuatum | (F) | 4.5 |
| | | Indigofera sp. | (F) | 2.8 |
| | | Bidens pilosa | (F) | 2.7 |
| | | Portulaca spp. | (F) | 2.1 |
| | | Solanum incanum | (F) | 1.7 |
| | | Hibiscus spp. | (F) | 1.4 |
| | | Asparagus sp. | (F) | 0.8 |
| | | Ipomea sp. | (F) | 0.7 |

**Table D. Continued**

| ID Number | Location | Species | S = Shrub<br>G = Grass<br>F = Forb | Percent Maximum Expression* |
|---|---|---|---|---|
| KE-LA-WAM-03 | Northern Wamba | Acacia lahai | (S) | 6 |
| | | Acacia tortilis | (S) | 1.6 |
| | | Cadaba farinose | (S) | 0.6 |
| | | Cyperus sp. | (G) | 1.8 |
| | | Bothrichloa insculpta | (G) | 1.6 |
| | | Other grasses | (G) | 1 |
| | | Tribulus sp. | (F) | 9.3 |
| | | Oxygonum sinuatum | (F) | 9.3 |
| | | Ocimum sp. | (F) | 9.4 |
| | | Solanum incanum | (F) | 1.8 |
| | | Indigofera sp. | (F) | 1.8 |
| | | Hibiscus spp. | (F) | 1.8 |
| | | Other forbs | (F) | 1 |

* Percent Maximum Expression = Percent effective canopy cover for shrubs, Percent basal cover for grasses, and Percent frequency for forbs.

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