

## Monitoring vegetation phenological stages using remote sensing data for pasture management in arid and semi-Arid lands of Kenya

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### Abstract

The objective of this study was to monitor grassland phenological stages in selected arid and semi-arid lands (ASALs) of Kenya, so as to provide information useful in pasture management. Five years of Normalized Difference Vegetation Index (NDVI) data from the VEGETATION instrument onboard SPOT were extracted over three ASAL districts. Extraction points were based on a land cover map that showed the location of grassland in the three districts. Piecewise logistic functions were applied on the NDVI data in order to identify phenological stages. RFE data were then used to relate the identified stages to rainfall using lagged correlation. Curves of the correlated lagged rainfall and NDVI from the determined phenological stages were plotted to compare their temporal patterns. Spatial patterns of length of the growth period were also assessed. Interannual phenological stages appeared to follow a clear growth – senescence temporal pattern. Two growth periods were identified in all the districts, consistent with known cycles of different grass and browse species in the areas. Peak growth was seen to occur during the short rains in Kajiado district and during the long rains in Baringo district. Growth in the two seasons was almost the same in Garissa district. Phenological stages were significantly correlated to different lags of rainfall, with response to a longer lag observed during the March to June growth period. Patterns of lagged rainfall were also found to be similar to those of NDVI at the different stages. The length of both growth periods showed spatially coherent patterns that signified the distribution of different pasture species. Given these results, logistic functions were able to model grassland phenological stages in the ASALs.

Key words: ASALs, logistic functions, NDVI, pasture, phenological stages

### Résumé

L'objectif de cette étude était de surveiller les stades phénologiques des prairies dans les zones arides sélectionnés et les terres semi-arides (ASALs) du Kenya, de manière à fournir des informations utiles dans la gestion des pâturages.

Cinq ans de différence normalisée d'indice de végétation (NDVI) les données à partir de l'instrument « VEGETATION à bord de SPOT » ont été extraites sur trois districts ASAL. Les points d'extraction ont été basés sur une carte de la couverture des terres qui a montré l'emplacement des prairies dans les trois districts. Par morceaux des fonctions logistiques ont été appliqués sur les données NDVI afin d'identifier les stades phénologiques. Les données de RFE ont ensuite été utilisées pour relier les étapes identifiées à l'aide des précipitations décalées de corrélation. Les courbes de corrélation décalée de la pluie et NDVI des étapes phénologiques déterminées ont été tracées et comparer aux modèles temporels. La répartition spatiale de la durée de la période de croissance a également été évaluée. Les stades phénologiques Interannuelle semblaient suivre une nette croissance - structure temporelle sénescence. Deux périodes de croissance ont été identifiées dans tous les districts, en conformité avec les cycles connus d'herbes et d'espèces différentes de naviguer dans les domaines. Le pic de croissance a été vu se produire au cours de la petite saison des pluies dans le district de Kajiado et pendant la longue saison des pluies dans le district de Baringo. La croissance dans les deux saisons était à peu près la même dans le district de Garissa. Les stades phénologiques étaient significativement corrélés aux différents décalages de précipitations, avec latence prolongée de la réponse observée au cours de la période de croissance de mars à juin. Du régime des pluies décalées se sont également révélées être similaires à ceux de l'NDVI dans les différentes étapes. La longueur des deux périodes de croissance a montré l'espace des modèles cohérents qui à expliquer la distribution des espèces pastorales différentes. Compte tenu de ces résultats, les fonctions logistiques ont été capables de modéliser des prairies dans les stades phénologiques ASALs.

Mots clés: ASALs, les fonctions logistiques, NDVI, les pâturages, les stades phénologiques

## **Background**

Arid and semi-arid lands (ASALs) comprising approximately over 80% of Kenya's landmass are fragile ecosystems that are characterized by low annual rainfall and high levels of evapotranspiration, which are climatic conditions that make it difficult to engage in rain-fed agriculture. A large percentage of the inhabitants therefore have livestock as their main, and sometimes only, source of livelihood. To feed their livestock, nomadic pastoralism is widely practiced in these areas as a system of pasture management, because it is thought to make

## Literature Summary

an optimal use of the available resources (Reid *et al.*, 2005). It is a system that relies on naturally occurring vegetation. The dynamics of natural vegetation is dependent on climate, making the pastoral communities vulnerable to changes in climate and subsequently, to changes in vegetation cycles. Close monitoring of natural vegetation growth cycles is therefore necessary so as to understand its occurrence, predict its future changes and hence help pastoral communities to cope with the changes. This study undertakes to identify key phenological stages of natural grasslands using NDVI data in selected ASALs of Kenya.

Altered rainfall amounts and seasonality, and increased levels of evapotranspiration due to climate change are expected to greatly affect vegetation productivity and species composition in the tropical rangelands (IPCC, 1997). This is indeed the type of land to which pastoral communities are relegated in order to feed their livestock (Reid *et al.*, 2005). Despite the risk that the pastoral communities are exposed to in the ASALs, there is emerging consensus that pastoral systems are best suited (as compared to other land use practises) for maintaining the integrity of rangelands (Reid *et al.*, 2005). However, benefits from pastoral systems can only be realized if there is sustainable management of the available natural resource. The growth cycles of natural grasslands, which are the source of forage for livestock in the ASALs, should thus be monitored so as to provide information for sustainable management strategies.

Vegetation growth cycles, in terms of phenological events, have been derived from NDVI data in a number of studies (Reed *et al.* 1994; White *et al.*, 1997; Myneni *et al.* 1998; Zhang *et al.*, 2003; Fisher and Mustard, 2007). In particular, Zhang *et al.* (2003) developed a method of identifying phenological stages by use of simple logistic functions of time fitted to NDVI data in a piecewise manner. This method was more adaptable to different vegetation types than other methods because it did not require an arbitrary assignment of thresholds. Further, piecewise fitting makes the method flexible enough to accommodate multiple growth cycles within any one year. The logistic functions approach was used in this study, but by applying the half-maximum method (Fisher and Mustard, 2007) to determine the phenological stages, rather than the rate of change of curvature method proposed by Zhang *et al.* (2003).

The aforementioned studies were based in regions of the world where vegetation phenological stages are more sensitive to seasonal changes in temperature. However, in the tropics and specifically the ASALs, rainfall is deemed as the dominant factor affecting vegetation greenness (Herrmann *et al.*, 2005). Moreover, the annual cycle of plant activity is expected to be altered by changes in precipitation patterns due to climate change in water limited systems (Badeck *et al.*, 2004). It was of interest, therefore, to find out if logistic functions performed as well in regions where rainfall is the limiting factor, hence providing a way for monitoring pasture growth cycles in the ASALs.

### **Study Description**

For each selected ASAL area, annual NDVI values were subdivided according to wet and dry seasons, i.e., January – February (dry), March – May (wet), June – September (dry) and October – December (wet). Logistic functions were then piecewise fitted to the subdivided NDVI data by determining different function parameters for each of the subdivision, using the Levenberg-Marquardt algorithm. The determined parameter values were then applied to the half-maximum (or half-minimum) method in order to identify transition NDVI values so as to discriminate the phenological stages in terms of onset of greenness and senescence. NDVI data from the identified phenological stages were then correlated with concurrent and lagged rainfall data so as to find out the relationship between phenological stages and rainfall. Additionally, this relationship was investigated by assessing the temporal patterns of the curves of correlated rainfall and NDVI from different phenological stages. Finally, the lengths of growth stages were computed from the difference between the time when the stages started and when they ended, after which the spatial patterns of the lengths of growth stages were assessed.

### **Research Application**

The resulting piecewise fitted logistic functions produced smoothed NDVI curves. These curves tended to follow the trend of the observed NDVI data. Although the logistic functions were fitted piecewise (i.e., a different function for a different period within a year) they were able to adequately model the annual NDVI time series.

The half-maximum (-minimum) method identified one transition point within each of the periods considered (January-February, March-May, June-September, and October-December). Phenological events identified by the transition NDVI values signified the onset of greenness or the start of growth (for the

transitions found between March – May and October-December) and the onset of senescence (for the transitions found between January-February and June-September).

Onset of greenness marked a point when there was persistent increase of NDVI values, meaning a corresponding increase in greenness and hence increased photosynthetic activity such as would be expected to occur in case of bud burst and leaf expansion (Richardson *et al.*, 2006). Conversely, at the onset of senescence NDVI values tended to decrease following loss of greenness by aging foliage and substantial leaf fall by the grasses. With the growth period clearly demarcated, the maximum point within the growth period could reasonably imply maturity of the grasslands.

Except in a few cases, the correlation coefficients between NDVI from the phenological stages and lagged rainfall up to 6 dekads prior were statistically significantly (Table 1). The year to year differences in lags and correlation coefficients was indicative of a response of the phenological stages to interannual rainfall variability.

**Table 1. Correlation coefficients between lagged rainfall and phenological stages for a selected ASAL district in Kenya (Garissa).**

Year	Senescence (Jan/Feb)	Growth (March)	Senescence (June/July)	Growth (November/ December)
1999		lag6 0.22	lag4 0.57	lag1 0.69
2000	lag6 0.63	lag6 0.60	lag2 0.37	lag2 0.91
2001	lag2 0.84	lag1 0.38	lag1 0.73	lag6 0.69
2002	lag4 0.67	lag4 0.61	lag9 0.27	lag6 0.40
2003	lag8 0.69	lag0 0.47	lag4 0.63	lag9 0.73

The lagged relationships showed that growth in March to June was likely influenced by rainfall in October to December, suggesting some dependence of this growing period to that in the November to January period. This follows from the fact that rainfall in October to December influences seed production during November to January period and enhances pasture reseeding in the March to May period. If the short rains allowed a good amount of seed production, then the response to the long rains would not only be rapid but there would also be more

germination occurring, which would translate into higher values of NDVI.

Lagged rainfall that had the highest positive correlation with NDVI values of a phenological stage appeared to have a temporal pattern similar to that of NDVI for that phenological stage. These patterns were observed over the five year study period across all the study districts, hence supporting the identified phenological periods. The patterns were such that a peak in the rainfall curve had a corresponding peak in the NDVI curve. This observation agrees with Camberlin *et al.* (2007) who stated that in semi-arid areas temporal and spatial variations of NDVI are unequivocally controlled by rainfall.

The length of growth periods seemed to gradually change from one part of each district to another. These identified patterns can be indicative of the possible direction of pastoralist migration following availability of pasture; for example, north to south in Garissa district. The areas where there is likely to be a concentration of livestock due to pasture can also be deduced and a possible alert for conflicts over the use of the resource.

## **Recommendation**

The information generated from this study can be used by policymakers in coming up with strategies for aiding pastoral communities to delineate and preserve pasture. This is especially because setting aside pasture for dry periods is already recognized as an important coping method for these communities (IIRR, 2005). The pastoral communities themselves can also take up the information on spatial distribution of the length of growth periods to better manage pasture in the ASALs. Another desirable quality of this information would be in the formulation of a spatial plan for alleviating land degradation by allowing known areas to rest and regenerate. The results, when used together with climate information, can be easily incorporated into guidelines for pasture management.

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