Egeru *et al. Pastoralism: Research, Policy and Practice* (2015) 5:19
DOI 10.1186/s13570-015-0037-6

Pastoralism
a SpringerOpen Journal

RESEARCH Open Access

Drivers of forage availability: An integration of remote sensing and traditional ecological knowledge in Karamoja sub-region, Uganda

Anthony Egeru[1*], Oliver Wasonga[2], John Mburu[3], Elhadi Yazan[1], Mwanjalolo G J Majaliwa[4], Laban MacOpiyo[1] and Yazidhi Bamutaze[4]

Abstract

Low-input pastoral production systems provide up to 90 % of livestock and livestock products consumed in Uganda. However, pastoral communities are increasingly faced with the challenge of meeting their livestock needs in terms of forage, a situation exacerbated by climatic variability. The study identified the patterns of forage availability and quality, compared perceived patterns of forage availability with normalized difference vegetation index (NDVI) and determined drivers of forage availability in Karamoja sub-region. Over a 12-month period, 75.3 % of the respondents perceived forage to be sufficiently available with differentiated availability in the livelihood zones and between livestock species (goats, sheep, cattle, donkeys and camels). A similar pattern was observed with regard to perceived forage quality. A significant relationship between perceived forage availability and long-term mean monthly NDVI dynamics was observed. A lag time of 2.9 months existed between rainfall and vegetation response peak periods. Mean monthly rainfall pattern was found to be correlated with perceived forage availability. The length of residence by a livestock keeper, frequency of grazing, number of kraals, presence of governing rules, and presence of conflicts and knowledge of pasture locations, restricted movement and ease of access to grazing areas significantly ($P \leq 0.05$) were the major perceived drivers of forage availability. Therefore, we find that pastoral communities in Karamoja have detailed traditional ecological knowledge of forage status and their perceived determinants. There is a need to conduct nutritional analysis of key forage species available in the different livelihood zones. Finally, there is a need to constantly monitor socio-political conditions that have potential of creating 'artificial' forage shortage in the sub-region.

Keywords: Dynamics; Livestock species; Pastoral; Semi-arid; Karamoja, Uganda

Background

Low-input livestock production systems strongly depend on natural grazing pastures (Hesse and Cotula 2006; Kerven and Behnke 2011). In such systems, vegetation growth and management are of paramount importance because the availability of pasture and water are important in grazing and grazing management (Rugadya et al. 2005; Butt 2010; Butt and Turner 2012; Namgay et al. 2013). For example, the availability of pastures in space and time influences power relations, access rights, societal co-existence and the existence of either peace or conflict (Gomes 2006; Senay et al. 2013). In the event of shortage during the grazing calendar, livestock is negatively affected (Rahman 2002). Thus, the presence and/or absence of a crisis in any given year is closely linked to water and pasture availability patterns. The catastrophic emergency situations often observed in semi-arid areas of East Africa are attributable to negative deviations in the availability of water and pasture resources (Hailegiorgis et al. 2010; Njiru 2012).

Different perspectives have been fronted to explain the availability of pastures in pastoral systems. For example, changes in policies on pasture use in the Chinese Tibet led to increased fencing of pastures as well as a shift in rangeland management goals (Xu et al. 2009). Such actions influence access to pastures and provide insights into availability patterns in the event of constrained access. Further, government interventions in the trans-Himalayan region of northern India to develop a market-based economy led to

---

* Correspondence: egeru81@gmail.com
[1]Department of Land Resource Management and Agricultural Technology, University of Nairobi, P.O. Box 29053-00625, Nairobi, Kenya
Full list of author information is available at the end of the article

higher preference for goats. This led to a shift in livestock herd composition with a relative increase in goats compared to traditionally herded sheep (Singh et al. 2013). Goats are however known for their generalist feeding habits and high forage consumption; this led to pasture degradation and reduced availability (Animut et al. 2005; Singh et al. 2013). In addition, prolonged livestock movement into grazing lands and watering around settled areas have been observed to decrease pasture availability among the Baringo pastoralists of Kenya (Kaimba et al. 2011). Further, increased stocking density caused by influx of migrant livestock led to forage shortage in the Kitengela plains of Kenya (Nkedianye et al. 2011). On the other hand, shifts in land use from livestock grazing to crop farming and settlements have a two-prong influence: first, vegetation cover and diversity is reduced, and second, seasonal livestock movements vital for the exploitation of spatio-temporally distributed rangeland resources are disrupted (Byakagaba 2005; Sulieman and Ahmed 2013). Consequently, the resulting forage unavailability in space and time leads to negative repercussions among others: livestock deaths, conflicts and loss of pastoral resilience (Kaimba et al. 2011; Nkedianye et al. 2011).

The influence of climate-rainfall has on forage patterns in pastoral areas has been well documented with several studies (e.g. Anyamba and Tucker 2005; Fensham et al. 2005; Oba 2012; Sulieman and Elagib 2012) showing a close connection between rainfall and vegetation patterns. The Karamoja rangelands, for example, are observed to be rich in pasture with a diversity of plant species compared to the Afar and Orma rangelands of Ethiopia (Oba 2012). Intermittent drought events regularly cause shortages in range resources in semi-arid lands of East Africa (Kaimba et al. 2011; Njiru 2012). Pastoralists in such areas have unique strategies to circumvent the oscillations in forage resources, for example, they exercise transhumant grazing movements between lowlands and marshes and mountains during wet and dry seasons, respectively (Oba 2012). Pastoralists also exercise agistment (reciprocal insurance), an alternative strategy that incurs low capital costs and is flexible to changing spatial rainfall patterns. The arrangement is facilitated through a network of kin, friends, friends of friends, relatives, business partners and adversaries; these interactions match pastoralists who have a shortage of forage to pastoralists who have an excess (McAllister et al. 2006; Dixit et al. 2013). Several researchers (e.g. Hill et al. 2004; Tubiello et al. 2007; Cullen et al. 2009; Seaquist et al. 2009) have examined the effect climate has on pastures from a biophysical perspective, and as a result, less attention has been given to the integration of local knowledge in such studies. The outcome of such investigations has been prescriptive policies and 'system blind' interventions that have created even worse-off problems (Burnaby and Gibson 2003; Kratli 2010). In Karamoja, for example, there has been a setting of abstract interventions that focus on 'technical' targets with little connection to the pastoral production system and the societies of the producers on the ground (Kratli 2010). Further, several agencies including the government of Uganda have ended focusing on the delivery of 'hardware' (borehole construction, pans and dams) with limited attention given to 'software' (traditional institutions and management arrangements) (Stites et al. 2007; Kratli 2010; Czuba 2011).

Pastoralists have well-developed 'software' systems that are embodied in a set of experiences and in-depth knowledge facets that have been used for generations to manage rangelands (Fratkin 1997; Bolling and Schulte 1999). Thus, pastoralists and the rangelands are mutually interrelated through a knowledge milieu held in community-based knowledge (Angassa et al. 2012); this knowledge system is widely referred to as traditional ecological knowledge (TEK) (Reid et al. 2002). In its broad sense, TEK refers to people's cumulative body of nonscientific knowledge, beliefs and practice about local ecosystems and their management that evolves through social learning and adaptive processes, which is supported by customary institutions and handed down through generations by cultural transmission (Huntington 2000; Reid et al. 2002; Angassa et al. 2012; Ruiz-Mallen and Corbera 2013). For the quest to find environmentally sound and culturally acceptable natural resource management practices, researchers have turned to community-based knowledge - TEK (Angassa et al. 2012). This is because local communities are repositories of local environmental knowledge; they are often aware of the environmental changes taking place in their surroundings (Sulieman et al. 2012). Thus, they hold holistic knowledge of the environmental context including the following: plant species composition, palatability to grazing animals and vegetation dynamics (Bolling and Schulte 1999; Oba and Kaitira 2006; Reed et al. 2008). Considerable benefits exist when this group is integrated in scientific research; for example, traditional ecological knowledge leads to expanded spatial and temporal scales of documented scientific knowledge (Gagon and Berteaux 2009). Further, traditional ecological knowledge is crucial in strengthening local institutions for sustainable use of indigenous vegetation and conservation (Angassa et al. 2012). Researchers have generally not fared well with incorporating local knowledge in their research as well as addressing how such knowledge may be applied (Oba 2012). Stringer and Reed (2007) observed that when local knowledge is incorporated in policies and interventions, communities are in a better position to monitor and respond to the existing and impending challenges of degradation and environmental change.

The integration of TEK has found a strong hold in rangeland management due to its ability to provide effective and efficient livestock management decisions when combined with scientific data (Kendrick and Manseau 2008; O'Flaherty et al. 2008). Among the pastoralists, this knowledge is finegrained and complex (Bolling and Schulte 1999) but measurable and comparable across communities (Oba 2012). It is possible to combine remote sensing data such as normalized difference vegetation index (NDVI) and TEK data to generate relevant information necessary for ecosystem management. For example, Polfus et al. (2014) integrated TEK and NDVI; their resource selection function (RSF) models showed a high spatial agreement. Because pastoralists have in-depth knowledge of the ecosystem functioning and the wider landscape conditions, we integrated the Karamojong pastoralists in assessing perceived forage availability and drivers of forage availability in Karamoja sub-region. Therefore, this study (i) identified the patterns of forage availability using TEK, (ii) compared the emerging patterns of forage availability with remote sensing NDVI, (iii) determined the perceived drivers of forage availability and (iv) determined the joint effect of rainfall and temperature on NDVI as a proxy of forage availability in Karamoja sub-region.

The study area

This study was conducted in Karamoja sub-region located in north eastern Uganda (Figure 1). Karamoja is part of the 'cattle corridor' of Uganda and epitomizes the semi-arid conditions in the country. Over time, the sub-region has been presented as an exceptional situation area, disconnected from 'the rest of Uganda' in cultural and economic terms, and desperately needing to 'catch up' (Kratli 2010). The sub-region receives variable rainfall in the range of 400 to 800 mm though some areas around the highlands (Mounts Moroto, Kadam, and Iriiri and the Labwor ranges) may receive up to 1,000 mm per annum (Mubiru 2010; Anderson and Robinson 2009). Karamoja's rainfall regime is unimodal with a peak period occurring between April and August (Mubiru et al. 2012). The rainfall is episodic in occurrence, alternating with a prolonged dry season and considerable variation from year to year in total annual rainfall. Further, rainfall is not well distributed (Musiitwa and Komutunga 2001; Mubiru et al. 2012). As

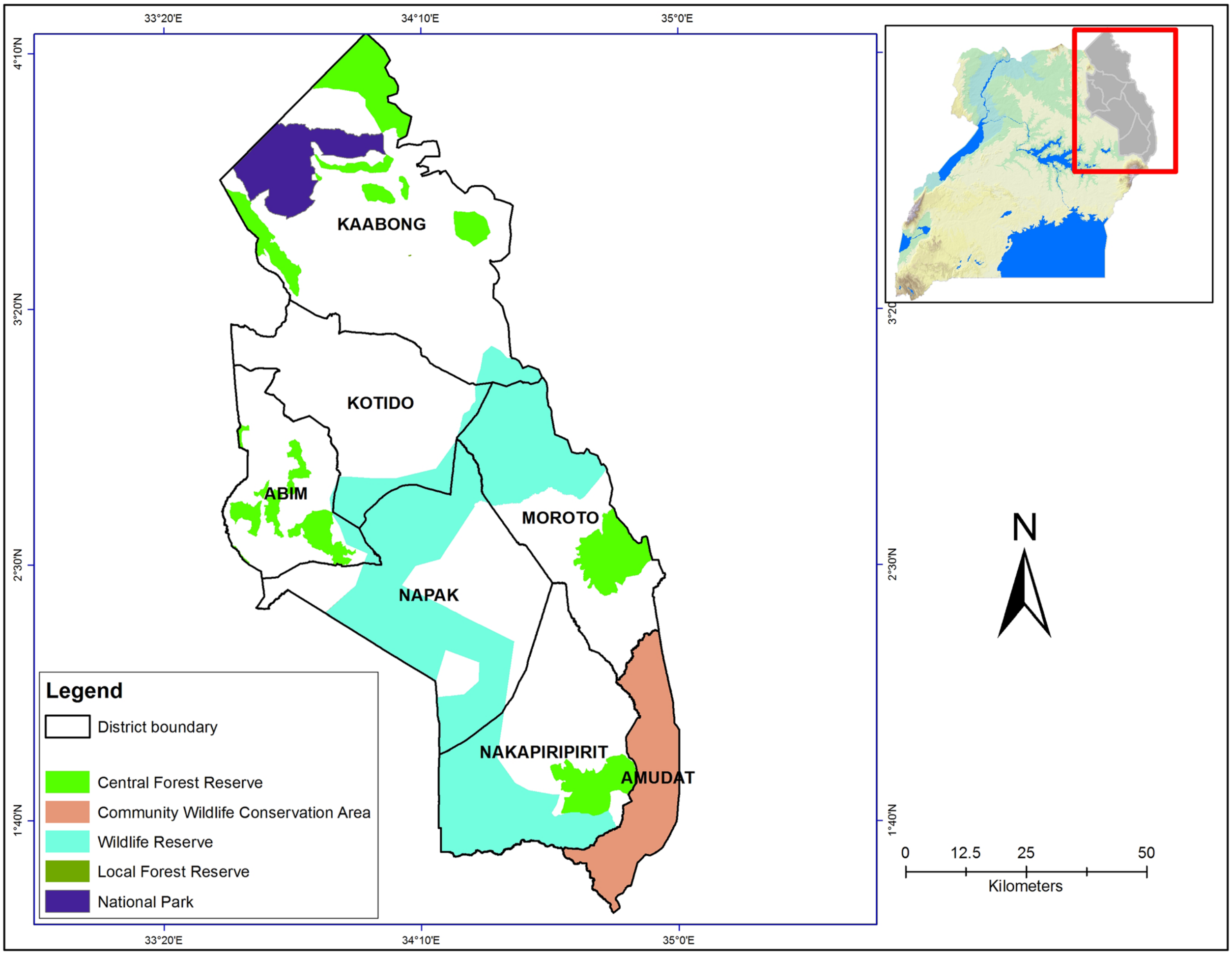


Figure 1 Location of Karamoja sub-region (source: from author, 2014)

such, there is a co-existence of pastoral and agro-pastoral practices in the sub-region. The sedentary communities (e.g. Tepeth, Ik, Kadam, Nyangia and Mening) mainly in the highland areas have a preference for crop agriculture. On the other hand, a transhumant life is exercised by the Jie, Pokot, Bokora, Pian and Matheniko in the plains (Nalule 2010). They move their animals to optimize forage use by grazing both pasture and browse, within the framework of drinking water availability and security of the territory. Thus, unless they are guaranteed of security, pasture management is a secondary consideration to family survival and retained ownership of the herd/flock. The grazing lands consist of savanna grasslands characterized by widely spaced trees with open tree canopies. These open tree canopies allow growth of understory herbaceous biomass consisting mainly of C4 grasses (Nalule 2010). However, these indigenous tropical grasses produce at a level of 10 % to 15 % of the dry matter potential exhibited by the same grasses on well-managed farms in similar climate regimes (Anderson and Robinson 2009).

Karamoja is characterized by black clay and dark grey clay soils that are low in organic matter but with medium moisture storage capacity (Musiitwa and Komutunga 2001). Earlier soil productivity classification showed that most of the region's soils are of low productivity with a few areas occurring in the medium productivity regime (Mubiru et al. 2012). Considering the variability of rainfall, low to medium soil productivity and low to no-input additions, Levine (2010) observed that settled dryland crop farming in Karamoja exposes people to greater risks from natural calamities than pastoral livelihood strategies. Further, Levine (2010) observed that in Karamoja, support to pastoral and agro-pastoral livelihoods represents a far better investment in disaster risk reduction than support to settled crop farming systems. In practice, this is not happening in the sub-region. Rather, more support is being channelled into settled crop farming through distribution of seeds and farm implements. Earlier observations by Barker in the 1970s about the pastoral production system in Karamoja urged for understanding of the pastoral production system 'as a working model' rather than dismissing it in principle as 'a practice' that needs to be replaced (Kratli 2010).

Materials and methods

Data and data sources

Identification of perceived forage availability pattern and quality

In order to identify perceived pattern of forage availability and quality, data was obtained using semi-structured questionnaires administered to 198 respondents in three of the seven districts of Karamoja sub-region. Districts were selected taking into consideration the livelihood zones in the sub-region with specific focus on the pastoral and agro-pastoral zones as well as northern and southern Karamoja representation. Thus, Kotido district represented the agro-pastoral and northern Karamoja zone, Moroto district represented the pastoral zone (Rupa and Katikekile sub-counties) and Napak district represented the agricultural and agro-pastoral zones of central to southern Karamoja (Lotome sub-county has close proximity to Lorengduat and Nabilatuk in southern Karamoja). Questionnaires were proportionately allocated to the three districts; thus, 75 households were interviewed in Napak district, 44 in Moroto district and 79 in Kotido district. Data was collected from two sub-counties and two parishes in each district, thus Lotome and Lokopo in Napak district, Rupa and Katikekile in Moroto district and Nakapelimoru and Panyangara in Kotido district. Twelve parishes including Moruongor, Akalale, Lorikitae, Namujit, Kalokengel, Lia, Mogoth, Watakau, Potoongor, Rikitae and Loposa were utilized in data collection. The survey team collected data from 53 villages in the sub-region. Respondents were asked to assess forage availability by month across the year using their long-held traditional ecological knowledge. Similarly, respondents were asked to assess perceived quality of available forages using a Likert scale (1 = excellent, 2 = very good, 3 = good, 4 = fair and 5 = poor). To help respondents arrive at a judgment of perceived forage quality, we jointly developed a list of indicators with the elders, youth and herders during the pre-test. These included the following: forage palatability, digestibility, animal health and size of faecal pats deposited by animals when grazing.

It is important to note that the use of rapid assessments, survey data and integration of traditional ecological knowledge in ecological assessment is not a new practice. Several studies have integrated traditional ecological knowledge and ecological methods in understanding how management practices affect indigenous vegetation as well as understanding the effect of grazing pressure on herbaceous cover (e.g. Bolling and Schulte 1999; Oba and Kotile 2001; Angassa et al. 2012; Kgosikoma et al. 2012). Further, using surveys in data collection for understanding ecological system changes is rewarding, due to the detail of resource trend information (White et al. 2005; Jones et al. 2008).

Normalized difference vegetation index data

In order to compare perceived patterns of forage availability with NDVI, a time series of National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR, 1981 to 2008) and the Moderate Resolution Imaging Spectroradiometer normalized difference vegetation index (MODIS NDVI, 2000 to 2013) were obtained. The NOAA-AVHRR NDVI-g (approximately 10 days, 36/year) monthly data were obtained from the Famine Early Warning Systems Network (FEWS NET) Africa portal. On the other hand, MODIS NDVI data was obtained from Global Agriculture Monitoring (GLAM) Project. The FEWS NET NDVI data originates from the Global Inventory Modeling and Mapping Studies (GIMMS) group at National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center (Tucker et al. 2005). The NOAA-AVHRR time series data is of 8 km spatial resolution and has considerable processing conducted on it including: residual sensor degradation and sensor intercalibration differences, effects of changing solar zenith and viewing angles, volcanic aerosols, atmospheric water vapour and cloud cover corrected (Pinzon et al. 2005). On the other hand, MODIS NDVI is produced from atmospherically corrected surface-gridded reflectance with per pixel quality assurance information that is cloud filtered (Huete et al. 2011). This study utilized a 250-m spatial resolution and 16-day temporal resolution MODIS NDVI imagery. Before, their joint use, a correlation analysis was conducted between NOAA-AVHRR and MODIS NDVI time series data of the nine overlapping years (2000 to 2009) to ascertain their consistency. This allowed us to use MODIS NDVI to fill the data gap for 2010 for AVHRR NDVI data is unavailable. A significant ($R^2 = 0.972$) correlation between the NOAA-AVHRR and MODIS NDVI was obtained. We resampled all MODIS NDVI imagery to NOAA-AVHRR spatial resolution.

Climate data

In order to determine the joint effect of rainfall and temperature on vegetation patterns using NDVI as a proxy for forage availability, rainfall and temperature time series data was obtained from the National Oceanic and Atmospheric Administration (NOAA) (1979 to 2009) provided by the National Centers for Environmental Prediction (NCEP). This is part of the global climate data provided by NOAA through the Climate Forecast System Reanalysis (CFSR) programme. The CFSR reanalysis data is provided on a global atmosphere resolution of approximately 38 km with 64 levels extending from the surface to 0.26 hPa. CFSR data is a result of an integration of satellite observations with available conventional-historical and operational archives of observations produced by meteorological research centres around the world. The satellite observations were utilized in radiance form and were bias corrected with 'spin up' runs at full resolution (Saha et al. 2010). The data is available for the past 31 years (1979 to 2009) with the reanalysis programme currently underway for 2010 and beyond. NOAA-NCEP data was preferred due to its consistency and the dense coverage of virtual stations in the sub-region. Sixteen stations were identified in the Karamoja sub-region (Figure 2). The NOAA-NCEP stations have a good spatial distribution (Figure 2), making it useful in providing completeness of the climate situation in Karamoja. It was not possible to obtain data past the 2010 period for the entire sub-region because this period's reanalysis is still underway.

Data analysis

Determination of the drivers of forage availability

An ordinary least squares (OLS) regression was used to determine the drivers of forage availability. An OLS procedure was preferred due to the fact that the dependent variable was drawn from a normally distributed population. Correlation analysis was conducted in order to test for multi-collinearity by identifying variables that are significantly correlated before the regression analysis was performed. Variables with higher *t*-values (Elhadi et al. 2012) were deliberately retained and utilized in the multiple regression analysis. The OLS equation took the following functional form:

$$\begin{aligned}\mathrm{DC} = {} & \beta_0 + \beta_1\mathrm{NR} + \beta_2\mathrm{HS} + \beta_3\mathrm{LR} + \beta_3\mathrm{WC} + \beta_4\mathrm{AG} + \beta_6\mathrm{FG} \\ & + \beta_7\mathrm{ST} + \beta_8\mathrm{NK} + \beta_9\mathrm{GR} + \beta_{10}\mathrm{CF} + \beta_{11}\mathrm{RM} + \beta_{12}\mathrm{KP} + \mu\end{aligned}$$

where

AG: ease of access to grazing site
CF: presence of conflicts in grazing
DC: distance covered in search of forage
FG: frequency of grazing at a site
GR: presence of rules governing grazing
HS: herd size in TLUs
KP: knowledge on pasture location
LR: livestock rustling in TLUs
NK: number of persons (kraals) grazing at a site
NR: length of residence at a location
RM: existence of restrictions in movement
ST: perceived quality of soils in the area
WC: perceived weather condition
β_0: intercept
$\beta_{1\ldots12}$: coefficients of determination
μ: error term

Determination of climate indices

In determining the joint effect of rainfall and temperature on NDVI as a proxy of forage availability; rainfall and temperature indices were computed from the time series climate data using the combined drought index calculator (CDI) software of Balint et al. (2011). The CDI software is a product of the United Nations Food and Agriculture Organization. It was designed with a purpose of developing drought indices, whereby precipitation, temperature and vegetation data are transformed into drought indices. For this study, we utilized the CDI because it has the ability to output combined rainfall and temperature index (CRT) in the absence of vegetation data and combined rainfall and vegetation index (CRV) in the

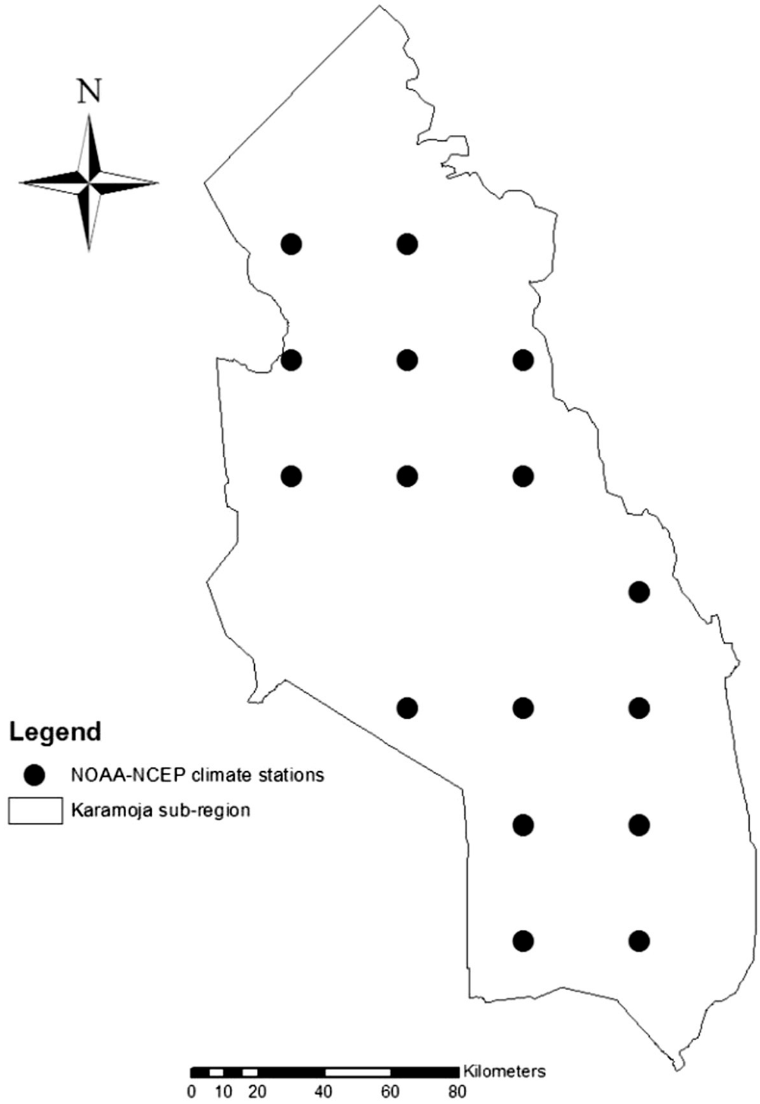


Figure 2 NOAA-NCEP climate stations distribution (source: from authors, 2014)

absence of temperature data. This unique attribute of the CDI allowed us to test the combined effect of rainfall and temperature on vegetation dynamics and thus potential forage availability dynamics in Karamoja. It is important to note that the CDI cannot function in the absence of precipitation data. The equations for computing rainfall and temperature indices and CRT are shown in 1, 2 and 3:

$$\mathrm{RVI}\ \ i,m=\frac{\frac{I}{\mathrm{IP}}\sum_{j=0}^{\mathrm{IP}-1}P*i,(m\text{–}j)}{\frac{1}{(n*\mathrm{IP})}\sum_{k=1}^{n}\left(\sum_{j=0}^{\mathrm{IP}-1}P*(m\text{–}j),k\right)}*\sqrt{\left[\frac{\mathrm{RL}m,i(P*)}{\frac{1}{n}\sum_{k=1}^{n}(\mathrm{RL})m,k^{(P*)}}\right]}\tag{1}$$

$$\mathrm{TVI}\ \ i,m=\frac{\frac{I}{\mathrm{IP}}\sum_{j=0}^{\mathrm{IP}-1}[T*i,(m\text{–}j)]}{\frac{1}{(n*\mathrm{IP})}\sum_{k=1}^{n}\left(\sum_{j=0}^{\mathrm{IP}-1}T*(m\text{–}j),k\right)}*\sqrt{\left[\frac{\mathrm{RL}m,i(T*)m,i}{\frac{1}{n}\sum_{k=1}^{n}\mathrm{RL}m,k^{(T*)}}\right]}\tag{2}$$

where RVI is the rainfall index; TVI is the temperature index; P^* is the modified monthly precipitation amount; T^* is the modified monthly temperature; IP is the interest period (e.g. months); RL (P) represents the run length (1979 to 2009), that is the maximum number of months below long-term average rainfall in the interest period; RL (T) is the maximum number of months above the long-term average temperature; n is the number of years with relevant data; j is the summation running parameter covering the IP; and k is the summation parameter covering the years where relevant data is available, in this case 1979 to 2009. We then compute for the CRT by following the same approach as specified by Balint et al. (2011); however, we modify this approach by excluding vegetation from the equation since in this case, vegetation will be the dependent variable leading to the functional form in Eq. 3:

$$\mathrm{CRT}_{i,m} = W_{\mathrm{RVI}} * \mathrm{RVI}_{i,m} + W_{\mathrm{TVI}} * \mathrm{TVI}_{i,m} \tag{3}$$

where W is the weight of the individual variability index. We utilized the CRT as an input variable to understand the joint effect of temperature and rainfall on vegetation dynamics in Karamoja sub-region. A simple regression analysis was thus performed and the significance inferred from the t-statistics at 5 % significance level. In addition, to obtain the rainfall-vegetation response lag time, a correlation curve was fitted on the RVI and NDVI data.

Relationship between perceived forage availability (TEK) and NDVI

In determining the relationship between perceived forage availability and remotely sensed NDVI, data was first descriptively analysed. Mean monthly forage availability perception assessment responses were transformed into monthly percentages, such that both perceived availability and NDVI data were summarized into a comparable percentage over a 12-month period (January to December). Thereafter, a generalized linear regression analysis was conducted using the functional approach: $\mathrm{FAV} = \beta_0 + \beta_1\mathrm{NDVId} + \mu$, where perceived forage availability (FAV) was regressed against NDVI dynamics (NDVId) and μ represents the error term. The analysis was conducted at 5 % significance level.

Results

Perceived pattern of forage availability

Over a 12-month period, perceived average forage availability was deemed sufficient by 75.3 % of the respondents. The availability assessment with respect to specific livestock species was however varied (Figure 3).

Perceived forage availability assessment from the different livelihood zones showed differences for cattle, goats, sheep and donkeys (see Appendix). Patterns of camel forage availability remained unchanged because camels were only observed in the pastoral zone of Moroto district. Declines in perceived availability for cattle were observed to commence after the peak period in mid-September (agricultural zone) and in mid-August in the pastoral and agro-pastoral zones (see Appendix). However, in the pastoral zone, a rapid rise in limited forage availability for cattle is observed outstripping availability in October with an extremely low period in January. This leads to a 38.8 % availability gap. On the other hand, the agro-pastoral and agricultural zones experience high availability gaps in February at 46.5 % and 43.3 %, respectively (see Appendix).

In the pastoral zone, perceived forage availability for goats was observed to rapidly reach a peak period in April before experiencing a fluctuating decline. This rise was however more rapid in the agro-pastoral zone. Meanwhile, the agricultural zone was perceived to have a relatively prolonged period (April-September) of perceived forage availability for goats. Pastoral and agro-pastoral zones showed marked variability in forage availability for sheep with early perceived deficit occurring in the pastoral zone around November. The agricultural zone generally had five months (April-August) of high sheep forage availability before a declining trend was observed around October. However, in the agricultural zone, a prolonged period (April-September) of limited forage availability for donkeys was observed (see Appendix). For donkeys, the months of low forage availability coincide with rainfall months in the sub-region. On the other hand, other livestock species' periods of limited forage availability coincide with low rainfall months in the sub-region.

Perceived quality of available forage for different livestock species

For cattle, goats, sheep and donkeys, respondents observed that the available forages were generally very good (>35 %), see Figure 4a. However, differences emerged with regards to the perceived quality available for the different livestock species (Figure 4b, c, d, e and f).

The relationship between perceived forage availability (TEK) and NDVI

The NDVI revealed that vegetation vigour was higher in the months of May to September. The decline in vegetation started in October with the lowest vegetation vigour observed in February (Figure 5b). Coincidentally, perceived forage availability assessment results had also revealed February as the month with limited forage availability. Thus, NDVI dynamics and traditional ecological knowledge assessment of perceived forage availability showed a similar pattern. However, perceived forage availability assessment revealed a sharper increase in forage availability between May and April much more than the gains observed in NDVI (Figure 5c). This reveals the community's appreciation of improvements in forage availability after the depressed months (from November to March) of low availability; these trends are therefore not reflected by the NDVI. Generally, a positive correlation between NDVI and perceived forage availability in Karamoja was observed ($r = 0.89$). The relationship was considerably strong ($R^2 = 0.79$, Figure 5c).

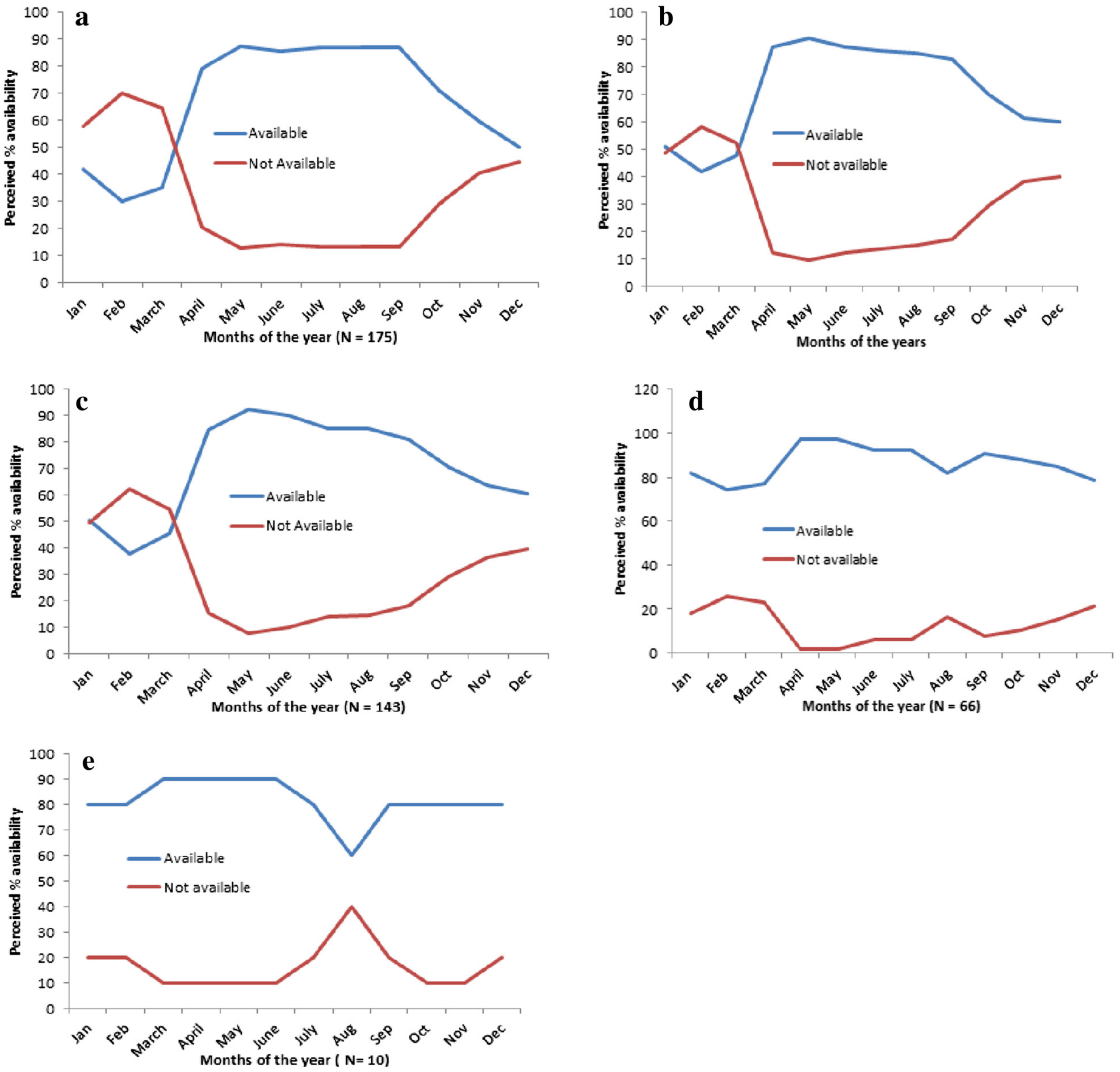


Figure 3 a Perceived forage availability for cattle. **b** Perceived forage availability for goats. **c** Perceived forage availability for sheep. **d** Perceived forage availability for donkeys. **e** Perceived forage availability for camels

Perceived drivers of forage availability

Table 1 presents a summary description of variables used to determine the perceived drivers of forage availability. The results showed the respondents covered 6.2 and 23.5 km in search of forage for wet and dry seasons, respectively. The respondents reported that an average of 16.0 herd size was lost to cattle rustling in the last 10 years. Over 60 % of the respondents reported that the weather conditions were currently good, evidenced by relatively higher rainfall total. On the other hand, 53.0 % respondents observed that temperatures were not good because they perceived them to be higher than in the past 10 years. The respondents noted that burning of pastures was frequent. A majority of the respondents indicated that there was ease of access to grazing sites, an absence of conflicts in grazing and over grazing areas. Although a majority indicated that there were no rules governing grazing, they also stated that restriction on movements exists.

The variables in Table 1 were subjected to a regression analysis to determine the extent of influence on forage availability. The results of this regression are presented in Table 2. Nine out of the 12 factors were significantly influencing forage availability at 5 % while the other two factors were significant at 10 % as indicated by the corresponding

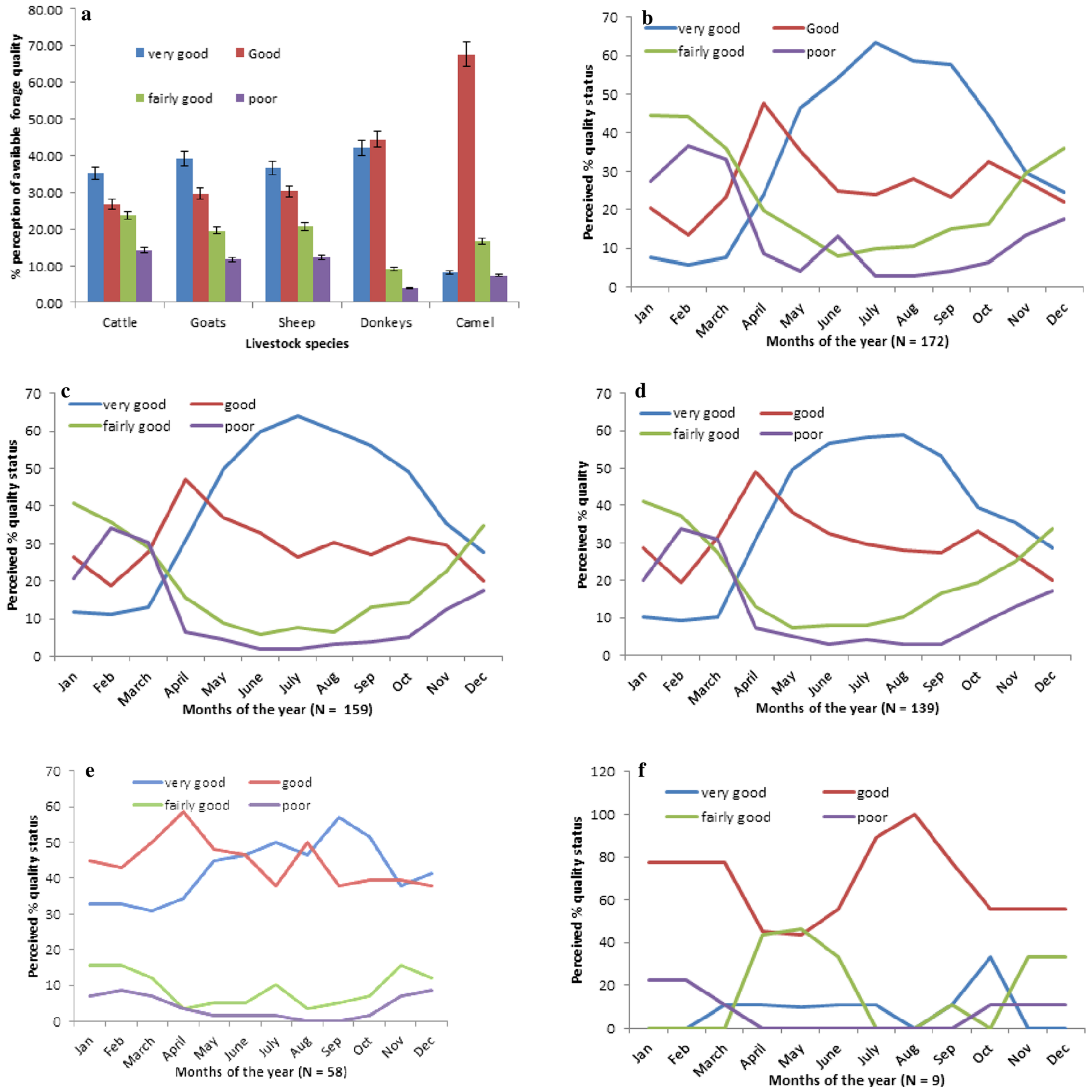


Figure 4 **a** Comparison of available forage quality for different livestock species. **b** Perceived forage quality for cattle. **c** Perceived forage quality for goats. **d** Perceived forage quality for sheep. **e** Perceived forage quality for donkeys. **f** Perceived forage quality for camels

t-value. The adjusted R^2 of 0.332 showed that only 33 % of the variation in forage availability was explained by the explanatory variables. The *F*-statistics was significant at 5 %; this indicated that explanatory variables jointly had a significant influence on forage availability. The results of this model indicated that forage availability was positively and significantly ($P \leq 0.05$) influenced by the following: length of residence by a livestock keeper, perceived rainfall availability, frequency of grazing, number of kraals, presence of governing rules, presence of conflicts and knowledge of pasture location. On the other hand, forage availability was negatively and significantly ($P \leq 0.05$) influenced by restricted movement and ease of access to grazing areas. Herd size in TLUs and quality of soils were found to be positively and significantly ($P \leq 0.1$) influencing forage availability.

The number of years a pastoralist stayed in an area positively influenced the distance to grazing areas and therefore reduced availability of forage. This indicates that the longer the residence period, the longer the distance covered in

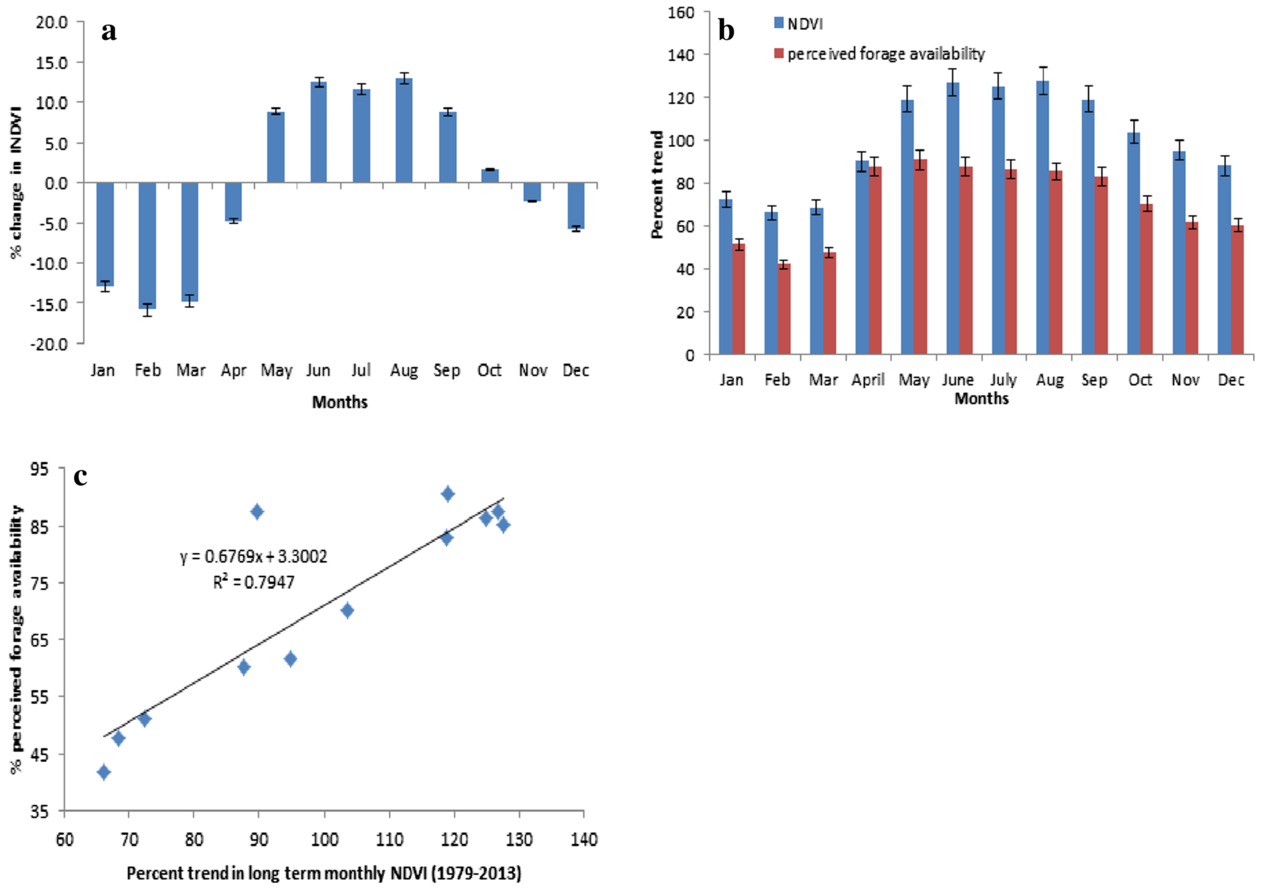


Figure 5 **a** Long-term NDVI annual deviations (1979 to 2013). **b** Long-term mean monthly NDVI and perceived forage availability patterns. **c** Relationship between perceived forage availability and long-term NDVI

Table 1 Description of variables used to determine drivers of forage availability in Karamoja

Variable	Description
Distance covered in search of forage	14.8-km average distance per day
Length of residence at a location	37.5 average number of years resident in a location
Herd size in TLUs	7.9 average tropical livestock unit
Livestock rustling in TLUs	16.0 average tropical livestock unit lost to rustling
Perceived weather condition	64.6 % (good; code 1), 35.4 % (not good; code 0)
Temperature	47 % (good; code 1), 53.0 % (not good; code 0)
Ease of access to grazing site	65.2 % (easy; code 1), 34.8 % (not easy; code 0)
Frequency of grazing at a site	52.5 % (high; code 1) 47.5 % (not high; code 0)
Frequency of burning the grasses	35.4 % (not frequent; code 0), 64.6 % (frequent; code 1)
Quality of soils in the area	26.8 % (soils are poor; code 0), 73.2 % (soils are good; code 1)
Number of persons (kraals) grazing at a site	39.1 average number of persons grazing at a location
Presence of rules governing grazing	63.6 % (no rules; code 0), 36.4 % (rules present; code 1)
Presence of conflicts in grazing	58.1 % (no conflicts; code 0), 41.9 % (conflicts exist; code 1)
Existence of restrictions in movement	76.8 % (restrictions exist; code 1), 23.2 % (no restrictions; code 0)
Knowledge on pasture location	29.8 % (no knowledge on pasture locations; code 0), 70.2 % (knowledge on pasture locations; code 1)

Table 2 Ordinary least square estimates for the drivers of forage availability

Driver of forage availability	β	Std. error	T	Significance
Constant	−11.178	4.778	−2.339	0.02
Length of residence at a location	0.164	0.065	2.539	0.012*
Herd size in TLUs	0.158	0.085	1.849	0.066**
Livestock rustling in TLUs	−2.738	1.995	−1.372	0.172
Perceived weather condition	5.684	2.082	2.73	0.007*
Ease of access to grazing areas	−3.515	2.103	−1.671	0.097**
Frequency of grazing	7.564	1.947	3.886	0.00*
Quality of soils in the area	3.975	2.303	1.726	0.086**
Number of persons (kraals)	0.157	0.063	2.476	0.014*
Presence of rules governing grazing	6.669	2.109	3.163	0.002*
Presence of conflicts in grazing	5.889	2.308	2.551	0.012*
Existence of restrictions in movement	−11.64	2.519	−4.62	0.00*
Knowledge on pasture location	5.062	1.998	2.534	0.012*

*Significant at 5 %; **significant at 10 %; $R^2 = 0.376$; Adj. $R^2 = 0.332$; $F = 8.531$; $N = 198$

search of forage, thus indicating less forage available in the grazing areas. Herd size was found to be negatively affecting forage availability. The larger the herd kept by a pastoralist, the less the forage available in the area. On the other hand, perceived weather conditions were found to positively influence forage availability, as prior postulated that good weather conditions (e.g. absence of heavy storms, flash floods and thunderstorms) will facilitate pastoralists to utilize wider areas for grazing compared to poor weather conditions which create temporal barriers that hinder the access to available grazing areas.

Forage availability was found to be negatively driven by frequency of grazing indicating that the more frequent an area is grazed, the less forage is available as indicated by the longer distance covered with such grazing patterns. Results also showed that the perceived quality of soils negatively influenced forage availability. The poorer the soils, the longer distance that was covered by pastoralists in search of forage, thus indicating poor forage performance and availability. This pattern was similarly observed with the number of kraals present in the grazing areas. Regarding knowledge on pasture locations, a negative relationship was established. The more knowledge a pastoralist had on forage locations, the higher the likelihood of covering a larger distance, thus exposure to more forage.

The presence of customary laws such as rules governing grazing was found to positively influence forage availability. These rules and regulations enhanced a circulating effect on grazing organization that allowed pastoralists to forage differentially. The absence of such rules was observed to have created concentric circulation that reduced forage availability. The customary rules when applied enhanced dispersion allowing the herders to graze differentially between the marshes and mountains in the dry season and lowlands in the wet season; this exposed the pastoralists to more forage. On the other hand, the presence of conflicts revealed positive elasticity coefficient indicating that an increase in conflicts increased forage availability. This appears rather contradictory, but for the Karamoja situation, conflicts particularly those arising from livestock raiding created mobility restrictions leading to forage availability in the wider area of rangelands in some areas.

Ease of access to grazing areas within the region was negatively affecting forage availability indicating that the easier the access, the more forage pastoralists had access to, to compared to when access is restricted. On the other hand, access to grazing outside the Karamoja subregion was found to be a negative driver of forage availability as indicated by the restriction of movement imposed by the formal institutions.

Effect of rainfall and temperature on forage availability

Results showed that there is a positive relationship between rainfall and NDVI, thus potential forage availability (Figure 6a). The correlation results were significant at 5 % level with R^2 of 0.56. However, temperature showed a positive but non-significant ($R^2 = 0.064$) relationship with NDVI. Despite rainfall and NDVI showing a positive significant synchrony, it was observed that there is a lag time between the increase in rainfall and increase in NDVI. Rainfall was observed to rise rapidly reaching a peak period in late May while vegetation response (NDVI) reached a peak period in early August. This resulted into a vegetation-rainfall response time lag of 2.9 months.

In Figure 6c, we show a long-term pattern of rainfall-NDVI; time lags have been marked 1 to 8 for ease of identification. It is observable that when rainfall increases, the NDVI response is delayed briefly, indicating that vegetation vigour response to rainfall is not a spur of the moment. In Figure 6c, labels 7 and 8 reveal unique patterns observed around this period (2002 to 2008); rainfall and NDVI time lags are more pronounced. However, rainfall indices are considerably higher with two major declines in 2006 and between 2007 and 2008. When the CRT influence on NDVI was analysed, an inverse relationship was observed between the CRT influence on NDVI, indicating that as the rainfall and temperature variation reduces (indication of improved climate condition), an increase in NDVI is observed (Figure 6b). This is indicated by a decrease in CRT values as the NDVI values take a positive rise (Figure 6b). The combined effect relationship was positively significant ($R^2 = 0.856$) and strongly correlated ($r = 0.744$). Similarly, we established that rainfall and perceived forage availability showed a strong and significant correlation ($R = 0.85$, $R^2 = 0.727$).

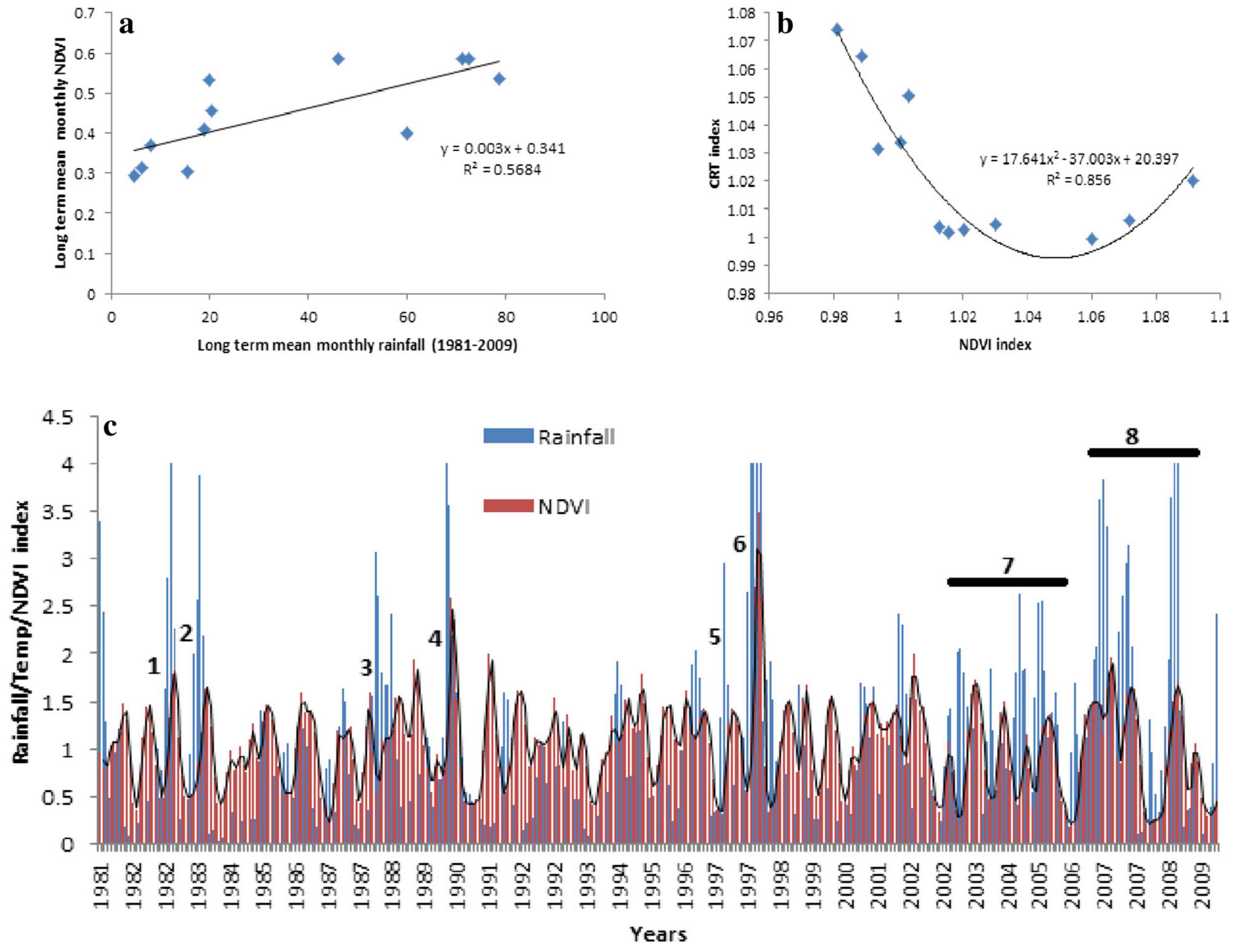


Figure 6 a Relationship between long-term mean monthly NDVI and rainfall. **b** Joint effect of rainfall-temperature on NDVI. **c** Long-term rainfall-temperature and NDVI trend (1981 to 2009)

Discussion

Perceived forage availability and quality

Local people's knowledge in assessing status vegetation is relevant in conducting integrated assessments (Angassa et al. 2012). Based on the results of this study, we have been able to establish that pastoralists and agro-pastoralists have detailed TEK of forage availability dynamics in Karamoja. Not only was it possible for the respondents to detail forage dynamics across the year, based on long-term to present-time observations, but they also possessed detailed understanding of forage availability and perceived forage quality with respect to particular livestock species. Such detailed understanding of vegetation dynamics is attributable to the community's knowledge of ecosystem variability (Angassa et al. 2012). The unique differences that exist between livestock species with respect to forage availability and perceived quality were similarly revealed. In particular, on one hand, cattle, sheep and goats tended to have similar dynamics while camels and donkeys also showed a much closer pattern. The difference in perceived availability between goats, sheep and cattle could be attributed to the fact that goats and sheep are generalist feeders that have access to a wide variety of forages than cattle (Sanon et al. 2007; Tabuti and Lye 2009). This could also explain the differences in perceived availability during the months of October to March. In particular, it explains the smaller forage deficit gap that goats and sheep have during the months of January to March (often the dry season) compared to the larger deficits for cattle during the same period. Goats and sheep have close feeding habits (browsing) following decline in forage resources during the dry season (Ouédraogo-Koné et al. 2006; Sanon et al. 2007). The deficit was slightly larger in sheep (refer to Figure 3a, b, c to see the tail-like appearance between the months of January and March). This could be explained by the grazing behaviours of the respective livestock species. According to Rutagwenda et al. (1990), goats browse more than sheep, which in turn consume more browse forage than cattle; this means that the respective livestock species have access to differentiated forage availability.

However, it is important to note that all livestock are generalist feeders but with expressed preferences when given a choice. Accordingly, predominant browsers will be inefficient grazers; predominant grazers will be particularly inefficient browsers (Schwartz 2009). Therefore, the patterns reported by the respondents in this study reveal their in-depth knowledge of vegetation dynamics and livestock feeding habits in Karamoja. According to Bolling and Schulte (1999), pastoral knowledge is built up around the interaction between herds and vegetation. Further, Oba and Kaitira (2006) have previously shown that the Maasai herders have detailed understanding of the grazing preference of their livestock species.

Differentiated forage availability across the three livelihood zones revealed the heterogeneity of Karamoja's rangelands. Particularly, the agricultural zone was observed to have minimal forage variability for goats and sheep compared to the pastoral and agro-pastoral zones. Similarly, forage availability deficits (between October and March) were smaller in the agricultural zone compared to the agro-pastoral and pastoral zones. These differences can be explained by differences in total rainfall received in these zones. Generally, the agricultural zone in western Karamoja receives relatively higher total rainfall compared to the pastoral zone (eastern Karamoja) and agro-pastoral zone running from north through central to southern Karamoja (Anderson and Robinson 2009). Importantly, these patterns of forage availability in the region explain the existence of transhumant livestock grazing in the sub-region. Transhumant livestock herding is a key pastoralist adaptation strategy for coping with resource uncertainty across space and time (Ickowicz et al. 2012). It allows pastoralists to opportunistically take advantage of patchy livestock resources as well as maintain multi-species herds (Behnke 1994; Mogamat 2013) and to continue strengthening the social networks (Bassett and Koné 2006).

Relationship between perceived forage availability (TEK) and NDVI

The utilization of traditional ecological knowledge to inform scientific process and/or support scientific approaches has been viewed as scepticism particularly because local observations are thought to erode with time, be subjective and lack methodological nesting (Gadgil et al. 2003; Vinyeta and Lynn 2013; Society for Ecological Restoration 2014). Our study's findings have shown a significant correlation between local perception assessment of forage availability and remotely-sensed vegetation patterns (NDVI). The positive correlation is attributable to detailed TEK of vegetation dynamics observed over time. Others have drawn the same conclusions; e.g. in Botswana (Kgosikoma et al. 2012) and Burkina Faso (Sop (2012). This knowledge informs their livestock management decisions such as herd movement (Oba 2012).

This pattern has also been observed by Galvin et al. (2004), with a particular emphasis on the seasonality of rainfall having influence on forage availability in East Africa. The ability of the pastoralists to match forage availability and rainfall patterns is a result of rainfall being an important control in regenerating pasture resources (Ahrens and AY Farah 1996). It thus does not come as a surprise that respondents were able to provide a distinctive assessment of forage availability between March and April, whose forage availability is a result of the first four to seven weeks after rainfall onset in the sub-region.

Further, there is a hybrid character between scientific and local knowledge in the understanding of vegetation dynamics, and TEK can provide reliable evidence of vegetation dynamics (Thomas and Twyman 2004). As such, our study recording of significant increase in forage availability (between March and April) observed by respondents but not readily reflected by the NDVI is a testament of a rich knowledge system of pastoral people about vegetation dynamics. By integrating traditional ecological knowledge and remote sensing, a conscious endeavour of recognizing the centrality of TEK in range management is appreciated.

Perceived drivers of forage availability

In addition to rainfall and temperature effects on vegetation-forage dynamics, livestock-related production factors such as herd size and number of kraals; environmental conditions such as soils; institutional-related conditions including rules and governance, restrictions on movement, and conflicts in the grazing areas; and socio-demographic factors such as length of residency at a location have been determined to either influence forage availability positively or negatively. Herds and herd sizes have important impacts on vegetation dynamics and. we have seen that livestock herd size has a negative influence on perceived forage availability. We are however cautious in the context of of our other results such as the existence of restrictions on movement and sedentarization that constrain pastoral mobility which can initiate constraints and increase conflicts through changes in land use. These actions dictated by increased crop cultivation often restrict movement and force livestock herders into more marginal areas (Glover 2005). Generally, a lengthy settlement can trigger shortage of pasture (Dongmo et al. 2012). It is however important to note that in Karamoja, a distinction ought to be made between the pastoral mobility and livestock herd mobility. This is because whereas the pastoral population is nearly becoming sedentary, livestock herd mobility is still practised, though on a more limited land area because the Karamojong no longer access dry season grazing areas neighbouring in Teso, Lango and Acholi sub-regions. Mobility of livestock herds without the entire household mobility has similarly been observed, for example among the Fulani of Ferlo in the Sahelian Senegal (Adriansen 2008).

Ease of access to grazing areas, knowledge of the location of pastures and presence of rules governing grazing were hypothesized to have a positive influence on forage availability in the area. Ease of access permits mobility, thus allowing the herders to exploit pastures from different landscapes, given the heterogeneity that often exists in rangelands (Lynn 2010). Imposition of restrictions that restrict mobility and access to resources will create conditions that limit pasture availability (Ayantunde et al. 2008; Lengoiboni et al. 2011). Pastoral rules and regulations are designed to allow for conservation, use and sustainability of available resources such as pastures and water sources (Nelson 2012). Therefore, rules and regulations that curtail the normal operations and affect the pastoral calendar may create artificial junctures that constrain forage availability (Dongmo et al. 2012; Degteva and Nellemann 2013).

Additionally, knowledge of pasture locations was found to enhance forage availability. Pastoral knowledge controls management decisions; for example, pastoralists often divide their grazing locations alongside wet versus dry season grazing areas. In northern Tanzania, for example, a practice known as *ngitili* where forage locations are retained during the rainy season and opened for grazing at peak dry seasons allows forage availability for pastoral and agro-pastoral communities (Selemani et al. 2012). Similarly, the Maasai have in-depth characterization of grazing landscapes that reveals vitality of herder knowledge in regulating grazing, depending on the status of the landscape and available forage (Oba and Kaitira 2006). On the other hand, presence of conflicts initiates 'artificial forage shortage' because it creates unnecessary restrictions on the mobility of herds and herders. Pastoralists often move to areas where pasture is available and negotiate for use rights (Temesgen 2010). In the presence of conflicts, pastoralists become ineffective in making such movements as well as building and managing herding territories that have considerable influence in forage availability (Dongmo et al. 2012).

It was not unusual for the respondents to associate perceived existence of good soils with forage availability. This is because pastoralists have robust knowledge of soils and soil quality; their soil classification is often based on the productivity of such soils on a given landscape. In a study conducted among the Maasai, Oba and Kaitira (2006) documented classification of degradation based on soils as one of the indicators, and a perceived variation of forage availability and grazing patterns depending on soils in a given landscape. Similarly, among the Orma, the Afar and the Karamojong (Turkana and Karamojong of Uganda), forage availability and quality has been documented to be consonant with the soils and soil moisture of a given landscape (Oba 1998; Notenbaert et al. 2007; Oba 2012). Similarly to a study by Oba (2012), we found, through informal interviews and focus group discussions, associative existence of landscape grazing potentials to perceived soil productivity and forage availability patterns. For example, the sandy landscapes (*eketela*) were perceived to experience heavier grazing than the black soil (*arro*) landscapes. This is because the *arro* is grazed during the dry season, thus associated with better forage availability compared to the *eketela*.

Conclusions

This study has shown that in semi-arid areas such as Karamoja, there is variability in the forage availability for different livestock species. The availability is differentiated across various locations in the Karamoja livelihood zones, leading to heterogeneity of grazing landscapes. In the different livelihood zones, forage availability deficit gaps vary with respect to livestock species. Similarly, perceived quality of the available forage varied across livestock species. The detail with which the respondents were able to provide perceived forage availability and quality assessment confirms that the pastoralists of Karamoja, like pastoralists elsewhere, have detailed TEK of vegetation dynamics. The matching trends of perceived forage availability and remotely sensed NDVI data have also shown that when carefully utilized, it is possible to integrate TEK survey assessment data with the wider scientific data. The quality of information generated from the community assessment has shown that it is possible to integrate TEK in ecological assessments to generate reliable information for understanding the state of grazing resources in space and time. This however depends on careful selection of methodologies and assessment protocols to allow for comparison across time and physical scales.

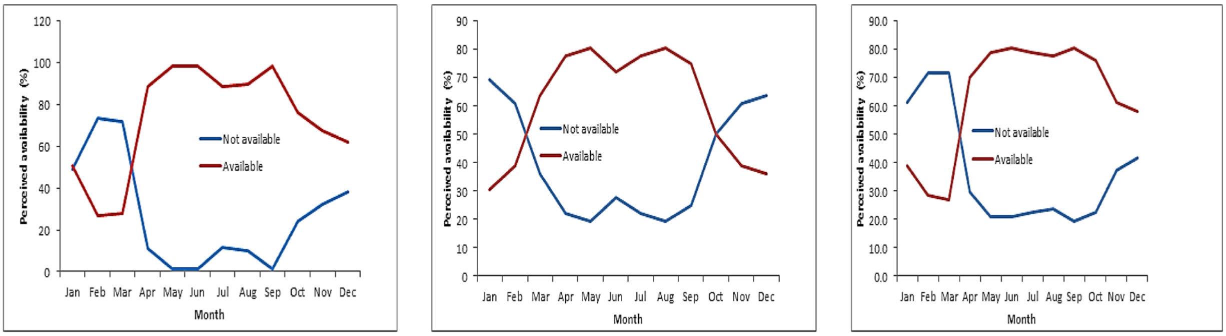
We have also recorded the connectivity between rainfall and vegetation patterns in the semi-arid region of Karamoja, of, a lag time of 2.9 months between rainfall and vegetation peaks. With regard to the perceived drivers of forage availability, we have shown that besides rainfall, livestock-related production factors (herd size, number of kraals), environmental conditions (soils), institutional factors (rules and regulations, movement restrictions) and socio-demographic factors such as length of residence at a location are perceived to influence forage availability. While this study has been able to show the spatio-temporal patterns of forage availability and quality, we are of the view that there is a need to undertake nutritional quality assessment of key forages in the sub-region. There should be continuous monitoring of socio-economic conditions in the region that has the potential of creating 'artificial forage shortage' situations. We also recommend the integration of TEK in the assessment of rangeland resources and in scientific research applications.

Appendix

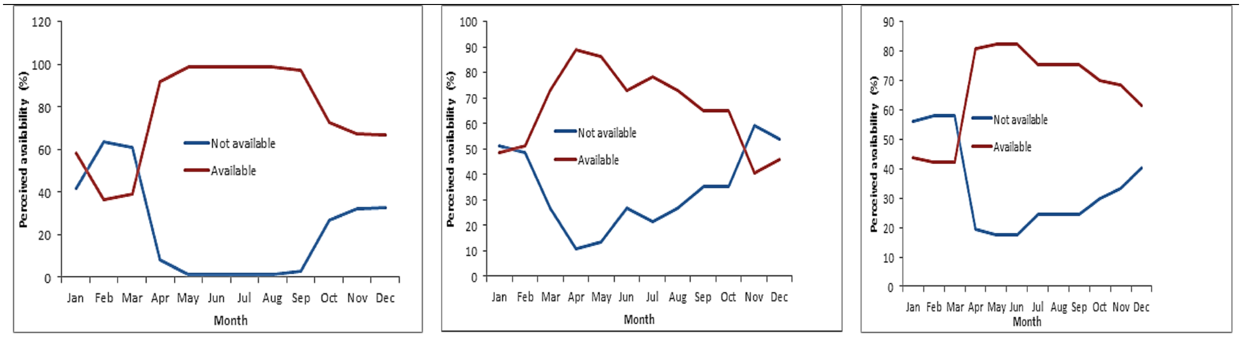
Perceived forage availability in Agro-pastoral livelihood zone by livestock species

Perceived forage availability in the Pastoral zone by livestock species

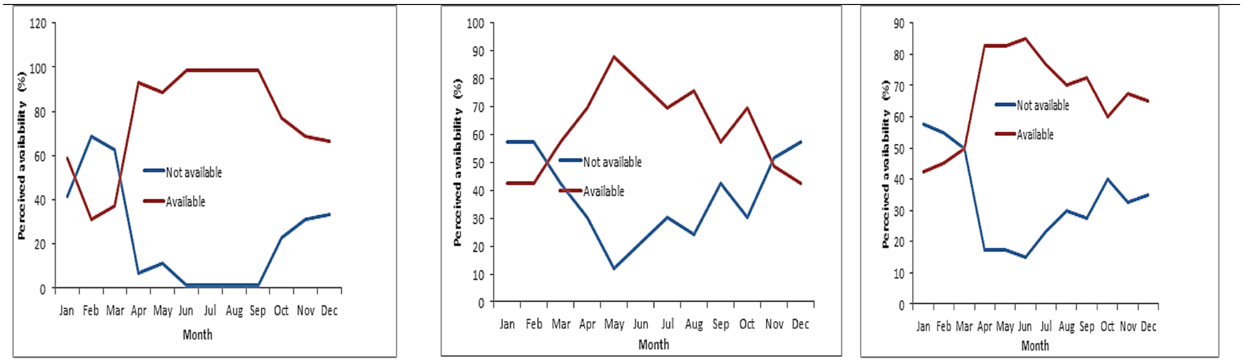
Perceived forage availability in the Agricultural zone by livestock species



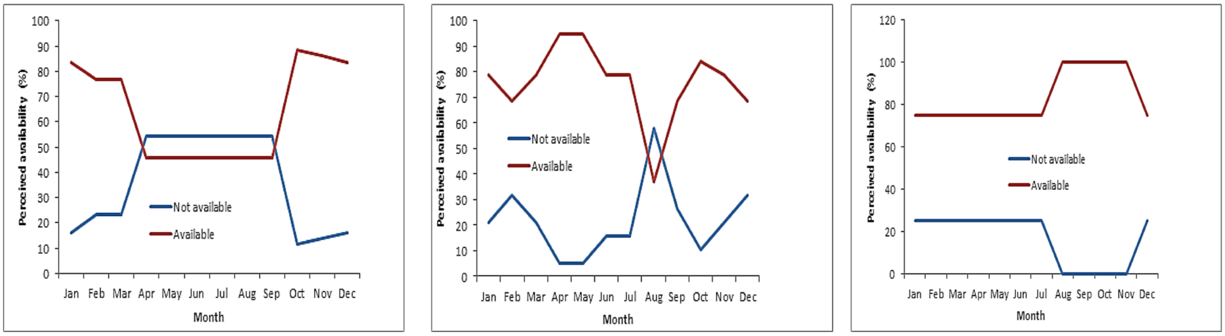
1.1 Cattle 1.2 Cattle 1.3 Cattle



2.1 Goats 2.2 Goats 2.3 Goats



3.1 Sheep 3.2 Sheep 3.3 Sheep



4.1 Donkeys 4.2 Donkeys 4.3 Donkeys

Figure 7 Perceived forage availability in different livelihood zones in Karamoja

Competing interests

The authors declare they have no competing interests.

Authors' contributions

AE designed the study with the guidance of OW, JM, LM and GJMM. AE also conducted the field data collection and drafted the manuscript. EY and YB provided technical guidance in analysis of socio-economic data and interpretation of the outcomes similarly this guidance was provided by OW, JM, LM, and GJMM. LM and GJMM were particularly instrumental in remote sensing data analysis and interpretation. OW and JM were vital in the traditional ecological knowledge backstopping. All authors read and approved the final manuscript.

Authors' information

AE is Assistant Lecturer at Makerere University, Uganda. OW (PhD), JM (PhD) and LM (PhD) are Lecturers at the University of Nairobi. EY is a PhD student at the University of Nairobi. GJMM and YB are Associate Professor and Senior Lecturer at Makerere University, Uganda, respectively.

Acknowledgements

This study was funded in part by Carnegie Corporation of New York, Makerere University and Regional Universities Forum for Capacity Building in Agriculture (RUFORUM).

Author details

[1]Department of Land Resource Management and Agricultural Technology, University of Nairobi, P.O. Box 29053-00625, Nairobi, Kenya. [2]German Institute for Tropical and Sub-Tropical Agriculture (DITSL) at University of Kassel, Steinstraße 19, D-37213 Witzenhausen, Germany. [3]Department of Agricultural Economics, University of Nairobi, P.O. Box 29053-00625, Nairobi, Kenya. [4]Department of Geography, Geo-informatics and Climatic Sciences, Makerere University, P.O. Box 7062, Kampala, Uganda.

Received: 27 February 2014 Accepted: 7 September 2015

References

Adriansen, HK. 2008. Understanding pastoral mobility: The case of Senegalese Fulani. The Geographical Journal 173(3): 207–222.

Ahrens, JD, and AY Farah. 1996. Borena and Liban affected by drought: Situation report on the drought affected areas of Oromiya and Somali Regions. UNDP Emergencies Unit for Ethiopia. Available from: http://www.africa.upenn.edu/eue_web/Borendec.htm. Accessed on 30th March, 2013.

Anderson, M, and WI Robinson. 2009. The 10th EDF Karamoja Livelihoods Programme (KALIP). Technical Reference Guide Submitted to EU. Kampala: Government of Uganda and FAO. Available from: www.opm.nulep.org/about…/436_f6ec429c540744f00d64b5ce83770ca. Accessed on 4th June, 2013.

Angassa, A, G Oba, and NC Stenseth. 2012. Community-based knowledge of indigenous vegetation in arid African landscapes. Consilience: The Journal of Sustainable Development 8(1): 70–85.

Animut, G, AL Goetsch, GE Aiken, R Puchala, G Detweiler, CR Krehbiel, RC Merkel, T Sahlu, LJ Dawson, ZB Johnson, and TA Gipson. 2005. Performance and forage selectivity of sheep and goats co-grazing grass/forb pastures at three stocking rates. Small Ruminant Research 59: 203–215. doi:10.1016/j.smallrumres.2005.05.015.

Anyamba, A, and CJ Tucker. 2005. Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003. Journal of Arid Environments 63(3): 596–614.

Ayantunde, AA, S Fernandez-Rivera, PH Hiernaux, and R Tabo. 2008. Implications of restricted access to grazing by cattle in wet season in the Sahel. Journal of Arid Environments 72: 523–533. doi:10.1016/j.jaridenv.2007.06.006.

Balint, Z, FM Mutua, and P Muchiri. 2011. Drought monitoring with the combined drought index, FAO-SWALIM Nairobi, Kenya.. Available from: http://www.faoswalim.org/userfiles/SWALIM_CDI_Brochure.pdf. Accessed on 20th September, 2012.

Bassett, TJ, and M Koné. 2006. Grazing lands and opportunistic models: The political ecology of herd mobility in northern Côte d'Ivoire. In Colloque International 'Les Frontieres de la Question Fonciere. Available from: https://www.mpl.ird.fr/colloque_foncier/Communications/PDF/Bassett.pdf. Accessed on 28 August 2012.

Behnke, R. 1994. Natural resource management in pastoral Africa. Development Policy Review 12(1): 5–28.

Bolling, M, and A Schulte. 1999. Environmental change and pastoral perceptions: Degradation and indigenous knowledge in two African pastoral communities. Human Ecology 27(3): 493–514.

Burnaby, N and B Gibson. 2003. Traditional ecological knowledge and environmental impact assessment. University of Waterloo. Available from: www.uwaterloo.ca/…/Burnaby_TEK%26Asmt.pdf. Accessed on 4th March, 2012.

Butt, B. 2010. Seasonal space-time dynamics of cattle behavior and mobility among Maasai pastoralists in semi-arid Kenya. Journal of Arid Environments 74: 403–4013. doi:10.1016/j.jaridenv.2009.09.025.

Butt, B, and MD Turner. 2012. Clarifying competition: The case of wildlife and pastoral livestock in East Africa. Pastoralism: Research, Policy and Practice 2: 9. http://www.pastoralismjournal.com/content/2/1/9. Accessed on 18th August, 2013.

Byakagaba, P. 2005. The Banyarwanda pastoralist's herder knowledge of range management in Kiboga District, Uganda. MSc thesis, Norwegian University of Life Sciences.

Cullen, BR, IR Johnson, RJ Eckard, GM Lodge, RG Walker, RP Rawnsley, and MR McCaskill. 2009. Climate change effects on pasture systems in south-eastern Australia. Crop and Pasture Science 60(10): 933–942.

Czuba, K. 2011. Governing the Karimojong: Tradition, modernity and power in contemporary Karamoja. A discussion paper. Available from: https://www.academia.edu/1438900/Governing_the_Karimojong_Tradition_Modernity_and_Power_in_Contemporary_Karamoja Accessed on 10th April, 2013.

Degteva, A, and C Nellemann. 2013. Nenets migration in the landscape: Impacts of industrial development in Yamal peninsula, Russia. Pastoralism: Research, Policy and Practice 3: 15. http://www.pastoralismjournal.com/content/3/1/15.

Dixit, AK, SA Levin, and DI Rubenstein. 2013. Reciprocal insurance among Kenyan pastoralists. Theoretical Ecology 6(2): 173–187.

Dongmo, AL, E Vall, MA Diallo, P Dugue, A Njoya, and J Lossouam. 2012. Herding territories in northern Cameroon and western Burkina Faso: Spatial arrangements and herd management. Pastoralism: Research, Policy and Practice 2: 26. http://www.pastoralismjournal.com/content/2/1/26.

Elhadi, YA, DM Nyariki, VO Wasonga, and WN Ekaya. 2012. Factors influencing transient poverty among agro-pastoralists in semi-arid areas of Kenya. African Crop Science Journal 20(1): 113–122. ISSN 1021-9730/2012.

Fensham, RJ, RJ Fairfax, and SR Archer. 2005. Rainfall, land use and woody vegetation cover change in semi-arid Australian savanna. Journal of Ecology 93(3): 596–606.

Fratkin, E. 1997. Pastoralism: Governance and development issues. Annual Reviews in Anthropology 26: 235–261.

Gadgil, M, P Olsson, F Berkes, and C Folke. 2003. Exploring the role of local ecological knowledge in ecosystem management: Three case studies. Navigating social-ecological systems: Building resilience for complexity and change, 189–209. Cambridge, UK: Cambridge University Press.

Gagon, CA, and D Berteaux. 2009. Integrating traditional ecological knowledge and ecological science: A question of scale. Ecology and Society 14(2): 19. http://www.ecologyandsociety.org/vol14/iss2/art19/.

Galvin, KA, PK Thornton, RB Boone, and J Sunderland. 2004. Climate variability and impacts on East African livestock herders: The Maasai of Ngorongoro Conservation Area, Tanzania. African Journal of Range and Forage Science 21: 183–189.

Glover, EK. 2005. Tropical dryland rehabilitation: Case study on participatory forest management in Gedaref, Sudan. Helsinki, Finland: PhD dissertation: Faculty of Agriculture and Forestry of the University of Helsinki, Finland.

Gomes, N. 2006. Access to water, pastoral resource management and pastoralists' livelihoods: Lessons learned from water development in selected areas of Eastern Africa (Kenya, Ethiopia, and Somalia). LSP Working Paper 26. Available from: ftp://ftp.fao.org/docrep/fao/009/ah247e/ah247e00.pdf.

Hailegiorgis, AB, WG Kennedy, GC Balan, JK Bassett and T Gulden. 2010. An agent based model of climate change and conflict among pastoralists in East Africa. In Proceedings of the International Congress on Environmental Modeling and Software (pp. 5-8). Available from: https://cs.gmu.edu/~eclab/projects/mason/publications/climate10.pdf Accessed on 27th June, 2012.

Hesse, C, and L Cotula. 2006. Climate change and pastoralists: Investing in people to respond to diversity. Sustainable Development Opinion, International Institute for Environment and Development. Available from: http://pubs.iied.org/pdfs/11059IIED.pdf. Accessed on 27th June, 2012.

Hill, MJ, GE Donald, MW Hyder, and RC Smith. 2004. Estimation of pasture growth rate in the south west of Western Australia from AVHRR NDVI and climate data. Remote Sensing of Environment 93(4): 528–545.

Huete, A, K Didan, W van Leeuwen, T Miura, and E Glenn. 2011. Moderate Resolution Imaging Spectroradiometer vegetation indices. In Land remote sensing and global environmental change, NASA's Earth Observing System and the Science of ASTER and MODIS, ed. B Ramachandran, C Justice, and M Abrams. New York: Springer.

Huntington, HP. 2000. Using traditional ecological knowledge in science: Methods and applications. Ecological Applications 10(5): 1270–1274.

Ickowicz, A, V Ancey, C Corniaux, G Duteurtre, R Poccard-Chappuis, I Touré, E Vall, and A Wane. 2012. Crop–livestock production systems in the Sahel – increasing resilience for adaptation to climate change and preserving food security. Building resilience for adaptation to climate change in the agriculture sector. Montpellier, France: Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), UMR SELMET, CIRAD-INRA-SUPAGRO. Available from: www.fao.org/docrep/017/i3084e/i3084e17.pdf. Accessed on 12th November, 2012.

Jones, JP, MM Andriamarovololona, N Hockley, JM Gibbons, and EJ Milner-Gulland. 2008. Testing the use of interviews as a tool for monitoring trends in the harvesting of wild species. Journal of Applied Ecology 45(4): 1205–1212.

Kaimba, GK, BK Njeha, and AY Guliye. 2011. Effects of cattle rustling and household characteristics on migration decisions and herd size amongst pastoralists in Baringo District, Kenya. Pastoralism: Research, Policy and Practice 1: 18. http://www.pastoralismjournal.com/content/1/1/18.

Kendrick, A, and M Manseau. 2008. Representing traditional knowledge: Resource management and inuit knowledge of barren-ground caribou. Society and Natural Resources 21: 404–418.

Kerven, C, and R Behnke. 2011. Policies and practices of pastoralism in Europe. Pastoralism: Research, Policy and Practice 1: 28. http://www.pastoralismjournal.com/content/1/1/28.

Kgosikoma, O, W Mojeremane, and BA Harvie. 2012. Pastoralists' perception and ecological knowledge on savanna ecosystem dynamics in semi-arid Botswana. Ecology and Society 17(4): 27. http://dx.doi.org/10.5751/ES-05247-170427.

Kratli, S. 2010. Karamoja with the rest of 'the rest of Uganda'. Nomadic Peoples 14(2): 3–23. doi:10.3167/np.2010.140202.

Lengoiboni, M, P van der Molen, and AK Bregt. 2011. Pastoralism within the cadastral system: Seasonal interactions and access agreements between pastoralists and non-pastoralists in Northern Kenya. Journal of Arid Environments 75: 477–486. doi:10.1016/j.jaridenv.2010.12.011.

Levine, S. 2010. What to do about Karamoja: Why pastoralism is not the problem but the solution. A food security analysis of Karamoja. A report to FAO/EU. Available from: http://www.celep.info.

Lynn, S. 2010. The pastoral to agro-pastoral transition in Tanzania: Human adaptation in an ecosystem context. Report to the Global Climate Adaptation Partnership. Available from: www.economics-of-cc-in-tanzania.org. Accessed on 4th March, 2013.

McAllister, RR, IJ Gordon, MA Janssen, and N Abel. 2006. Pastoralists' responses to variation of rangeland resources in time and space. Ecological Applications 16(2): 572–583.

Mogamat, IS. 2013. Pastoral mobility in a variable environment. PhD Thesis, University of Cape Town. Available from: http://uctscholar.uct.ac.za/PDF/100412_Samuels_MI.pdf. Accessed on 28th December, 2013.

Mubiru, DN. 2010. Climate change and adaptation options in Karamoja. A report submitted to FAO/EU.. Available from: http://www.fao.org/fileadmin/user_upload/drought/docs/1_Karamoja%20Climate%20Change%20and%20Adaptation%20Options.pdf. Accessed on 4th March, 2013.

Mubiru, DN, E Komutunga, A Agona, A Apok, and T Ngar. 2012. Characterising agrometeorological climate risks and uncertainties: Crop production in Uganda. South African Journal of Science 108: 3/4. http://dx.doi.org/10.4102/sajsv108i3/4.470.

Musiitwa, F, and ET Komutunga. 2001. Agricultural systems. In Agriculture in Uganda, vol. 1, ed. JK Mukiibi, 220–230. Kampala: Fountain Publishers.

Namgay, K, J Millar, R Black, and T Samdup. 2013. Transhumant agro-pastoralism in Bhutan: Exploring contemporary practices and socio-cultural traditions. Pastoralism: Research, Policy and Practice 3: 13. http://www.pastoralismjournal.com/content/3/1/13.

Nelson, F. 2012. Natural conservationists? Evaluating the impact of pastoralist land use practices on Tanzania's wildlife economy. Pastoralism: Research, Policy and Practice 2: 15. http://www.pastoralismjournal.com/content/2/1/15.

Njiru, BN. 2012. Climate change, resource competition, and conflict amongst pastoral communities in Kenya. In Climate change, human security and violent conflict, 513–527. Berlin Heidelberg: Springer.

Nkedianye, D, J de Leeuw, JO Ogutu, MY Said, TL Saidimu, SC Kifugo, DS Kaelo, and RS Reid. 2011. Mobility and livestock mortality in communally used pastoral areas: The impact of the 2005–2006 drought on livestock mortality in Maasai land. Pastoralism: Research, Policy and Practice 1: 17. http://www.pastoralismjournal.com/content/1/1/17.

Notenbaert, A, P Thornton, and M Herrero. 2007. Livestock development and climate change in Turkana district, Kenya. International Livestock Research Institute, Discussion Paper No. 7. Available from: https://cgspace.cgiar.org/handle/10568/575.

O'Flaherty, RM, IJ Davidson-Hunt, and M Manseau. 2008. Indigenous knowledge and values in planning for sustainable forestry: Pikangikum First Nation and the Whitefeather Forest Initiative. Ecology and Society 13(1): 6. http://www.ecologyandsociety.org/vol13/iss1/art6/.

Oba, G. 1998. Effects of excluding goat herbivory on *Acacia tortilis* woodland around pastoralist settlements in northwest Kenya. Acta Oecologica 19(4): 395–404.

Oba, G. 2012. Harnessing pastoralists' indigenous knowledge for rangeland management: Three African case studies. Pastoralism: Research, Policy and Practice 2: 1. http://www.pastoralismjournal.com/content/2/1/1.

Oba, G, and LM Kaitira. 2006. Herder knowledge of landscape assessments in arid rangelands in northern Tanzania. Journal of Arid Environments 66(1): 168–186. doi:10.1016/j.jaridenv.2005.10.020.

Oba, G, and DG Kotile. 2001. Assessments of landscape level degradation in southern Ethiopia: Pastoralists versus ecologists. Land Degradation & Development 12(5): 461–475.

Ouédraogo-Koné, S, CY Kaboré-Zoungrana, and I Ledin. 2006. Behaviour of goats, sheep and cattle on natural pasture in the sub-humid zone of West Africa. Livestock Science 105(1): 244–252.

Pinzon, J, ME Brown and CJ Tucker. 2005. Satellite time series correction of orbital drift artifacts using empirical mode decomposition. Hilbert-Huang transform: Introduction and applications. N. Huang: Chapter 10, part II. Applications.

Polfus, JL, K Heinemeyer, and M Hebblemewhite. 2014. Comparing traditional ecological knowledge and western science woodland caribou habitat models. The Journal of Wildlife Management 78(1): 112–121. doi:10.1002/jwmg.643.

Rahman, AR. 2002. Seasonal availability and utilization of feed resources and their impact on the nutrition of livestock in an agro-pastoral system of the Hindu Kush–Karakoram–Himalayan region of Pakistan. PhD thesis, University of Aberdeen, UK.

Reed, MS, AJ Dougill, and TR Baker. 2008. Participatory indicator development: What can ecologists and local communities learn from each other? Ecological Applications 18: 1253–1269.

Reid, A, K Teamey, and J Dillon. 2002. Traditional ecological knowledge for learning with sustainability in mind. Trumpeter, 18, No. 1. Available from: http://trumpeter.athabascau.ca/index.php/trumpet/article/view/124/136. Accessed on 11 h April, 2011.

Rugadya, M, E Obaikol, and H Kamusiime. 2005. Critical pastoral issues and policy statements for the National Land Policy in Uganda. Land Research Series, No. 5, 1–27. Kampala, Uganda: Associates for Development. ISBN 9970 889 00 7.

Ruiz-Mallen, I, and E Corbera. 2013. Community-based conservation and traditional ecological knowledge: Implications for social-ecological resilience. Ecology and Society 18(4): 12. http://dx.doi.org/10.5751/ES-05867-180412.

Rutagwenda, T, M Lechner-Doll, H Schwartz, W Schultka, and W Von-Engelhardt. 1990. Dietary preference and degradability of forage on a semiarid thorn-bush savanna by indigenous ruminants, camels and donkeys. Animal Feed Science and Technology 31: 179–192.

Saha, S, S Moorthi, H LuPan, X Wu, J Wang, and S Nadiga. 2010. The NCEP climate forecast system reanalysis. Bull. American Meteorological Society 91: 1015–1057. http://dx.doi.org/10.1175/2010BAMS3001.1.

Sanon, HO, C Kaboré-Zoungrana, and I Ledin. 2007. Behaviour of goats, sheep and cattle and their selection of browse species on natural pasture in a Sahelian area. Small Ruminant Research 67(1): 64–74.

Schwartz, HJ. 2009. Forage trees and shrubs – integrating livestock production and landscape rehabilitation. Nairobi, Kenya: World Congress of Agroforestry 2009. Available from: http://amor.cms.hu-berlin.de/~h1981d0z/pdf/2009-09-kenia/icraf-schwartz.pdf. Accessed 28th July, 2012.

Seaquist, JW, T Hickler, L Eklundh, J Ardö, and BW Heumann. 2009. Disentangling the effects of climate and people on Sahel vegetation dynamics. Biogeosciences 6(3): 469–477.

Selemani, IS, LO Eik, O Holand, T Adnoy, E Mtengeti, and D Mushi. 2012. The role of indigenous knowledge and perceptions of pastoral communities on traditional grazing management in north-western Tanzania. African Journal of Agricultural Research 7(40): 5537–5547. doi:10.5897/AJAR12.1468.

Senay, GB, NM Velpur, H Alemu, S Md Pervez, KO Asante, G Kariuki, A Taa, and J Angerer. 2013. Establishing and operational waterhole monitoring system using satellite data and hydrologic modelling: Application in the pastoral regions of East Africa. Pastoralism: Research, Policy and Practice 3: 20. http://www.pastoralismjournal.com/content/3/1/20.

Singh, NJ, YV Bhatnagar, N Lecomte, JL Fox, and NG Yoccoz. 2013. No longer tracking greenery in high altitudes: Pastoral practices of Rupshu nomads and their implications for biodiversity conservation. Pastoralism: Research, Policy and Practice 3: 16. http://www.pastoralismjournal.com/content/3/1/16.

Society for Ecological Restoration. 2014. TEK and Western Science. IPRN Indigenous People's Restoration Network. Available from: http://www.ser.org/iprn/traditional-ecological-knowledge/tek-western-science. Accessed on 5th February, 2014.

Sop, TK. 2012. Local perceptions of woody vegetation dynamics in the context of a "greening Sahel": A case study from Burkina Faso. Nairobi, Kenya: IUFRO-FORNESSA Regional Congress and ITTO/AFF Forest Policy day. Available from: www.fornis.net/system/files/local_perceptions-Tene%20SOP.pdf. Accessed on 3rd February, 2014.

Stites, E, D Akabwai, D Mazurana and P Ateyo. 2007. Angering Akujù: Survival and suffering in Karamoja. A report on livelihoods and human security in the Karamoja region of Uganda. Tufts University. Available from: http://reliefweb.int/report/uganda/angering-akuj%C3%B9-survival-and-suffering-karamoja. Accessed on 28th December, 2013.

Stringer, LC, and MS Reed. 2007. Land degradation assessment in Southern Africa: Integrating local and scientific knowledge bases. Land Degradation & Development 18(1): 99–116. doi:10.1002/ldr.760.

Sulieman, HM, and AG Ahmed. 2013. Monitoring changes in pastoral resources in eastern Sudan: A synthesis of remote sensing and local knowledge. Pastoralism: Research, Policy and Practice 3: 22. http://www.pastoralismjournal.com/content/3/1/22.

Sulieman, HM, and NA Elagib. 2012. Implications of climate, land use and land-cover changes on pastoralism in eastern Sudan. Journal of Arid Environments 85: 132–141. doi:10.1016/j.jaridenv.2012.05.001.

Sulieman, HM, MF Buchroithner, and MM Elhag. 2012. Use of local knowledge for assessing vegetation changes in the southern Gadarif region, Sudan. African Journal of Ecology 50(2): 233–242. doi:10.1111/j.1365-2028.2011.01318.x.

Tabuti, JRS, and KA Lye. 2009. Fodder plants for cattle in Kaliro district, Uganda. African Study Monographs 30(3): 161–170.

Temesgen, AK. 2010. The impact of environmental and political influences on pastoral conflicts in Southern Ethiopia. A paper presented at the conference on climate change and security 21st–24th June, 2010. Trondheim, Norway. Available from: http://www.eldis.org/go/home&id=55522&type=Document#.Vg_xeVFqud8. Accessed on 28th December, 2013.

Thomas, DSG, and C Twyman. 2004. Good or bad rangeland? Hybrid knowledge, science, and local understandings of vegetation dynamics in the Kalahari. Land Degradation and Development 15: 215–231. doi:10.1002/ldr.610.

Tubiello, FN, JF Soussana, and SM Howden. 2007. Crop and pasture response to climate change. Proceedings of the National Academy of Sciences 104(50): 19686–19690.

Tucker, CJ, JE Pinzon, ME Brown, D Slayback, EW Pak, R Mahoney, E Vermote, and N El Saleous. 2005. An extended AVHRR 8-km NDVI data set compatible with MODIS and SPOT vegetation NDVI data. International Journal of Remote Sensing, in press.

Vinyeta, K, and K Lynn. 2013. Exploring the role of traditional ecological knowledge in climate change initiatives. United States Department of Agriculture (USDA): Notes. Available from: http://www.fs.fed.us/pnw/pubs/pnw_gtr879.pdf. Accessed on 4th February, 2014.

White, PCL, NV Jennings, AR Renwick, and NHL Baker. 2005. Questionnaires in ecology: a review of past use and recommendations for best practice. Journal of Applied Ecology 42: 421–430. http://dx.doi.org/10.1111/j.1365-2664.2005.01032.x.

Xu, J, E Grumbine, A Shrestha, M Eriksson, X Yang, Y Wang, and A Wilkes. 2009. The melting Himalayas: Cascading effects of climate change on water, biodiversity, and livelihoods. Conservation Biology 23: 520–530.