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Rangeland forage availability and management in times of drought — A case study of pastoralists in Afar, Ethiopia

Anna C. Treydte [a, b, *], Andrea Schmiedgen [a], Gebreyohannes Berhane [c], Kidanie D. Tarekegn [d]

[a] Agroecology in the Tropics and Subtropics, University of Hohenheim, Germany
[b] Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania
[c] Veterinary Medicine and Agriculture, Addis Ababa University, Ethiopia
[d] Werer Agricultural Research Center, EIAR Addis Ababa, Ethiopia

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ABSTRACT

Many Eastern African rangelands comprise marginal land, where climatic conditions are poor, access rights are increasingly limited, and land degradation is progressing. We conducted participatory land use mapping and vegetation assessment to identify the most important rangeland locations and their condition in Afar, Ethiopia. Further, we conducted 79 interviews across six villages to assess pastoralist adaptation strategies during drought times. In the dry season, livestock feed resources represented rangelands far away from the village (in 76% of the cases) while 50% and 40% of pastoralists also used cake concentrates and crop residues, respectively. During the wet season, rangeland resources close to villages, albeit with rather low herbaceous cover (<25%), contributed 80% to livestock forage. In times of severe drought, migrating with livestock was the most common (70%) adaptation, in combination with purchasing feed (50%) while <40% of the pastoralists sold or slaughtered animals. Afar pastoralists applied little conservation and mitigation methods, most commonly they removed livestock pressure to allow the pasture to recover. Overall, pastoralists in Afar still strongly depended on natural rangelands and their resources. Hence, to manage these sustainably a monitoring scheme must urgently be established for investigating rangeland quality and resilience to drought and grazing pressure.

1. Introduction

Marginal land is difficult to cultivate and threatened by desertification and soil erosion worldwide (Izzo et al., 2013; Mandal and Sharda, 2013; Zhao et al., 2013). While the demand for livestock products is increasing globally (McMichael et al., 2007), rangelands are degrading across the world due to poor rangeland management (e.g., Vetter and Bond, 2012; Li et al., 2013). Degradation and large cattle herds representing wealth to the livestock herder community have rapidly diminished grazing resources, for example in Ethiopia, South Africa and Argentina (Tadesse, 2001; Bennett et al., 2012; Kröpfl et al., 2013). With high grazing pressure in drylands, nutritious grass species are disappearing and soil erosion and compaction often prevent fresh grass re-growth (e.g., Markakis, 2003; Palacio et al., 2014). Additionally, climatic conditions have worsened over the last decades; in the Afar region of Ethiopia, unpredictable rainfall and increasing drought intervals have had strong impact on livestock numbers, pastoralists' health and food security (USAID, 2011). The result has been a severe decline, particularly of breeding females, in herd size due to die-off (Angassa and Oba, 2007; Headey et al., 2012). Further, less than 2% of the land encompasses agricultural fields that can also supply crop residues for animal forage — and, thus, a semi-nomadic pastoralism prevails (ANRS, 2010). Additionally, this region has been challenged by various conflicts between different clans and tribes (e.g., Reuveny, 2007), rendering access to grazing lands and movement patterns increasingly difficult. Another problem is the rapid spread of invasive non-palatable plant species such as *Prosopis juliflora*, occupying large areas of the grazing lands (Rettberg and Müller-Mahn, 2012; Treydte et al., 2014). These phenomena

* Corresponding author. Agroecology in the Tropics and Subtropics, University of Hohenheim. Germany.
E-mail addresses: anna@treydte.com (A.C. Treydte), spondrea@gmx.net (A. Schmiedgen), g.berhane216@yahoo.com (G. Berhane), kdessalegn@yahoo.com (K.D. Tarekegn).

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have led to undernourished livestock and a non-sustainable use of vegetation resources, making a further adaptation to drought and climatic change even more difficult. Pastoralists who have adapted their lifestyle to the dry environment in the Afar region for centuries are facing ever more difficult environmental and social conditions.

Opportunistic movements of livestock and trading grazing rights have been reported as adaptation strategies to drought in Africa (e.g., Swallow, 1994; Goodhue et al., 2005) and Australia (McAllister, 2012). The question remains whether supplementary feeding or rather conservative stocking rates are good adaptation strategies (Scoones, 1992; Aklilu and Wekesa, 2002; McAllister, 2012) and whether these strategies apply to Afar pastoralists. Despite various studies on pastoralism and drought consequences in Ethiopia (Abule et al., 2005a; Angassa and Oba, 2007; Hassen, 2008), little research has been done on the availability and use of natural resources, i.e., herbaceous and woody vegetation, for livestock in the Afar region. In Botswana, forage alternatives during drought times consisted of crop residues, commercial feed or even alternative income sources (Mogotsi et al., 2013) whereas not much is known about these alternatives in the Afar region. We expected that, due to the nomadic nature of pastoralists in Afar, alternative food resources such as crop residues, cake or hay storage are barely available for livestock in drought times. Therefore, we hypothesize that *during both non-drought and drought years, the main forage resource for livestock in the Afar region will consist of natural herbaceous and woody vegetation, i.e., grass and browse.*

Further, livestock composition and movement patterns have rarely been documented for the Afar region (Sonneveld et al., 2009). The forage availability in rangelands will determine where grazing and browsing patches are located. In general, one would expect that the availability of forage species is closely linked to the livestock preference; we wanted to test this so-called "ecological apparency hypothesis" (*sensu* Lucena et al., 2012). We expected that the demand for forage species by livestock, as stated by the pastoralists, would, therefore, resemble the relative abundance of the species in the rangeland. We therefore hypothesized that *the availability of forage plant species will show parallel patterns with the demand by the different livestock species.*

Further, vegetation status, i.e., low forage biomass production, has usually been used as indicators of a drought approaching by farmers in Botswana (Mogotsi et al., 2013). If pastoralists in Afar also use this indicator, we would expect that a *decrease in herbaceous vegetation biomass will lead pastoralists to use alternative forage resources or rangelands further away from their village*.

During a severe drought, it has been reported that livestock numbers drastically decline – pastoralists watch livestock die and little is done to reduce herd numbers by selling livestock (Kebebew et al., 2001; Angassa and Oba, 2007). This reduction of livestock populations can lead to an unintended resting period, which helps the landscape to recover (Müller et al., 2007). Further, cattle performance seems to be strongly related to rainfall, impacting grass biomass and composition in combination with long-term overgrazing (Fynn and O'Connor, 2000). We hypothesized that, *during severe drought, supplemental feed is provided only rarely and herds are not reduced in advance.*

Resting periods of the vegetation, particularly under adequate precipitation, have been shown to be crucial in Namibia (Müller et al., 2007). While agro-pastoralists and small-scale farmers in Ethiopia have established soil and water conservation and irrigation mechanisms to cope with drought (e.g., Awulachew et al., 2005; Beyene, 2009) conservation and mitigation strategies against drought by pastoralists, who are constantly on the move, are largely unknown. We expected that *rangeland conservation and restoration measures are rarely conducted by Afar pastoralists*.

Various studies have included the perception of the environment through local communities (Nabahungu and Visser, 2013; Özgüner et al., 2013). Our research focused on an assessment of the availability and management of rangeland forage resources by pastoralists in Afar. We further wanted to assess the current vegetation in the differently used rangeland regions (grazing and browsing sites), including vegetation cover, species diversity and the abundance of preferred and palatable plant species. We also investigated how Afar pastoralists react to severe drought and whether they use conservation methods to restore natural resources in their pasture lands. To answer these questions, we used interviews and conducted vegetation analyses in the field in combination with secondary data on livestock numbers and type.

2. Materials and methods

2.1. Study area

Our study was carried out at representative sites for the Afar region: study sites were located in and around six villages in the Chifra, Awra and Ewa districts (Table 1), where natural resources have recently experienced environmental and human induced stresses (ACCRA, 2012).

All districts face similar climatic challenges such as increasing temperatures and erratic rainfall patterns followed by other trends such as human population growth and rangeland degradation (ACCRA, 2012). The Afar regional state, located in northeastern Ethiopia, covers about 270,000 km^2 (CSA, 2008). It consists of five administrative zones (sub-regions), 32 districts, 28 towns, and 401 rural and urban villages (Fig. 1).

About 15% of the total land area of the Afar region is covered by grassland, 32% is shrubland, 2% represents woodland and <1% remaining forest areas while the vast area of the region (50%) is covered by exposed soil, sand or rock (Bureau of Finance and Economic Development, 1999). The region is characterized by arid and semi-arid climatic conditions with mean annual rainfall of 150–500 mm. The main rains (60% of annual rainfall) fall in June–September while short rainy showers occur in December and during March–April (Fig. 2).

Out of a population of roughly 1.4 million people, around 87% reside in rural areas, being mainly dependent on pastoral and agro-pastoral livelihood systems (CSA, 2008). Livestock species in the Afar region were mainly composed of cattle, goat, camels and sheep (Tilahun and Schmidt, 2012), varying strongly across regions (Table 1). The estimated number of cattle per household ranges from 7 to 10 and that of goat and sheep >10, while the overall number of livestock is still rising (Tilahun and Schmidt, 2012).

2.2. Study design

2.2.1. Interviews and vegetation survey

Interviews and vegetation assessment were conducted from October to November 2013, at the beginning of the dry season (Fig. 2). After meeting with the responsible Pastoralist Offices of each district, the villages were chosen based on their accessibility and nearby grazing area location. Semi-structured questionnaires were used to receive qualitative and quantitative data on pastoralist knowledge about livestock management and rangeland condition during drought periods. The questionnaires were in English and translated into Afar with the help of interpreters. In each of the three districts 9 to 15 households within two villages were examined. Households were chosen randomly with the agreement of the chairman and elders of each village. In total, 79 interviews were conducted; all of the respondents were livestock owners. The number of female and male interviewees was 15 and 64,

Table 1
Number of each livestock species, total livestock population, land area and livestock densities (in tropical livestock units/TLU) across the three study sites Chifra, Ewa and Awra (oral and written information, 2013).

	Number of livestock				Total livestock (TLU[a])	Land area (ha)	Livestock density (TLU/ha)
	Camel	Cattle	Goat	Sheep			
Chifra	126,340	252,316	306,720	324,286	366,062	333,300	1.1
Ewa	47,809	225,525	145,220	196,013	239,800	123,700	1.9
Awra	11,000	25,000	122,996	122,996	53,099	309,600	0.2

[a] TLU = Tropical Livestock Unit (an animal of 250 kg live weight).

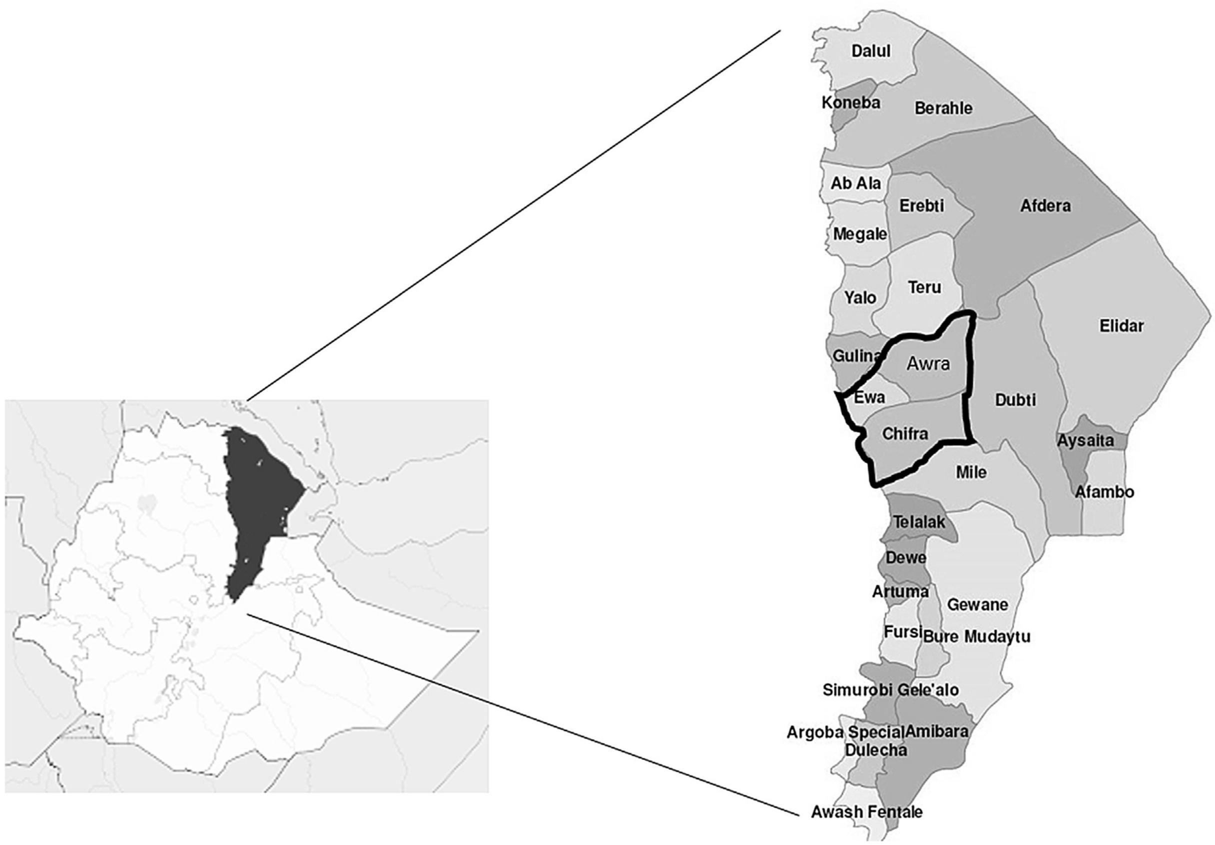

Fig. 1. Study site (Afar region) in northern Ethiopia – the three districts Awra, Ewa and Chifra, are shown.

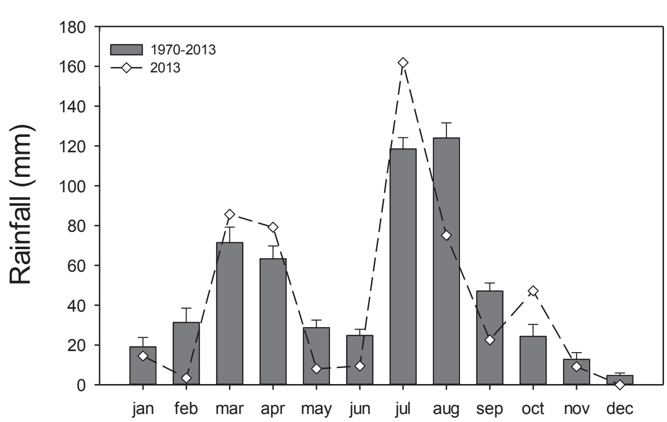

Fig. 2. Average annual rainfall (±SE) from 1970 until 2013 and current rainfall of the year 2013 (Werer Agricultural Research Center, 2013; unpublished report).

respectively; their age ranged from 20 to 82 years.

Vegetation was assessed using a participatory approach. For our land use mapping, interviewees and village elders highlighted the most important rangeland sites (including grazing and browsing pasture types) located nearby the village (<15 km away). We defined the selected pasture type as "grazing sites", i.e., areas for grazing livestock species such as cattle, sheep and goat, which mainly consisted of grasslands interspersed with bushes or trees. "Browsing sites", dominated by woody vegetation, were mainly located along riverine areas and were used for browsing livestock species such as camel and goats. All rivers or streams visited in each district were seasonal, drying out during dry periods of the year. In total, we surveyed six grazing and six browsing sites. At each grazing site, along a 2 km transect, three quadrants were laid out perpendicular to the transect line, 20 m apart from each other to avoid spatial autocorrelation (Legendre, 1993). Quadrants were 1×1 m^2 in size as vegetation cover was generally low and rather uniform. The three quadrants were located every 500 m along the transect. Within these twelve quadrants herbaceous species abundance (adapted to Braun-Blanquet, 1964), cover and life form were assessed to provide a measure of availability of certain species in the rangelands. Grazing sites were bare of trees and, therefore, woody vegetation assessment was neglected at these sites. At the browsing sites, mostly riverine areas, one transect of 500 m each was established along a seasonally dry river bed. Along this transect, the woody vegetation was mapped within two plots of 20 m × 20 m each at every 100 m. Woody and herbaceous species and their abundance were determined with the help of local experts who comprised pastoralists selected by the community of the study districts who was highly knowledgeable in species identification based on local (indigenous) plant names, purposes and seasonal availability, researchers and ecologists (from various Universities and Research Centers), agricultural development agents of each study district, as well as literature (Seifu, 2004; ESGPIP, 2009; Van Oudtshoorn, 2009). Plant species available at each site were then compared to interview information, in which pastoralists were asked to name up to six preferred foraging herbaceous and woody vegetation species.

Interviews investigated the number of livestock as well as differences in the distance herders would walk with their livestock in dry and wet years in order to find forage. The number of livestock per domestic animal species differed slightly across districts (Table 1), with Chifra having almost twice and five times as much total livestock compared to Ewa and Awra, respectively. Goats and sheep dominated in Chifra and Awra while cattle were most abundant in Ewa. Despite their similar size, Awra had a three times lower average livestock density compared to Chifra while Ewa livestock density was highest with 1.9 TLU/ha (Table 1).

2.3. Data analysis

The frequency of mentioning forage resources during dry and the wet season was compared using paired t-tests across all districts. All quadrants and plots were treated as independent samples. Plant species availability vs demand was tested using a X^2 test. The relations between the herbaceous vegetation cover and the interview data on alternative forage or using rangelands away from villages were tested using one-way analysis of variance ANOVA. To obtain the minimal adequate models, predictor variables/fixed effect terms were removed from the maximal model by stepwise backward selection and using the F-statistic (Crawley, 2013). Correlation of herbaceous cover (arcsin sqrt(x) transformed) and livestock numbers (Pastoralists Office, 2013) were tested by Pearson correlation (Revelle, 2014). Descriptive statistics compared the strategies of pastoralists to cope with drought, involvement in conservation and restoration practices across the different study sites. To compare expected vs observed use of rangeland and browsing sites under varying herbaceous vegetation cover X^2 tests were used. Linear Models (LM) were applied using the package (nlme) in R (version R 2.6.2; R Development Core Team, 2008). Significance level for all analysis was set at $P < 0.05$.

3. Results

3.1. Natural forage resources for livestock

Resources fed to livestock during the dry season, in addition to using the natural pasture land, were similar across the three districts. Generally, a large part was comprised of rangeland sites far away, i.e., more than 20 km of travelling distance, from the village and crop residues contributed to less than 20% while "cake" was also an option considered in about 10% of the cases. For all villages combined, browsing resources were the most important additional feed resources during the dry season, mentioned in 72 cases, as well as grazing sites outside the villages (76 cases), crop residues and cake (41 and 47 cases, respectively); the latter three were barely (<10 cases) mentioned during the wet season (Table 2).

Grass resources inside the village were about seven times more frequently, used during the wet season than during the dry season ($t = 18.82$, $P = 0.003$). In contrast, during the dry season, the rangeland resources outside of the villages were used eight times more frequently than those inside the villages ($t = -8.74$, $P = 0.012$). Crop residues, cake and browse were 14, 15 and 12 times more frequently used in the dry than in the wet season ($t = -5.17$, $P = 0.035$; $t = -8.69$, $P = 0.013$; $t = -7.94$, $P = 0.015$, respectively). Hay stores as forage supply were only mentioned by two pastoralists, and in Chifra roadsides were used in only six cases for grazing.

Woody cover ranged between 38% and 76% but did not differ strongly across village rangeland sites. Herbaceous total cover was with 42% and 23% highest in the rangeland adjacent to the villages Mesgid (Chifra) and Buti (Ewa), respectively. As reported in Table 3, the herbaceous vegetation was dominated by grasses (about 90% of the entire cover) and overall cover was positively correlated with grass abundance ($R^2 = 0.81$, $\beta = 0.75$).

Lowest herbaceous cover (<10%) was found close to the villages Badoli (Ewa), Deraitu (Awra) and Tagri (Chifra). Overall, grass species richness was low with 8 species on average, 3 of which were found in Ewa, 4 in Awra and 7 in Chifra. The lowest number - only two - of grass species were found in Badoli (Ewa), Hida (Awra) and Tagri (Chifra).

The locations of the various livestock species within the pastoral landscape varied slightly but not significantly during the dry season. Forest areas were particularly preferred in Awra and Ewa, and mainly camel and goats were taken there to feed. In Ewa, the forage locations were often close to a river for all livestock species during the dry season (data not shown).

3.2. Demand and availability of forage plant species

The preferred plant species of the different livestock species as mentioned by the pastoralist community were similar for the grazing animals, cattle and sheep, except for *Panicum coloratum* L., being preferred by cattle and *Ipomoea sinensis* (Desr.) chosen by sheep (Table 4).

The browsing or mixed feeders, camel and goat, also preferred similar species (Table 4). Except for *Brachiaria eruciformis* (J.E. Sm.) Griseb., which matched the grazing livestock preference and availability quite well (Table 4), demand and availability was highly incompatible for the other species ($X^2 = 192.4$, $df = 5$, $P < 0.001$). The same was true for browsing livestock, while *Salvadora persica* availability matched demand, the other species were much less abundant than would have been expected based on demand

Table 2
Feed resources in the wet and dry season used by pastoralists for their livestock. Data show the number of responses of the interviewed pastoralists (n = 79). Multiple answers (combinations of different strategies) were possible.

	Wet season	Dry season
Grassland close to village	79	11
Grassland far away from village	10	76
Crop residues	2	41
Cut and carry	0	2
Cake	1	47
Hay store	0	2
Browse	7	72
Purchased feed	0	18
Along roadsides	1	7
Other	0	0

Table 3
Mean cover values (%) of the herbaceous layer (divided into annual grasses, perennial grasses and forbs), woody cover and the bare ground cover of each village at the district level. All cover was estimated visually.

District	Village	Cover in %				
		Bare ground	Perennial	Annual	Forbs	Woody
Chifra	Mesqid	20	25	13	4	58
	Tagri	90	1	0	8	78
Awra	Deraitu	88	0	5	1	58
	Hida	31	0	15	1	38
Ewa	Buti	44	3	19	2	38
	Badoli	2	0	1	1	60

was visible for the total grass alone ($X^2 = 7.7$, $df = 1$, $P < 0.01$) and the perennial grass cover ($X^2 = 108.3$, $df = 1$, $P < 0.01$) versus livestock numbers. The walking distance of camels to the rangelands increased significantly with the number of animals per hectare ($F_{1,28} = 5.32$, $P = 0.029$) whereas the other livestock species showed no significant correlation. Lower rangeland herbaceous vegetation cover (%) was significantly correlated with higher overall livestock numbers per district ($F_{1,78} = 22.21$, $P < 0.001$). A similar pattern was also observed for the number of cattle per district ($F_{1/26} = 10.21$, $P = 0.004$). Further, a lower vegetation cover was significantly negatively correlated with the walking distance of camels ($F_{1,27} = 4.28$, $P = 0.048$) and slightly negatively correlated with the walking distance of sheep ($F_{1,30} = 3.80$, $P = 0.061$).

Table 4
Demand (in %) of the five most preferred herbaceous plant species of the pastoralists for cattle, sheep, camel and goat and their present availability (average % cover of the total vegetation cover) for Chifra, Awra and Ewa combined. Woody and herbaceous species and their abundance were determined with the help of local experts and plant species availability at each site was then compared to interview information, in which pastoralists were asked to name up to six preferred foraging herbaceous and woody vegetation species.

	Demand		Available
	Cattle	Sheep	% cover
Durfu (*Chrysopogon plumulosus* Hochst.)	27	25	3
Musa (*Brachiaria eruciformis* (J.E. Sm.) Griseb.)	25	24	54
Melif (*Andropogon canaliculatus* Schumach.)	23	21	0
Bunket (*Tribulus terrestris* L.)	14	17	3
Denekto (*Panicum coloratum* L.)	11	0	1
Halal (*Ipomoea sinensis* (Desr.) Choisy)	0	13	0
	Demand		**Available**
	Camel	**Goat**	**% cover**
Halal (*Ipomoea sinensis* (Desr.) Choisy)	25	25	0
Bunket (*Tribulus terrestris* L.)	23	30	3
Hdayto	22	25	4
Adayto (*Salvadora persica* L.)	25	0	27
Madera	15	11	11
Aytodoyta (*Tetrapogon tenellus* Chiov.)	0	9	–

($X^2 = 83.4$, $df = 5$, $P < 0.001$).

3.3. Decreasing herbaceous vegetation biomass and alternative forage resources

Correlating interview data as presented in Table 2 with field data on vegetation cover, we observed that during dry times, with decreasing herbaceous cover there was a non-significant tendency for herders to use the foraging alternatives, e.g., crop residues for their livestock ($r = -0.23$, $P = 0.66$). The vegetation/perennial grass abundance at the main rangeland site and the number of pastoralists taking livestock to grazing far away from the village was significantly negatively correlated; the use of grazing/browsing land away from the village increased with a decreasing total herbaceous vegetation cover ($X^2 = -10.5$, $df = 1$, $P < 0.01$), a decreasing perennial grass cover ($X^2 = -0.44$, $df = 1$, $P < 0.001$) and a decreasing total grass cover ($X^2 = -0.27$, $df = 1$, $P < 0.01$) at the main rangeland site. The structure of the surrounding browsing area influenced the feed resources of the pastoralists for their livestock. When comparing interview results of browsing site use with our field data on woody vegetation cover for each browsing site, the pastoralists used dense woody vegetation sites less often than sites with more open vegetation (for all livestock combined: $r = -0.74$, $P = 0.001$). In less than 12% of the cases pastoralists led their livestock to areas covered by >55% woody cover.

The total herbaceous layer, i.e. grasses and herb cover combined, significantly decreased with increasing livestock numbers on the rangeland ($X^2 = 22.2$, $df = 1$, $P < 0.001$). A similar statistical relation

3.4. Strategies in times of severe drought

Strategies of the pastoralists to avoid livestock losses during severe drought were predominantly (in 69 cases) moving with their herds to different foraging grounds (Fig. 3).

Further, pastoralists claimed to purchase feed (46 cases), sell (37 cases) or slaughter (31 cases) their animals in times of drought. Thirteen pastoralists declared that they do not have any strategy for their livestock in times of drought and 13 claimed that they reduce

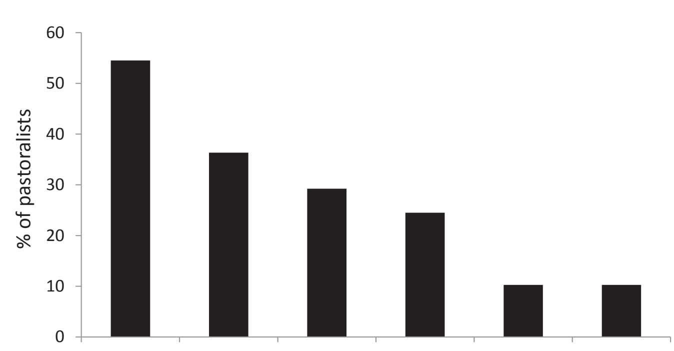

Fig. 3. Strategies of the pastoralists during severe drought. Multiple answers were possible, n = 79.

the livestock herd numbers through selling, mainly the grazer livestock species, in times of drought. Generally, pastoralists noted that drought events have become more severe, frequent, and longer in the recent years. Consequently, they emphasized their need to adapt to the drought events through strategies mentioned in our study.

3.5. Conservation and restoration practices

One of the most common methods to conserve important grazing lands was to build soil terraces against erosion (for 41 pastoralists). Soil terraces were mainly established in Awra (in 18 cases) while other conservation activities such as tree and legume planting were conducted, albeit on a small scale, in Chifra (in 3 cases). Almost a third (25 cases) of the pastoralists claimed that they let the pasture rest for a duration of one month after intensive use by cattle and sheep (Table 5). Further, 22% of the pastoralists interviewed migrated to a different region, sometimes covering several districts, for about 2.5 months. The distances covered for this migration varied greatly between 1 and 120 km and were on average for herds of camels 12 km, cattle 14 km, goats 6 km, and sheep 8 km.

However, this did not necessarily mean that the land from which they moved was at rest during this time as it was likely used by other herders. Few (4 cases) pastoralists claimed that they use enclosures to let rangeland parts rest while none practiced cut and carry or irrigation activities to maintain or restore rangeland resources. A conservation activity such as reseeding was done by only one pastoralist.

4. Discussion

4.1. Natural forage resources for livestock

Natural resources, particularly rangelands, still provide the largest proportion of forage for livestock in the Afar region. In the past, the lack of rain has had a severe impact on the availability of pasture and water as well as the overall food security situation of the pastoral and agro-pastoral communities (PARDB, 2007; ANRS, 2010). The pasture quality at the time of the study visit was rather poor: a low ground coverage of the herbaceous layer (<25%) at most sites highlights how dry and overgrazed conditions prevail in Afar, even shortly after the rainy season. Overgrazing in combination with droughts has been shown to decrease herbaceous ground cover heavily, with low chances of recovery (Breman and de Wit, 1983). The herbaceous layer of our assessed rangelands was strongly utilized by livestock (on average, >90% of herbaceous vegetation in our 1×1 m^2 quadrats were grazed), even shortly after the rains. Further, grass species richness was rather low, mainly dominated by *B. eruciformis*, an annual grass species of good fodder value (Myalyosi, 1992). Movement distances of pastoralists with their livestock herds differed strongly across seasons, crossing various clan borders in the dry season; the location of grazing and browsing sites were well known within the pastoral communities as is the long-term pastoralist tradition of migrating (Sonneveld et al., 2009). As expected, rangeland vegetation resources at grazing and browsing sites are still very important for local livelihoods as more than two thirds of the pastoralists claimed that livestock foraging was dependent on the available natural vegetation. This dependency is important to understand drought resilience of pastures as privatization and efforts to settle pastoralists may undermine the current lifestyle and knowledge about resources of pastoralists (Impink and Gaynor, 2010). Using supplemental feeding such as crop residues or cake, practiced in less than 50% of Afar pastoralists, has been shown to have negative effects on the rangeland as it keeps the livestock population artificially high, despite low natural resources (e.g., Illius and O'Connor, 1999;Vetter and Bond, 2012).

4.2. Demand and availability of forage plant species

The pastoralists' knowledge of palatable species availability and good foraging grounds was very detailed and has been passed on over generations. For grazing and browsing livestock, the abundance of and demand for herbaceous species on pastoral rangelands was not congruent. Various preferred fodder grass species have been reported to have drastically declined over the last decades in Afar (Atanga et al., 2013). This mismatch is in contrast to the “ecological apparency hypothesis” (Lucena et al., 2012) stating that abundant perennial species are also the preferred ones. The only match, *B. eruciformis*, is an annual grass species adapted to high grazing pressure while the perennials *Chrysopogon plumulosus* and *Andropgon canaliculatus* were preferred but rarely available. *Chrysopogon plumulosus* was shown to be grazing tolerant (Jacobs and Schloeder, 2002) but reduced in abundance under heavy grazing (Abule et al., 2005b) and is well adapted to drought (Bokhari et al., 1987), which might be a reason why this species was mentioned frequently in our study as preferred species. Although *A. canaliculatus* was also named as a preferred perennial grazing species in Ghana (Blair, 1960), and southern Ethiopia (Tefera et al., 2007) it was not available at our study sites. It might have been present in the past (Atanga et al., 2013), when it was preferred by grazing livestock, but then had declined gradually with increasing grazing pressure on the communal grazing lands (Tefera et al., 2007). Pastoralists noted that the availability of preferred grass species strongly depends on rainfall. The average annual rainfall in 2013 was 516 mm, only slightly lower than the long-term average of 570 mm between 1970 and 2013 (Werer Agricultural Research Center, 2013; unpublished report). Particularly the October rains in 2013 were twice as high (47 mm) as the long-term October rainfall. Hence, we expected that rainfall would not be the limiting factor for grass species presence in general. Preferred browse species were reported to be available even during the dry season and drought periods. Further, the woody vegetation along rivers, which was used as browsing resources, seemed intact with a cover of 50–70%. Woody vegetation is less vulnerable to drought periods compared to the grass layer, particularly if growing close to potential below-ground water resources (e.g., Le Roux et al., 1995).

Table 5
Mitigation, rehabilitation and soil conservation methods for the rangeland areas in the different study districts of Afar as mentioned by pastoralists (in% of cases), n = 79.

	Soil terracing	Migrating	Resting	Enclosure	Herd reduction	Irrigation	Cut & Carry
Awra	18	6	4	2	0	0	0
Chifra	7	4	1	0	1	0	0
Ewa	16	13	15	2	0	0	0
Total	41	22	20	3	1	0	0

4.3. Decreasing herbaceous vegetation biomass and alternative forage resources

A low herbaceous vegetation cover did not necessarily lead to pastoralists using alternative forage such as crop residues or cake for their livestock. However, vegetation cover influenced whether rangelands further away from villages were visited or not. Further, higher livestock densities were associated with lower vegetation cover, indicating that grazing pressure strongly reduced vegetation biomass and cover (Lambin et al., 2001). Low herbaceous plant cover is mainly caused by livestock grazing pressure, which negatively influences plant regrowth and overrides the positive effects that low woody cover or enclosures have on the vegetation (e.g., Good et al., 2013; Treydte et al., 2013). Rangelands with dense woody cover were rarely visited, confirming a low rangeland value of bush-encroached areas as was shown, e.g., in South Africa (Wigley et al., 2009). We did not discover any trends for herd size reduction or a replacement of grazer by browser species, which could have been a potential response to fewer herbaceous layer resources in the districts (e.g. Kassahun et al., 2008; Österle, 2008). Monitoring and resting of vegetation resources, particularly in the wet season, is advisable (Müller et al., 2007) but in our study the resting efficiency was not clear and pastoralists noted that they leave the rangeland only once the vegetation has been in decline. We recommend that vegetation cover is quantified and herbaceous species abundance monitored regularly.

4.4. Strategies in times of severe drought

To cope with drought, moving livestock to neighboring districts and rangelands far away from the village, where grazing resources are available, was the most common practice. Abule et al. (2005a) found that Oromo pastoralists in Ethiopia regarded these migratory movements an undesired practice, which is done only out of necessity. Further, poorer households were shown to have fewer strategies available to adapt to drought (Lybbert et al., 2004), which might explain why we found only few strategies in our study. Less than half of the respondents sold (37 cases) or slaughtered (31 cases) their livestock, while 17 of those did both, to reduce numbers during severe times. This also might cause future livestock population break downs as was shown in the Borana rangelands (Angassa and Oba, 2007). However, these breakdowns, so-called “unintended resting”, might be helping the rangelands to recover (Müller et al., 2007; Martin et al., 2014) rather than keeping livestock numbers artificially high. Purchasing feed and selling or slaughtering animals was also common, albeit in less than 50% of the interviewed pastoralists. The slaughtered animals were mainly the less drought resistant cattle or sheep rather than camels or goats. Further, mothers were saved for future use while calves were often sold or slaughtered as they might not survive severe drought. However, pastoralists also noted that livestock market places were far away from the study area and difficult to access. The lack of sufficient infrastructure that would encourage pastoralists to sell their animals during the drought period was also another constraint mentioned, which has been shown to be a general problem in East African pastoralist communities (McPeak and Barrett, 2001). While emergency market interventions (Morton, 2006), e.g., transport subsidies, have shown potential success, the reduction in livestock numbers still seems the most cost-effective and environmentally sustainable option (Little et al., 2008). Livestock breeding conservation practices of the pastoralists were highlighted as: (1) Selection of drought-tolerant bulls born from productive cows, (2) keeping herds dominated by females and (3) as a post drought herd restoration by purchasing from known stock of relatives or other pastoralists. These findings agree with Barrett et al., 2013 found for northern Kenya that < 30% of female cattle were sold on the market. Markets in northern Kenya and southern Ethiopia were further used only in <10% of the cases to stock up livestock numbers while a herd increase through own breeding strategies was most important (McPeak and Barrett, 2001).

4.5. Conservation and restoration practices

Little effort was conducted to improve the foraging resources or grazing lands, which often has been blamed on lacking land ownership and property rights (Atanga et al., 2013). During the wet season, grazing sites inside the villages were still strongly used, in contrast to suggestions by Müller et al. (2007) who claimed that wet seasons are the most crucial time for resting. This strong utilization might, if no long-term resting period is implemented, contribute to further overgrazing syndromes.

This study combined interview data with vegetation assessment and secondary data on livestock numbers in a dry rangeland ecosystem. The combination of socio-economic and ecological data has long been neglected (White et al., 2005) but is now becoming an increasingly attractive methodology in science (Schnabel et al., 2013). This study was conducted at the end of wet season in the Afar region —it thus only provides a snapshot of the vegetation in grazing and browsing lands. A detailed vegetation assessment study should be conducted over the entire year as some more grass species might be identifiable and cover might change over the year. More detailed movement patterns of livestock herds can be assessed and related to vegetation abundance using GPS collars/following herders over several months (e.g., Sonneveld et al., 2009). However, this study showed that natural rangeland vegetation resources are still strongly used by Afar pastoralists, despite low forage availability and, except for soil terracing conducted by about 50% of the pastoralists interviewed, little is being done to conserve or restore the last remaining natural resources. Drought frequencies will likely increase in times of climate change and will negatively impact livelihoods but Afar pastoralists are not likely to reduce their livestock numbers, which will inevitably lead to further frequent breakdowns of the livestock population (Mogotsi et al., 2013). Additionally, movement patterns will become increasingly limited for pastoralists in the Afar region due to environmental and political developments (Rettberg, 2010). The associated shifts in property rights towards more privatization of land as well as efforts of the government to settle pastoralists have greatly hampered the use of natural resources by pastoralists in the Afar region (Abule et al., 2005a; Piguet, 2007). This development poses that urgent measures of drought adaptation need to be taken, see for example Mekuria and Aynekulu (2013). Crop residues or hay storage as alternative forage might be suitable along rivers and in rather fertile areas of Afar. However, supplemental feed will keep livestock populations unsustainably high, leading to a de-coupling of natural livestock-vegetation cycles, and further accelerating the problem of overgrazing (Illius and O'Connor, 1999; Vetter and Bond, 2012). Thus, resting periods for the vegetation and a slow decrease in livestock numbers, in combination with better market access and land property rights need to be urgently re-evaluated and implemented.

5. Conclusion

This study highlighted adaptation strategies of pastoralists in the Afar region. Overall, pastoralists in Afar still strongly depended on natural rangeland resources for their livestock. Herbaceous vegetation cover was low, plants were strongly grazed, and plant species preferred by livestock were low in abundance. In times of severe drought, migrating with livestock was the most common

(70%) adaptation, followed by purchasing feed and selling/slaughtering animals. While reducing herd sizes would be the most environmentally sustainable option, livestock numbers still represent an important asset to pastoralists. Hence, to manage the remaining resources sustainably a monitoring scheme must urgently be established for investigating rangeland quality and the resilience of ecosystems to drought and grazing pressure. The monitoring should include supervision and management of rangeland resources particularly of feed and water across seasonal variability. This should be done in terms of seasonal feed availability, livestock numbers, and carrying capacity, supported by integrating approaches such as herd management and early warning systems into local adaptation practices. The monitoring scheme should be designed by experts, legalized by policy makers, and implemented by communities under close supervision of the local administration. Further, the provision of market infrastructure and a political and social possibility to quickly adapt to environmental conditions by moving and exploring alternative rangelands will be of high importance in the future.

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References

Abule, E., Snyman, H.A., Smit, G.N., 2005a. Comparisons of pastoralists perceptions about rangeland resource utilisation in the Middle Awash Valley of Ethiopia. J. Environ. Manag. 75, 21–35. http://dx.doi.org/10.1016/j.jenvman.2004.11.003.

Abule, E., Snyman, H.A., Smit, G.N., 2005b. The influence of woody plants and livestock grazing on grass species composition, yield and soil nutrients in the Middle Awash Valley of Ethiopia. J. Arid Environ. 60, 343–358. http://dx.doi.org/10.1016/j.jaridenv.2004.04.006.

Africa Climate Change Resilience Alliance (ACCRA), 2012. Climate Trends in Ethiopia: Summary of ACCRA Research in Three Sites. UK Department for International Development (DFID), London.

Afar National Regional State (ANRS), 2010. Programme of Plan on Adaptation to Climate Change (Semera).

Aklilu, Y., Wekesa, M., 2002. Drought, Livestock and Livelihoods: Lessons from the 1999-2001 Emergency Response in the Pastoral Sector in Kenya. ODI.Humanitarian Practice Network, London.

Angassa, A., Oba, G., 2007. Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia. Agric. Syst. 94, 715–725. http://dx.doi.org/10.1016/j.agsy.2007.02.012.

Atanga, N.L., Treydte, A.C., Birner, R., 2013. Assessing the sustainability of different small-scale livestock production systems in the afar region, Ethiopia. Land 2.4, 726–755. http://dx.doi.org/10.3390/land2040726.

Awulachew, S.B., Merrey, D.J., Kamara, A., Van Koppen, B., Penning de Vries, F.W.T., Seleshi, B., Boelee, E., 2005. Experiences and Opportunities for Promoting Small-scale/Micro Irrigation and Rainwater Harvesting for Food Security in Ethiopia. International Water Management Institute (IWMI), Addis Ababa. Working Paper 98.

Barrett, C.B., Chabari, F., Bailey, D., Little, P.D., Coppock, D.L, 2003. J. Afr. Econ. 12 (2), 127–155. http://dx.doi.org/10.1093/jae/12.2.127.

Bennett, J.E., Palmer, A.R., Blackett, M.A., 2012. Range degra0dation and land tenure change: insights from a “released” communal area of Eastern Cape Province, South Africa. Land Degrad. Dev. 23, 557–568. http://dx.doi.org/10.1002/ldr.2178.

Beyene, F., 2009. Property rights conflict, customary institutions and the state: the case of agro-pastoralists in Mieso district, eastern Ethiopia. J. Mod. Afr. Stud. 47, 213–239. http://dx.doi.org/10.1017/S0022278X09003814.

Blair, I.J., 1960. International development of grazing and fodder resources. Grass Forage Sci. 15, 246–251. http://dx.doi.org/10.1111/j.1365-2494.1962.tb00271.x.

Bokhari, U.G., Alyaeesh, F., Al-Nori, M., 1987. Adaptive strategies of desert grasses in Saudi Arabia. J. Range Manag. 40, 19–22.

Braun-Blanquet, J., 1964. Pflanzensoziologie: Grundzüge der Vegetationskunde. Springer Verlag, Wien.

Breman, H., de Wit, C.T., 1983. Rangeland productivity and exploitation in the Sahel. Science 221, 1341–1347. http://dx.doi.org/10.1126/science.221.4618.1341.

Bureau of Finance and Economic Development, 1999. Regional Atlas of Afar Region (Addis Ababa).

Crawley, M.J., 2013. The R Book. John Wiley & Sons, Chichester.

CSA - Central Statistical Authority, 2008. Summary and Statistical Report of the 2007 Population and Housing Census (Addis Ababa).

Ethiopia Sheep and Goat Productivity Improvement Program (ESGPIP), 2009. A Simple Guide to Identification of Rangeland Plants. Technical Bulletin No.24: Addis Ababa.

Fynn, R.W.S., O'Connor, T.G., 2000. Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. J. Appl. Ecol. 37, 491–507. http://dx.doi.org/10.1046/j.1365-2664.2000.00513.x.

Good, M.K., Schultz, N.L., Tighe, M., Reid, N., Briggs, S.V., 2013. Herbaceous vegetation response to grazing exclusion in patches and inter-patches in semi-arid pasture and woody encroachment. Agric. Ecosyst. Environ. 179, 125–132. http://dx.doi.org/10.1016/j.agee.2013.08.002.

Goodhue, R.E., McCarthy, N., Di Gregorio, M., 2005. Fuzzy access: modeling grazing rights in sub-Saharan Africa. In: Collective Action and Property Rights for Sustainable Rangeland Management. CARPI Research Brief, Washington.

Hassen, A., 2008. Vulnerability to Drought Risk and Famine: Local Responses and External Interventions Among the Afar of Ethiopia, a Atudy on the Aghini Pastoral Community. University of Bayreuth, Bayreuth. PhD thesis.

Headey, D., Seyoum Taffesse, A., You, L., 2012. Enhancing resilience in the Horn of Africa. An exploration into alternative investment options. International Food Policy Research Institute (IFPRI), Addis Ababa, Washington. IFPRI Discussion Paper 01176.

Illius, A.W., O'Connor, T.G., 1999. On the relevance of nonequilibrium concepts to arid and semiarid grazing systems. Ecol. Appl. 9, 798–813. http://dx.doi.org/10.1890/1051-0761.

Impink, E., Gaynor, K.M., 2010. Understanding sustainability through traditional Maasai pastoral systems in Southern Kenya. J. Sustain. Dev. 4, 167–180.

Izzo, M., Araujo, N., Aucelli, P.P.C., Maratea, A., Sánchez, A., 2013. Land sensitivity to desertification in the Dominican Republic: an adaptation of the ESA methodology. Land Degrad. Dev. 24, 486–498. http://dx.doi.org/10.1002/ldr.2241.

Jacobs, M., Schloeder, C., 2002. Defoliation effects on basal cover and productivity in perennial grasslands of Ethiopia. Plant Ecol. 169, 245–257. http://dx.doi.org/10.1023/A:1026081723022.

Kassahun, A., Snyman, H.A., Smit, G.N., 2008. Impact of rangeland degradation on the pastoral production systems, livelihoods and perceptions of the Somali pastoralists in Eastern Ethiopia. J. Arid Environ. 72, 1265–1281. http://dx.doi.org/10.1016/j.jaridenv.2008.

Kebebew, F., Tsegaye, D., Synnevag, G., 2001. Traditional coping strategies of the Afar and Borana pastoralists in response to drought. Dryl. Coord. Group 62. Report No. 17, Nov 2001.

Kröpfl, A.I., Cecchi, G.A., Villasuso, N.M., Distel, R.A., 2013. Degradation and recovery processes in Semi-Arid patchy rangelands of northern Patagonia, Argentina. Land Degrad. Dev. 24, 393–399. http://dx.doi.org/10.1002/ldr.1145.

Lambin, E.F., et al., 2001. The causes of land-use and land-cover change: moving beyond the myths. Glob. Environ. Change 11, 261–269. http://dx.doi.org/10.1016/S0959-3780.

Legendre, P., 1993. Spatial autocorrelation: trouble or new paradigm? Ecology 74, 1659–1673. http://dx.doi.org/10.2307/1939924.

Le Roux, X., Bariac, T., Mariotti, A., 1995. Spatial partitioning of the soil water resource between grass and shrub components in a West African humid savanna. Oecologia 104, 147–155. http://dx.doi.org/10.1007/BF00328579.

Li, X.-L., Gao, J., Brierley, G., Qiao, Y.-M., Zhang, J., Yang, Y.-W., 2013. Rangeland degradation on the Qinghai-tibet plateau: implications for rehabilitation. Land Degrad. Dev. 24, 72–80. http://dx.doi.org/10.1002/ldr.1108.

Little, P.J., McPeak, C.B., Barrett, P., Kristjanson, S., 2008. Challenging orthodoxies: understanding poverty in pastoral areas of East Africa. Dev. Change 39, 587–611. http://dx.doi.org/10.1111/j.1467-7660.

Lucena, RFPD.Medeiros, PMD., Araújo, E.D., Alves, A.G.C., Albuquerque, U.P.D., 2012. The ecological apparency hypothesis and the importance of useful plants in rural communities from Northeastern Brazil: an assessment based on use value. J. Environ. Manag. 96, 106–115. http://dx.doi.org/10.1016/j.jenvman.2011.09.001.

Lybbert, T.J., Barrett, C.B., Desta, S., Layne Coppock, D., 2004. Stochastic wealth dynamicsa and risk management among a poor population. Econ. J. 114, 750–777. http://dx.doi.org/10.1111/j.1468-0297.2004.00242.x.

Mandal, D., Sharda, V.N., 2013. Appraisal of soil erosion risk in the Eastern Himalayan region of India for soil conservation planning. Land Degrad. Dev. 24, 430–437. http://dx.doi.org/10.1002/ldr.1139.

Markakis, J., 2003. Anatomy of a conflict: afar & ise in Ethiopia. Rev. Afr. Political Econ. 30, 445–453. http://dx.doi.org/10.1080/08r.

Martin, R., Müller, B., Linstädter, A., Frank, K., 2014. How much climate change can pastoral livelihoods tolerate? Modelling rangeland use and evaluating risk. Glob. Environ. Change 24, 183–192.

McAllister, R.R.J., 2012. Livestock mobility in arid and semiarid Australia: escaping variability in space. Rangel. J. 34, 139–147. http://dx.doi.org/10.1071/RJ11090.

McMichael, A.J., Powles, J.W., Butler, C.D., Uauy, R., 2007. Food, livestock production, energy, climate change, and health. Lancet 370, 1253–1263. http://dx.doi.org/10.1016/S0140-6736.

McPeak, J.G., Barrett, C.B., 2001. Differential risk exposure and stochastic poverty traps among East African pastoralists. Am. J. Agric. Econ. 3, 674–679. http://www.jstor.org/stable/1245098.

Mekuria, W., Aynekulu, E., 2013. Exclosure land management for restoration of the soils in degraded communal grazing lands in northern Ethiopia. Land Degrad. Dev. 24, 528–538. http://dx.doi.org/10.1002/ldr.1146.
Mogotsi, K., Nyangito, M.M., Nyariki, D.M., 2013. The role of drought among agro-pastoral communities in a semi-arid environment: the case of Botswana. J. Arid Environ. 91, 38–44. http://dx.doi.org/10.1016/j.jaridenv.2012.11.006.
Morton, J., 2006. Pastoralist coping strategies and emergency livestock market intervention. In: McPeak, J.G., Little, P.D. (Eds.), Pastoral Livestock Marketing in Eastern Africa: Research and Policy Challenges. Intermediate Technology Publications Ltd, London.
Müller, B., Frank, K., Wissel, C., 2007. Relevance of rest periods in non-equilibrium rangeland systems – a modelling analysis. Agric. Syst. 92, 295–317. http://dx.doi.org/10.1016/j.agsy.2006.03.010.
Myalyosi, R.B.B., 1992. Influence of livestock grazing on range condition in south-west Masailand, northern Tanzania. J. Appl. Ecol. 29, 581–588. http://dx.doi.org/10.2307/2404465.
Nabahungu, N.L., Visser, S.M., 2013. Farmers' knowledge and perception of agricultural wetland in Rwanda. Land Degrad. Dev. 24, 363–374. http://dx.doi.org/10.1002/ldr.1133.
Österle, M., 2008. From cattle to goats: the transformation of east Pokot pastoralism in Kenya. Nomadic Peoples 12, 81–91. http://dx.doi.org/10.3167/np.2008.120105.
Özgüner, H., Eraslan, Ş., Yilmaz, S., 2013. Public perception of landscape restoration along a degraded urban streamside. Land Degrad. Dev. 23, 24–33. http://dx.doi.org/10.1002/ldr.1043.
Palacio, R.G., Bisigato, A.J., Bouza, P.J., 2014. Soil erosion in three grazed plant communities in northeastern Patagonia. Land Degrad. Dev. 25, 594–603. http://dx.doi.org/10.1002/ldr.2289.
Piguet, F., 2007. Complex development-induced migration in the afar pastoral area (North-East Ethiopia). In: Paper Prepared for the Migration and Refugee Movements in the Middle East and North Africa. The American University, Cairo.
R Development Core Team, 2008. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. http://www.R-project.org.
Rettberg, S., 2010. Contested narratives of pastoral vulnerability and risk in Ethiopia's Afar region. Pastoralism 1, 248–273.
Rettberg, S., Müller-Mahn, D., 2012. Human-environment interactions: the invasion of *Prosopis juliflora* in the drylands of northeast Ethiopia. In: Mol, L., Sternberg, T. (Eds.), Changing Deserts. Whitehorse Press, Cambridge, pp. 297–316.
Reuveny, R., 2007. Climate change-induced migration and violent conflict. Polit. Geogr. 26, 656–673. http://dx.doi.org/10.1016/j.polgeo.2007.05.001.
Revelle, W., 2014. Psych: Procedures for Psychological, Psychometric, and Personality Research. Northwestern University, Evanston, Illinois, 165.
Schnabel, S., Pulido-Fernández, M., Lavado-Contador, J.F., 2013. Soil water repellency in rangelands of Extremadura (Spain) and its relationship with land management. CATENA 103, 53–61. http://dx.doi.org/10.1016/j.catena.2011.11.006.
Scoones, I., 1992. Coping with drought: responses of herders and livestock in contrasting savanna environments in Southern Zimbabwe. Hum. Ecol. 20, 293–314.
Seifu, T., 2004. Ethnobotanical and Ethnopharmaceutical Studies on Medicinal Plants of Chifra District, Afar Region, North Eastern Ethiopia. Addis Ababa University. MSc Thesis.
Sonneveld, B.G.J.S., Keyzer, M.A., Georgis, K., Pande, S., Seid Ali, A., Takele, A., 2009. Following the Afar: using remote tracking systems to analyze pastoralists' trekking routes. J. Arid Environ. 73, 1046–1050. http://dx.doi.org/10.1016/j.jaridenv.2009.05.001.
Swallow, B.M., 1994. The role of mobility within the risk management strategies of pastoralists and agro-pastoralists. International Institute for Environment and Development IIED, London.
Tadesse, G., 2001. Land degradation: a challenge to Ethiopia. Environ. Manag. 27, 815–824. http://dx.doi.org/10.1007/s002670010190.
Tefera, S., Snyman, H.A., Smit, G.N., 2007. Rangeland dynamics in southern Ethiopia: botanical composition of grasses and soil characteristics in relation to land-use and distance from water in semi-arid Borana rangelands. J. Environ. Manag. 85, 429–442. http://dx.doi.org/10.1016/j.jenvman.2006.10.007.
Tilahun, H., Schmidt, E., 2012. Spatial Analysis of Livestock Production Patterns in Ethiopia. ESSP II Working Paper 44, Ethiopia Strategy Support Program-II. The International Livestock Research Institute (IFPRI), Addis Ababa.
Treydte, A.C., Baumgartner, S., Heitkönig, I.M.A., Grant, C.C., Getz, W.M., 2013. Grazing ungulates as system designers: characteristic grass assemblages and their use under varying mammalian herbivory in African savannas. PLoSOne 8, e82831. http://dx.doi.org/10.1371/journal.pone.0082831.
Treydte, A.C., Birhane, E., Eshete, A., 2014. Ecological challenges and potential carbon storage benefits of *Prosopis juliflora* in Afar. In: Managing Prosopis Juliflora for Better (Agro-) Pastoral Livelihoods in the Horn of Africa. GIZ report, Addis Ababa, p. 20.
USAID, 2011. Policy Framework 2011 – 2015. http://www.usaid.gov/sites/default/files/documents/1870/USAID%20Policy%20Framework%202011–2015.PDF. Accessed March 2014.
Van Oudtshoorn, F., 2009. Guide to Grasses of Southern Africa, second ed. Briza Publications, Pretoria.
Vetter, S., Bond, W.J., 2012. Changing predictors of spatial and temporal variability in stocking rates in a severely degraded communal rangeland. Land Degrad. Dev. 23, 190–199. http://dx.doi.org/10.1002/ldr.1076.
White, P.C.L., Jennings, N.V., Renwick, A.R., Barker, N.H.L., 2005. Questionnaires in ecology: a review of past use and recommendations for best practice. J. Appl. Ecol. 42, 421–430. http://dx.doi.org/10.1111/j.1365-2664.2005.01032.x.
Wigley, B.J., Bond, W.J., Hoffman, M.T., 2009. Bush encroachment under three contrasting land-use practices in a mesic South African savanna. Afr. J. Ecol. 47, 62–70. http://dx.doi.org/10.1111/j.1365-2028.2008.01051.x.
Zhao, G., Mu, X., Wen, Z., Wang, F., Gao, P., 2013. Soil erosion, conservation, and eco-environment changes in the Loess Plateau of China. Land Degrad. Dev. 24, 499–510. http://dx.doi.org/10.1002/ldr.2246.