



Land-use/cover dynamics in Northern Afar rangelands, Ethiopia

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ABSTRACT

This study uses a combination of remote sensing data, field observations and information from local people to analyze the patterns and dynamics of land-use/cover changes for 35 years from 1972 to 2007 in the arid and semi-arid Northern Afar rangelands, Ethiopia. A pixel-based supervised image classification was used to map land-use/cover classes. People's perceptions and ecological time-lines were used to explain the driving forces linked to the changes. A rapid reduction in woodland cover (97%) and grassland cover (88%) took place between 1972 and 2007. Bushland cover increased more than threefold, while the size of cultivated land increased more than eightfold. Bare land increased moderately, whereas bushy grassland and scrubland remained stable. According to accounts from local people, major events that largely explain the changes include: (1) severe droughts in 1973/74 and 1984/85; (2) increase in dry years during the last decade; and (3) immigration and increased sedentarization of pastoralists. If the present land-use/cover change were to continue, coupled with a drier climate, people's livelihoods will be highly affected and the pastoral production system will be under increasing threat.

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1. Introduction

An estimated 4.7 million km² grassland areas and 6 million km² of forests/woodland, have been converted to croplands worldwide since 1850 (Lambin et al., 2001, 2003). In recent years, African grassland, woodland, and other vegetated areas have increasingly been converted into cropland (Millennium Ecosystem Assessment, 2005). For instance, an estimated 3.4 million km² of woody vegetation in dryland zones of Africa have become degraded through human activities such as agricultural expansion and deforestation (Kigomo, 2003).

Land-use shifts caused by external and internal drivers have influenced many traditional resource management regimes in arid and semi-arid areas where often a pastoral way of life has been the tradition (Campbell et al., 2005; Reid et al., 2004). The equilibrium paradigm, which states that ecosystem regulation is maintained in a stable way through negative feedback mechanisms, guided most rangeland management policy until the 1970s (Briske et al., 2003). Based on the concept of 'tragedy of the commons' (Hardin, 1968), pastoralism was considered as an environmentally destructive resource exploitation strategy that resulted in overstocking

and the disruption of a perceived ecological equilibrium. This dominant paradigm was increasingly criticized in the 1980s partly due to a growing concern that interventions based on equilibrium assumptions were inappropriate for some pastoral systems (Behnke and Scoones, 1993; Ellis and Swift, 1988; Sandford, 1983).

Current theoretical evidence indicates that both equilibrium and non-equilibrium dynamics occur in ecosystems across both spatial and temporal dimensions (Briske et al., 2005; Oba et al., 2000; Wessels et al., 2007). Although conclusive empirical evidence does not exist to terminate the debate, rangeland degradation is still a widely occurring phenomenon in many African rangelands, threatening national economic values and also the lifestyles of pastoralists. Despite all the rhetoric and the policy discussions, the current pace of degradation is unprecedented both in arid and semi-arid areas (Millennium Ecosystem Assessment, 2005).

There have been some studies of land-use/cover changes at regional or local levels, but they often deal exclusively with quantifying land-use/cover changes using remote sensing tools or they focus on causes of land-use/cover changes through socio-economic surveys. Mapping spatial changes using remote sensing tools gives quantitative descriptions but does not explain or provide understanding of the relationship between the patterns of change and their driving forces (Olson et al., 2004). Some recent advances in remote sensing play a major role in linking social models with the spatial dynamics of land-use changes (e.g., Mottet et al., 2006; Serneels and Lambin, 2001; Serra et al., 2008). However, studies such as these linking land cover changes with drivers are rare

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and the few attempts have been mainly outside the rangelands in Ethiopia (e.g., Garedew et al., 2009; Reid et al., 2000). The Afar rangeland in North-eastern Ethiopia is one notable example where no information exists regarding land-use/cover changes.

The goal of this study is to map and to offer an increased understanding of the patterns of land-use/cover changes over time by linking this to the main drivers of change in the arid and semi-arid Northern Afar rangelands, Ethiopia. The objectives were first to explore the dynamics of the land-use/cover in Northern Afar rangeland – that is, what are the main land-use/cover types; to what degree do land-use and cover change; and what have been the most important transitions (i.e., conversions) among the land-use/cover classes between 1972 and 2007? Secondly, what are the major driving forces of the land-use/cover changes, and what are the consequences associated with these changes?

2. Study area and methods

The study area covers 2506 km² in the Northern Afar rangelands of Ethiopia (including a small area in Eastern Tigray) and is located between 13°00' to 13°45' N and 39°40' to 40°12' E. The study site (Aba'ala district) encompasses a transitional area between the Danakil depression of the Rift Valley and the North Western Rift Valley escarpments. Aba'ala is characterized by an arid and semi-arid climate and lies between 100 and 2500 m a.s.l., with elevation increasing from East to West. Mean annual rainfall varies from 150 to 500 mm, the amount and reliability declining from West to East (HTS, 1976; Tsegaye et al., 1999). Recurring droughts are common in localized areas and sometimes affect the whole region (Meze-Hausken, 2004). Although the long-term annual mean (379 mm) has not changed greatly since the 1970s (Tsegaye et al., unpublished), variability is high, with a 33% coefficient of variation between years (Meze-Hausken, 2004). The most common vegetation cover types include scrubland and bushland dominated by *Acacia* spp. with poor or no herbaceous cover (Tsegaye et al., 1999).

Historically, Aba'ala was inhabited by Afar pastoralists engaged in subsistence livestock production. For most of the pastoralists, camels and goats are the main livestock species, while a few pastoralists and agro-pastoralists also keep cattle and sheep (Tsegaye et al., 1999). Before the 1960s, the Northern Afar rangelands had no permanent agricultural areas or settlements due to the pastoralist way of life and the low human population. The total human population in the study area increased from 27,259 in 1996 to 37,943 in 2007 (CSA, 2008). Although not specified for the study area, the annual growth rate for the Afar region between 1996 and 2007 was 2.2% (CSA, 2008).

Landsat MSS (Multispectral Scanner) acquired on November 2, 1972 (path 181, row 51), Landsat TM (Thematic Mapper) acquired

on January 5, 1986 (path 168, row 51), and ETM+ (Enhanced Thematic Mapper Plus) acquired on March 12, 2007 (path 168, row 51) were used for this study. These dates were selected on the basis of historical events such as droughts and policy changes, and availability of satellite images. The ETM+ image was geo-referenced using ground control points with a root mean square error (RMSE) of 0.6 pixel. The MSS and TM images were geo-referenced using the ETM+ as a master image. The Universal Transverse Mercator (UTM) geographic projection, Clarke 1880 spheroid, and Adindan (Ethiopia) zone 37 North datum were used in geo-referencing the images. To make the three images compatible (Lillesand and Kiefer, 2000), all the MSS (57 m), TM (28.5 m), and ETM+ (30 m) images were re-sampled to a 60 m × 60 m pixel size using the nearest-neighbor re-sampling technique after Serra et al. (2003).

Seven land-use/cover classes were identified for image classification based on classification criteria for East African rangelands (Pratt and Gwynne, 1977) and the new land cover map of Africa (Mayaux et al., 2004), with minor modifications (Table 1). A pixel-based supervised image classification with maximum likelihood classification algorithm was used to map the land-use/cover classes (Lillesand and Kiefer, 2000). A total of 570 ground truth points collected from the field were used for 2007 image classification (285) and validation (285). Aerial photographs from 1964 and 1994 were used to acquire 400 and 452 points for the 1972 and 1986 image classification and validation, respectively (i.e., half were used for training and the other half for validation). The overall classification accuracies and accuracies of the single land-use/cover classes are shown in Table 1.

Then, the land-use/cover changes between the three periods (i.e., 1972, 1986 and 2007) were quantified and a change detection matrix of 'from-to' change was derived (Brammoh, 2006; Pontius et al., 2004) to show land cover class conversion transitions during the 35-year period by overlaying the 1972 and 2007 images. In relation to the transition matrix, net change and net change-to-persistence ratio (Brammoh, 2006; Pontius et al., 2004) were computed to show the resistance and vulnerability of a given land-use/cover type. Image processing and mapping were undertaken using ILWIS Open 3.7 Remote Sensing and GIS software (ITC, 2009).

To further understand the dynamics of land-use/cover change, possible major drivers and consequences of the changes were explored using 35 key informants and group discussions (i.e., elders and clan leaders of Afar pastoralists, immigrants, administrators and development workers). In this study, more emphasis was given to the most common drivers of change, including: (1) economic factors related to agricultural expansion combined with infrastructural development and firewood extraction; (2) institutional factors such as land tenure changes; (3) demographic factors such as population growth and migration interlinked with previous factors; and (4) rainfall variability and shocks such as drought and

Table 1
Description of land-use/cover classes and accuracy assessment of classified images.

Land-use/cover class	Description	Accuracy (%)					
		1972		1986		2007	
		Producer's	User's	Producer's	User's	Producer's	User's
Woodland	Land with woody species cover >20% (height ranges 5–20 m)	92.31	85.71	100.00	76.67	80.77	87.50
Bushland	Land with >20% bush or shrub cover (<5 m in height)	81.48	73.33	77.50	91.18	88.24	90.00
Bushy grassland	Grassland with <20% bush or shrub cover	79.17	63.33	81.82	77.14	78.26	87.80
Grassland	Grass and herb cover with scattered trees and shrubs	71.79	93.33	93.33	84.85	100.00	90.00
Scrubland	Land with <5% total vegetation cover	64.86	80.00	66.67	87.50	81.13	86.00
Cultivated land	Cropping fields. It also includes settlements	95.24	80.00	100.00	86.67	97.22	87.50
Bare land	Non-vegetated areas such as rock outcrops, sand, and lava (volcanic ash)	96.15	92.59	96.88	96.88	100.00	92.50
Overall accuracy		81.00		85.84		88.77	
Kappa coefficient ^a		0.79		0.84		0.87	

^a Kappa coefficient is dimensionless.

Table 2
Land-use/cover in 1972, 1986 and 2007 in Northern Afar rangelands, Ethiopia.

Land-use/cover	Absolute area cover (km ²)			Cover change between periods (%) ^a			Proportion of dry-season grazing land (%) ^b		
	1972	1986	2007	1972–1986	1986–2007	1972–2007	1972	1986	2007
Woodland	209.13	70.07	7.02	–66.50	–89.98	–96.64	3.17	0.03	0.07
Bushland	98.55	236.49	375.68	139.98	58.86	281.22	0.51	2.71	1.50
Bushy grassland	444.01	322.97	409.23	–27.26	26.71	–7.83	41.56	21.62	16.50
Grassland	194.30	44.79	22.85	–76.95	–48.99	–88.24	25.58	10.47	2.89
Scrubland	1490.61	1660.69	1530.09	11.41	–7.86	2.65	26.83	59.05	54.47
Cultivated land	7.68	18.22	67.24	137.22	269.11	775.62	2.35	5.90	24.53
Bare land	61.82	152.86	93.99	147.29	–38.51	52.05	0.00	0.23	0.04
Total	2506.09	2506.09	2506.09						

^a Cover change between periods was calculated as $100 \times (A_{final\ year} - A_{initial\ year}) / A_{initial\ year}$, where A = area of the land-use/cover type.

^b Proportion of each land-use category in the dry-season grazing alluvial plain (total area = 125.44 km²).

conflicts. Scores were given for the identified drivers using pairwise ranking. Although focused on identifying the specific changes and causes, discussion questions were open-ended and designed mainly to construct a time-line of historical events and identify linkages to the land cover change trends. Published works and public statistics were also used to document the scale and scope of the major drivers.

The 'ecological time-lines' method developed by Reid et al. (2000), who used this approach to elicit reasons for changes in landscape-level as seen by local residents, was used to develop a time-line of historical events.

3. Results

3.1. Land-use/cover change

Table 2 provides the magnitude of land-use/cover change in the Northern Afar rangelands, and the supplementary electronic material (Fig. S1) depicts the spatial land-use/cover changes. A rapid reduction in woodland from 8.35% to 0.28% and grassland from 7.75% to 0.91% cover in the landscape took place between 1972 and 2007 (Table 2). During the 35-year period, the proportion of bushland trebled, while the area of cultivated land increased eightfold (Table 2). Although cultivated area still covered a small proportion of the landscape in 2007, its proportion in the alluvial dry-season grazing land is large (Table 2). The increase in bushland and cultivated land cover was large during the time period 1986–2007 compared to the earlier time period 1972–1986, whereas both time periods saw similar declines in woodland and grassland (Table 2). Bare land increased moderately, whereas bushy grassland and scrubland cover showed little change during the 35-year period (Table 2). Although it recovered between 1986 and 2007, bushy grassland cover was reduced in the earlier period, 1972–1986 (Table 2). Bare land increased between 1972 and 1986, but then declined between 1986 and 2007 (Table 2).

Table 3

Land-use/cover transition matrix showing major changes in the landscape (%), Afar, Ethiopia, 1972–2007.

	To final state (2007)							Total 1972	Loss
	Woodland	Bushland	Bushy grassland	Grassland	Scrubland	Cultivated land	Bare land		
From initial state (1972)									
Woodland	0.13	4.69	1.22	0.00	2.16	0.05	0.09	8.35	8.22
Bushland	0.06	2.57	0.27	0.00	0.91	0.02	0.11	3.93	1.37
Bushy grassland	0.02	1.57	4.19	0.03	10.56	1.32	0.03	17.72	13.53
Grassland	0.00	0.05	3.33	0.68	3.26	0.42	0.00	7.75	7.07
Scrubland	0.07	5.83	7.23	0.20	43.62	0.78	1.74	59.48	15.86
Cultivated land	0.00	0.03	0.07	0.00	0.11	0.09	0.00	0.31	0.21
Bare land	0.00	0.25	0.02	0.00	0.42	0.00	1.78	2.47	0.69
								53.06^a	
Summary									
Total 2007	0.28	14.99	16.33	0.91	61.05	2.68	3.75		
Gain	0.15	12.43	12.14	0.23	17.43	2.59	1.98		
Net change ^b	–8.07	11.06	–1.39	–6.84	1.58	2.38	1.28		
Net persistence (Np) ^c	–62.08	4.31	–0.33	–10.06	0.04	26.44	0.72		

Bolded diagonal elements represent proportions of each land-use/cover class that were static (persisted) between 1972 and 2007. The loss column and gain row indicate the proportion of the landscape that experienced gross loss and gain in each class, respectively.

All the figures in the table are in percent except Np, which is a ratio.

^a The shaded figure is the sum of diagonals and represents the overall persistence (i.e., the landscape that did not change).

^b Net change = gain – loss.

^c Np refers to net change to persistence ratio (i.e., net change/diagonals of each class).

Between 1972 and 2007, the woodland in the landscape was mainly converted to bushland, scrubland and bushy grassland (Table 3). Grassland was mainly converted to scrubland and bushy grassland (Table 3). Cultivated land mainly converted from scrubland, bushy grassland, and grassland. Although scrubland gained from bushy grassland and others, at the same time an equivalent area of scrubland reverted to bushy grassland and other land covers. The greatest net increase was for bushland, primarily converted from scrubland and woodland cover types (Table 3).

Of the natural vegetation cover types, woodland and grassland experienced the lowest persistence, whereas scrubland was the most persistent cover type (Table 3). 'Persistence' is indicated in Table 3 as the bolded diagonal elements for each land-use/cover class. The net change-to persistence ratio was large for woodland (negative), cultivated land (positive), grassland (negative) and bushland (positive) indicating the most dominant trends in the changing landscape (Table 3). The net change-to persistence ratio is closer to zero for the remaining land-use/cover classes, indicating that they had a higher tendency to persist rather than decline or increase (Table 3). Overall, 53.06% (i.e., sum of diagonal elements) of the total landscape remains unchanged (Table 3).

3.2. Drivers of land-use/cover change

From a range of biophysical, demographic, economic, infrastructural and technological factors, more than 15 drivers were perceived by the informants as being important to land-use/cover changes in the study area (Fig. 1). Major historical events (i.e., underlying causes of change) and consequent changes drawn from responses of informants are shown in Fig. 2. Table 4 also shows the linkage between the perceived drivers and the most important land-use/cover transitions between 1972 and 2007.

According to the Afar informants and local administrators, increased sedentarization of Afar pastoralists and a high influx of migrants from the Tigray highlands to the area took place, particularly after the severe 1984/85 drought, resulting in an expansion of cultivation in the alluvial plains (Fig. 2, Table 4). The migrants mentioned two critical push factors for migrating to the study area from Tigray highlands. They were: (1) less favorable economic opportunities at their origin of

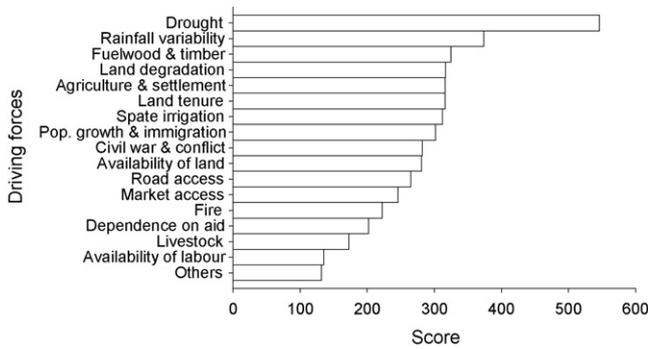


Fig. 1. Key driving forces of land-use/cover change perceived and ranked by Afar pastoralists, Northern Afar rangelands, Ethiopia, 2007. The score is based on pairwise ranking of the driving forces.

migration caused by high human population densities and increased land degradation following the extreme droughts of 1973 and 1984/85; and (2) access to arable land as a share croppers at their point of destination. The indigenous Afar pastoralists listed access to relief distribution centers following the 1984/85 drought, free access to arable land, and the availability of farm labor, as inducements for them to sedentarize and become involved in agriculture.

The informants stated that migrants are the main cause of woodland cover reduction as they are highly involved in charcoal and firewood sale (Table 4) in addition to crop production. The migrants also added that woodland was highly exploited for the purpose of permanent house construction (Table 4). It also functions as an important safety net in time of hardship, and the sale of firewood serves as a major source of income when coping with the effects of drought (Table 4). According to the informants, the use of fire as a management tool was abandoned because of bans imposed by extension agents (not legally enforced) and this was perceived as contributing to bush encroachment in the escarpments (Table 4). Although some areas have good vegetation cover, species less palatable to livestock, such as *Tarchonanthus camphoratus*, *Cadia purpurea* and *Aloe* spp. commonly dominate. The most threatened multipurpose tree species listed by the local people include

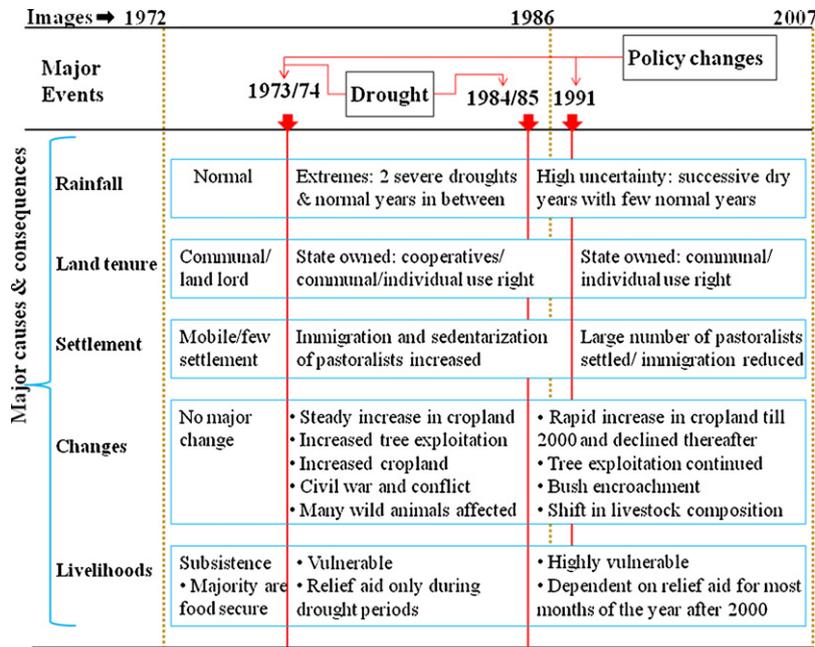


Fig. 2. Major events, causes and consequences of land-use/cover changes from 1972 to 2007 as seen by local people, Northern Afar rangelands, Ethiopia.

Table 4

Linkage between major land-use/cover change transitions and drivers as perceived by the local people.

Transition (from 1972 to 2007)	Immediate causes	Drivers
Woodland to bushland, bushy grassland, scrubland, cultivated land	Exploitation of trees for firewood and construction Alternative source of income to cope with the drought effects When woodland loses, bushland replaces in the hilly areas	Drought in 1973/4 and 1984/85 Immigration of people from other areas Infrastructural development such as roads and town establishment Settlement policy
Bushland to bushy grassland, scrubland and bare land	Exploitation of shrubs for firewood near settlements	Increased settlement and population growth
Bushy grassland to bushland, scrubland and cultivated land	Overgrazing reduces grass cover and gives way to bush cover Overgrazing and firewood exploitation leads to less vegetation cover (i.e. scrubland) Conversion to agriculture in the alluvial plains reduces bushy grassland	Land tenure change from communal to private use right Sedentarization policy that promotes agriculture Increased livestock with the growing human population Increased demand for firewood Absence of burning as a management tool
Scrubland to bushland, bushy grassland, cultivated land and bare land	In some areas secondary succession leads to more vegetation cover and in other areas disturbance leads to bare land or cultivated fields	Expansion of agriculture into marginal areas Protection of some areas around homesteads
Scrubland to bushland, bushy grassland, cultivated land and bare land	In some areas secondary succession leads to more vegetation cover and in other areas disturbance leads to bare land or cultivated fields	Expansion of agriculture into marginal areas Protection of some areas around homesteads
Cultivated land to scrubland	Scrubland replaces when crop production is abandoned	Increasing dry years in recent years
Bare land to bushland and scrubland	Some bare areas were turned to bushland and scrubland when left untouched (this occurred in areas where there was volcanic ash)	Natural succession: succession to more vegetation cover in good years

Dobera glabra, *Cordia gharaf* and *Olea europaea*. The informants particularly stated that recruitment failure of *D. glabra*, an important food plant for both humans and livestock in the wet-season grazing alluvial plains, could be an important indicator of either grazing/browsing pressure or rainfall variability, or combinations of the two.

The pastoralists explained a shift in livestock species composition from domination by camel-cattle to small stock-camel has occurred as a response to changes in vegetation types in recent years. They also remember that many of the wild animals have disappeared including cheetah (*Acinonyx jubatus soemmerringii*), oryx (*Oryx gazella beisa*), eland (*Taurotragus oryx*) and others are threatened – ostrich (*Struthio camelus*) and soemmerring's gazelle (*Nanger soemmerringii*) – in the study area. This was attributed mainly to the long civil war that took place in the study area and to the loss of woodland (Fig. 2, Table 2).

Overall, people stated that the changes in land-use/cover, mainly caused by frequent droughts and increasing numbers of dry years among other drivers, highly affected their lifestyles and have made them more dependent on relief aid.

4. Discussion

The arid and semi-arid rangelands in Northern Afar experienced substantial and increasing rates of land-use/cover changes during 35 years from 1972 to 2007. There have been persistent changes, both spatially and temporally, resulting in 47% of the total area experiencing transitional changes among the land cover types. The poor vegetation cover observed in 1986 compared to 1972 and 2007 indicates that most of the vegetation types suffered from short-term direct and indirect drought effects. Bushland cover increase, particularly in the hills and escarpments, indicates partial recovery after the drought.

In the first period (1972–1986), the overall net transition to less vegetation (i.e., bare land, scrubland and cultivated land) covered about 272 km², showing the direct and indirect impact of drought and related causes. During this period, a rapid loss of woodlands was mainly caused by the severe droughts in 1973 and 1984/85 (Meze-Hausken, 2004). There was also a change in the land tenure system in 1975 encouraging subdivision of communal dry-season grazing areas for crop production on either an individual basis or through the establishment of farmers' cooperatives (Omiti et al., 1999). These events were important underlying causes of the influx of people into Northern Afar from the highly populated and degraded areas in the neighboring Tigray region (Meze-Hausken, 2004; Tsegaye et al., 1999). Campbell et al. (2005) note that this form of migration is an adaptation strategy of people affected by drought in arid and semi-arid areas.

As a result of continued migration of people from neighboring areas together with the increased sedentarization of pastoralists, more alluvial dry-season grazing areas were converted to cropland in the second period (1986–2007). However, immigration to the study area very much reduced after 1991 following the establishment of ethnic-based administration and availability of labor employment opportunities in the rapidly growing urban areas in Tigray. In the second period, the net transition to more vegetation cover was 143 km², indicating some recovery after the 1984/85 drought, the process perhaps being related to natural and secondary re-growth.

As in other areas of East Africa (Reid et al., 2004), agricultural expansion related to shifts in government policy has been one of the key driving forces behind the land-use/cover changes in Northern Afar. Cultivation is seen by some as a better livelihood strategy (e.g., Campbell et al., 2005) stemming from increasing population and changes in relative prices between input and output (Vedeld, 1995), while others (e.g., Little et al., 2008) view it as an unsustainable option that increases the risk to pastoralists. Although pastoralists have persistently resisted sedentarization and farming in the past (Chatty, 2007), we observed more voluntary farming activities and sedentarization in Afar in recent years. Such changes may be either intentionally driven by external factors or a spontaneous response to new opportunities or challenges (Reid et al., 2004).

Before the introduction of other land-uses such as agriculture, traditional institutions of the Afar communities were strongly organized to serve the needs of the members living within specified physical boundaries. Although land is legally owned by the state, grazing lands are communal properties accessible to all members of a clan or groups of clans within the boundary (Hundie and Padmanabhan, 2008). However, land under cultivation by agro-pastoral communities is considered to be private property. Although not fully implemented (Hundie and Padmanabhan, 2008), the 1994 constitution declares (in Article 40) “Ethiopian pastoralists have a right to free land for grazing and cultivation as well as the right not to be displaced from their own lands”.

Although sedentarization of pastoralists is still continuing, more involvement in agriculture may not continue in the study area due to both increasing drought occurrence and a lack of technological progress in favor of the existing spate irrigation practice. It is observed in the field that many cropping fields left uncultivated gradually revert to bushy grasslands mainly dominated by annual forbs and *Aloe* spp. less palatable to livestock. Although there has been a decline in agricultural activities due to reduced rainfall since 2000, a tendency to shift to irrigated agriculture is linked to the increased sedentarization of pastoralists. There is a strong demand for the use of improved gabions and dikes that allow better use of the available floodwaters. Development actors (e.g., the Afar Integrated Pastoral Development Programme) operating in the area have introduced such improved systems and assisted the agro-pastoralists in improving their flood diversion activities and have in fact contributed to halting the practice of shifting cultivation that converts more vegetated areas to cropping fields. While it is true that such activities improve food security, it can also be argued that more people may be attracted to sedentarize and become involved in agriculture in the long-run.

Many studies conducted in African drylands have documented a decline in woody vegetation cover (Lykke, 1998; Wezel and Haigis, 2000). Woodland loss is usually attributed to land clearing for crop production (e.g., Vedeld, 1995), while bush encroachment is attributed to overgrazing and absence of fire (e.g., Angassa and Oba, 2008; Oba et al., 2000). This is not the case in the study area, as both woodland and bushland covers dominate hillsides and escarpments unsuitable to either crop production or grazing. Rather, observations revealed modification of woodland cover caused by increased tree exploitation (i.e., tree felling for firewood and construction).

The increased bushland cover at the expense of woodland also indicates the impact of altered disturbance regimes such as avoiding fire as a management tool besides continued wood harvesting (Wiegand and Jeltsch, 2000). Like many rangelands in Africa, the increase in bushland cover in the study area was not unexpected, but the presence of more bushy cover mainly on the hilly areas and escarpments where there is little or no grazing is striking. Other studies have also noted the occurrence of bush encroachment in areas where there is shallow soil depth and grazing is infrequent (Brown and Archer, 1999).

The changes in land-use/cover in the study area thus indicate resource degradation and vulnerability of people. The drivers and related changes discussed above may therefore influence ecosystem functioning in the rangelands through their impact on the traditional mobility pattern between the wet- and dry-season grazing areas. This may also lead to a decrease in the size of dry-season grazing areas, isolation of crucial habitats such as permanent water sources, particularly for large wild animals, indirectly resulting in changing livestock species composition and directly disturbing some plant species that may be threatened with extinction. For instance, the failure of *D. glabra* recruitment in Northern Afar rangelands was mainly a contribution of intense livestock browsing (Tsegaye et al., 2009), indicating the severity of degradation. Most

pastoralists no longer keep cattle and have shifted to small stock that can utilize bush-encroached areas. The increasing demand for meat from the growing population in nearby towns in recent years is also an opportunity to increase the goat population that can browse on the increasing bush cover. It should therefore be underscored that the shift from cattle-camel to small stock-camel dominated livestock is not only a response to bush encroachment but also a strategy to meet market demands.

The findings of this study support Illius and O'Connor's (1999) explanations regarding the rangeland management debate. In conditions where key resource dry-season grazing areas are encroached by agriculture, grazing-induced degradation often occurs in other areas as they are heavily utilized during the dry-season (Illius and O'Connor, 1999). In the study area, mobility is constrained with a consequent overgrazing in the remaining areas. This is evident in Northern Afar where the dry-season grazing areas are encroached by other land-uses including agriculture. Such circumstances can occur in climatically highly variable environments where mobility of pastoralists has been severely restricted (Vetter, 2005). The non-equilibrium approach, in which arid and semi-arid rangelands conditions are seen as being driven by rainfall and not by grazing (Behnke and Scoones, 1993; Ellis and Swift, 1988) may not be fully applicable in a situation where pastoral groups have been removed from part of their traditional grazing land, as witnessed in this study.

The general trend observed in the study area implies a loss of grassland and woodland cover and an increase in cultivated areas and bushland cover. The present tendency may lead to more land degradation if no assisted restoration is made. Continued land-use/cover change, coupled with a drier climate, greatly affects people's livelihoods and puts the pastoral production system under increasing threat.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.agee.2010.07.017.

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