Afar pastoralists in a changing rangeland environment

Afar-gjetere i et skiftende beitelands-miljø

Philosophiae Doctor (PhD) Thesis

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Abstract

Pastoralists have been using arid and semi-arid rangelands to produce their livelihood outputs through livestock production for centuries. However, recent changes in land use and associated impacts on biodiversity and peoples' livelihood contributed to the growing crisis of pastoralism in Africa. This study was thus aimed at understanding the patterns of land-use changes (and consequences) that pose threats to key resources and peoples' livelihood in northern Afar rangelands, Ethiopia. In addition, the recruitment dynamics of an important food and fodder plant, *Dobera glabra* (Forssk.) Poir, was examined.

The results in this thesis are based on several methods that include a combination of remote sensing data (Paper I), perceptions of local people (Paper I and II), comparative descriptions of abundance and population structure of *D. glabra* in habitats with different land use histories (Paper III), and manipulative nursery and field experiments (Paper IV and V). Combining patterns of land-use/cover change with the processes underlying the change helps in understanding when, how, and why the changes are taking place in the landscape.

The results in this thesis revealed that rangelands in northern Afar have changed considerably during the past 35-years between 1972 and 2007, in that 47% of the total area changed land cover type (Paper I). The general trend observed implies a loss of grassland and woodland cover and an increase in cultivated area and bushland cover. If the present land-use/cover change continues, coupled with a drier climate, people's livelihoods will be greatly affected and the pastoral production system will come under an increasing threat. The findings in this thesis also demonstrate that all households in the study area were generally poor and the Afar pastoralists are in transition to a sedentary life through increasing involvement in farming and non-farm/non-pastoral activities (Paper II). Although pastoralism has traditionally been the major economic activity for the Afar society and is the main reason for continuing the practice, households specializing only in livestock earn less income compared to those who practice farming or both in recent years.

This thesis also constitutes the first step in understanding the recruitment status of the important food and fodder plant, *D. glabra* in Afar rangelands (Papers III-V). The findings indicate that natural recruitment of *D. glabra* is unlikely with the existing continuous and intensive grazing/browsing coupled with a drier climate. Although moisture is not a crucial limiting factor for seedling growth, it may lead to a narrow window of opportunity for *D. glabra* regeneration from seeds. *Dobera glabra* may only be sustained if protective measures are put in place in some key range sites where it is commonly occurring.

List of papers

This PhD thesis consists of the following papers which are referred by their Roman numerals (I-V).

Paper I

Tsegaye, D., Moe, S.R., Vedeld, P., and Aynekulu, E. in press. Land-use/cover dynamics in northern Afar rangelands, Ethiopia. *Agriculture, Ecosystems and Environment*: *doi:10.1016/j.agee.2010.07.017*

Paper II

Tsegaye, D., Vedeld, P., and Moe, S.R. Livelihood adaptation among Afar pastoralists in a changing rangeland environment (*Manuscript*)

Paper III

Tsegaye, D., Haile, M., and Moe, S.R. 2010. The effect of land use on the recruitment and population structure of the important food and fodder plant, *Dobera glabra* (Forssk.) Poir., in northern Afar, Ethiopia. *Journal of Arid Environments 74*, 1074-1082

Paper IV

Tsegaye, D., Moe S.R., and Haile, M. What determines the seed germination of the important food and fodder plant, *Dobera glabra* (Forssk.) Poir., in northern Afar rangelands, Ethiopia? (*Submitted*)

Paper V

Tsegaye, D., Moe, S.R., and Haile, M. 2009. Livestock browsing, not water limitations, contributes to recruitment failure of *Dobera glabra* in semiarid Ethiopia. *Rangeland Ecology and Management 62*, 540-549

1. Introduction

There has been an increasing interest in the study of pastoral societies due to alarming reports of drought and desertification in the 1970s. The predicament has necessitated research on the physical, ecological and social processes in these societies. Since then much has been said about pastoral land-use systems. Transition to other types of land-use has occurred in many pastoral areas largely due to climate change, human population growth and globalization (e.g., Sala et al., 2000; Homewood, 2004; Vetter, 2005). Predictions also indicate that the anthropogenic environmental impacts between 1950 and 2050 are likely the most severe in human history (Grau and Aide, 2008). Land-use/cover change is a multifaceted process caused by the interaction between anthropogenic and natural factors at different temporal and spatial scales (Lambin and Geist, 2001). However, understanding of land-use/cover dynamics and consequences is negligible due to lack of empirical information at local levels, particularly in the Ethiopian rangelands (Reid et al., 2000). The present study (Paper 1), therefore, addresses the dynamics of land-use/cover changes in the arid and semi-arid northern Afar rangelands.

The arid or semi-arid areas are suited for extensive livestock production and cover nearly half of the African continent south of the Sahara (Cossins, 1983). Many of these areas are inhabited by pastoral people that depend on a range of assets and livelihood activities (Coppock, 1994; Hogg, 1997; McPeak and Barett, 2001). Pastoralists occupy about 52% and 72% of the total area of Ethiopia and Kenya, respectively (Markakis, 1993). Pastoralists in these areas experience frequent droughts, animal and human disease epidemics, and reduced mobility due to cropping, settlement, and protected areas (Coppock, 1994; Fratkin, 1997; Fratkin, 2003). Despite several common features among pastoralists in arid and semi-arid areas of Africa, there is considerable heterogeneity in responding to the risks associated with the above mentioned problems (Barrett et al., 2001). The countries of the Horn, including Ethiopia, are mainly characterized by the four broad based systems of land utilization; pastoralism, agropastoralism, rain-fed and irrigated agriculture (Ahmed and Teka, 1999). Within and between each of these groups there are different adaptive specializations dependent on varying ecological, economic and cultural factors (Barrett et al., 2001). A range of different development interventions have attempted to address the crisis of pastoralism since the 1970s (Fratkin, 2001) and the issue of sedentarization of pastoralists has always been a subject of debate between researchers and governments (Ahmed et al., 2002).

Governments polices in Africa have been encouraging pastoralists to settle in order to provide them with service delivery systems similar to other groups in the society since the 1970s (Getachew, 2001; Rahmato, 2007), without generating many tangible benefits (Little et al., 2008). Because of transformation to other modes of livelihoods, there are now hardly any true nomadic societies left in Ethiopia (Coppock, 1994; Hogg, 1997; Sandford and Habtu, 2000; Ahmed et al., 2002). The sedentarization of pastoralists is also evident in pastoral areas in the Eastern and Horn of Africa at an increasing rate, without the national government interventions (Ahmed et al., 2002). Change of land tenure from communal to individual ownership led to permanent settlements of Masai people in Kenya (Rukwaro and Mukono, 2000). Similarly, the Tugens in northern Kenya have been settled and the traditional livestock inheritance right has been replaced by a land inheritance system (Vedeld, 1990). Based on past research and associated debates centered around pastoralists, there is a weak link between the available information and important components of livelihoods in rangelands, such as harvesting and trade in other natural resources, crop cultivation, non-farm employment and migration in and out of the pastoral system (Vetter, 2005). Paper II in this thesis, thus, addresses livelihood adaptations of Afar pastoralists focusing on how households differ in their ability to access the livelihood assets and how they diversify their income.

Owing to the current changes in land use and emerging livelihood adaptations, disturbances are likely to affect natural regeneration of trees in the arid and semi-arid areas. Some woody species in these areas have tended to disappear as natural regeneration is inadequate (Menaut et al. 1995; Lykke, 1998). One woody species of high food security importance for the pastoral Afar people in northern Ethiopia and many pastoralists in the Horn of Africa is the important food and fodder plant, *Dobera glabra* (Forssk) Poir. Recently, there appears to be a serious concern among Afar pastoralists about the lack of recruitment of *D. glabra* as young seedlings are almost absent in the rangeland sites where the plant is occurring (Tsegaye et al., 2007). The lack of regeneration seems a widespread problem in the arid and semi-arid habitats where the species grows, but attempts have not been made to address the causes so far. An important research challenge is thus to understand the current recruitment failure of *D. glabra*, given the existing climatic and land-use changes in the arid and semi-arid African rangelands. Papers III-V in this thesis addressed why an important food and fodder plant, *D. glabra* (Forssk.) Poir., fails to recruit in the arid and semi-arid rangelands of northern Afar, Ethiopia.

The intention of this study is thus to help narrow the confusion regarding the management of rangeland in Afar as there is lack of empirical information in understanding

the changes in rangeland resources and associated consequences on the livelihood of the people. This thesis describes a few of these concerns and my goal here is not to describe the issues of pastoralism in detail but rather to portray some of the changes and how they are affecting the system and people's livelihoods. The scope of the five papers that make up these thesis helps illustrate the range of issues concerned. Specifically, I discuss three major issues in the five papers. The first is land use change, drivers and consequences linked to the changes (Paper I). The second is livelihood adaptations among Afar pastoralists (Paper II). The third is recruitment dynamics of an important food and fodder plant (*D. glabra*) in relation to habitat pressures (i.e., linked to land use histories and grazing/browsing), and associated environmental factors (Papers III-V).

The reminder of the synopsis is organized in the following manner. First, I describe the objectives of the study corresponding to the specific papers. Second, I present theory and conceptual basis that provides an understanding of the land-use changes and the existing debates regarding rangelands and pastoralism. Third, I describe the study area and provide an overview of the Afar pastoralists. Fourth, I present a summary of the main methods. Fifth, I highlight the main findings and discussion of the five papers. Finally, I provide concluding remarks.

2. Objectives

Why study land use changes and recruitment dynamics of a selected plant species? Combining patterns of land-use/cover change with the processes underlying the change helps in understanding when, how and why the changes are taking place in the landscape. Thus, this study was aimed at understanding the patterns of land-use changes and consequences that pose threats to key resources and people's livelihoods in northern Afar rangelands, Ethiopia. The study focused on land use change, livelihood adaptations and recruitment dynamics of an important food and fodder plant, *Dobera glabra* (Forssk.) Poir., given natural and anthropogenic changes in the Afar rangeland environment. To attain this goal I specified explicit objectives, which correspond to the five papers included in this thesis:

1) Analyze the patterns and dynamics of land-use/cover changes for the past 35-years (1972-2007) in the arid and semi-arid north Afar rangelands, Ethiopia (Paper I). Specifically, the objectives were: (i) to quantify and detect land-use/cover changes between 1972 and 2007; and (ii) to identify and analyze the drivers of change and consequences linked to the changes.
2) Examine the patterns and implications of present livelihood adaptations among the Afar pastoralists in northern Afar region of Ethiopia. The study presents how access to livelihood activities and diversification of incomes vary across household (i.e., mode of production) and income groups (Paper II).
3) Examine how recruitment and population structure of the important food and fodder plant, *Dobera glabra* (Forssk.) Poir., is influenced by habitat pressures (i.e., areas with different land use histories) and associated environmental factors on a local scale (Paper III).
4) Investigate what determines the germination of *D. glabra* seeds under nursery and natural environmental conditions (Paper IV). Examine how herbivory, moisture, nature of seeds and their occurrence (i.e., exposure at germination site) affect the germination capacity of *D. glabra* seeds.
5) Elucidate why recruitment of *D. glabra* fails through examining the effects of moisture and browsing on seedlings recruitment (Paper V).

3. Theory and conceptual basis

3.1 Rangeland management and pastoral development

Pastoralists have been using the arid and semi-arid rangelands to produce their livelihood outputs through livestock production for centuries. However, there has been considerable discussion and debates concerning the rangeland resource use in drylands of Africa since the 1970s (Briske et al., 2003). The range model (i.e., 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). Since the 1970s, the form and content of rangeland management policy in Africa has been guided by the two powerful narratives of land degradation and the tragedy of the commons (Rohde et al., 2006). The land degradation narrative states that there are strong synergies and causality chains linking rapid population growth, degradation of the environmental resource base, and poor agricultural production performances (Stocking, 2000; Rohde et al. 2006). This narrative remains popular among environmental policy makers in sub-Saharan Africa. The tragedy of the commons narrative derives from a powerful metaphor (Hardin, 1968) based on the mainstream view (i.e., equilibrium paradigm), and argued that pastoralism is economically irrational and detrimental to the natural resource base and that it results in overgrazing which is claimed to be an important cause of desertification (Dregne et al., 1991). This perspective has influenced policy-makers in Africa that encouraged resource privatization imposed from outside. However, these views were criticized partly due to a paradigm shift in range science and pastoral development in 1980s in response to a growing concern that interventions based on the mainstream view were inappropriate for some pastoral systems (Sandford, 1983; Ellis and Swift, 1988; Behnke and Scoones, 1993; Sullivan and Rohde; 2002; Homewood, 2004). Ostrom (1999, 2009) also argues that assumption of resource users as norm-free maximizers is a poor foundation for policy analysis.

An alternative view advocates that African pastoral ecosystems are not at equilibrium state (Ellis and Swift, 1988). The ‘state-and-transition model’ was then introduced as an alternative to the ‘range succession model’ for application in rangeland systems characterized by event-driven (i.e., occurrence of periodic and often stochastic climatic events) vegetation dynamics (Westoby et al., 1989). This alternative approach to pastoral development recognizes the high resilience and variability of the African pastoral environment (non-equilibrium state) and the need for flexibility and mobility in time and space (Behnke and

Scoones, 1993; Sandford, 1983; Westoby et al., 1989). According to this view, degradation by overgrazing is unlikely. Cases of degradation related to overstocking may exist, but the main causes of this are often due to agricultural interventions in key grazing areas with permanent water sources that confine livestock owners to small areas of the rangelands (Rohde et al., 2006). Based on this alternative view, changing land use and tenure arrangements should not ignore the customary systems since the local ecological conditions and the management objectives of the resource users are essential (Swift, 1994).

Over time, it seems more accepted to think that the non-equilibrium theory may have overemphasized the vagaries of climate and the thinking that grazing has negligible impact to long-term vegetation productivity (Illius and O'Connor, 1999; Wessels et al., 2007). Briske et al. (2003, 2005) also argued that there has been no real paradigm shift in the rangeland debate, but that it has been redirected from a dichotomy between equilibrium and non-equilibrium paradigms to seeing the two more as complementary. Current theoretical evidences indicate that both equilibrium and non-equilibrium dynamics occur in ecosystems across spatial and temporal dimensions (Oba et al., 2000; Briske et al., 2005; Vetter, 2005; Wessels et al., 2007). Despite all the rhetoric and policy discussions, the current pace of degradation is unprecedented both in arid and semi-arid areas (Millennium Ecosystem Assessment, 2005).

3.2 Land-use change

Land-use/cover change refers to changes in the attributes of a part of the Earth's surface and immediate sub-surface (Diouf and Lambin, 2001). Land-use refers the way in which humans exploit the land cover, whereas land cover is a biophysical characteristic which refers to the cover of the surface of the earth (Lambin et al., 2003). Land-use/cover change is a dynamic process driven mainly by anthropogenic activities and natural phenomena (Lambin et al., 2001; 2003). In response to the increasing demands for food production, croplands are expanding at the expense of natural vegetation including marginal areas which are less suitable for many crops (Lambin et al., 2000). Although changes in land-use/cover are common in many areas of the sub-Saharan Africa, the speed of change is so rapid in arid and semi-arid areas where vast rangelands are being converted into cropping fields (Barrett et al., 2001; Reid et al., 2004). These changes have an adverse effect on biodiversity of the ecosystems and sustainability of rangeland productivity (Sala et al., 200; Lambin et al., 2003).

It has been widely argued that drought, fire and grazing, are considered to be the driving forces that allow for the observed long-term coexistence of trees and grasses in savanna ecosystems (e.g., McNughton, 1992; Skarpe, 1992; Jeltsch et al., 2000). Accumulating evidence since the 1970s, however, suggest that the long-term coexistence of trees and grasses in savanna ecosystem are being altered by bush encroachment and land clearing for cropping (Scholes and Archer, 1997). Tree–grass coexistence and bush encroachment in savannas have been explained with different theories. (1) Competition-related mechanisms based on the two-layer hypothesis that assumes trees have access to deeper soil layers than grasses for water uptake (Walker et al., 1981) and phenological niche separation based on temporal separation of the regeneration niches of trees and grasses (House et al., 2003). Recently, Rignos (2009) also reported that grass competition in productive savanna limit tree growth similar to the effect of herbivory and fire. (2) Demographic bottleneck models that take life stages explicitly into account and focus on disturbances and climatic variability limiting tree recruitment and growth (Sankaran et al., 2004). In the demographic bottleneck models, tree–grass coexistence is explained by the storage effect explaining that tree is pulsed in time following stochastic rainfall patterns (Higgins et al., 2000) and the ecological buffering mechanisms (i.e., a unifying concept) which states that break-down of woody dominance is caused by disturbance-driven mechanisms such as fire, grazing, or wood cutting (Jeltsch et al., 2000). (3) The patch dynamic model states that bush encroachment is a natural phenomenon occurring in arid and semi-arid areas governed by patch-dynamic processes. The patch dynamic model also integrates most of the coexistence mechanisms proposed thus far for savannas (Meyer et al., 2009). All these theories are mainly based on systems where there are no agricultural interventions.

The major drivers of land-use/cover changes are still disputed (Rowcroft, 2008), but there are still other important reasons than the ecological dynamics mentioned above. A better understanding of the socio-environment interactions associated with land-use/cover changes requires an in-depth analysis how the changes affect the physical environment (i.e., land degradation) and the feedback on livelihood strategies and vulnerability of the people (Lambin et al., 2003). To track landscape structural changes and complexities over time requires mapping of changes from past to present. In this regard, the recently increased availability of satellite data and advancements of remote sensing and geographic information systems (GIS) tools helps to quantify and detect land-use/cover changes (e.g., Jensen, 1996). To enhance the understanding of spatio-temporal land-use/cover processes and interactions

between environmental and socio-economic factors this study employs an approach that identifies the drivers of land-use/cover change linked to the quantified changes. To elicit landscape-level explanations for long-term changes from local residents, the 'ecological time lines' method developed by Reid et al. (2000) was adopted for this study.

3.3 Livelihood adaptation

Many of the arid or semi-arid areas are inhabited by pastoral people that depend on a range of assets and livelihood activities (Coppock, 1994; Hogg, 1997; McPeak and Barett, 2001). The ability to exploit the resources in such uncertain environment necessitates the understanding of pastoral livelihoods (Kratli, 2001; Davis and Bennett, 2007). Heterogeneity in economic, cultural and social status of households influences their access to livelihood assets such as land, labor and capital and may lead to varying diversification strategies (Vedeld et al., 2007; Kamanga et al., 2009). The basic resources like land, labor and livestock are limited and they also vary in access at household level. This creates competition for resources between households (Vedeld, 1990). In such cases, the internal relations may also be a push factor towards sedentarization or other forms of adaptations such as livelihood diversification (Reid et al., 2000). Chambers and Conway (1992) describes livelihood as the 'capabilities, assets (stores, resources, claims and access) and activities required for a means of living'. Ellis (2000) also explicitly defined 'a livelihood comprising the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household'. Ellis (1998) further defines livelihood diversification as 'the process by which rural families construct a diverse portfolio of activities and social support capabilities in order to survive and to improve their standards of living'. In understanding diversification, Ellis (1998) explains three main categories of income sources as (1) farm income referring to incomes from livestock and crops; (2) off-farm income typically refers to wage or exchange labor on other farms (i.e., within agriculture); and (3) non-farm income referring to non-agricultural income sources that include non-farm rural wage employment, non-farm rural self employment, property income (rents, etc.), urban-to-rural remittances arising from within national boundaries, and international remittances arising from cross-border and overseas migration. Berhanu et al. (2007) thus classified the household income sources of Borana pastoralists into three main categories: pastoralism, dryland farming, non-farm/non-pastoral (NFNP) activities.

Access to assets and diversification of activities play a particularly important role in reducing vulnerability to shocks and in determining distribution of income in the society (Ellis, 2000). Ribot (1995) defined vulnerability as the 'risk that the household's entitlements failure in buffering against hunger, famine, dislocation or other losses shaped by ongoing political-economic possesses of extraction, accumulation, social differentiation and marginalization'. A livelihood is sustainable when it can cope with and recover from stresses and shock, maintain or enhance its capabilities and assets, while not undermining the natural resource base (Scoones, 1994, 1998). The adoption of a particular livelihood strategy is highly influenced by the asset status of households mediated by social factors, institutions and exogenous trends or shocks (Kamanga et al., 2009). Dependence to such new engagements, either by choice or necessity other than the main livelihood activity, is seen in terms of the share of income derived from such involvement relative to all other sources (Mamo et al., 2007; Vedeld et al., 2007; Kamanga et al., 2009). Studies on pastoral livelihoods must thus focus on how households differ in their ability to access the different natural and capital assets and how they diversify their income. The sustainable livelihoods framework approach (Ellis, 2000) may thus be an important tool in understanding how adaptation strategies operate in a changing and uncertain arid and semi-arid environment as it centers the household and the basic rangeland resources (land, labor and livestock).

3.4 What determines tree recruitment in African rangelands?

Trees provide browse for livestock, particularly during the long dry-season when other feed resources are scarce, and a variety of services such as food, fuelwood, shade, and medicine to humans who occupy the arid and semi-arid areas in Africa (Le Houerou, 1980; Reid and Ellis, 1995). However, low recruitment rate of some of the important trees in these areas is becoming a concern in recent years (e.g., Lykke, 1998; Venter and Witkowski, 2010). The classic inverse J-shaped size class distribution is generally used as an indication of a healthy, regenerating population, deviation from this (i.e., bell-shaped or positively skewed size-class distributions) would normally be a cause of concern (Wilson and Witkowski, 2003). It has been argued that several interacting factors including herbivores (Russo, 2005; Moe et al., 2009), fire (Oba 1990) and rainfall (Garcia-Fayos and Verdu, 1998; Wilson and Witkowski, 2003; Angassa and Oba, 2008) affect natural regeneration of trees.

African rangelands or savannas have evolved with an adaption to large wild and domestic herbivores (Fryxell et al., 1988; Fryxell and Sinclair, 1988; Wickens, 1997; Shaw et

al., 2002; Riginos and Grace, 2008). The African rangelands have been also the homeland of man with a migratory pastoral and later followed by transhumant/sedentary land use systems (Wickens, 1997). Traditional pastoral production system have for centuries used migratory strategies to meet challenges of seasonal water and food supply (e.g., Behnke and Scoones, 1993). However, pressures from centralized administration favoring agricultural expansion and privatization of land has increased the rate of sedentarization of many pastoralists (e.g., Fratkin, 1997; Ahmed and Teka, 1999; Getachew, 2001) without a concomitant reduction of livestock (e.g., Coppock, 1994).

Large densities of wild herbivores characterize relatively intact savanna areas (Prins, 1992) but livestock has in many areas more or less replaced wild herbivores (du Toit and Cumming, 1999). While both wild and domestic herbivores typically fluctuate due to climatic variations (e.g., Sinclair, 1995) or disease outbreaks (e.g., Sinclair, 1995; Sinclair et al., 2007), livestock densities are commonly held at higher stable densities through active human management interventions (e.g., Matzke, 1983). Low seedling recruitment in many of the rangelands in Africa is thus mainly attributed to high livestock densities. While some studies have focused on the effects of medium sized seedling predators (Belsky, 1984; Mwalyosi, 1990; Prins and van der Jeugd, 1993; Sinclair, 1995), other experimental studies have found that invertebrates (Shaw et al., 2002) and rodents (Goheen et al., 2004) are important seedling predators.

Lack of safe germination sites and high seed predation levels by animals are also considered as major bottlenecks for the recruitment of woody species (Kollmann and Pril, 1995; Kollmann, 2000; Aerts et al., 2006), but these studies have focused mainly on seed bank dynamics of a few species. Depending upon desiccation tolerance and storage behavior, seeds are commonly categorized as orthodox or recalcitrant (Daws et al., 2006; Yu et al., 2008). Orthodox seeds have extended viability in soil and are stored for long periods, while recalcitrant seeds (i.e. desiccation sensitive) lose viability if they do not germinate quickly after seed dispersal (Tybirk et al., 1994; Pritchard et al., 2004). Sullivan and Rhode (2002), however, argue that herbivory may have only a limited impact in determining vegetation, but rainfall variability largely controls dynamics of plant productivity and life history attributes.

Given the marked land degradation and rapid reduction in important plant species in the arid and semi-arid areas in Africa, efforts to study the recruitment failure of these species are rare and almost nonexistent for Ethiopian rangelands. A notable case in Ethiopia is *D. glabra*, which is under threat due to lack of recruitment in recent years. Three of the five studies covered in this thesis thus targeted this species.

4. Materials and methods

4.1 Study area and Afar pastoralists

The study was carried out in Aba'ala district in northern part of Afar region bordering eastern Tigray where there are meager information regarding the rangeland environment and peoples' livelihood. The Afar region, one of the pastoral areas in Ethiopia, has a total area of 100,860 km^2 located in north eastern part of Ethiopia sharing international border with Eritrea and Djibouti (Hundie, 2006). The pastoral areas in Ethiopia are mostly situated in the peripheral regions of the country (i.e., bordering Eritrea, Djibouti, Somalia, Kenya and Sudan) and cover about 60% (i.e., 780,000 km^2) of the land area of the country in seven regional states (i.e., Afar, Benshangul Gumuz, Gambella, Diredawea, Oromia, Southern Nation and Nationalities People, and Somali). Acording to Eshetu (2008), these areas provide a way of life for close to 15 million people. However, others (e.g., Yemane, 2008) reported only 10 million in these areas indicating unreliable population estimates for pastoral areas in Ethiopia.

The study area covers an area of 2506 km^2 in the northern Afar rangelands of Ethiopia and is located between $13^o00'$ to $13^o45'$ N and $39^o40'$ to $40^o12'$ E (Figure 1). The study site lies in a transitional area between the Danakil depression of the Rift Valley and the north western Rift Valley escarpments. It is characterized by an arid and semi-arid climate and lies between 100 to 2500 m a.s.l. with an increasing elevation from east to west. The average daily temperature varies from a minimum of 20 ^oC at higher elevations to a maximum of 48 ^oC at lower elevations. Mean annual rainfall varies between 150 to 500 mm and the amount and reliability declines 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). Patches of scattered *Acacia* woodland, bushland and scrubland are the key features of the rangeland in the study area (Tsegaye et al., 1999, 2003)

The Afars are one of the largest pastoral groups in the Horn of Africa, inhabiting the rangelands of north-eastern Ethiopia, south-eastern Eritrea and Western Djibouti. Based on the 2007 census (CSA, 2008), the Afar Region in Ethiopia has a total population of 1,411,092 (1.9% of the total population in the country), of which 37,943 people live in Aba'ala district (i.e., the study area). About 95.3% of the Afar population is Muslim (CSA, 2008) and 78% are pastoralists (Sonneveld et al., 2009). The majority of Ethiopia's Afar follow a pastoral,

transhumant lifestyle keeping multispecies, multi-purpose livestock to provide sufficient milk and meat for consumption, social exchange and occasional sale (Getachew, 2001). They form a highly traditional society that has received less development attention than many comparable societies in Africa where traditional practices and institutions remain strong (Davis and Bennett, 2007). Although the majority of Afars are pastoralists mainly depending on livestock husbandry for their livelihoods, there are few agro-pastoralists practicing both livestock keeping and cultivation (Tsegaye et al., 1999). Afar pastoralism, however, has undergone profound transformations during the last three decades due to appropriation of their prime grazing lands, particularly in the Awash Valley, for commercial irrigated farms, a game park, and urban settlements (Getachew, 2001). No extensive commercial farm exists in northern Afar where this study was carried out, but both the indigenous Afars and settled Tigryans practice farming in key dry-season grazing areas where the rainfall pattern allows them to do so.

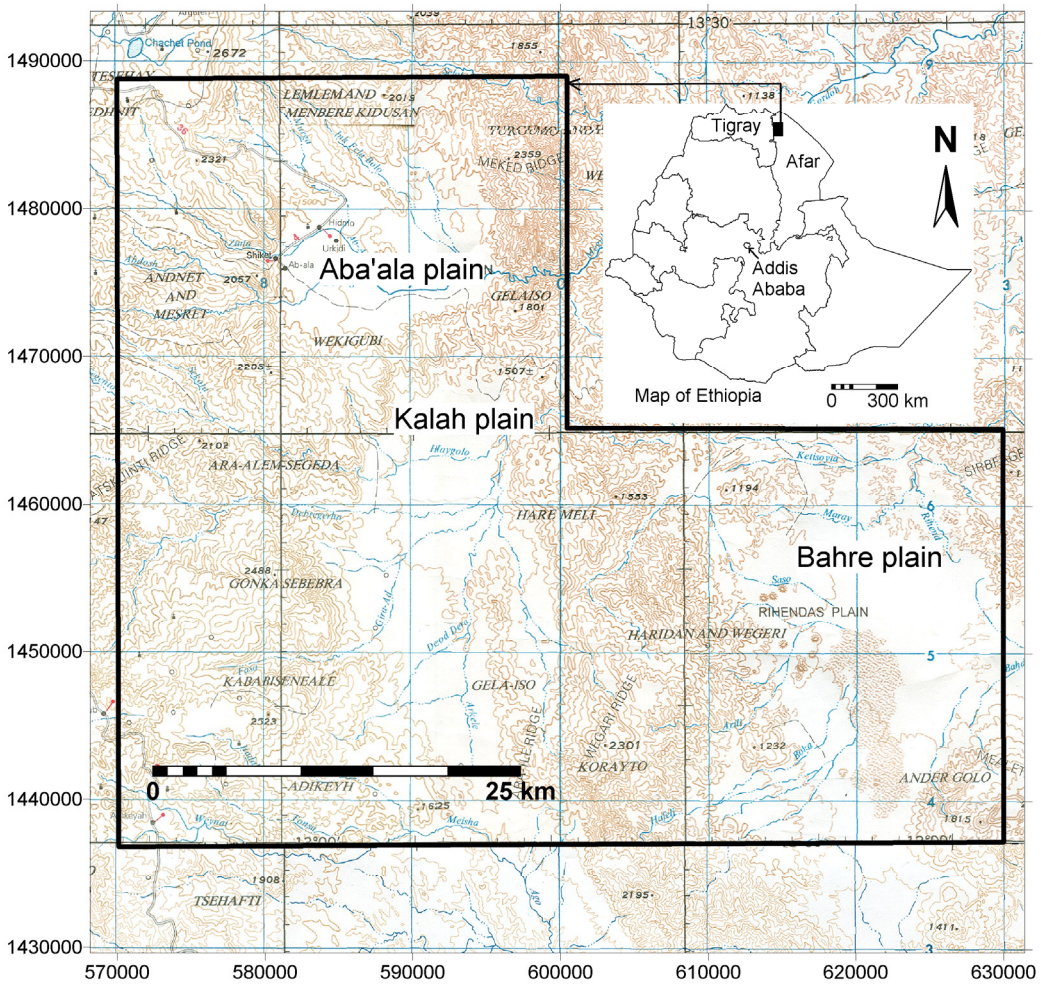

Figure 1. Location map of the study area in northern Afar rangelands, Ethiopia (Projection: UTM, Zone 37 North; Datum: Adindan).

4.2. Methods

Several methods were applied to attain the aim of this thesis. A combination of remote sensing data, field observations and information from local people were used to analyze the patterns and dynamics of land-use/cover changes for the past 35-years between 1972 and 2007 (Paper I). Figure 2 depicts the general approaches used in Paper I.

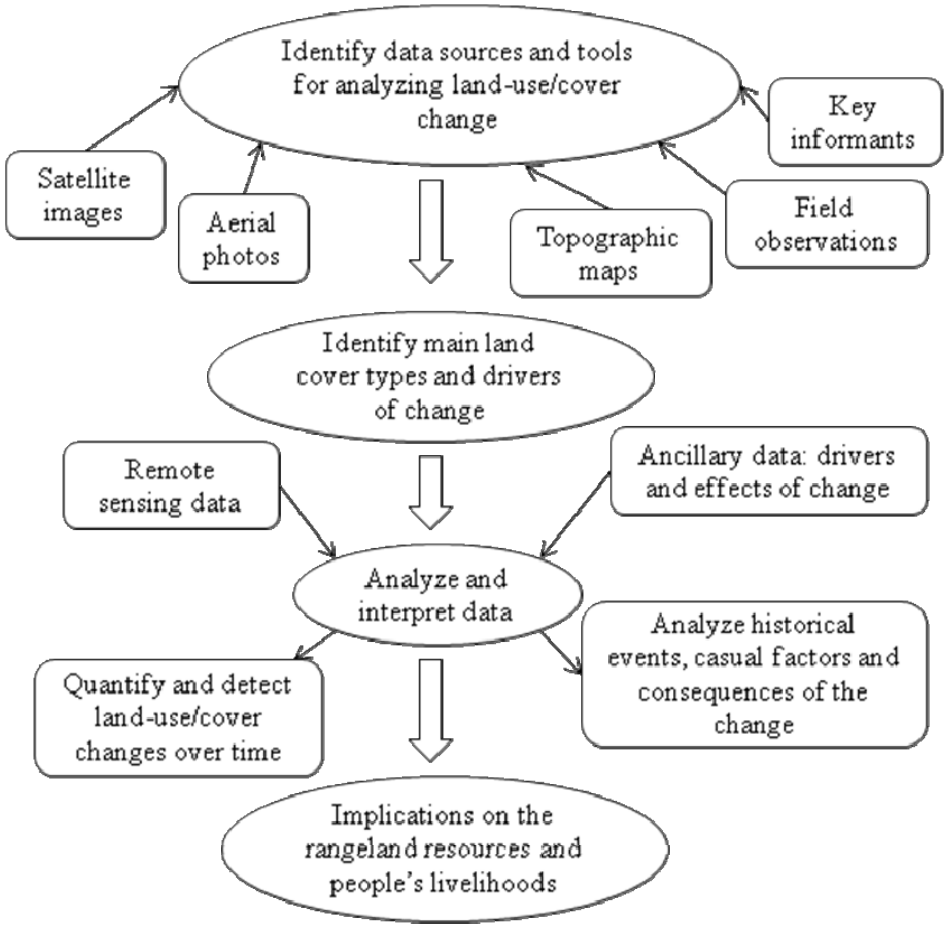

Figure 2. General framework outlining approaches for analyzing land-use/cover dynamics in the context of north Afar rangelands, Ethiopia.

Land-use/cover maps were produced using Landsat MSS (Multispectral Scanner) 1972, Landsat TM (Thematic Mapper) 1986, and ETM+ (Enhanced Thematic Mapper Plus) 2007. Seven land cover classes (i.e., woodland, bushland, bushy grassland, grassland, scrubland, bare land and cultivated land) were identified for image classification. A pixel-based supervised maximum likelihood image classification was used to map the land cover classes. While understanding the patterns of land-use/cover changes over time, the key drivers and consequences of land-use/cover change are often neglected in many studies. In this study, the

possible major drivers and consequences of the changes were explored using key informants and group discussions to further understand the dynamics of land-use/cover change. To develop a time line of historical events we also used the 'ecological time lines' method developed by Reid et al. (2000).

Semi-structured interviews were used to explore the livelihood adaptations among Afar pastoralists (Paper II). A household was a unit of analysis and a total of 223 randomly selected households from the three pastoral (n = 93), two semipastoral (n = 60), one agropastoral (n = 36), and one farming (n = 34) communities were used to generate information. To analyze the income diversification among income groups, wealth status of the different household groups was categorized into better-off, average, and poor based on the number of livestock and size of cultivated land owned by a household. The income sources were also disaggregated as: (1) livestock income, (2) crop income, (3) non-farm non-pastoral (NFNP) income, (4) relief aid, and (5) remittances following Berhanu et al., (2007) and Ellis (2000). In exploring the interrelationships of patterns of resource use and livelihood diversification processes, the sustainable livelihood' framework approach adapted from Ellis (2000) was employed.

Population structure and abundance of *D. glabra* in the northern Afar rangelands was examined using two data sets (Paper III). The first data set related to the overall spatial distribution, was determined by establishing 50 plots (50 m x 50 m) systematically on uniform grids at similar elevation (1000-1250 m.a.s.l.). The second data set related to the influence of land-use and site characteristics on abundance of *D. glabra* was determined by establishing transects in four land-use types (i.e., little disturbed, moderately disturbed, disturbed and highly disturbed). Sampling plots (50 m x 50 m) were established at interval of 400 m intervals along each transect. For the highly disturbed site an interval of 5 km was used as this area was much larger than the others. Physical and chemical properties of the soil were also measured at each sampling interval in each land-use type. The abundance of seedlings, shrubs and trees of *D. glabra* were then analyzed using generalized linear models with land- use type, landform, aspect, elevation and soils as explanatory variables.

Papers IV and V address why *D. glabra* fails to recruit in the Afar rangelands through manipulative germination and seedling survival experiments under varying moisture, mulching/and or shade and browsing exclusion treatments. All the measurements presented in Paper IV were carried out between July and September in 2006 and 2007, and Paper V between October 2006 and September 2007 under nursery and field conditions. To determine the germination capacity of *D. glabra* seeds two sets of experiments were used (Paper IV):

(1) a nursery experiment that included two seed forms ('intact fruit' and 'true seed'), two seed storage levels (fresh and stored for 1-yr), two levels of mulching (with and without mulching), three levels of moisture regimes (none, one day and three days wk^{-1}watering); and (2) how seed predation (with and without vertebrate herbivores) and seed occurrence (exposure at germination site) affect germination of fresh seeds (i.e., 'true seed') in three sites having different disturbance pressure (little disturbed, disturbed and highly disturbed). For the nursery experiment, 20 randomly selected seeds were applied to each treatment combination plots (seed form × storage × mulching × watering) and each treatment combination was replicated five times forming a total of 120 seed bed plots (1 × 1 m). For the field experiment, 30 plots were established 50 m apart from each other in each site. Then, half of the 30 plots were randomly selected and protected (caged with a mesh size of 2 cm) from vertebrate herbivores to avoid loss of seeds by animals whereas the other half was left open as a control. In each plot, 20 fresh 'true seeds' were used as follows: (1) buried and covered with soil (2-3 cm depth), (2) placed on the ground surface and covered by grass mulch (2-3 cm thick), and (3) placed on bare ground surface and left uncovered.

To examine the recruitment of seedlings, three sets of experiments were used to examine regeneration success (Paper V): (1) seedling performance in response to shade and watering in a nursery, (2) field regeneration with and without browsing, and (3) regeneration beneath trees with and without browsing. The seedlings used at nursery and field experiments were from seeds artificially planted directly into the soil during the 2006 main rainy season (i.e., from the germination experiment). But, the seedlings beneath trees were naturally germinated during the same season. We recorded seedling survival (i.e., as number of success or failure) and height every month for one year. Then we calculated relative growth rate in height (RGR) for 12 months (from October 2006 to September 2007) following Hunt (1990). To further examine to what extent seedling survival was affected by moisture stress (i.e., drought) or other factors, we estimated the relative importance of drought as a cause of seedling mortality during the nine months in the dry season for the nursery experiment following Engelbrecht et al. (2005, 2007).

As both germination and seedling survival data were recorded as number of success or failure, a binomial distribution was assumed, except for RGR where normal error distribution was used (Crawley, 2007). The generalized linear model (GLM) with binomial errors (link = logit) was used to analyze the germination success of seeds and seedling survival both for nursery and field experiments.

R software version 2.7.0 (Papers III-V) and 2.11.0 (Papers II) was used for all the analyses (R Development Core Team, 2008). Landsat images processing and mapping (Paper I) were undertaken using ILWIS 3.7 Remote Sensing and GIS software (ITC, 2009).

5. Results and discussion

The findings in this thesis highlight the patterns of land-use/cover change (Paper I), livelihood adaptations (Paper II), distribution and population structure of an important food and fodder plant (*D. glabra*) in areas with different land use histories (Paper III), and effect of seed predation, browsing and moisture on recruitment of *D. glabra* (Paper IV-V) in northern Afar rangelands in Ethiopia. The findings presented in this thesis bring patterns and processes of disturbance from a landscape to a single-species level.

5.1 Extent and trend of land-use/cover change

When assessing management options for rangelands resources in a given bio-physical and socio-economic context, it is convenient to start with an assessment of the land-use/cover changes from the perspective of temporal and spatial extent. Land-use/cover change is a major driver of habitat modification and can have important implications for the health of the entire ecological systems, including the distribution of animal and plant species (Serneels and Lambin, 2001).

Paper I in this thesis describes the magnitude and trends of land-use/cover change in the context of northern Afar rangelands. As shown in the land cover maps (Figure 3), the landscape in northern Afar rangelands changed considerably between 1972 and 2007, in that 47% of the total area changed land cover type. Scrubland vegetation has dominated in all years with 63%, 71% and 62% cover in 1972, 1986 and 2007, respectively. This is not surprising as the northern Afar rangelands are mainly typified by arid semi-arid vegetation types. The most notable changes between 1972 and 2007 were reductions in woodland (97%) and grassland cover (88%), and increase in bushland (281%) and cultivated land (776%) cover. Although cultivated area still covers about 3% of the landscape in 2007, it amounted to about 24% of the alluvial dry-season grazing land.

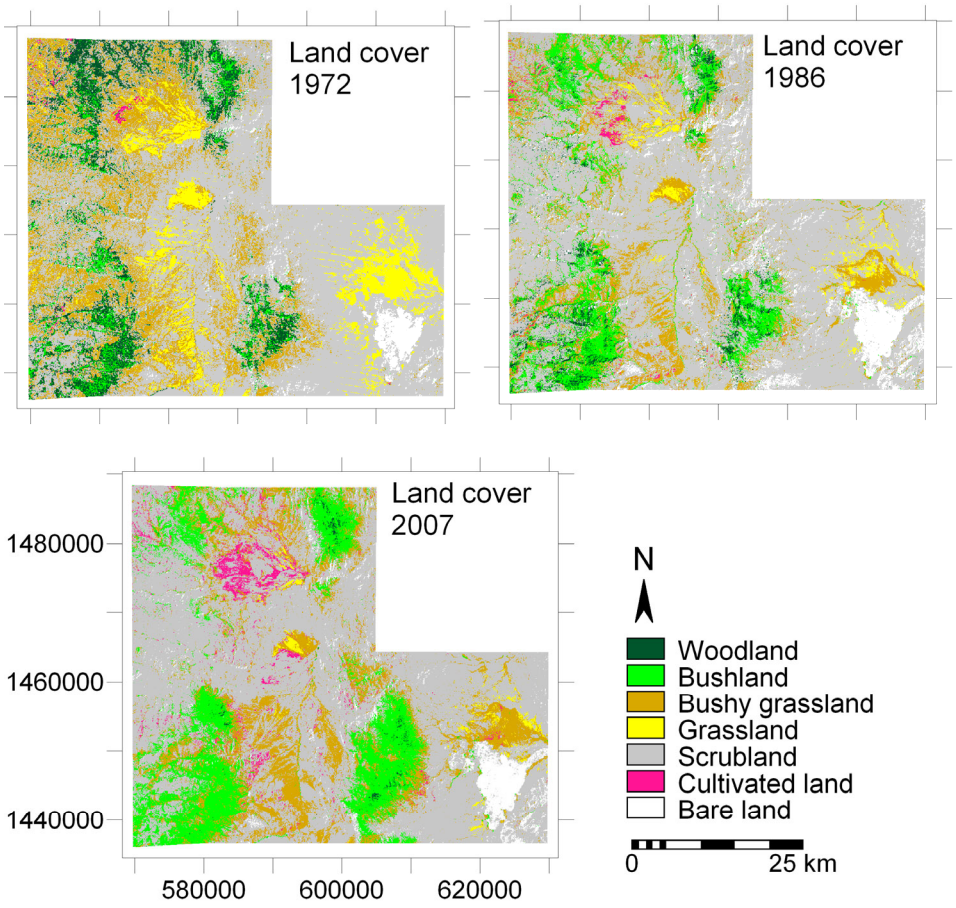

Figure 3. Land-use/cover types of northern Afar rangelands in 1972, 1986 and 2007.

The net change-to persistence ratio (NP) was large for woodland, grassland and cultivated land indicating that they had a higher tendency to decline or increase than persist (Table 1). Although scrubland and bare land cover increased between 1972 and 1986, increased bushland and bushy grassland cover between 1986 and 2007 indicates natural recovery after the severe droughts in 1973/74 and 1984/85.

Table 1. Gain-to-persistence (Gp) and loss-to-persistence (Lp) ratios of the land cover classes.

Land-use/cover	Gp[a]	Lp[b]	Np[c]
Woodland	1.15	63.23	-62.08
Bushland	4.84	0.53	4.30
Bushy grassland	2.90	3.23	-0.33
Grassland	0.34	10.40	-10.06
Scrubland	0.40	0.36	0.04
Cultivated land	28.78	2.33	26.44
Bare land	1.11	0.39	0.72

[a]Gp = Gain/persistence; [b]Lp= Loss/persistence; [c]Np (Net persistence) = Gp-Lp.

Like many rangelands in Africa (e.g., Oba et al., 2000; Angassa and Oba, 2008), 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. The result in this study did not directly match to the traditional view claiming that land clearing for crop production (e.g., Vedeld, 1995) and overgrazing (Oba et al., 2000; Angassa and Oba, 2008) for the decline of woodland cover and bush encroachment, respectively. Rather it is a modification of the woodland cover towards bushland type of vegetation on the hilly areas due to increased tree exploitation. However, increased bush 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 (Lykke, 1998; Wiegand and Jeltsch, 2000).

In line with other studies in African rangelands (e.g., Coppock 1994; Campbell et al., 2005) a reduction in grassland cover in the alluvial plains, caused mainly by encroachment of agriculture, lead to a decrease in the size of the dry-season grazing areas, indirectly resulting in changing livestock species composition, and cause direct disturbance to some plant species that may be threatened to extinction. The failure of *D. glabra* recruitment in northern Afar rangelands (Papers IV-V) was mainly a contribution of such land-use changes indicating the significance of the changes in the system. The non-equilibrium approach where arid and semi-arid rangelands conditions are seen as driven by rainfall and not by grazing (Ellis and Swift, 1988; Behnke and Scoones, 1993) may not be applicable in a situation where pastoral groups have been removed from part of their traditional grazing areas due to conversion of some dry season grazing areas to other land-use types (e.g., Illius and O'Connor, 1999) as witnessed in this study. Although many argue that some large disturbances, such as drought, fire and grazing, are considered to be driving forces that allow for the long-term coexistence of trees and grasses in savanna ecosystem (e.g. Jeltsch et al., 1998; McNaughton, 1992; Skarpe, 1992), altered disturbances such as introduction of cultivation, fire ban and intensive wood clearing for construction and fuelwood did not allow such coexistence in the study area.

5.2 Drivers of land-use/cover change

A number of interacting variables and processes contributed to land-use/cover changes. According to the elder informants, the principal form of land cover change prior to the 1960s was temporary shifts from grassland to bushy grassland and vice versa dictated by fire and

grazing. Based on accounts from local people and secondary sources, major events that largely explain the changes in land-use/cover in the study area since the 1960s include: (1) policy changes in land tenure that favors crop farming (Box 1); (2) sedentarization of pastoralists and increased overgrazing in dry-season grazing areas since the 1960s; (3) severe droughts in 1973/74 and 1984/85; and (4) shortage and poor distribution of rainfall during the last decade.

The results from this study demonstrate that the dominant anthropogenic land cover change processes responsible for the loss of the grassland and woodland cover during the first period (1972-1986) were: (1) wood extraction for domestic uses and charcoal production for commercial purposes, mainly by immigrants; (2) conversion of grassland into cropland; and (3) overgrazing in the remaining alluvial plain dry-season grazing lands. The driving forces behind these processes were the occurrence of two severe droughts in 1973/74 and 1984/85 (Meze-Hausken, 2004) and land tenure policies (Box 1) that encouraged sedentarization of pastoralists and crop farming. These two driving forces were important underlying causes that encouraged influx of people into northern Afar from highly populated and degraded areas in the neighboring Tigray region (Meze-Hausken, 2004; Tsegaye et al., 1999). As a result of continued migration of people from neighboring areas and increased sedentarization of pastoralists, more alluvial dry-season grazing areas were converted to cropland in the second period (1986-2007).

In-migration, sedentarization of pastoralists, shrinkage of grazing land, and a shift in livestock species composition from camel-cattle to small stock-camel dominated, recruitment failure of some plant species were the main consequences of land-use/cover change in northern Afar rangelands. The pastoralists explained a shift in livestock species composition is a response to changes in vegetation types and high demand for goat meat in recent years. The Afars particularly stated that recruitment failure of the important food and fodder plant, *D. glabra*, in the alluvial plains could be an important indicator of either grazing/browsing pressure or rainfall variability or combinations of the two (Papers III-V). They also remember that many of the wild animals disappeared. They attributed this mainly to the loss of woodland and long civil war that took place in the area between 1980 and 1990.

Box 1. Land tenure policies since the 1960s

Here I provide a brief review of the major land tenure policies since the 1960s as they relate to pastoral areas in Ethiopia. Policy makers in all the three governments since the 1960s (i.e., Imperial, Socialist regime and the current) have consistently encouraged settlement and crop farming in pastoral areas (e.g., Getachew, 2001; Rahmato, 2007). During the Imperial period, the land tenure in Ethiopia was a feudal system directed towards individualized property (Omiti, 1999; Kebede, 2002). The Constitution during the Imperial period gave a decisive power to the state both as landlord in its own right and according to Article 130 of the 1955 Constitution "all property not held in the name of any person including all forests and grazing lands" are state domain (Rahmato, 2007). As a result, much of the land utilized by pastoralists in the country fell under state domain, which gave the state control over nearly 65 percent of the land (Rahmato, 2007). For instance, the appropriation of large tracts of land for a variety of purposes including mechanized farms, livestock development programs, and settlement schemes in the Awash River Valley traditionally belonged to Afar and Kereyu pastoralists, is a reflection of the coercive action of the imperial state (Getachew, 2001; Hundie, 2006; Rahmato, 2007; Yemane, 2008).

The imperial land tenure system was brought to an abrupt end by the land reform of 1975 with nationalization of all land by the state (Kebede, 2002) and consequent establishment of state farms, cooperatives and small-holder farms (Omiti et al., 1999). The provision by the Proclamation (No. 31 of 1975) gives "the state, as the trustee of the people, the right of ownership of all rural land and other resources, and that prohibits private ownership of land". Regarding pastoral areas, Article 26 states that "nomadic people shall have possessory rights over the lands they customarily use for grazing or agricultural purposes". According to this article, the state took away the authority of pastoralists' customary institutions (i.e., absolute rights to the land were turned into possessory rights with the ultimate right vested in the state), but was not successful at the end (Rahmato, 2007). Although land appropriation continued for the establishment of state farms in the Awash Valley, in reality customary rights to land and community institutions in other areas remained largely unchanged (Rahmato, 2007).

After the fall of the Socialist regime in 1991, the existing Federal Government's land policy is quite similar to the previous regime. In effect land is state property, and peasants thus have only use rights over plots they have in their possession which cannot be sold, exchanged or mortgaged. Although difficult to translate into concrete measures, the present Constitution recognizes pastoral land in a better way and declares (Article 40) that Ethiopian pastoralists "have the right to free land for grazing and cultivation as well as the right not to be displaced from their own lands". On the other hand, the government is still facilitating the gradual conversion of pastoralists into more sedentary livelihoods (Hundie and Padmanabhan, 2008). In line with this, the Federal land law of 2005 declares that the government can decide to transfer "communal land" (i.e., land communally held by pastoralists) to private holdings if it deems it necessary (Article 5 No. 3). The government has also embarked on new measures that include land certification and registration (Rahmato, 2007). How registration and certification is to be undertaken in pastoral areas where land is held in common, however, is not clear. All these lead to a conclusion that customary institutions in pastoral areas of Ethiopia are progressively being undermined owing to lack of clear land tenure policies as they appear today.

Although efforts by governments in Africa to sedentarize pastoralists as a means of control seems unsuccessful so far (e.g., Rahmato, 2007), pastoralists settle for a variety of reasons in response to 'push' (such as drought, privatization of land, population growth, etc.) and 'pull' (such as modernization or urban life) factors (Roth and Fratkin, 2005). Sedentarization is a process that operates along a continuum from highly mobile pastoral

households to permanently settled households, of which individuals may move from one domain to another (Roth and Fratkin, 2005). Sedentarization, thus, entails costs and benefits. For instance, Roth and Fratkin (2005) indicated that settled pastoralists often have increased access to health care, education and markets, but they may also incur losses in nutritional status and new health hazardous. Campbell et al. (2005) also emphasized the positive benefits of migration in northern Kenya as an adaptation strategy of people to the effects of drought.

Sedentarization of Afar pastoralists is still continuing, whereas the increased influx of people to the study area is now very much less due to establishment of ethnic based administration and availability of labor employment opportunities in the rapidly growing urban areas in Tigray since 1991. Although there is a decline in agricultural activities due to reductions in rainfall over the last decade, the Afar pastoralists continue sedentarization processes but dependent on relief aid. There is also a tendency to shift to irrigated agriculture linked to the increased sedentarization of pastoralists. Thus, the internal push from the pastoralists themselves and the political decisions made by national governments including Ethiopia that compel pastoralists to settle will determine the future of pastoralism (Blench, 2001).

5.3. Livelihood adaptations

Paper II in this thesis examines the patterns and implications of present livelihood adaptations among Afar pastoralists living in arid and semi-arid harsh environments in north eastern Ethiopia. Based on their involvement in pastoralism and farming as well as their historical background, four groups of households – pastoral, semipastoral, agropastoral and farming – were identified in the study area. Categorized based on the number of livestock and size of cultivated land owned, a majority of the households are in the average (i.e., less poor) wealth category (50%), while the better-off and poor represent 21% and 29% of the total households, respectively. These distinctions thus might be important to distinguish livelihood adaptations between the different groups and in order to address any intervention that might take place in the study area.

The findings in this study (Paper II) revealed that livestock, land and family labor constitute the main livelihood assets in the study area. All the household groups in the study area share similar agroecological environment and have equal access to grazing lands and natural water sources (i.e., communally owned) for their livestock, but they vary in their access to other livelihood assets such as livestock and cultivated land. Livestock is

economically the most important livelihood asset in Afar and this agrees with the notion that livestock are second only to land as an important form of physical capital for rural families worldwide (de Sherbinin et al., 2008). On average, a household in the study area own 6.3 ± 6.4 TLU (Tropical Livestock Unit) ranging between 0 and 48 TLU. Cultivated land holding was 1.9 ± 1.3 ha, 1.8 ± 1. ha, and 2.9 ± 1.2 ha for semipastoral, agropastoral and farming households, respectively. Better-off households often have either a high number of livestock or better access to cultivable land or both compared to poor households, indicating that variations in access to assets has led to differences in the welfare of households. In this scenario, households with greater livestock asset holdings will reduce risk as their assets allow them to benefit from the increasing demand for meat from the growing urban areas. The result in this study also revealed that better-off households tended to have more diversified income activities indicating that households with a greater concentration of assets were more likely to diversify more compared to poor households. This agrees with Ellis (2000) who described that access to assets play a major role in determining distribution of income in the society.

In terms of household income, pastoral households had significantly lower annual income compared to semipastoral and agropastoral households indicating that combining livestock production and dryland farming is a better option that has encouraged livelihood transformation. This indicates that pastoral households are less likely to diversify their livelihoods, while others (semipastoral and agropastoral households) use livestock as an insurance against failure in other livelihood activities such as farming. Households in the study district were generally poor with an average annual household income of 2764.7 ± 1849.1 USD adjusted for purchasing power parity (PPP). This gives an average per capita income of 363.8 USD (PPP-adjusted) including relief aid or 279.4 USD (relief aid deducted), much lower than the national average of 552 USD (PPP-adjusted: World Bank, 2010) in the year 2006. Despite significant differences in the household annual income between wealth groups, all households, including the better-off income groups, are generally poor and face food shortages of more than six months in a year. On average, the per capita income per day was 0.55, 0.35 and 0.21 USD (unadjusted for PPP) for better-off, average and poor households, respectively. The national average per capita per day was 0.52 USD (World Bank, 2010). Relief aid is an important source of income particularly for households that are attached only to livestock production; it contributed 23% of the total income in 2006 for pastoral households. Surprisingly, better-off households receive a higher income from relief aid compared to the poor. This may be because relief aid distribution is based on the family

size and all households receive relief aid regardless of their income in the district. Such distribution is welcomed in Afar society where the better-off share food to the poor in times of shortage.

> "*Any poor Afar household does not regard itself as poor so long as there are many better-off relatives or other households in his clan*" (An Afar elder).

The findings in this study (Paper II) demonstrated that livestock still remains the principal source of Afar livelihoods. Income from livestock contributed 39% to the total household income, followed by crops (32%), relief aid (20%), NFNP (8%), and remittances (1%) for all the studied household groups. A case study for Borana pastoralists in southern Ethiopia also reported a similar trend, but the share of livestock capital (72%) for Borana was much higher relative to other income sources (Berhanu et al., 2007). Better-off households derived 64%, 54% and 51% of their total household income from livestock in 1996, 2002 and 2006, respectively. This thus suggests a pattern that the likelihood of remaining in pastoralism is increasing with wealth status. In recent years, however, many households shifted into a lower wealth group in terms of livestock ownership compared to 1996. This arises because of drought in 2002 and increasing dry years thereafter. Davis and Bennett (2007) also reported similar trends in southern Afar.

As many people become poor, an increased involvement into NFNP activities was observed in recent years in addition to receiving relief aid. NFNP accounted for 19% (better-off), 20% (average) and 24% (poor) of the total household income in 2006, indicating that the contribution from NFNP income was almost similar for all wealth groups. Although not significantly different, involvement in NFNP activities generally appears to follow an inverse J-shape pattern in the study area, showing that the poor are more involved in such activities compared to the better-off. Ellis (2000) explained such trends as uncommon livelihood pursuits by poor households in response to shocks and consequent substantial asset loss. However, NFNP income was particularly important for farming households and increased from less than 5% in 1996 to 26% in 2006. About 68% of the farming households were involved in natural based resources activities such as firewood, charcoal and construction pole harvesting and sale. It is a common practice that crop failure guide diversification decisions for farming households (Block and Webb, 2001). Diversification of economic activities is a typical strategy reported in many studies on rural livelihoods (e.g., Ellis, 2000; Berhanu et al., 2007; Davis and Bennett, 2007). In east Africa, involvement of pastoralists in

non-pastoral activities is mainly to survive the effects of shocks (such as drought) and in response to market opportunities (Campbell et al., 2005; Reid et al., 2004). Inhabitants in marginal environments diversify their income to avoid dependency on only one or two income sources and to withstand exogenous shocks (Barrett et al., 2001; Ellis, 2000). The commitment to diversification by poor households in such risky environments reflects constraint rather than choice (Block and Webb, 2001). However, the recently increasing involvement in natural resource based non-pastoral activities such as firewood and charcoal making for commercial purposes, particularly by the settled farming households in the study area is a response to poverty driven dryland farming engagements in an environment unsuitable for crop production.

The result in this study thus suggests that transformation from pastoral to agropastoral mode of production practiced in northern Afar is not wholly driven by constraints (i.e., external shocks and trends in the system), but could also be a choice to earn additional income and help them to supplement the growing cereal based diets (Little et al., 2001). Drawing on perception of local people, pertinent linkages between land-use change and livelihood adaptation that reveals the transition of Afar pastoralists to sedentary life is evident. All pastoral, semipastoral and agropastoral households believe that pastoralism forms a significant form of the identity of the Afar society and is the main reason for continuing the practice. With the introduction of crop farming by settled Tigryans in the early 1960s, involvement of some pastoralists in farming directly or indirectly became more significant and in some areas even replaced pastoralism as the main activity.

The findings in this thesis thus demonstrate that the Afar pastoralists are in transition to a sedentary life through increasing involvement in farming and NFNP activities without total detachment to the traditional mobile herding.

5.3 Why *D. glabra* fail to recruit in Afar rangelands?

Due to various changes in the environment and associated changes in land use, there is a shift in plant species composition in Afar rangelands of Ethiopia (Tsegaye et al., 1999). *Dobera glabra* is among valuable woody species under threat in Afar rangelands of Ethiopia. Although the importance of *D. glabra* is highly appreciated by the local people in terms of food source and livestock feed, there are some critical problems regarding this plant. Although scattered *D. glabra* tree stands are still a common feature of some localities in Afar, the local people have observed that they rarely see seedlings and saplings. Yet, no work has

been done so far to identify the causes responsible for the recruitment failure of *D. glabra*. Thus, this study addressed why *D. glabra* fails to recruit in the Afar rangelands through analyzing population trends in relation to land-use histories (Paper III), germination (Paper IV) and seedling survival (Paper V) under varying moisture, mulching/and or shade and seed predation/browsing exclusion experiments.

5.3.1 Effect of land-use histories on structure and population trends

This study (Paper III) has revealed a number of important patterns of *D. glabra* abundance in areas with different land-use histories, land forms, elevational gradients and related environmental factors (i.e., soils). Differences in densities exhibited in areas with different land-use histories are particularly important. In all the land-use types, seedlings and trees were only present in low numbers indicating a bell-shaped size-class distribution confirming that regeneration of *D. glabra* is poor. During the surveys, we did not come across any saplings of *D. glabra* confirming that seedlings had not been able to grow to sapling stage because of high browsing pressure.

The classic inverse J-shaped size-class distribution is generally used as an indication of a healthy regenerating population for many woody species (Wilson and Witkowski, 2003). However, low recruitment rates may not be a cause for concern for long-lived trees that commonly exhibit low adult mortality rate such as the Baobab tree in Africa (Venter and Witkowski, 2010). This could be true in a situation where there are sufficient trees in reproductive size-classes and trees which grow rapidly in small size-classes with a higher rate of survival (Condit et al., 1998) are able to sustain population levels with low or episodic-linked recruitment for long-lived trees.

In this study, however, low number of large trees (Paper III), and high browsing pressure combined with slow growth rates of seedlings (Paper V) indicate a poor recruitment for *D. glabra* that necessitate a concern for conservation. Despite the acceptability of low recruitment rates for long-lived trees (Venter and Witkowski, 2010), it seems unlikely to sustain the population of *D. glabra* with such poor recruitment and may disappear from Afar rangelands with the rapidly changing land use (Paper III) and climatic patterns in the arid and semi-arid areas of Africa (Tews and Jeltsch, 2004; Maranz, 2009). Rangeland managers, thus, should encourage assisted regeneration in areas where there is relatively better *D. glabra* stands.

5.3.2 Nature of seeds and current trends in climate

Dobera glabra fruits mature in the late dry season following the short rains (in March or April) and seeds are dispersed before or just at the beginning of the long rainy season (July-September). Such occurrences are common for many tree species in the tropics (Khurana and Singh, 2004). However, fruit development and seed maturity of *D. glabra* may be reduced or fail completely (i.e., only very few trees managed to produce seeds) as it was witnessed in 2007 where no single shower occurred. This suggests that *D. glabra* requires few showers at the middle of the dry season for seed production and good rains in the subsequent long rainy season. In addition to the occurrence and timing of rain events, the availability of seeds for germination depends on the level of predation of the fruit and seeds by humans and animals. Both humans and animals are in short of food and feed supply at time of *D. glabra* fruit maturation and the majority of the fruits or seeds are removed before getting the chance to germinate. The herders move animals to all range sites where *D. glabra* trees are available and target these trees for the consumption of edible pulp and this in turn lead to high seed predation that prevents regeneration from seeds.

Nursery experiment showed that germination capacity of *D. glabra* seeds varied significantly between seed storage (fresh vs. stored), mulching conditions (with and without mulching), seed forms ('intact fruit' vs. 'true seed'), and watering regimes (none, one and three days wk^{-1}). Stored seeds had poor germination performance compared to fresh seeds indicating desiccation sensitivity (Paper IV). If not germinated immediately after dispersal, recalcitrant seeds are either easily lose viability (Tybirk et al., 1994) or lost to predators (Kollmann and Pril, 1995). This supports the hypothesis that recalcitrant seeds, a strategy not common in semi-arid areas, are vulnerable to large variations in moisture availability and high seed predation pressure. However, a germination success up to 22% for 1-yr stored 'true seed' apparently contradicting what has been reported about recalcitrant storage behavior of *D. glabra* seeds (Schaefer, 1991). But this should be understood in such a way that germination success (22%) is unlikely for *D. glabra* seeds 1-yr after dispersal in their natural environment if seeds miss the germination possibilities during the same season they are dispersed for two main reasons. First, the seeds can easily be lost due to consumptions by predators, especially during the dry-season when other feed resources are scarce in the arid and semi-arid areas. Second, seeds can easily lose their viability under the scorching sun during the long dry-season even if they escape from predators.

5.3.2 Regeneration

Nursery experiments showed that *D. glabra* seeds that received either mulching or supplementary watering (three days wk^{-1}) had a higher germination success than non-mulched and not supplementary watered seeds in nursery (Paper IV). Although *D. glabra* seedlings that received either supplementary watering (one day or three days wk^{-1}) or shade, or a combination of shade and watering had higher survival compared with the control, water limitation is not a crucial limiting factor as 53% of the seedlings survived without shade and watering treatments (Paper V). Similarly, shade treatments resulted in minimal increase on relative growth rate of seedlings suggesting that moisture limitation does not affect growth much once seedlings are properly established. Confirming this scenario, *D. glabra* seedlings mortality due to drought for non-watered plots in the nursery was 28% implying that *D. glabra* is drought resistant and seedlings may persist if there are no additional limiting factors. In agreement with this findings, other studies have also shown that relative mortality due to drought is lower for species associated with dry habitats than species associated with more humid habitats (Engelbrecht and Kursar, 2003; Engelbrecht et al., 2005; Zida et al., 2008). Higher root length to shoot height (9.2:1) and root to shoot biomass (2.2:1) ratios for non-watered *D. glabra* seedlings (Paper V) indicate how seedlings persist in drier conditions by allocating more resources to roots to ensure better access to lower moist soil layers. Hence, germination is a crucial stage for the recruitment of *D. glabra* when considering moisture, regardless of other factors such as herbivory.

The field experiments showed that control plots (i.e., open to herbivory) had extremely poor germination success (below 11%, Paper IV) and seedling survival (below 15%, Paper V) compared to plots protected from herbivores suggesting that seed predation and browsing highly contribute to the recruitment failure of *D. glabra*. The field experiment, thus, supports previous findings from dry savanna systems where herbivory controls woody vegetation regeneration (e.g., Moe et al. 2009). However, *D. glabra* seeds that were freely exposed on the ground had low germination success also within the protected plots indicating moisture constraint at time of germination. This is in support of previous studies in tropical areas where plant recruitment is hampered by poor soil moisture conditions in the absence of herbaceous cover or poor litter accumulation, (e.g., Tybirk et al., 1994; Prider and Facelli, 2004). In addition to the moisture conserving benefits, covered seeds have the advantage of escaping seed predation by animals (Fenner and Thompson, 2005).

Although moisture is not a limiting factor for seedling growth (Paper V), both the nursery and field experiments showed that *D. glabra* seems a slow growing species as the mean height did not reach 50 cm in a year. This exposes the seedlings to repeated browsing that disrupts the apical dominance, particularly in a situation where other feed resources for livestock are scarce. This is also reflected in that *D. glabra* mainly remain as shrubs, which have morphologically regressed to a medium-sized vegetative stage (i.e., failed to reproduce, constrained by intense browsing) (Paper III).

Germination failure caused by seed predation and moisture stress coupled with intense browsing as witnessed in this study may result in local extinction of the rarely occurring tree species having recalcitrant seeds in dryland environments. The results of this study revealed that seedlings may persist under existing moisture constraints if protected from intense browsing, whereas both seed predation and moisture limitation negatively affected seed germination. Thus, natural recruitment of *D. glabra* seems unlikely or limited due to: (1) current changes in climate and land use that does not allow frequent regeneration from seeds for *D. glabra* that does not form a seed bank (i.e., having recalcitrant seed that requires enough moisture for immediate germination after dispersal), (2) the existing continuous and intensive grazing/browsing, where the mobility of pastoralists is restricted. Since *D. glabra* seedlings can withstand moisture stress, maintaining a seedling bank (i.e., protecting from intense browsing) might represent an efficient strategy towards a better recruitment of *D. glabra* whenever there is a chance of episodic-linked germination in some key range sites in Afar rangelands. Additionally, planting nursery raised seedlings in home gardens of settled pastoralists and establishment of grazing reserves in some key range sites that contain *D. glabra* could help offset the recruitment failure of this important food and fodder plant species in Afar rangelands.

6. Concluding remarks

The empirical studies presented in this thesis lead to the following overall conclusions:

The findings in this thesis underlines that the arid and semi-arid rangelands in northern Afar experienced substantial and increasing rates of land-use/cover changes during the 35-years from 1972 to 2007. The present tendency thus may lead to more land degradation if no assisted restoration is made. The Afar pastoralists are in dramatic transition from traditional mobile pastoralism to sedentary life since the 1960s, resulting in high competition between different land-use types (i.e., farming and pastoralism). The change

from being traditional pastoral to settled life (i.e., agropastoral) has been associated with a change in land-use/cover, and emerging livelihood adaptations. Although pastoralism still remains important for the majority of Afar households, it has shifted from being a core economic activity to being an insurance against failures in other livelihood activities for some groups of households.

Despite the debates and policy discussions about the sustainability of pastoralism, it seems more appropriate to accept and understand the changing trends in pastoral areas at all levels. This, therefore, suggests appropriate pastoral development policies, approaches and programs in line with the pace of fast changes happening in the pastoral areas. Moreover, follow-up of the land-use changes in the northern Afar rangelands is required, and the methods used in this study can serve as a potential tool for such monitoring.

The results in this thesis also serve as a benchmark for *D. glabra* recruitment status in the light of land-use changes that may arise from increased sedentarization of pastoralists and a predicted reduction in rainfall due to climate change. It should be underscored that the important food and fodder plant, *D. glabra*, is currently under increasing pressure in northern Afar rangelands with the pace of fast changes in pastoral areas. Although *D. glabra* is a long-lived tree that may maintain population with low recruitment, the findings in this thesis indicate poor seedling recruitment caused by high browsing pressure and seed predation linked to land-use changes. Furthermore, predicted drop in rainfall attributed to climate change may negatively affect future recruitment and may increase tree mortality. Thus knowledge of current recruitment will guide resource management decisions and serve as a valuable reference point in future population studies. In areas, where *D. glabra* populations have relatively low recruitment rates, resource managers should encourage a 'culture' that will enhance regeneration.

This study also calls for a change from a traditional pattern of exploitation to a more conscious utilization and management of *D. glabra*. It is unlikely that *D. glabra* will be able to survive without conservation efforts. It may only be sustained if protective measures are put in place.

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