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The Dynamics of Savanna Ecosystems and Management in Borana, Southern Ethiopia

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in
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Abstract

Ayana Angassa. **The dynamics of savanna ecosystems and management in Borana, southern Ethiopia.** Department of International Environment and Development Studies, NORAGRIC, Norwegian University of Life Sciences (UMB).

This thesis discusses the dynamics of savanna ecosystems and management in southern Ethiopia by investigating the roles played by rainfall variability and the impact on cattle population under the communal rangelands and ranch system. The thesis considers the variability in terms of impact of multi-year droughts on livestock of different reproductive classes and their recovery patterns, comparing the traditional and ranch management systems. The thesis also investigates the importance of using herder environmental knowledge in understanding historical changes in patterns of land use and shifts in vegetation, with implications for pastoral production. Using herder concerns about shifts in grassland vegetation to bush encroachment, the thesis presents studies that examine the ecological mechanisms of bush encroachment in relation to protection, grazing and time of protection. The studies demonstrate the control of bush encroachment and evaluate the responses of individual woody and herbaceous species using six demonstrations.

This study is based on ecological models, focusing on the equilibrium and non-equilibrium models. The thesis seeks to understand the drivers of change behind cattle population variability, mechanisms of bush encroachment and effects of control demonstrations on woody and herbaceous plant species in Borana. Traditionally, the Borana land use system involves extensive livestock production based on mobility between the key and non-key resources. The thesis uses household interview and field based data collected between 2002 and 2005. Household cattle data (21 years) and the ranch cattle data (15 years) were related to long-term rainfall variability.

Breeding cows in the key resource *tula* well rangelands showed longer reproductive life than the non-key resource pond-water rangelands. Average calving rates were greater in the communal rangelands than in the ranch system. Severe mortality and greater reduction in calving rates during multiple droughts resulted in reduced herd growth potential. Inter-annual variability in rainfall seems to have a considerable effect on cattle populations compared to density dependence. The combined effects of variable rainfall and increased bush cover might lead to risks of drought induced herd die-offs. Specifically, herder perceptions indicated that the emergence of range enclosures and expansion of crop farming have reduced the extent of grazing, while fire suppression has promoted bush encroachment.

Furthermore, the study found greater densities of invasive woody species in enclosures as opposed to the open grazed areas. This implies that additional causes might be involved in the process of bush encroachment apart from grazing. The use of the state-and-transition model showed complex successional pathways of changes with regard to variability in rainfall, management interventions and

timescales (i.e. the age chronosequence of enclosures) that are relevant for making management decisions.

The thesis suggests that protection from disturbance promotes bush encroachment. It was found that four out of the six bush control methods substantially reduced bushy plants, with varied effects on individual species. Overall, the tree cutting, fire and grazing treatment was more effective in controlling coppicing after disturbance. Different woody species showed varied adaptation strategies in response to disturbances by either adapting to increased seedling recruitment or coppicing after disturbance.

The disturbance control treatment had no advantage in terms of herbaceous biomass and basal cover over other treatments, while herbaceous species richness was enhanced. This thesis suggests that grazing with bush cover greatly reduces herbaceous biomass. Generally, tree cutting and fire seemed superior in terms of herbaceous biomass, while fire and grazing, and tree cutting are recommended for the conservation of herbaceous species diversity. The outcomes in terms of herbaceous biomass and species diversity have important policy implications for bush encroachment control and public education. This thesis emphasizes the importance of the fire and grazing method which can reasonably be recommended for control of bush encroachment with the overall objective of promoting herbaceous biomass and species diversity.

Results presented in this thesis suggest the following views: (i) The study acknowledges the evidence of density dependence at the level of local land use, but overall density independence at the regional level. The findings further confirm the failure of ranch management in reducing herd mortality and signify the role of rainfall variability even under a controlled system. The need for drought management, focusing on post-drought herd rehabilitation through the distribution of bulls, depends on the breed conservation ranch and is important for the maintenance of the Borana cattle breed; (ii) The use of communities' environmental knowledge as a framework for understanding the impacts of land use change on the environment, may provide a strong foundation on which to reconstruct scientifically and culturally acceptable methodological approaches. Sustainable use of the savannas of southern Ethiopia in the future will require paying greater attention to regulating expansion of enclosures, crop farming and ranching, as well as re-introducing fire, where necessary, to control bush encroachment; (iii) The state-and-transition model is appropriate for describing the mechanisms of bush encroachment; (iv) Responses of individual woody and herbaceous species to bush control methods have important implications for management, conservation policy and public education which in the future should be promoted through public education and extension.

1. General introduction

The thesis examines the dynamics of savanna ecosystems and management in Borana, southern Ethiopia, by investigating the role played by long-term rainfall variability on cattle populations managed under the communal rangelands (i.e. key and non-key resource grazing lands) and the ranch management system. The thesis considers the variability in terms of the impact of multi-year droughts on livestock of different reproductive classes and their recovery patterns, comparing the traditional and the ranch management systems. Specific hypotheses were posed and tested in a comparative study.

The thesis also investigates the importance of using herder environmental knowledge in understanding historical changes in patterns of land use and shifts in vegetation, with implications for pastoral production. Using herder concerns about shifts in vegetation from grassland to bush encroachment, the thesis presents studies that examine the ecological mechanisms of bush cover changes in relation to protection, grazing and time of protection. The studies demonstrate the control of bush encroachment and evaluate the responses of individual woody and herbaceous species. The results were used to recommend public education and land use policy for the management of the dry savannas of southern Ethiopia. Although the terms ‘savanna’ and ‘rangelands’ are used interchangeably in this thesis, the former refers mostly to the ecosystem and the latter to the systems of resource exploitation for livestock production.

Dry savannas are generally complex systems (Westoby *et al*., 1989), alternating between woodland and grassland states (Van De Koppel and Prins, 1998). In this thesis, the concept ‘dry savanna ecosystem dynamics’ refers to the biological components in terms of the discontinuous grass vegetation and woody vegetation influenced by fire, grazing and climate variability (Menault *et al*., 1985; Long *et al*., 1992). The dynamics of dry savanna ecosystems would be better understood if key research hypotheses are addressed at both regional and local levels. Such dynamics include rainfall variability, livestock (e.g. cattle) population, effects of droughts on livestock populations, human exploitations and the drivers responsible for the shifts in vegetation on large spatial scales.

The present study considers fire, grazing and human exploitation as the main drivers of the savanna ecosystem, with rainfall variability playing an overriding role. The remarkable variations in seasonality and year-to-year rainfall result in fluctuating forage that induces fluctuations in animal populations (Le Houerou and Hoste, 1977; Le Houerou *et al*., 1988). Inter-annual rainfall variability in dry savanna ecosystems is typically characterized by a high coefficient of variation that reflects periodic ungulate population crashes (Ellis and Swift, 1988; Owen-Smith, 1990). For example, the fluctuating rainfall causes fluctuating forage production, which influences cattle population dynamics (e.g. Oba, 2001; Desta and Coppock, 2002; Angassa and Oba, 2007). Periods of high rainfall are followed by lagged increases in livestock numbers, while periods of stress lead to collapse of livestock populations.

Pastoral communities who exploit the dry savannas of Africa respond to spatial rainfall variability through herd mobility. On the other hand, development programs focus on ranches, where livestock populations can be controlled around the carrying capacity, by providing better forage buffers during drought stress periods (Behnke and Scoones, 1993). It is generally assumed that stocking densities have a strong influence on the effects of climatic variability. This thesis tests such a hypothesis, by comparing pre- and post-drought cattle populations. If the density is an important driver of livestock mortality during periodic droughts, a high correlation between the populations before and after the droughts would shed some light on the influence of stocking density. If, however, the relationship between before and after drought populations fails to explain the greater proportion of the variability, then we might have to seek other explanations. This thesis attempts to do this. Furthermore, the responses might vary between local and regional situations. The thesis investigates the livestock of communal rangelands managed in key- and non-key resources (Illius and O'Connor, 1999) and between different management systems (communal versus government ranch). The key and non-key resources in the drylands refer to differences in ecological, spatial and temporal grazing resource management (see also Paper I).

It is understood that the management of pastoral production in savanna ecosystems should be based on proper understanding of how local pastoralists understand the changes in their environment. However, given the frequency of short-term field based research and the absence of long-term monitoring, it is impossible to make any tangible conclusions about environmental change. Researchers might therefore find it more fruitful to rely on local knowledge of the herding communities, who experience the changes and are knowledgeable about their environment. This will assist researchers in understanding the long-term changes in the environment and the corresponding drivers of change. This thesis has taken precisely this approach by evaluating herder knowledge of environmental change and its effect on land use. The assumption is that traditional resource managers have comprehensive knowledge of their environment and what drives changes in land use, which in turn induces shifts in vegetation cover (Oba and Kotile, 2001). Indeed, the need for incorporating local herders' knowledge in assessing the impact of land use changes on the environment is widely acknowledged (Berkes, 1998; Berkes *et al*., 1998; Calheiros *et al*., 2000; Fernández-Giménez, 2000; Gadgil *et al*., 2000; Olafsdottir and Juliusson, 2000; Mackinson, 2001; Huntington, 2000; Oba and Kaitira, 2006). Wezel and Haigis (2000) suggest that the integration of community-based knowledge into research methods is an important factor in solving problems related to ecosystem management. Such understanding of the relevance of local knowledge will guide the design of appropriate land use policies (Oba and Kotile, 2001). This thesis uses the local time recalling system of the *gada* used by the Borana (Legesse, 1973), to reconstruct environmental change in terms of the adoption of range enclosures, establishment of crop farming, use of and the banning of fire, and shifts in vegetation towards bush encroachment (see Paper II).

The dynamics of bush encroachment in response to grazing pressure, rainfall variability and the suppression of fire (Grover and Musick, 1990) result in the gradual replacement of grassland vegetation (Scholes and Archer, 1997; Oba *et al.*, 2000a; Sheuyange *et al.*, 2005). Understanding the mechanisms of bush encroachment alone is insufficient in exploring how sustained use of the range could be achieved. In the example of Borana rangelands, bush encroachment has now become a serious problem for management (Oba, 1998; Angassa and Baars, 2000; Oba *et al*, 2000a; Gemedo-Dalle *et al.*, 2006). Invasive bush encroachment has fundamentally changed the communal rangelands from open savanna grasslands to bush thickets. The interviews with the herders (Paper II) showed that bush encroachment has adversely affected cattle dominated pastoral production. Van Wijngaarden (1985) reports that in East African savanna ecosystems increases in bush cover by 10% reduce grazing by 7%, while grazing is eliminated completely when bush cover reaches 90%. Oba *et al.* (2000a) report that bush encroachment in the Borana rangelands reduces livestock productivity and survival particularly during drought years, when forage scarcity is the greatest.

In the Borana rangelands of southern Ethiopia, a progressive increase in bush encroachment and loss of grass cover (Coppock, 1994) is associated with changes in patterns of livestock grazing (Bille *et al.,* 1983). Heavy livestock grazing in turn has reduced the herbaceous vegetation cover (Coppock, 1993). The ban on fire in the 1970s might also have facilitated the expansion of bush encroachment (Coppock, 1993), due to a reduced fuel load and fire frequency (e.g. Archer, 1995; Scholes and Archer, 1997). This thesis investigates selected drivers of grazing and seasonal protection over a period of control ranging from a maximum of 30 years to a minimum of 12 years (Paper III). Although the need to control bush encroachment has been acknowledged both by herders and ecologists, there have not been any attempts in the Borana rangelands to demonstrate methods of bush encroachment control. This thesis presents the first study on bush encroachment control in which herders and extension workers participated. The findings were used to suggest management policy and public education for controlling bush encroachment in the Borana rangelands of southern Ethiopia (Papers IV and V).

Different ecological models for describing savanna dynamics were comprehensively investigated in specific studies. As an overview, the thesis considers the application of equilibrium and non-equilibrium theories for describing the dynamics of cattle populations and shifts in vegetation. The thesis does not, however, make any attempts to prove the said theories, but rather seeks explanations on the relevance of the different models for aiding managers and policymakers in decision making. More specifically, the author used the ecological models to understand the responses of cattle populations to variable climate conditions, under the communal (i.e. key and non-key resources) and ranch systems, as well as the dynamics of bush encroachment in relation to grazing pressure (i.e. enclosures vs. grazed). The theoretical models are the subject of Section 2. Section 3 presents the methodological approach and summary of statistical analyses for the individual studies. In Section 4, the main findings of the five papers are presented, while Section 5 briefly discusses the main findings. Finally, in Sections 6, 7 and 8, the implications of the findings for management policy, conclusions and the scope for future research are presented.

2. Theoretical considerations

2.1. The ecological models

Ecological theories are the basis for seeking explanations to promote understanding of ecosystem dynamics and the forces that change them (Sayre and Fernández-Giménez, 2003). The assumption of this thesis is that ecological models could provide guidance in assessing changes and identifying key components in complex systems, to assist policymakers in the process of decision making for future management (see also, Oba *et al.*, 2000b). The way the environment responds to various disturbance forces may influence management decisions. Since dry savannas are dynamic ecosystems, we investigate various forces of disturbance, which, in this thesis, refer to processes that induce livestock population dynamics (Paper I), mechanisms of bush encroachment (Papers II and III) and bush encroachment control methods such as hand removal of trees, fire, grazing and their combinations (Papers IV and

V). Pickett and White (1985) describe ‘disturbance’ as a major driving force in shaping the spatial structure and temporal dynamics of grazing systems. Ludwig *et al.* (1997) show that the shifts between tree-grass states are mediated by disturbances such as heavy grazing pressure that diminishes perennial grasses. Under heavy grazing, the herbaceous plant abundance is reduced, which may lead to bush encroachment (Coppock, 1993; 1994). Displacement of individual plant species as a result of disturbance may cause shifts in plant communities (e.g. Hobbs and Mooney, 1985); interrupted patterns of dominance (Wiegand *et al.*, 1998); opportunities for the establishment of new species (Dean and Milton, 1991; Milton and Dean, 2000); and improved species richness and diversity (Ansley and Castellano, 2006). By demonstrating different bush encroachment control methods, the present thesis (Paper V) shows comparable patterns in herbaceous species richness and diversity, therefore suggesting that disturbance alone does not provide sufficient explanation of vegetation changes.

This thesis is therefore concerned with the following questions: Which ecological models would be most effective in understanding changes in response to relationships between inter-annual rainfall variability and cattle population dynamics (Paper I), herder perceptions of the impact of land use change on the environment (Paper II), bush cover dynamics in relation to grazing pressure (enclosures vs. grazed) (Paper III) and responses of individual plant species to bush encroachment control demonstrations (Papers IV and V)? Recent debates on the role played by disturbance in savanna ecosystems appear to favour the non-equilibrium models (e.g. Ellis and Swift, 1988; Oba *et al.*, 2000a, Oba *et al*., 2003, Sullivan and Rohde, 2002; Benjaminsen *et al*., 2006), while others have questioned such propositions (e.g. Illius and O’Connor, 1999, 2000; Briske *et al*., 2003). Equilibrium and non-equilibrium models are discussed in the following sections.

2.1.1. The equilibrium model

The present thesis postulates a hypothesis that the relationship between variable rainfall and fluctuations in cattle populations may vary in terms of the different land use systems (i.e. key and non-key resources). It is postulated that cattle population fluctuations might depend on whether they are managed under the communal rangelands or ranch management systems. The primary goal of grazing policy in transforming the traditional land use to ranch management was to reduce cattle losses in times of drought (see Paper I). The thesis describes pastoral land use in terms of local adaptations to rainfall variability and seasonality of resources through mobility. Since the equilibrium grazing model usually assumes dry savannas as stable ecosystems with predictable forage production, the high rainfall variability that drives forage production cannot be accurately described by the model. In addition, this model suggests optimum stock density where livestock populations are limited by the available forage resources. However, the assumption of the current thesis is that variable rainfall limits both animal populations and forage availability. This was tested in terms of cattle population patterns related to variable rainfall under the communal and ranch management systems (Paper I). Therefore, it may be speculated that recurrent droughts that induce severe mortality probably prevent livestock populations from increasing beyond the optimum level of stocking density, thereby reducing the potential impact of grazing on the savanna ecosystem. The present study (see Paper I) questions the assertion that the ranch system represents the optimal way of using dry savanna ecosystems by adjusting stocking density. The hypothesis is that it might not be stocking density, but rainfall variability that probably regulates the dynamics of cattle populations in the dry savanna ecosystems of Borana, southern Ethiopia. This thesis emphasizes that management approaches that focus on transforming the traditional way of resource management may not fit with the assumptions of the equilibrium model (Paper II), and suggests mobility as a strategy for the efficient utilization of scarce resources.

For example, the equilibrium ecological model considers high livestock population (and thus heavy grazing) as a factor contributing to the expansion of bush encroachment. Conversely, the current thesis (see Paper III) suggests that heavy grazing alone does not promote bush encroachment in southern Ethiopia (for a contrasting view see Coppock, 1993). The thesis suggests that without understanding the role played by time in terms of the age of vegetation cover and management, linear changes that are predictable under equilibrium might not be appropriate. Rather, as the thesis has shown, age chronosequence in relation to vegetation states might offer a better explanation (see Paper III). Most importantly, this thesis shows that the growth of bush cover is promoted more under protection than it is under heavy grazing (although the age of the grazed pastures is not accounted for). Thus, in confirmation of Behnke *et al.* (1993), the equilibrium model may be inadequate for describing the dynamics of dry savanna ecosystems. The thesis suggests the opposite for dry savanna ecosystems where disturbances such as grazing and fire are expected to promote range productivity and conservation of species diversity (Paper V, see also Frank and McNaughton, 1993; Oba, 1996). Overall, the present study acknowledges the limitations of the equilibrium ecological model in failing to describe appropriately the dynamics of dry savanna ecosystems or to guide range management policy (see also Oba, 1996; Oba *et al.*, 2000b; Fernández-Giménez and Allen-Diaz, 1999).

2.1.2. The non-equilibrium model

The work of Ellis and Swift (1988), and Westoby *et al.*, (1989), among others, has generated a new debate on the limitations of the equilibrium model, providing the alternative non-equilibrium theory. The non-equilibrium behaviour of savanna ecosystems implies that they are less predictable, with a limited capacity for influences that could be induced by stocking density (Ellis and Swift, 1988; Briske *et al.*, 2003). The dynamics can be described best by the state-and-transition model, which identifies key components that drive the dynamics of bush encroachment. However, the mechanisms of bush encroachment have been a subject of much conjecture (Noy-Meir, 1982; Archer, 1995; Skarpe, 1992; Westoby *et al.*, 1989; Oba *et al*., 2000a). This thesis considers the equilibrium (in relation to heavy grazing) and non-equilibrium ecological models (in relation to time of protection), in order to understand the dynamics of bush encroachment.

The alternative model suggests that the mechanisms of bush encroachment could be understood in terms of the state-and-transition model, which is based on the non-equilibrium ecological model (Paper III). This model implies that rainfall variability and time are more important in driving bush encroachment than grazing pressure (Westoby *et al.*, 1989; Asefa *et al*., 2003). Vegetation dynamics of savanna ecosystems can also be triggered by management practices due to human interferences (see Paper III). Thus, the mechanisms of bush encroachment in southern Ethiopia cannot be explained by simple linear relationships between management and shifts in vegetation. The probable explanation may be linked to the incidences of multiple drivers that operate on various spatial and temporal scales (Paper III). For example, shifts in vegetation structure and composition between states could be considered as non-linear factors (see Paper III).

This study uses the state-and-transition model to describe the mechanisms of bush encroachment in terms of spatial and temporal variability that combines different aspects of ecological processes in response to disturbances. Disturbance forces have shifted vegetation structure and composition along different trajectories and along alternative pathways. The forward and reverse shifts all result from different types of disturbances. This thesis therefore uses the state-and-transition model as a conceptual framework for describing the dynamics of savanna ecosystems that incorporate multiple successional pathways. Iglesias and Kothmann (1997) report that the state-and-transition model probably informs management directions and decision-making by considering the existing transitions that are expected to link distinct vegetation states. This thesis suggests that because of its practical approach, the state-and-transition model may provide an alternative in understanding the dynamics of dry savanna ecosystems in response to varied management scenarios (Westoby *et al.*, 1989; George *et al.*, 1992; Oba, 1996; Asefa *et al.*, 2003). In this study, vegetation states and transitions were analyzed in terms of the age chronosequence of range enclosures. The model for identifying the key drivers involved in the processes of bush encroachment was applied (Paper III), while disturbances such as grazing, fire and their combinations were used to evaluate the effects on the regeneration of invasive woody species and herbaceous plants (Papers IV and V).

2.2. Pastoral development policy

Pastoral development in the East African rangelands has been influenced by a widely perceived impression of environmental change such as decline in vegetation resources linked to overstocking of drylands. The perception of pastoral development in the African rangelands lies in the essence of the tragedy of the commons (Hardin, 1968) following the introduction of the concept of range management into East Africa in the early 1960s. The theory has been extremely powerful on pastoral development in terms of promoting ranching as an alternative to communal land use by reducing mobility and adjusting livestock numbers to match the available forage. The theory was applied to justify rapid and widespread use of standardized environmental conservation by transforming pastoral production without realizing the impacts of changing land use on the environment. In the eyes of policymakers, pastoralists are singled out as the main cause of environmental problems. The main arguments of these policies have consistently been that pastoral land use systems are environmentally destructive and lack economic rationality and market orientation.

According to the “tragedy of the commons” theory, “every pastoralist has access to the grazing lands, while nobody takes care of it. It was believed that pastoralists would like to maximize their livestock numbers at the expense of communally owned grazing lands, thereby causing environmental impact on the rangelands”. It was therefore thought that the ranch model as an alternative to the communal system would minimize environmental variability and reduce livestock losses during droughts. Regardless of the efforts that have been made during the past decades, ranch development programs in the East African rangelands proved to be ineffective (see also Paper I). This was probably attributed to the variability in rainfall, and spatial and temporal distribution of resources across key and non-key resource rangelands. Generally, the indigenous system of land use was misinterpreted by policymakers because of preconceived concepts of "stocking rates" and "carrying capacity" principles (see Oba *et al.,* 2000b). Furthermore, recent studies (e.g. Ellis and Swift, 1988; Behnke *et al.,* 1993; Scoones, 1995) have challenged the validity of the equilibrium ecological theory on which policy frameworks for guiding pastoral development in East Africa are built.

Rather, recent debates on pastoral development emphasize that East African rangelands are heterogeneous in space and time. Therefore, traditional land use systems are the best way to make efficient use of the available forage resources. Any barrier to pastoralist ways of managing resources and loss of the communal rangelands to range enclosures, crop farming and ranching were found to be more likely to cause environmental change (see Paper II).

However, African pastoralists were considered as backward and causing environmental problems for the way they manage their resources. Such negative conclusions in the development of African rangelands have not only undermined indigenous knowledge, but also have had negative implications on the environment. The poor understanding of the dynamics of pastoral production and indigenous knowledge in resource management have resulted in inappropriate policies and development interventions. Such policies have systematically weakened the traditional institution and strategies for responding to environmental variability.

In Ethiopia, rangeland policies were designed on the basis of the ranch model as an alternative to the communal rangelands without understanding the consequences of changing land use on the environment. It was believed that pastoralists contribute little to the national economy, while causing negative environmental impact. During the last decades, various government policies have affected the efficient utilization of rural resources, especially land (Omiti *et al*., 1999). Keeley and Scoones (2004) also argued that many past development interventions in Ethiopia were supported by unjustified claims which have had potentially negative impacts on the environment.

As part of the Ethiopian rangeland development projects, the Borana rangelands have for decades been a focus of rangeland development programs such as expansion of ranches as an alternative to the communal rangelands. As a result, the introduced interventions and modifications have resulted in considerable changes in traditional patterns of resource use (Papers II and III). The impact of policy-induced interventions with the aim of improving the life of pastoralists has failed to realize the indigenous knowledge in resource management. The lack of a policy approach in rangeland development further contributed to the processes of bush encroachment and environmental impact (Oba *et al.,* 2000b).

The Borana rangelands in southern Ethiopia have been substantially altered with the advancement of bush encroachment. The expansion of bush encroachment has been attributed to the official banning of fire due to the policy of forest land conservation in the form of enclosures to foster the regeneration of naturally occurring plant species. Fire was banned as a result of inappropriate management policy. The policy never considered the implications in terms of the threat of bush encroachment on pastoral production. As a result, the density of bush encroachment has been increased to the extent that the capacity of grazing is reduced (see Papers II and III). The threat to the pastoral economy is often the main reason for the control of bush encroachment (Paper IV). The official banning of fire had previously assumed that the use of fire would be damaging to the rangeland ecosystems. This assumption is not supported when the response of the herbaceous vegetation to fire and grazing is considered in the long-term (Paper V). In order to maintain the sustainability of the Borana pastoral system, it is important to consider the roles played by the different bush encroachment control methods that might help in future development endeavors and public education. Bush control methods are disturbance methods that reduce the threat of bush encroachment. The new management policy has to recognize that re-introduction of fire combined with grazing would probably sustain the savanna ecosystems of southern Ethiopia, rather than fire suppression.

The current thesis informs about the negative role of bush encroachment on forage production (see Papers II and V). The evidence suggests that protection from fire and grazing, as promoted by state conservation policies, has failed to promote production of herbaceous biomass which is contrary to herder objectives (Paper V). For the herders, bush control demonstrations showed more beneficial gains in terms of forage production for livestock. The thesis therefore suggests that a management strategy needs to be planned so that bush control treatments are followed by rest, before grazing by livestock is resumed. This kind of management strategy has been promoted by the community during previous decades and is more appropriate for range enclosures near settlements. Currently in southern Ethiopia, this type of management has been initiated through the activities of Non-Governmental Organizations (NGOs) that utilize community labor to clear bushy plants in limited areas. Thus, pastoral development in the future has to recognize the variability in terms of climate, indigenous knowledge and benefits of different bush control methods when considering herders' priorities for herbaceous biomass and the government's conservation strategy.

The thesis posed the following specific questions that guided the separate studies (Papers I-V):

(i) What are the long-term relationships between rainfall variability and cattle population dynamics under communal rangelands (i.e. key and non-key resources) and the ranch system (Paper I)?

(ii) What are pastoralists' perceptions about land use change, fire suppression, bush encroachment and the impact on the rangelands, based on indigenous ecological knowledge and the historical effect of land use on vegetation change (Paper II)?

(iii) How does bush encroachment vary in relation to different land use systems (i.e. traditional range enclosures versus open grazed areas) and time of protection (Paper III)?

(iv) What are the effects of tree cutting, fire, grazing and their combinations on the regeneration of woody species (Paper IV)?

(v) What are the effects of tree cutting, fire, grazing and their combinations on herbaceous plant species (Paper V)?

3. The study area

3.1. Borana rangelands of southern Ethiopia

The Borana pastoral production in southern Ethiopia was considered until the early 1980s as one of the few remaining productive pastoral systems in East Africa (Cossins and Upton, 1987). Since then, there is evidence that the system is experiencing a decline in productivity, associated with periodic losses in cattle populations (Cossins and Upton, 1988; Desta and Coppock, 2002; Angassa and Oba, 2007); changes in land use; and suppression of fire that have resulted in the proliferation of bush encroachment and a general decline in forage production (Oba *et al.,* 2000b). This thesis suggests that the present crisis might be the result of the combined effects of climatic variability and increases in bush cover that may increase the risk of drought-induced herd die-offs (Paper I). By the mid-1980s about 40% of the Borana rangelands were affected by bush encroachment (Assefa Eshete *et al*., 1986; Coppock, 1994), while recent estimates suggest a 52% increase in bush cover (Gemedo-Dalle, 2004). Similar evidence has shown that suppression of fire is followed by bush encroachment (Bille *et al*., 1983; Corra, 1986). Coppock (1994), in agreement with Bille *et al*. (1983) and Corra (1986), suggests that the official ban on fire in the 1970s has facilitated the process of bush encroachment, which is also the concern of herders (Paper II).

3.2. Location and climate

The study was conducted in southern Ethiopia, in the Borana zone of Oromia Regional State (Figs 1 and 2). The Borana rangelands cover about 95 000 km^2 (Coppock, 1994). The area exhibits a bimodal pattern of rainfall, with the main rains falling between March and May, and the short rains between September and November. A prominent feature of the Borana ecosystem is the erratic and variable nature of the rainfall, with most areas receiving between 238 mm and 896 mm annually, with a high coefficient of variability ranging from 18% to 69% (Angassa and Oba, 2007). Droughts are common every five years (Oba, 1998). The ecological environment of the Borana rangelands is more suitable for extensive grazing than for crop production, which is unreliable due to the erratic nature of rainfall. The regional variation in climate influences the agricultural production potential of the region. The Borana rangelands are exploited mainly by a mobile herd management system. Pastoralism is the primary mode of life. The decision-making process for resource management rests with the *madda*[1] council. The *gada*[2] system (a traditional institution of the Borana society) and/or the *Gumi-Gayo Assembly*[3] make decisions at the higher level on local resource use and determine the management of grazing and water resources. The key and non-key resources are the major land use systems. However, recent changes in land use and declines in communal grazing lands have eroded the effectiveness of traditional grazing management, with major impacts on the environment in terms of range enclosures, crop farming, ranching and fire suppression that in turn have increased the threat of bush encroachment on the communal rangelands. Furthermore, the creation of regional administrative boundaries has greatly reduced access to communal resources (Fig. 1).

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[1] The term *madda* applies to a natural resource administrative unit or water source (Oba, 1998).

[2] The word *gada* is a system of social organization in the Oromo society that used to be regulated by the *gada* principles. In the Borana region of southern Ethiopia *gada* is a system of classes (*luba*) that succeed each other every eight years in assuming military, economic, political, and ritual responsibilities (Legesse, 1973). Each *gada* class remains in power during a specific term (*gada*), which begins and ends with a formal transfer ceremony. The concept *gada* has three related meanings: it is a period of eight years during which elected officials take over power from the previous ones; it is the grade during which a class of people are in power by having politico-ritual leadership; it is the institution of Oromo society.

[3] The highest level of political and economic power in the Borana society. It is the assembly of justice, equality and democracy. It is a place where a dispute that is beyond the authority of the clans which requires a recollection of the unwritten seera, customs (traditions), is resolved (Huqqaa, 1996). The *Gumii-Gaayo Assembly* (GGA) decision is final and cannot be reversed by any Borana authority or assembly until the next GGA reconsiders it. The GGA is held once in an eight-year period.

Fig. 1. Map of the Study Area

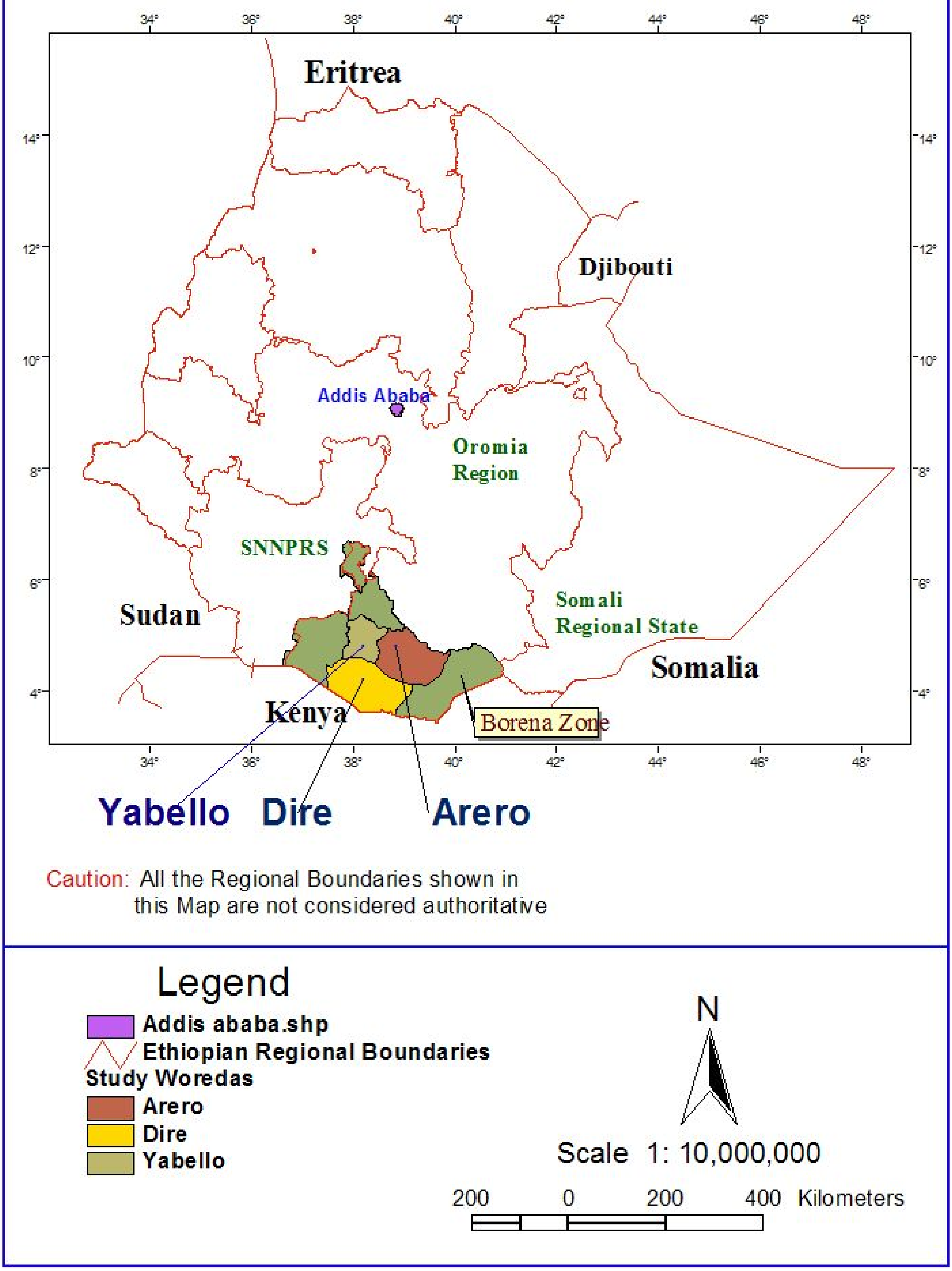
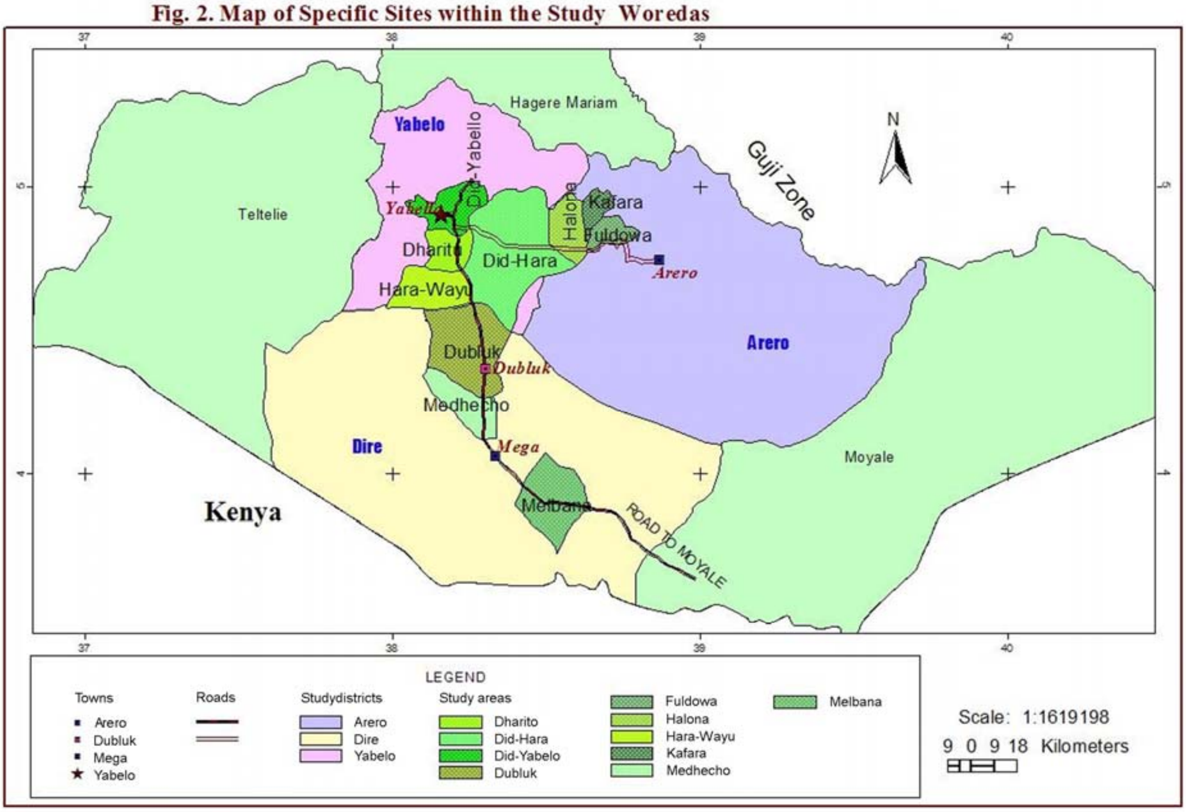


Fig. 2. Map of Specific Sites within the Study Woredas



3.2. Individual studies and methodological approach

The investigation of the dynamics of cattle populations (Paper I) was conducted in the key and non-key resource rangelands in southern Ethiopia, in the districts of Dirre and Yabello in 2003. A sample of 72 households stratified by the deep *tula* wells (key resource) and pond-water (non-key resource) rangelands was interviewed using a semi-structured questionnaire, to evaluate cattle population dynamics in the communal rangelands. Cattle population dynamics under the ranch system were evaluated using 15 years of ranch cattle data obtained from ranch annual records.

The study of herder perceptions of impacts of land use on environmental change (Paper II) was conducted in the districts of Arero, Dirre and Yabello across nine Peasant Associations (Fig. 2). A two stage survey was carried out between 2002 and 2003. In 2002 region-wide interviews were conducted with oral historians and the elderly, to reconstruct the environmental history of land use change in Borana. In 2003 a sample of 245 households randomly selected from lists of all existing households, was interviewed using a structured questionnaire.

The study of the dynamics of bush encroachment along age chronosequence of range enclosures (Paper III) was conducted in Dida-Hara (Fig. 2) in the Yabello district. Six traditional range enclosures with varied ages were selected in the upland landscapes. For each enclosure, the immediately adjacent open grazed rangelands were selected as controls. The study investigated the dynamics of bush encroachment by comparing the effects of management and the age of the enclosures in November 2003.

In the fourth and fifth papers, six bush encroachment control methods (i.e. tree cutting, fire, grazing and their combinations) on the responses of woody vegetation (Paper IV) and herbaceous plants (Paper V) were evaluated. These studies were conducted on two ranch sites in Dida-Tuyura (04º57.383´N, 38º12.403E´) and Dambala-Wachu (04º29.432´N, 38º16.339´E), and were replicated across bottomland and upland landscapes, from June 2003 to June 2005.

3.3. Statistical analysis

Depending on the nature of the data, the type of the response variable (normal versus binomial) and the research questions that were addressed, different analytical methods were employed as follows: descriptive statistics (Papers I, II, III, IV and V), general linear models (Papers I, III and V), regression models (Paper I), polynomial tests (Paper III), *t*-tests (Papers I and III) and χ^2-tests (Papers II, III, IV and V). The statistical software SAS (SAS Institute, 2001) was used for all analyses.

4. Summaries of the main results

The main results and conclusions of all the five studies are summarized in this section, per research question.

Q1**:** What are the long-term relationships between cattle population dynamics and rainfall variability under communal rangelands (i.e. key and non-key resources) and the ranch system (Paper I)?

Paper I

Angassa, A., and Oba, G. 2007. Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia. *Agricultural Systems* 94: 715-725.

This paper discusses the role of rainfall variability (local and regional) on cattle population dynamics and the implications for regional drought management, based on empirical evidence from southern Ethiopia, Borana. In particular, the paper raises the following questions (i) what are the effects of rainfall variability and evidence of density dependence under different land use and management systems? (ii) do variable rainfall or stock density play a role in regulating cattle populations? The impact was evaluated in terms of the relative resilience of the key and non-key resources, their performance under the communal and ranch systems and the degree to which different land use systems are influenced by rainfall variability.

Household perceptions in terms of the reproductive life of breeding cows, the number of calves per cows in a life time, calving rates, herd mortality related to multiple droughts, and evidence of density dependence in the *tula* wells (key resource) and pond-water (non-key resource) rangelands were compared. Additionally, long-term ranch cattle data obtained from annual records were used to evaluate calving rates, herd mortality during multiple droughts and evidence of density dependence.

Breeding cows in the key resource *tula* well rangelands showed longer reproductive life than the non-key resource pond-water rangelands. Average calving rates were greater in the communal rangelands than in the ranch system. Severe mortality and greater reduction in calving rates during multiple droughts resulted in reduced herd growth potential. Inter-annual variability in rainfall seems to have a considerable effect on cattle populations. Furthermore, the combined effects of variable rainfall and increased bush cover might lead to risks of drought induced herd die-offs. Generally, repeated drought has threatened the lifestyle of the pastoral community, through considerable loss of cattle holdings over the last two decades. The study acknowledges the evidence of density dependence at the level of local land use, but overall density independence at the regional level. The findings confirm the failure of ranch management in reducing herd mortality and signify the role of rainfall variability in shaping the dynamics of cattle populations, even under a controlled land use system. Overall, the paper highlights the principal effect of rainfall variability on cattle populations, calving rates and herd mortality, under both the communal and ranch management systems. The paper concludes by highlighting the need for drought management, focusing on post-drought herd rehabilitation through the distribution of bulls, which will depend on the breed conservation ranch and is important for the maintenance of the Borana cattle breed.

Q2: What are pastoralists' perceptions about land use change, the fire ban, bush encroachment and the impact on the rangelands, based on indigenous ecological knowledge and the historical effect of land use on vegetation change (Paper II)?

Paper II

Angassa, A., and Oba, G. Herder perceptions on impacts of range enclosures, crop farming, fire ban and bush encroachment on the rangelands of Borana, southern Ethiopia. Human Ecology: In press.

This study focuses on the relevance of herders' perceptions in understanding the impacts of range enclosures, crop farming, fire suppression and bush encroachment on the communal rangelands in Borana, southern Ethiopia. Harnessing local knowledge is a practical and valuable technique in reconstructing environmental changes for decision-making processes. The Borana oral history that focuses on the *gada* timeline was used to reconstruct environmental variability.

Herder perceptions indicated that the evolution of range enclosures and the expansion of crop farming led to the fragmentation of the communal rangelands, while fire suppression resulted in the proliferation of bush encroachment. The subdivision of the communal rangelands and shifts in the ecological balance between woody plants and grass species resulted in forage scarcity and greater vulnerability of stock during drought years. The use of communities' knowledge as a framework for understanding the impacts of land use changes on the environment, may provide a strong foundation on which to reconstruct scientifically and culturally acceptable methodological approaches. The paper suggests that sustainable use of the savannas of southern Ethiopia in the future will require paying greater attention to regulating the expansion of enclosures, crop farming and ranching, as well as re-introducing fire, where necessary, to control the expansion of bush encroachment. The paper concludes that policymakers should use communities' knowledge of environmental change to improve the use of the rangelands.

Q3: How does bush encroachment vary in relation to different land use systems (i.e. traditional range enclosures versus open grazed areas) and time of protection (Paper III)?

Paper III

Angassa, A., and Oba, G. Effects of time and grazing on bush encroachment related to age chronosequence of range enclosures in southern Ethiopia. African Journal of Ecology: OnlineEarly.

This paper uses the state-and-transitional model in search of better understanding of the mechanisms of bush encroachment in traditional enclosures along timescales of 12 to 14 (younger), 17 to 24 (medium) and 26 to 30 years (older), versus the adjacent open grazed communal rangelands. The vegetation states differed significantly in terms of total woody density. Significant differences were observed among woody vegetation states in terms of the invasive woody species ratio, which showed greater increments in the younger enclosures compared to the vegetation states in the open grazed areas. However, the invasive woody species ratio declined between the younger and the medium age enclosures. The paper indicates that the proliferation of bush encroachment in the younger enclosures (12 to 14 years) was greater than that in the 17 to 24 years and 26 to 30 years old enclosures.

Greater densities of invasive woody species in enclosures as opposed to the open grazed areas, implies that additional causes might be involved in the process of bush encroachment, apart from grazing. The use of the state-and-transition model showed complex successional pathways of changes with regard to inter-annual rainfall variability, management interventions and timescales (i.e. the age chronosequence of enclosures) that are relevant for making management decisions.

Overall, the paper concludes that the proliferation of bush encroachment is a major threat in the enclosures, as compared to the grazed rangelands, with the invasive woody species ratio being greater in the younger enclosures. Furthermore, the nonlinearity of patterns between invasive woody plant species and age chronosequence of enclosures suggests that the mechanisms of bush encroachment are probably related to multiple drivers, such as inter-annual rainfall variability.

Q4: What are the effects of tree cutting, fire, grazing and their combinations on the regeneration of woody species (Paper IV)?

Paper IV

Angassa, A., and Oba, G. Demonstration of bush encroachment control in Borana, southern Ethiopia: 1. Evaluation of tree cutting, fire and grazing on woody plants. Journal of Arid Environments: submitted

This paper focuses on responses of individual woody plants to the effects of bush encroachment control methods in the savanna ecosystems of southern Ethiopia. During the post-treatment periods, tree stump total kill (TK), partial kill (PK), coppicing (C) and seedling regeneration (CR) in response to the different demonstrations were monitored. Protection from disturbance (i.e. the disturbance control treatment) promoted bush encroachment. The paper found that disturbances such as tree cutting and fire significantly reduced bushy plants, while tree cutting, fire and grazing treatments were more effective in controlling coppicing after disturbance. The paper demonstrates that the old traditional methods of fire and grazing are effective in reducing the regeneration of tree seedlings. The paper further suggests that grazing with bush cover (i.e. the traditional management under the current system) has no effect on the regeneration of tree seedlings. A range rehabilitation method that is often promoted by non-governmental organizations (NGOs), such as hand removal of trees, showed comparable performance with the following control combinations: tree cutting and fire, as well as tree cutting, fire and grazing. The paper suggests that the combination of bush encroachment control methods of tree cutting, fire and grazing, was more effective in suppressing invasive bushy plants. Different woody species showed varied adaptation strategies in response to disturbances. Disturbance vulnerable species such as *Commiphora terebinthina* and *Boscia coriacea* adapted to increased seedling recruitment, while the capacity of coppicing during post-disturbance is a characteristic of most invasive woody species. Only about 10% of the species were relatively adapted (i.e. ranked between 1 and 10) to either of the strategies. The findings are discussed in terms of management policy and public education, with particular focus on the control of bush encroachment in southern Ethiopia.

Q5: What are the effects of tree cutting, fire, grazing and their combinations on herbaceous plant species (Paper V)?

Paper V

Angassa, A., Oba, G., and Tolera, A. Demonstration of bush encroachment control in Borana, southern Ethiopia: 2. Evaluation of tree cutting, fire and grazing on herbaceous vegetation. Journal of Arid Environments: submitted

This paper demonstrates, on two ranches, the effects of six bush encroachment control methods, namely disturbance control (CO), tree cutting and fire (C+F), tree cutting, fire and grazing (C+F+G), the old traditional method of fire and grazing (F+G), grazing with bush cover (GBC) and tree cutting alone (C), on herbaceous species composition, relative abundance of species, biomass, basal cover and species diversity.

The findings show that the disturbance control treatment had no advantage in terms of herbaceous biomass and basal cover over other treatments, while herbaceous species richness was enhanced. Bush encroachment control methods such as tree cutting and fire, tree cutting followed by fire and grazing, the old traditional method of fire and grazing, and tree cutting alone enhanced herbaceous biomass, basal cover and species diversity. The paper suggests that the current system of land use (i.e. grazing with bush cover) greatly reduces herbaceous biomass. Generally, tree cutting and fire treatments seemed superior in terms of herbaceous biomass, while the old traditional method of fire and grazing, and tree cutting are recommended for the conservation of herbaceous species diversity. When considering herders' priorities in terms of herbaceous biomass for livestock forage production, protection from disturbance showed no advantage. The outcomes in terms of herbaceous biomass and herbaceous plant biodiversity have important policy implications for bush encroachment control and public education. The paper emphasizes the importance of the fire and grazing method which can reasonably be recommended for control of bush encroachment with the overall objective of promoting herbaceous biomass and species diversity. The recommendations suggest specific policies and public education interventions for future bush encroachment control programs in the Borana rangelands of southern Ethiopia.

5. Discussion

5.1. Cattle population dynamics

Better performance of breeding cows in the *tula* well rangelands compared to the pond-water rangelands probably reflects the reliability of traditional grazing regulations and more suitable water and grazing resources associated with key mineral nutrient sources. The long-term decline in household cattle holdings is probably linked to severe mortality during multiple droughts that constrained post-drought recovery and interruptions of recovery phases by new droughts. The findings suggest that cattle populations in the savanna ecosystems of southern Ethiopia are highly vulnerable to the effects of rainfall variability (Paper I). The evidence clearly shows that variable rainfall associated with periodic drought had induced severe herd mortality. Other evidence from southern Ethiopia (e.g. Cossins and Upton, 1988) similarly showed the influence of rainfall variability on livestock population dynamics. In the savanna ecosystems of southern Ethiopia where key and non-key resource rangelands are the main land use systems, livestock populations showed increased fluctuations between years, due to the effect of rainfall variability (Paper I, see also Cossins and Upton, 1988). In this region, the traditional land use systems are now being influenced by land use policies (Paper II) and the increased threat of bush encroachment (Paper III).

In summary, severe mortality in cattle populations is related predominantly to multiple droughts (Paper I) and forage scarcity linked to bush encroachment (Paper III) which is a consequence of fire suppression (Papers II, IV and V). Additionally, rainfall fluctuations between years significantly correlated with diminished cattle populations, both under the communal and ranch management systems, suggesting that cattle populations could be influenced by regional climate (see Paper I). The similarity of patterns in cattle populations between years for the communal and ranch systems implies that density-dependence may be less important for the proportions of cattle die-offs than is rainfall variability in southern Ethiopia. This suggests that maintaining the stocking density below the carrying capacity (i.e. ranch system) did not improve calving rates, herd mortality and post-drought recovery. In southern Ethiopia, drought management involves herd mobility and herd accumulation during periods of favourable rainfall. Finally, the study emphasizes the importance of government ranches in breed conservation, for the maintenance of the Borana cattle breed through distribution of bulls during drought recovery phases.

5.2. Herders' environmental knowledge

Herders stated (Paper II) that the adoption of range enclosures and crop farming has resulted in the fragmentation of the communal rangelands and a scarcity of forage for vulnerable herd classes such as calves, due to the influence of land use policies that ignore the importance of traditional resource utilization in terms of key and non-key resources (Paper I). In support of herders' perceptions, for example, Calheiros *et al.* (2000) emphasize the integration of community participation into research methods, realizing its relevance in ecological research and sustainable ecosystem management. Nevertheless, the paper suggests that inappropriate interventions and misconceptions of indigenous knowledge have undermined traditional resource management strategies, leading to the expansion of crop farming in the communal rangelands.

The paper recognizes that the settler soldiers and later the immigrant farmers from the Ethiopian highlands introduced the crop farming culture to the Borana rangelands. Evidence shows that changes in land use have negatively influenced traditional resource management, including the use of fire as a tool for range management (Papers II, IV and V). Herders suggested that the fire suppression of the early 1970s enhanced the proliferation of bush encroachment that was effectively reconstructed using the historical *gada* timelines (see Legesse, 1973) of changes in historical vegetation over recent decades in the savanna ecosystems of southern Ethiopia (Papers II, III and IV). Pastoralists are knowledgeable about the negative effect of fire suppression on the dynamics of savanna ecosystems and threats of bush encroachment on perennial grasses (see also Cossins and Upton, 1988; Coppock, 1994; Oba, 1998; Oba *et al.*, 2000a; Mbow *et al*., 2000; Laris, 2002; Natcher, 2004; Sheuyange *et al.,* 2005). This implies that reduced herbaceous biomass is probably linked to the proliferation of bush encroachment as a result of the ban on fire, which was also confirmed by the bush control demonstrations (see also Paper V).

Overall, herder perceptions in terms of the main economic goals of cattle management aiming at improved forage productivity and conservation of biodiversity (Papers I and V) should be acknowledged. The undesirability of bush encroachment is associated with a decline in forage production (Papers II and V). Consequently, the Borana pastoralists may respond to the threat of bush encroachment through diversification of stock such as camels, which are mainly browsers (Desta and Coppock, 2002). The establishment of range enclosures and the expansion of crop farming have reduced the extent of grazing, while fire suppression has promoted the expansion of bush encroachment (Papers II and IV). Herders' perceptions suggest that the ecological balance between woody plants and grass layers were shifted due to the ban on the use of fire (Papers II, IV and V). In general, the negative effects may be described in terms of forage scarcity and greater vulnerability of stock during drought years (Papers I, II and V).

5.3. Causes of bush encroachment

The findings of the present study suggest that although grazing might influence the balance between woody species and grasses, communal land use is not the single cause for the spread of bush encroachment (see Papers II, III and IV). Rather, reduced grazing pressure in the enclosures promoted bush encroachment compared to the open grazed communal rangelands, suggesting that pastoral land use has little impact in driving bush encroachment (Papers II and IV). Similarly, it has been shown that protection from grazing in East African savanna ecosystems increases the regeneration of woody plants (Paper IV, see also Smart *et al.*, 1985; Western and Maitumo, 2004). Furthermore, the use of the state-and-transition model of woody vegetation suggests that the processes of bush encroachment might be related to such drivers as fire suppression (Papers II, III and IV), inter-annual rainfall variability, exclusion of browsers, competition, and hand removal of bushy plants (see Fig. 2 in Paper III). The lack of linear patterns between the regeneration of invasive woody plants and age chronosequence of enclosures might suggest that the mechanisms of bush encroachment are probably linked to stochastic events such as rainfall variability, rather than grazing alone.

5.4. Demonstration of control methods

Bush encroachment control methods combining tree cutting, fire and grazing were more effective in suppressing the regeneration of invasive woody plants. Among the woody plants, some species invested in survival through coppicing, while others invested in seedling recruitment (Paper IV). Disturbance vulnerable species such as *Commiphora terebinthina* and *Boscia coriacea* were adapted to increased seedling recruitment, while the capacity of coppicing was the most common strategy used by most invasive woody species in the savannas of southern Ethiopia (Paper IV). The present demonstrations provide a good opportunity to understand the effects of bush control methods and meeting herder objectives in terms of improved forage for livestock and conservation of biodiversity (Paper V), suggesting that exclusion of fire and grazing have provided no advantage in promoting herbaceous biomass. For example, herder perceptions suggested the use of fire in the restoration of savanna ecosystems in terms of forage for livestock (Paper II) and maintenance of species composition (Paper V). Herders also suggested that fire removes old grasses and kills tree saplings, while post-fire grass growth is preferred by grazing animals above unburned grasses (Paper II). Furthermore, herders' observations indicated that in the absence of fire, forage production has declined and the threat of ticks infesting livestock has increased (Paper II), while the results also suggest a decline in herbaceous biomass (Paper V). Herbaceous biomass increased when fire was used in combination with other bush encroachment control methods, suggesting that the presence of fire probably enhanced forage production (Papers II and V). Finally, the findings confirm that the exclusion of fire from the savanna ecosystems of southern Ethiopia has resulted in reduced herbaceous biomass as evidenced by the disturbance control demonstration and grazing with bush cover treatments (Paper V).

6. Implications for management and policy

Extensive livestock grazing is the main production system in dry savanna ecosystems. Pastoral communities normally use a traditional strategy of stock mobility following the spatial and temporal distribution of forage resources, in response to rainfall variability. Traditional resource management was in harmony with the variability of the ecosystem and it had significant implications for the sustainable use of scarce resources and the overall stability of the pastoral production system. Pastoral herders in southern Ethiopia are largely dependent on cattle herding for their livelihood and preservation of their traditional culture (see Oba, 1998; Desta, 1999; Angassa and Beyene, 2003; Kamara *et al.*, 2004). Attention should therefore be given to appropriate and locally adapted management strategies, including the recognition of traditional land use practices, drought coping mechanisms, herd mobility, and rehabilitation and management of bush invaded rangelands. Based on the findings of the five papers presented in this thesis, implications for management and policy can be highlighted.

The variability in terms of cattle populations within different land use systems reflects multiple resource use adaptations. Strategies to reduce livestock losses to drought should be reconsidered. This could be achieved in terms of drought management strategies that focus on improved market access through subsidies to transport animals to markets outside the region during droughts; supporting the traditional systems of post-drought restocking; and a drought insurance system for pastoralists, such as the provision of emergency feed to protect breeding stock and immature animals. Furthermore, the focus on ranch breed conservation may be more crucial for serving as a gene pool for the communal rangelands, than as a strategy for rehabilitating pastoralists' herds after drought. Although pastoralists have rich experience in post-drought herd rehabilitation, the traditional systems of post-drought restocking that rely on poor breeds of cattle from the neighboring highland communities contribute to the genetic dilution of the Borana cattle breed. Thus, better breed conservation would be part of improved drought management strategies and would continue to distribute quality bulls during drought recovery phases.

Furthermore, the use of community knowledge as a basis for understanding how historical changes in land use have impacted rangeland ecosystems provides important insight in evaluating communities' responses to changing land use. Inappropriate policies and misconceptions of traditional resource management have resulted in the expansion of bush encroachment and reduced grazing capacity of the communal rangelands. The changes are reflected in terms of forage scarcity and greater vulnerability of stock, particularly during drought years. The ban on the use of fire has shifted the ecological balance between woody plants and grass species. Following the introduction of government land use and fire ban policies, vast areas of the savannas of southern Ethiopia have experienced a proliferation of bush encroachment, with a drastic decline in grass cover, thus posing a serious threat to livestock production. Given the failure of past policies to preserve the local environment, communities' knowledge may provide logical guidelines for revising pastoral development policies. This could be achieved by considering local people's contributions to range management policies, rather than focusing on strategies imposed by outsiders. On account of its practical and valuable contribution in developing a more effective land use policy and sustainable use of local resources, the integration of herders' knowledge into management decisions should be considered a priority.

In addition, mechanisms to promote the expansion of bush encroachment may be understood in terms of different land use systems, namely traditional range enclosures and immediately adjacent open grazed communal rangelands. The evidence shows that reduced grazing pressure in the enclosures greatly increased the density of bush encroachment, implying that grazing is not the principal factor in driving bush encroachment. Rather, the mechanisms of bush encroachment might be linked to stochastic events such as inter-annual rainfall variability, as well as fire suppression. The effects of inter-annual rainfall variability were visible in terms of tree seedling regeneration (Paper III), while the long-term exclusion of fire promoted the proliferation of woody encroachment (Paper II). Overall, understanding the dynamics of dry savanna ecosystems and the complexity of factors that drive shifts in vegetation is useful in making management decisions in terms of bush encroachment control. In this regard, the evaluation of individual woody species in response to different demonstration methods may be useful in identifying possible intervention strategies for controlling bush encroachment.

Observations of the performance of individual woody species in response to different bush encroachment control methods yielded various management and policy implications. The long-term implication of fire suppression in the savanna ecosystems of southern Ethiopia has been the proliferation of bush encroachment. The results show that the combined use of fire with other disturbances substantially reduced the abundance of woody species. However, the variability in terms of individual species responses to the different bush encroachment control methods probably reflects their capacity to respond accordingly to the various disturbance factors. Hence, understanding the reaction of individual woody species to the different control methods has important implications for management policy in terms of the sustainable use of savanna ecosystems. Effective bush encroachment control methods could be achieved if policymakers consider the various policy implications, rather than focusing on fire suppression. Furthermore, public education through participatory research and extension programs would encourage better adoption by herders of effective management strategies for the control of bush encroachment.

The final focus of this thesis aims at demonstrating participatory methods for the management of bush encroachment, with the hope that the outcomes in terms of promoting herbaceous biomass and conservation of species diversity will encourage the adoption of effective bush control methods by both the extension department and local communities. The findings suggest that bush encroachment control methods have significant impact on the recovery of herbaceous species composition and productivity. The integration of fire with other bush encroachment control methods showed advantages over the current system that promotes bush encroachment. This suggests that excluding certain disturbances, such as fire and grazing, may hinder the improvement of forage productivity for livestock. Rather, greater herbaceous biomass and diversity were recorded in response to the disturbance treatments, implying that the combined effects of grazing and bush cover have a tendency to reduce fuel load. Thus, the present study found no justification for the policies that promote the exclusion of fire and grazing from the savanna ecosystems of southern Ethiopia. The implication is that the threats to pastoral production and biodiversity can only be reduced if management strategies focus on the use of different bush encroachment control methods and promote sound public education through extension programs. Public awareness is required to encourage the sustainable use of savanna ecosystems and the conservation of biodiversity.

7. Conclusions

This thesis provides empirical evidence on the dynamics of savanna ecosystems in southern Ethiopia, drawing on existing ecological theories and the findings of five inter-related studies. The review of ecological theories suggests that past grazing management models in southern Ethiopia were unsuccessful due to misconceptions of indigenous environmental knowledge that were based on the equilibrium guiding principles. It is suggested that alternative models, such as the non-equilibrium and state-and-transition models, would more appropriately describe the dynamics of dry savanna ecosystems, as opposed to the equilibrium policy of land use. The empirical evidence was in the form of the relationship between rainfall records and cattle population data; perceptions of the impact of changes in land use and bush cover dynamics on the rangelands in terms of enclosures and open grazed areas; and the effects of different bush encroachment control methods on woody and herbaceous vegetation.

Rangeland dynamics in terms of cattle populations and the processes of bush encroachment are considered in Papers I, II and III, while bush encroachment management strategies are addressed by the summaries in Papers IV and V. A cattle-based economy is the main production system in the central region of Borana, southern Ethiopia, where herd management and land use systems are regulated by traditional institutions. The main land use systems are the key and non-key resources, which are crucial for seasonal herd management. Currently, the traditional land use systems are being influenced by inappropriate land use policies (Paper II). In Paper I, the study highlights the role of seasonality, suggesting that rainfall variability is an important regulatory factor in controlling livestock populations in the region, both under the communal and ranch systems. Since inter-annual rainfall variability emerged as the principal regulatory factor, the equilibrium model seems unsuitable for such ecosystems. Instead, the non-equilibrium model appears to be appropriate for better understanding of the dynamics of savanna ecosystems.

Pastoralists' observations show that the impact of changes in land use have resulted in the evolution of semi-private range enclosures, crop farming and the fire ban, leading to bush encroachment. The study therefore suggests that the sustainable use of the savanna ecosystems of southern Ethiopia will require paying greater attention to regulating the expansion of enclosures, crop farming and ranching, as well as re-introducing fire where necessary to control the bush cover.

The evidence that the regeneration of invasive woody species failed to show linear relationships with age chronosequence of range enclosures, discloses the fact that the drivers of bush encroachment are probably controlled by stochastic events such as inter-annual rainfall variability, rather than grazing pressure. Bush encroachment is a major threat to sustainable land use and the conservation of biodiversity, which were traditionally maintained in the past. The study suggests that the exclusion of disturbances such as fire and grazing from the savanna ecosystems of southern Ethiopia have transformed the vegetation to a state of bush encroachment. To reduce the negative effect of bush encroachment on the pastoral economy, the reintroduction of fire is recommended. Finally, the studies concluded that the old, traditional use of fire and grazing was effective in reducing the regeneration of invasive woody plants, while promoting herbaceous biomass and the conservation of species diversity.

8. Future research

The research produced basic information on the dynamics of Borana pastoral systems in terms of the long-term effects of rainfall variability on livestock population, herders' environmental knowledge, the processes of bush encroachment and management strategies. Important areas for future research include:

1. In paper I, it was suggested that the effects of rainfall variability, combined with forage scarcity during drought years, which is also linked to bush encroachment probably contribute to severe herd mortality. Therefore, the threat of bush encroachment on the pastoral economy needs further research. Overall, the link between climate change and grazing pressure in driving bush encroachment and the consequences on cattle populations requires long-term investigation.

2. In Paper II, although some findings were inferred from pastoralists' perceptions of historical patterns of vegetation change, field based monitoring and continued research is

needed to confirm these findings. In this regard, the use of earlier aerial photographs combined with long-term vegetation monitoring might be required in order to confirm pastoralists' observations of vegetation changes.

3. In Paper III, the process of bush encroachment was considered. Several research issues remain that need to be addressed as part of a long-term monitoring plan that will promote better understanding of the mechanisms of bush encroachment in the savanna ecosystems of southern Ethiopia. These include: effects of human settlements; soil seed banks; and competition for soil moisture and soil nutrients affecting the regeneration of invasive woody plants across different landscapes related to grazing pressure.

4. The long-term effects and continued monitoring of bush encroachment control methods on the regeneration of invasive woody plants and the restoration of herbaceous plant biodiversity require more research in order to be better understood.

5. Follow-up research is needed to demonstrate the different bush encroachment control methods on a small scale that could be linked to communities' forage reserves to strengthen public education and introduce range rehabilitation.

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PAPER I

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Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia

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Abstract

This study reconstructed 21 years of household cattle population data in key resource (*tula* wells) and non-key resource (pond-water) rangelands in southern Ethiopia, as well as 15 years of government cattle breed conservation ranch data, to analyze the relationship between long-term rainfall and cattle population dynamics. For the key-and-non-key resource rangelands, we assessed the reproductive life of cows and the number of calves. For both the communal and ranch systems, we analyzed impacts of multiple droughts on calving rates and herd die-offs. Relationships between pre-drought and post-drought cattle populations were used to evaluate evidence of density-dependence. Breeding females in the key resource *tula* well rangelands had a longer reproductive life than in the pond-water rangelands, and they produced more calves per reproductive life. Average calving rates were 55% for the communal and 52% for the ranch. Greater reductions in calving rates during droughts implied reduced herd growth potential. Breeding females and immature animals were influenced to a much greater degree by inter-annual rainfall variability than were mature males. The data showed a downward spiral for the total cattle holdings over a 21-year period, with a decline of 54%. The evidence of density-dependence was relatively important at the local land use level as compared with the regional level. Cattle population below carrying capacity under ranch management did not reduce herd die-offs, suggesting that rainfall variability, not density, had greater influence on cattle population dynamics. Long-term trends of cattle populations in the communal and ranch systems synchronized with mean deviations of rainfall. Our results indicate that rainfall variability under the different management systems strongly influenced the dynamics of cattle population, calving rates and mortality. The claim that ranching could be a superior model for range management in Borana over the communal system was not confirmed. The decline in cattle population in southern Ethiopia indicates a need for improved drought management policy. The evidence that droughts were more harmful to breeding females and immature animals than to mature males suggested that drought management needs to focus on herd recruitment potential. For the herders in southern Ethiopia, drought management involved herd mobility and accumulation of herds during periods of favourable rainfall. In the future, the importance of government ranch could be in breed conservation for the maintenance of the Borana cattle breed through distribution of bulls during the drought recovery phase.

Keywords: Cattle population; Drought management; Ethiopia; Herd-die-offs; Key-and-non-key resources; Pond and *tula* well rangelands

1. Introduction

Drought induced cattle die-offs in the arid and semi-arid rangelands pose serious challenges to drought management policies (White et al., 1998; O'Meagher et al., 1998). The problems of drought management are greater die-offs of cattle followed by slow recovery (Oba, 2001a,b). Future drought management could be improved if the relationship between variable rainfall and the fluctuations in cattle populations were better understood. Responses by cattle populations to rainfall variability might vary depending on whether they are managed in key and non-key resources or communal and ranch management systems. Furthermore, the policy goals of transforming the communal systems to ranch management often aimed at reducing cattle

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losses to drought need to be examined. The response of cattle populations to variable rainfall is explained in terms of the relationships between stocking densities or the pre-drought total populations to post-drought population. Pre-drought stocking densities are presumed to induce greater cattle mortality in key-resources, while in non-key resource systems the responses are more related to rainfall variability (see also Illius and O'Connor, 1999, 2000). In this paper, we discussed the responses by cattle populations to rainfall variability in terms of

- the relative resilience of the key and non-key resources,
- the performance under the communal and ranch systems and
- the degree to which the different systems were driven by climate variability.

The key and non-key resources in the dry lands refer to differences in ecological, spatial and temporal grazing resource management. For local pastoral communities in East Africa, for example, the key resources refer to those parcels of land where access during periods of climatic stress are crucial for livestock survival. Key resources could also refer to the wet season arid ecosystems where growth of vegetation during the early rains is rapid and which are often used for post-drought weakened herds to recoup from losses of body conditions and lowered reproduction. The latter resources are considered as "key" only during the short window of plant growth although pastoralists would usually consider a key-resource in association with permanent sources of water and more reliable feed growth. Because of the crucial role they play during the drought periods, the key resources are strictly regulated in terms of the allowable stocking densities.

Ecologists for their part have used variations of landscapes between bottomlands and uplands in the dry savannahs as a scale for separating the key from non-key resources. For example, wetlands in the dry environments are considered as key resources for seasonal grazing and farming (Scoones, 1991, 1993). However, there are important questions that are rarely answered in relation to the roles played by key and non-key resources in the fluctuations of livestock population and variable rainfall. First, would reproductive performance, calving rates and mortality vary between the key and non-key grazing resources? Second, would effects of long-term rainfall variability show similar responses at local and regional scales? The different responses will highlight the main differences in patterns of cattle mortality managed in the key and non-key resources. Lack of patterns of mortality between the key and non-key resources might limit the use of the terms to spatial and temporal management decisions but not differences in terms of plant-grazer relationships. This makes the comparison of communal and ranch management relevant.

The information on cattle population responses to multiple droughts managed under communal rangelands (Oba, 2001a; Desta and Coppock, 2002) and the ranching systems have been poorly documented. The development of ranches as an alternative to the communal rangeland management system is often aimed at transforming pastoral production, thus making ranches the models of range management. The claim is that the ranch system represents the most optimal way of using rangelands by controlling stocking rates and reducing drought year losses. It is further claimed that ranch production is more stable in response to multiple droughts than the communal rangelands, where multiple droughts were associated with greater cattle population die-offs. In the present study we questioned these premises. First, patterns of calving rates and mortality in relation to inter-annual rainfall variability in the communal systems compared with the ranch management system are rarely reported. Second, there are no analyses on whether maintaining the stocking density below the carrying capacity would improve calving rates, reduce mortality and increase post-drought recovery as compared with cattle managed under the communal system. Third, cattle population trends in relation to variable rainfall and periodic droughts have not been evaluated in an effort to understand the driving force behind cattle population dynamics in the communal and ranch management systems.

The comparative performances of the communal and ranch managements would be understood in terms of the degree to which different ecological and management systems respond to rainfall variability in the key and non-key resources in terms of calving rates and cattle die-offs. At landscape level, ecologists proposed that in the key-resources grazer-vegetation coupling is stronger (i.e. effects of density dependence will be greater) compared to the non-key resources, where effects of grazing on plants are coupled to a lesser degree (i.e. effects of density dependence will be weaker) and herbivore populations are linked more to rainfall variability (Illius and O'Connor, 2000). At regional level, it has been assumed that herbivore populations may be driven less by density (Desta and Coppock, 2002) and more by variability of rainfall (e.g. Scoones, 1993; Fernández-Giménez and Allen-Diaz, 1999; Oba et al., 2000a; Sullivan and Rohde, 2002). Research is however unclear on the relationship between the pre-and post-drought cattle populations related to cattle die-offs in key and non-key resources and the communal to ranch management system. For example, would cattle mortality induced by density-dependence be greater in the key than in non-key resources or communal than the ranch management?

Previously, no studies compared a long-term population database of cattle to variable rainfall in key and non-key grazing resources and compared cattle population dynamics under the communal and ranch management systems. In this paper, we intended to understand how cattle population dynamics under communal management in key and non-key resource systems and government ranch responded to long-term rainfall variability and the implications for regional drought management policies. We analyzed 21 years of household reconstructed cattle population data and 15 years of government cattle breed conservation ranch cattle data in an effort to understand whether our data on cattle populations in the different land use systems (i.e. key and non-key resources) and management systems (communal vs. government ranch) could be used to shed more light on the different ecological explanations (i.e. density-dependence vs. density-independence) of cattle population die-offs in Borana, southern Ethiopia.

2. Background

2.1. The Borana pastoral production

Until the early 1980s the Borana pastoral production was considered to be one of the few remaining sustainable pastoral systems in East Africa (Cossins and Upton, 1987). Since then, the savannah ecosystem of southern Ethiopia has been experiencing greater cattle population die-offs during periodic droughts (Cossins and Upton, 1988a; Desta and Coppock, 2002) and deterioration of the range as evidenced by the proliferation of bush encroachment and a general decline in forage production (Oba et al., 2000b). The average annual primary production of the Borana rangeland is estimated at 2000 g DM ha^{-1} yr^{-1}, which might drop in drought years (Cossins and Upton, 1988b). Considerable variation in primary productivity between sites and seasons is also likely (Upton, 1986). The present crisis might therefore result from the combined effects of climatic variability and increase in bush cover that could increase risks of drought-induced die-offs (Oba, 2001a).

Previously, a robust natural resource base and stable system of traditional land use were related to extensive grazing lands (Upton, 1986). Under communal rangeland management, seasonal movements of stock and the use of different landscapes between the dry and wet season grazing areas were the most common features of land use (Oba et al., 2000b). The central plateau of Dirre, which is composed of key grazing resources that correspond with the traditional deep *tula* wells of which there are nine clusters across the southern region of Borana (Helland, 1980) has been utilized during the dry season for several centuries (Oba, 1998). From the herders' perspectives, the landscapes of the *tula* ecosystems are special varieties of savannah with permanent water that have generated regular usage rare in East Africa. In southern Ethiopia, the limestone geological formations of the *tula* well complexes are extensive extending across the region into north-eastern Kenya. The Borana pastoralists refer to the land forms associated with the *tula* well complexes as the "bottomlands of the white waters" (*qaa'a biisaan aadhi*). Thus, unique limestone geology, deep accessible aquifers reached through ancient civil engineering works and strong social regulations of stocking rates benchmarked on available water are some of the important features of the *tula* rangelands that distinguish them from other ordinary savannah landscapes (Oba, G., Angassa, A. and Uma, T. W., unpubl.).

For the *tula* well rangelands the 20 km radius of the wells is rested from grazing during the wet season and conserved for dry season grazing. By comparison, the less watered rangelands are preferred for grazing during the wet season. The rapid growth of annual grasses is important for helping the livestock to recover from previous drought stresses. As soon as the surface rain pools had dried up, the population would disperse to the shallow well waters. During the last decade and a half, however, these former wet season rangelands have been made more accessible through the development of ponds that temporarily store water. A characteristic feature of the pond-water rangelands is their support of semi-sedentary communities and heavy stocking densities because of the lack of social regulations of stocking rates similar to the *tula* well rangelands. Thus, in this paper our use of the terms key and non-key resources refer strictly to the dry and wet season usage as applied by the Borana pastoralists.

In both land use systems (i.e. key and non-key resources), the traditional grazing management comprised the division of herds between the mobile (*loon fora*) and the home herds (*loon warra*). These management strategies are an adaptation to coping with droughts (Oba, 2001b; Kamara et al., 2004). The dry animals are sent to the *fora*, which are highly mobile, while lactating cows are moved back to the home herds and *vice versa* (Gemedo-Dalle, 2004). During the dry season, the *fora* and the *warra* herds are moved to the *tula* or the shallow *adadi* wells rangelands (for the pond rangelands), while in the wet season, land use by the *fora* herds in both systems might overlap. Information on stocking densities under communal rangeland management was unavailable. Previous studies reported the potential stocking rates in the central Dirre district to range from 11.3 to 22.5 Tropical Livestock Units km^{-2} (1 TLU = 250 kg bovine), with the actual stocking rates varying from 17.1 to 18.1 TLU km^{-2} (Cossins and Upton, 1987, 1988b). In the present study, we used the relationships between pre-drought and post-drought cattle population as proxies of the stocking densities in the two land use systems. Our interest was to understand if the communal grazing system was inferior or comparable to the government ranch system under multiple droughts.

2.2. The government ranch

In southern Ethiopia, the programme for development of the Borana rangelands was set forth in the AGROTEC report of 1972–1974. The programme was aimed at promoting ranching systems as an alternative to traditional grazing systems. The government breed conservation ranch at Did-Tuyura (6000 ha) is among the four ranches established in Borana in the 1980s. [The other ranches are Sarite (17,000 ha), Dambala-Wachu (12,000 ha) and Walensu

(25,000 ha), but these lacked regular cattle census data.] The cooperative ranches were discontinued after 1991 as a result of financial constraints and were sold off to a private investor in 1997 (Oba, 1998).

The breeding ranch was stocked at below the carrying capacity ceiling of 26.8 TLU km^{-2} (Ministry of Agriculture, unpublished data). The Borana cattle breed in southern Ethiopia has been considered to be among the superior breeds of the indigenous East African Zebu (Alberro, 1986). The genetic pool of the breed has been conserved in Kenya for a long time (Alberro, 1986), and the conservation of the breed in Ethiopia was also considered a priority (Hogg, 1990). The breed is highly adapted to the arid and semi-arid environments and has unique physical and physiological features of coping with stress and being able to recover rapidly after drought stress (Rewe et al., 2006). The Borana breed of cattle is generally known for high fertility and good mothering ability, producing more beef and yielding more milk than other native cattle breeds in East Africa (Alberro, 1986; Rewe et al., 2006).

The stated goals of the government ranch in establishing the breed conservation ranch were, first, to conserve the breed and, second, to provide opportunities for the pastoralists to upgrade their breeds through the purchase of bulls. Yet, the implicit policy remains the same – that the establishment of ranching will be superior to the communal grazing systems. As mentioned earlier, the development of ranches as an alternative to the communal rangeland management system was aimed at transforming pastoral production, thus making ranches the models of range management. This study considered if the ranch system is more stable in response to multiple droughts than the communal rangelands in terms of cattle population die-offs. We investigated whether patterns of calving rates and mortality in relation to inter-annual rainfall variability in the communal systems were comparable with the ranch management system. Furthermore, we analyzed whether maintaining the stocking density below the carrying capacity would improve calving rates, reduce mortality and increase post-drought recovery as compared to cattle managed under the communal systems. The information will be useful for rationalizing effective drought management policies for the Borana rangelands of southern Ethiopia.

3. Methods

3.1. Study area

The survey was conducted in southern Ethiopia (4–6°N and 36–42°E) in the districts of Yabello and Dirre across six peasant associations. The Dirre district represented the *tula* well rangelands (Dubluk, Madhacho and Melbana) and the Yabello district represented the pond-water rangelands (Dida-Hara, Did-Yabello and Harawayu). The breed conservation ranch in Did-Tuyura is located in the Yabello district. The climate of the two districts varied from arid to semi-arid and sub-humid. Rainfall is bimodal with 60% of the annual precipitation expected during March–May (*ganna*) and the remaining expected during September–November (*hagaya*). The long dry season is from late November to early March with drought recurring every five to 10 years (Coppock, 1994). The *tula* well rangelands received on average 464 mm yr^{-1} compared to the pond-water rangelands with a mean annual rainfall of 539 mm yr^{-1}. Land for grazing is mostly communal although the recent introduction of cooperative and breeding ranches, farming and semi-private range enclosures may have transformed the traditional systems of land use (Ayana Angassa and Gufu Oba unpubl.).

3.2. Descriptions of rainfall data

The rainfall data for the period 1983–2003 was obtained from the meteorological section of the Southern Rangeland Development Unit (SORDU, personal comm.). From the rainfall data for the different sites representing the stations in southern Ethiopia across the semi-arid/sub-humid (including Arero, Moyale, Yabello, Hiddi-Lola, Dida-Tuyura and Dambala-Wachu) to arid ecological zones (e.g. the stations of Dillo, Sarite, Web and Wachile), we calculated the regional annual mean for 21 years. Because of the lag-time between rainfall and cattle population, we related rainfall from the previous year with cattle numbers for the current year (Fig. 1). The mean annual precipitation for the Borana rangelands of southern Ethiopia over the 21-year period was approximately 500 mm (SD ± 163 mm) ranging from 238 to 896 mm. Generally, below average rainfall years occurred 11 out of the 21 years (see Fig. 1). During the major drought years of 1983–1984, 1992–1993 and 1999–2000, the mean annual rainfall declined by 14%, 35%, 18%, 17%, 52% and 43%, respectively.

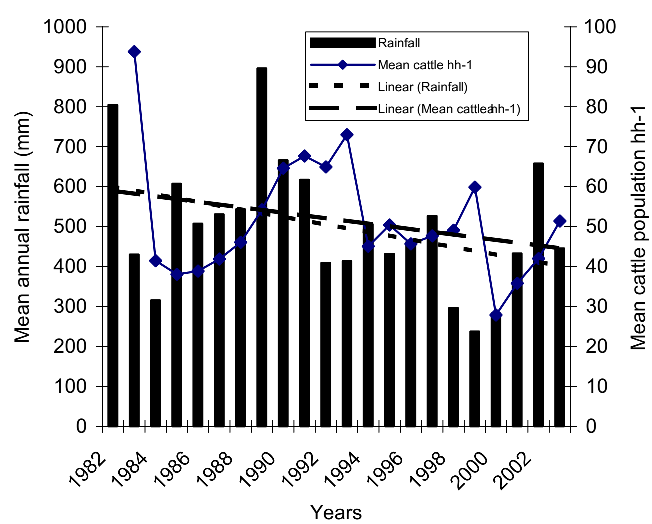

Fig. 1. Mean annual rainfall and cattle population per household (1983–2003) in Borana, southern Ethiopia. Trends in mean annual rainfall (dotted lines) and mean cattle population (dashed lines) are shown.

3.3. Descriptions of household cattle data

From the interviews with 72 households, we reconstructed cattle population data in terms of reproductive life of cows and number of calves per reproductive life of cows, calving rates, herd mortality, mortality by reproductive and age classes, and relationships between the pre-drought and post-drought cattle populations (from 1983 to 2003), comparing the deep *tula* wells (key resource) and pond-water (non-key resource) rangelands. Sample households were randomly selected from six peasant associations (PAs) in the Dirre and the Yabello districts. Equal samples of 36 households representing the *tula* well and pond-water rangelands were surveyed. Herders were interviewed using a semi-structured questionnaire. The method was similar to that used by Desta and Coppock (2002). We limited the sample size to 72 households due to the detailed interviews that required a significant investment of time to collect herder recall data over a period of two decades. The interviews were conducted in Afaan *Oromo* (the *Oromo* language). The enumerators took one day to complete one questionnaire for each household. Data were collected on the recall of households in relation to the *gada* time (Legesse, 1973) and the numbers of "cow-families" (*mina looni*) owned by individual households. (Cattle owned by individual households are grouped by "cow-families" in terms of matriarchal cows and their genealogies.) The number of calves born and deaths were recalled in a step-wise fashion using the cow-families' oral history (Oba, G. unpublished) during each year, of the eight *gada* years (Legesse, 1973). The households reconstructed herd histories from 1983 to 2003, spanning three *gada* periods that included three regional droughts (i.e. 1983–1984, 1992–1993 and 1999–2000). The reproductive life and number of calves per reproductive life of cows, number of cattle per household before and after droughts, calving rates and cattle mortality categorized by cows, bulls and immature animals (<2 years old) during individual years were finally tallied for each household. To account for the potential role of cattle population density effects on mortality in the key and non-key grazing resources and for the region, we related pre-drought and post-drought cattle populations (Oba, 2001a). A high regression coefficient of variation (e.g. $r^2 > 50\%$) between the pre-drought to post-drought populations for both the local and regional land use systems would provide strong evidence of density-dependence, while lower coefficients would provide weaker evidence.

3.4. Descriptions of the ranch data

We used the government ranch cattle population data of 15 years obtained from annual records (from 1989 to 2003) to understand calving rates and herd mortality by reproductive and age classes. The data had gaps in the figures on mortality, for which we had four years of complete entries (1991, 1993, 1999 and 2000), and on calving rates, for which we had five years of complete entries (1993, 1997, 1999, 2000 and 2002). The mean stocking density was estimated at $12 \pm 0.3\ \mathrm{TLU\ km^{-2}}$, which was below the carrying capacity. Using the available data, we related pre-drought and post-drought stocking density as well as pre-drought and post-drought total populations to evaluate evidence of density-dependence.

3.5. Statistical analyses

For the communal rangelands, we used households (72 levels), land use types (2 levels) and number of years (21 levels), and for the ranch management we used rainfall of 15 years (15 levels) as categorical variables. For the response variables we used reproductive life of cows, number of calves per reproductive life (communal system only), calving rates and mortality (both systems) in a General Linear Model (SAS, 2001). The data were analyzed in five steps. First, the mean age per reproductive life of cows and number of calves per reproductive life were grouped according to the *tula* well (key resource) and pond-water rangelands (non-key resource). To separate individual year effects, calving rates grouped by the *tula* and pond-water rangelands for the household data were compared by a *t*-test. Secondly, we used ANOVA to understand the impact of inter-annual rainfall variability on cattle populations grouped by reproductive and age classes according to land use types (i.e. the key and non-key resource rangelands), and changes in cattle household holdings by year. Third, we used a *t*-test to compare differences in mortality by reproductive and age classes, comparing the key and non-key resource rangelands. Fourth, the ranch data were analyzed alone using a General Linear Model to determine mean annual herd size and stocking density (for 15 years), calving rates (for five years), and the herd mortality by reproductive and age classes (for four years). Fifth, linear regression analyses were run between rainfall and cattle population, calving rates and mortality. We correlated the pre-drought and post-drought cattle populations (for communal) for different land use types (*tula*, pond and the Borana region) and pre- and post-drought density vs. pre- and post-drought population for the ranch system. We also determined trends for the regional and ranch cattle populations as deviations from the long-term means. All tests were considered significant at $P < 0.05$.

4. Results

4.1. Cattle population dynamics in key and non-key resources

The *tula* well and pond-water rangelands were significantly different in terms of the reproductive life of breeding females ($F_{1,20} = 360.74$, $P < 0.001$) and number of calves per reproductive life of cows ($F_{1,20} = 288.25$, $P < 0.001$).

Respondents reported that breeding females using the *tula* well rangelands had a longer reproductive life (26.8 ± 0.5 years) compared with those using pond-water rangelands (13.4 ± 0.5 years). Additionally, a greater number of calves per reproductive life of cows were born in the *tula* well rangelands (15.0 ± 0.3 calves per reproductive life of cow^{-1}) relative to the pond-water rangelands (8.4 ± 0.3 calves per reproductive life of cow^{-1}). Calving rates between the key and non-key resource rangelands showed significant differences in eight out of the 21 years, which were lower during drought years than during the above average rainfall years (Table 1). Generally, calving rates were higher in the key resource rangelands compared with non-key areas, particularly during years of stress (Table 1). Overall, the average annual calving rate for the Borana communal herds was 55%. There were positive relationships between calving rates and mean annual rainfall in the two land use systems, the relationships being stronger in the *tula* than in the pond-water rangelands (*tula* $r^2 = 0.34$, $P = 0.006$, pond $r^2 = 0.28$, $P = 0.014$). Calving rates for the regional herds (i.e. communal system) were strongly correlated with mean annual rainfall ($r^2 = 0.81$, $P = 0.012$).

Cattle populations by reproductive and age classes were significantly influenced by rainfall variability both in the key and non-key resource rangelands, and at regional and household levels (F-test, $P < 0.05$, Table 2). Generally, bulls were less affected by inter-annual rainfall variability than reproducing cows and immature cattle (Table 2). The mean cattle population per household closely followed the patterns of rainfall in the previous years (Fig. 1). The average cattle holdings at the household level declined from 94 animals in 1983 to 51 animals in 2003. The lowest average herd size was reported in 2000 (Fig. 1). The cattle population die-offs during the droughts in 1983–1984 was 56% of the total population, while during the droughts of 1992–1993 and 1999–2000 mortality accounted for 38% and 53%, respectively. The trends of mortality closely followed rainfall fluctuations (Fig. 2a). Comparison of key

Table 1
Comparison (t-test) of calving rates (%) in the key and non-key communal rangelands during each year over a 21-year period in southern Ethiopia

Year	*Tula*	Pond	Test
1983	81 ± 8.5	79 ± 8.5	*
1984	21 ± 1.2	17 ± 1.2	NS
1985	65 ± 4.2	63 ± 4.2	NS
1986	60 ± 3.8	59 ± 3.8	*
1987	61 ± 3.7	60 ± 3.7	NS
1988	62 ± 3.7	62 ± 3.7	NS
1989	76 ± 5.6	73 ± 5.6	NS
1990	71 ± 5.5	61 ± 5.5	*
1991	65 ± 4.4	65 ± 4.4	NS
1992	52 ± 4.6	50 ± 4.6	**
1993	47 ± 4.0	42 ± 4.0	**
1994	65 ± 4.8	61 ± 4.8	NS
1995	52 ± 4.2	53 ± 4.2	NS
1996	64 ± 5.9	63 ± 5.9	NS
1997	50 ± 3.4	50 ± 3.4	NS
1998	60 ± 3.0	57 ± 3.0	NS
1999	23 ± 1.6	23 ± 1.6	NS
2000	12 ± 0.6	13 ± 0.6	*
2001	61 ± 3.0	60 ± 3.0	*
2002	67 ± 3.4	67 ± 3.4	NS
2003	62 ± 4.0	60 ± 4.0	*

* $P < 0.05$.
** $P < 0.01$, NS $P > 0.05$.

Table 2
GLM for long-term household (HH) recall cattle population database in the different land use systems as affected by the 21-year mean annual rainfall (i.e. in the model we have accounted for the effects of rainfall variability) in Borana, southern Ethiopia

Variables	Source	d.f.	F
Cows	*Tula*-pond	1	72.38***
	Regional	1	94.16***
	HH	71	3.43***
	Year	20	3.40***
Bulls	*Tula*-pond	1	64.53***
	Regional	1	78.78***
	HH	71	2.09***
	Year	20	1.32NS
Immature	*Tula*-pond	2	18.88***
	Regional	1	21.72***
	HH	71	1.48**
	Year	20	1.95**

** $P < 0.01$.
*** $P < 0.001$, NS $P > 0.05$.

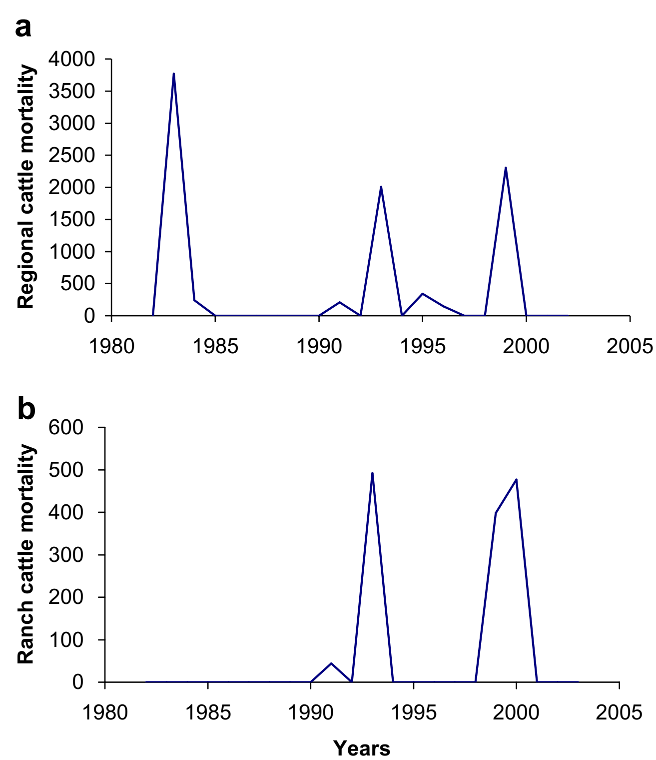

Fig. 2. Total cattle mortality under (a) communal rangelands and (b) ranch system in Borana, southern Ethiopia

Table 3
Comparison (t-test) of cattle mortality (%) by age and reproductive classes in the key and non-key communal rangelands during three major droughts in southern Ethiopia

Age classes	Year	*Tula*	Pond	Test
Cows	1983–1984	56 ± 3.4	56 ± 3.4	NS
	1992–1993	39 ± 3.4	38 ± 3.4	**
	1999–2000	53 ± 2.3	54 ± 2.3	*
Bulls	1983–1984	54 ± 1.1	55 ± 1.1	NS
	1992–1993	35 ± 0.8	38 ± 0.8	*
	1999–2000	55 ± 0.5	52 ± 0.5	*
Immature	1983–1984	56 ± 2.1	56 ± 2.1	NS
	1992–1993	38 ± 4.3	38 ± 4.3	NS
	1999–2000	53 ± 1.6	53 ± 1.6	NS

* $P < 0.05$.
** $P < 0.01$, NS $P > 0.05$.

and non-key resource rangelands in terms of mortality of breeding females and mature males showed significant variations during multiple droughts, but the immature animals were always vulnerable (Table 3). Cattle mortality in relation to annual rainfall was comparable between the two land use systems (*tula* $r^2 = 0.46$, $P = 0.037$, pond $r^2 = 0.44$, $P = 0.017$). The pre-drought population explained on average 34% of the post-drought population in both the *tula* and the pond-water rangelands (i.e. 66% of the variability was unaccounted for). At the regional level the pre-drought population explained on average 18% of the post-drought population (i.e. 82% of the variability was unaccounted for), with the relationships varying between different droughts (Table 4).

4.2. Ranch cattle population

The analysis of variance showed highly significant variations in total ranch population in relation to rainfall variability ($F_{14} = 7.84$, $P < 0.001$, $r^2 = 0.19$, $P = 0.027$). Rainfall variability had a strong positive influence on the ranch cattle calving rates ($r^2 = 0.71$, $P = 0.079$). The ranch cattle on average (five years) had calving rates of 52%. Drought induced mortality for the ranch-breeding females during 1992–1993 (58%) and 1999–2000 (55%) were comparable. Generally, mortalities of immature animals during the 1992–1993 (59%) and 1999–2000 (57%) were also comparable, but greater than those of mature males (i.e. 53% vs. 52%). The trends of mortality closely followed rainfall fluctuations (Fig. 2b). In the ranch system, the relationship between the pre-drought and post-drought stocking density explained 28% of the total mortality (i.e. 72% of the variability unaccounted for), while when we used the pre-drought population against post-drought population, it explained 17% for 1992–1993 drought and 19% for the 1999–2000 drought (i.e. 83% to 81% of the variability unaccounted for).

Table 4
Coefficient of variation (r^2) as predictor of pre-drought and post-drought populations

Pre- and post-drought	*Tula*	Pond	Regional
1983–1984	0.46^{***}	0.35^{***}	0.21^{**}
1992–1993	0.36^{***}	0.46^{***}	0.16^{NS}
1999–2000	0.20^{**}	0.21^{**}	0.17^{***}

** $P < 0.01$.
*** $P < 0.001$, NS $P > 0.05$.

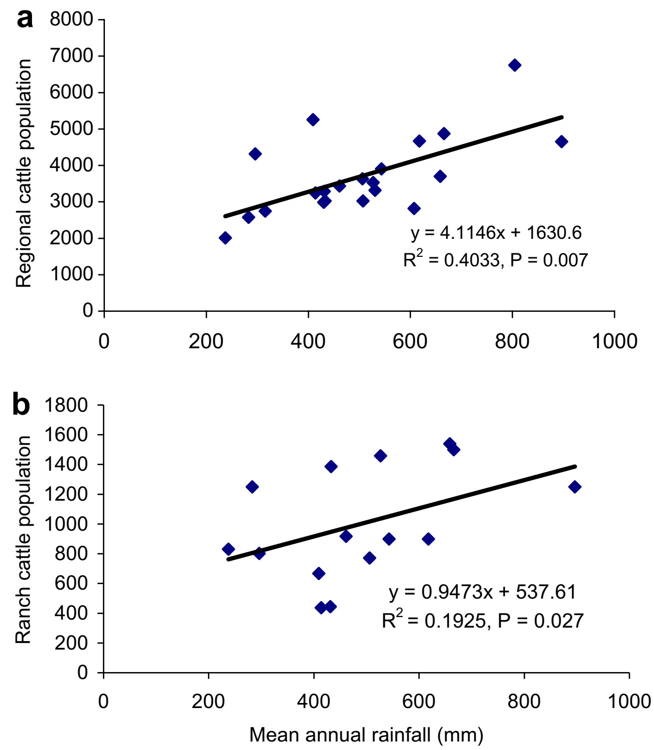

Fig. 3. Regression between mean annual rainfall (1983–2003) (a) regional cattle population (1983–2003) and (b), and ranch cattle population (1989–2003) in Borana, southern Ethiopia.

4.3. Trends of regional and ranch cattle populations

The trends of cattle mortality for the region and ranch systems closely followed the annual patterns of rainfall punctuated with periodic droughts (Fig. 2a and b). The regression values between mean annual rainfall and cattle population were relatively greater for the communal than for the ranch cattle population (Fig. 3a and b). Drought induced population crashes delayed the recovery in both systems (Fig. 4a–c). The r^2-values for the regression between the annual cattle mortality and mean annual rainfall under the communal ($r^2 = 0.26$, $P = 0.003$) and the ranch ($r^2 = 0.32$, $P = 0.033$) were greater in the latter system. The greatest cattle population crashes occurred during the drought years of 1983–1984 (i.e. for the communal) and 1992–1993 (for both the communal and the ranch system) (Fig. 2a and b). Population crashes were followed by gradual recovery (Fig. 4b and c).

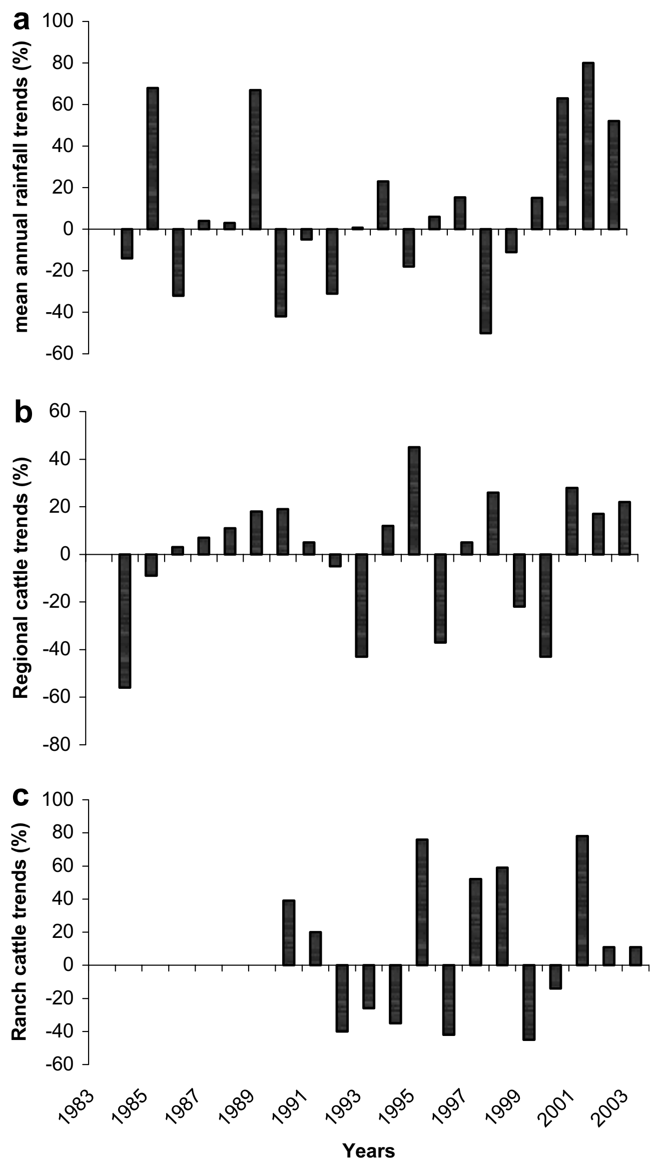

Fig. 4. The relationships between (a) percent deviations from long-term mean annual rainfall, (b) regional cattle population and (c) ranch cattle population in Borana, southern Ethiopia.

5. Discussion

5.1. Cattle population dynamics in key and non-key resources

The information provided by the households that the breeding females using the *tula* well rangelands had longer reproductive life and a greater number of calves per cow than the pond-water rangelands could probably be explained in terms of more suitable water sources as well as better availability of grazing linked to traditional grazing regulations. Herders also maintained that the *tula* water, which had all key mineral nutrients, was more suited for maintaining cattle health than those of the pond-water rangelands. In the *tula* system the Borana watered cattle every third day. The ILCA study showed that the three-day watering regimes had little effect on the performances of cattle compared with experimental controls where water was provided *ad libitum* (e.g. see King, 1983).

The higher calving rates in the key resources as opposed to the non-key resources would suggest that these rangelands supported a more stable cattle population compared with the non-key resource rangelands. For the Borana communal rangelands, however, the calving rates over the 21-year period varied from the highest of 81% to the lowest of 12% with a much lower average (i.e. 55% vs. 70%) than the value reported by Coppock (1994). We suspect that in the latter case, the period 1980–1991 experienced a single drought, while in our case the lower calving rate probably reflected the effects of multiple droughts. Brumby and Trail (1986) on Borana cattle reported calving rates of 55% under communal rangelands, which is similar to our findings. Moreover, FAO (2004) reported an average calving rate of 50% under the communal systems of range management in Botswana, which compares with our average figure. From the greater r^2 value between calving rates and inter-annual rainfall in the key-resource rangelands, we would speculate that the *tula* cattle population had greater potential for recovery from drought stress than those in the pond-water rangelands (see below).

Another significant finding was that household cattle holdings of the Borana appeared to have declined over the 21-year period by 54%. Over the last two decades, household cattle numbers were at their peak in 1983 and have been declining ever since. In the pre-1999–2000 periods the herd recovered and grew to a new peak, albeit below the pre-1992–1993 levels, while household cattle holdings never recovered to their pre-1983 levels. The decline could be explained by the greater die-offs of cattle that delayed post-drought recovery and interruptions of recovery phases by new droughts (see Oba, 2001a). We also suspect a system memory of the deteriorating conditions of the Borana rangelands, associated with increased bush encroachment, loss of grazing lands to expanding crop farming and shrinking home-range due to inter-ethnic conflicts (Oba, 1998). We further suspect that the cumulative effects would reflect the declining pastoral production in Borana rangelands of southern Ethiopia in general.

The greater vulnerability of breeding females and immature animals to multiple droughts compared with the mature males was probably related to feed scarcity (e.g. Desta and Oba, 2004; Oba, 2001a) and pre-drought animal body conditions. The breeding females and immature animals were more adversely influenced by the inter-annual rainfall variability than mature males, probably due to less body fat reserves than the mature males (Oba, 2001a). Additionally, breeding females were nursing calves, as well as supplying milk for the household, which might have put them under greater stress (Coppock, 1994).

The associations between cattle mortality and inter-annual rainfall in the key resources during multiple droughts showed relatively greater r^2 than that of the non-key resource rangelands, which confirmed the suggestion made by Illius and O'Connor (1999) that animal numbers during the dry season were probably more constrained by the limited forage availability in key resources than in non-key resources. Thus, the severity and duration of drought can result in increased mortality. Additionally, the low r^2 value for the region could have been caused by the uneven distribution and regulated use of key resources that affected seasonal mobility of livestock. Yet, the lower r^2 for the 1999-2000 droughts at the local and regional scales was probably associated with the slow herd recovery (see Fig. 1).

In the current study, the lack of consistency in pre-drought density on the post-drought populations in the key and non-key resource rangelands implied that the evidence of density-dependence varied between local and regional levels. Density-dependence was weaker at the regional level relative to the local land use systems (i.e. key and non-key resources). The low coefficient at the regional level and the relatively higher r^2 for the local land use systems suggested that stocking densities might have had some limited influence on herd mortality at local scales. This suggested that cattle population might compete more for the scarce resources at local scales than at regional scales (e.g. Illius and O'Connor, 1999). This might further be explained in terms of the nature of land use in the key and non-key resources during the wet and dry seasons. Yet, we would also caution that the failure to account for much of the variability might indicate that many of the causes can be found elsewhere.

Cattle would move into the *tula* well rangelands from the early dry season and remain there until the breaking of the drought. The population is likely to use the forage resources heavily if the previous wet season failed. The pond-water cattle by comparison would shift to the shallow well rangelands. Thus, for the pond-water rangelands, it is the ability to be mobile and seek better resources that made them less sensitive to drought stress. Both in the *tula* and the pond-water rangelands, however, cattle populations dispersed with the breaking of the drought and joined the mobile herds.

From our data we may infer that pre-drought population density was not as strong as rainfall variability in explaining post-drought population. The greater part of the population variability was unaccounted for by the population variables alone. We suspect that other environmental factors play important roles in population variability. Similarly, previous research in southern Ethiopia (Cossins and Upton, 1988a) and northern Kenya (Oba, 2001a) suggested that cattle population fluctuations were explained better in terms of variable climate than density-dependence. By comparison, Desta and Coppock (2002) in southern Ethiopia reported that a high stocking density interacted with variable rainfall to create a vicious cycle of "boom" and "bust" in cattle populations, while in the South African study, Fynn and O'Connor (2000) suggested that the stocking rates influenced animal condition on overgrazed rangelands during drought years. Our household data showed strong control of cattle populations by variable rainfall. The greater variations that could not be explained by the pre-drought population as a predictor of the post-drought populations did not support the evidence of density-dependence particularly at the regional level, while at the local level a weak density dependence might account for cattle population variations.

5.2. Ranch cattle population

The findings of our study suggest that the effects of long-term rainfall variability on the ranch cattle population could be explained in terms of the close relationships between calving rates and rainfall. The calving rate of the ranch cattle was lower than that of the communal management system. Brumby and Trail (1986) showed that the calving rates for Borana cattle under the ranching system were about 78%. Lower calving rates during droughts as compared with normal rainfall years would suggest that rainfall is a good indicator of the cattle population dynamics (Cossins and Upton, 1988a). In the ranch system, the finding that drought induced mortality affected more breeding females and immature animals than mature males held true for the communal rangelands. The evidence acquired from the long-term ranch cattle database in the current study showed that maintaining the ranch herd at below carrying capacity did not reduce cattle die-offs. Rather, the ranch cattle declined during periodic droughts in a manner similar to the cattle managed under the communal systems. If cattle population dynamics were driven by density and stocking rates thus influencing herd mortality, then we would expect a more stable population under the ranch management, which we did not confirm. Mellink and Martin (2001) in the Sonoran desert in Arizona also suggested that the fluctuation in cattle population under the ranch system could be attributed to rainfall variability rather than to stocking density. Similar patterns of population responses to droughts have been reported for other arid regions of the world (e.g. Illius et al., 1998; O'Meagher et al., 1998; White et al., 1998; Georgiadis et al., 2003). In our findings, the pre-drought density effects on the post-drought cattle population in the ranch system demonstrated weak evidence of density-dependence of 28%. The regression coefficient (~18%) between pre-and post-drought populations in the ranch system also suggested weak density-dependence, comparable with the proportions of herd mortality directly attributable to rainfall variability (19%). We can reiterate that the evidence showed that a greater proportion of the variability (81–72%) is unaccounted for and could only be explained by other external factors.

5.3. Trends of regional and ranch cattle populations

The results of this study showed similar patterns of total cattle mortality for the region and ranch management systems during multiple droughts although ranch management has been viewed as more stable than the communal system. However, greater die-offs of the cattle population during multiple droughts in the two management systems showed delayed recovery, suggesting that the cattle populations would remain below the pre-drought levels for a long time (Cossins and Upton, 1988a; Oba, 2001a). Overall, multiple droughts drastically reduced cattle populations in the communal and ranch management systems to levels below pre-drought years (see Figs. 2 and 4). A similar pattern for livestock and wild ungulates; has been reported by Kay (1997).

The evidence from the linear regression analysis between cattle population and mean annual rainfall showed that cattle populations managed under the communal rangelands were more sensitive to rainfall fluctuations than the ranch cattle population, but this does not necessarily suggest that the ranch system is more stable. Rather, the ranch system has better access to feed reserves than the cattle in the communal rangelands. During the breaking of drought through compensatory growth, the emaciated animals in the communal rangelands probably recovered rapidly using high quality forage in the wet season dispersal rangelands. It has been suggested that emaciated animals have greater energy conversion efficiencies than stronger animals (King, 1983). Thus, greater recovery potential for the communal cattle population could be linked to more rapid body weight gains following the breaking of drought stress (i.e. compensatory growth is greater) (Western and Finch, 1986), while the ranch cattle might have had more feed reserves during drought years and therefore showed low capacity for compensatory growth. Other studies have also shown that different livestock classes experiencing feed restrictions often exhibited compensatory growth by accumulating more body weight once feed was availed (Ryan et al., 1993).

Trends of cattle populations as deviations from the long-term mean for the communal and ranch management systems were comparable. This mirrored the deviations of rainfall, suggesting that inter-annual rainfall probably exerted considerable pressure on growth of cattle population mediated through primary range productivity. The similarity of patterns in the inter-annual cattle populations for the communal rangelands and for the ranch system for part of the 15-year period implied that rainfall variability would probably account for the proportions of cattle die-offs than population density of the remaining cattle in southern Ethiopia. We can reiterate the earlier remarks that in the ranch system, maintaining the stocking density below the carrying capacity did not improve calving rates, reduce mortality and increase post-drought recovery as compared with cattle managed under the communal system.

6. Conclusions

By examining the long-term records of rainfall and cattle population data in southern Ethiopia, we found that major droughts triggered a significant decline in cattle populations under the communal and ranch management systems. We analyzed the data to understand how variable rainfall might explain the dynamics of cattle population under different land use systems. Overall, rainfall variability had significant effects on breeding females and immature animal classes at local, regional and household levels, although it was less influential on mature males. Generally, greater reduction in calving rates during multiple droughts adversely affected herd growth potential. The *tula* cattle were more vulnerable to rainfall variability than cattle that relied on pond-water when drought conditions were extreme due to feed scarcity. From the results of our study, therefore, several issues have emerged. The variability in terms of a cow's reproductive life, calving rates and mortality within different land use systems reflected multiple resource use adaptations. Losses to drought and economic decline of the community could be avoided if the drought management policy focused on improved market access through subsidies to transport animals to markets outside the region during droughts, supporting the traditional systems of post-drought restocking and a drought insurance system for pastoralists, such as provision of emergency feed to protect breeding stock and the immature animals.

Despite the claim that ranching has an advantage over the communal management system, our study inferred that such advantages were limited to a better buffer in forage availability during drought years, which could have explained the low response to rainfall variability compared with the cattle populations of the communal rangelands. Furthermore, the greater calving rates of the ranch system over the communal system were not confirmed. Rather, in the periods for which we had data, greater calving rates were reported for the cattle of the communal rather than the ranch management system. Thus, we found no rationale for policies that promoted ranch development as opposed to maintaining the communal systems of land use in the Borana region. Consequently, we could make some tentative suggestions for effective drought management policies considering both systems as they are. Based on the evidence, we have shown that pastoral production and drought management can only be sustainable if policy makers take into account the indigenous systems of range management. However, ranch breed conservation may be crucial for serving as a gene pool for the communal rangelands as a strategy for restocking pastoralists' herds during post-drought periods. During post-drought restocking, herders often are forced to buy poor breeds of cattle from the highland communities that further contribute to the genetic dilution of the Borana breed. Thus, through improved drought management plans, better breed conservation would contribute to improved drought management policy that could continue to service the distribution of quality bulls during drought recovery.

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PAPER II

Herder Perceptions on Impacts of Range Enclosures, Crop Farming, Fire Ban and Bush Encroachment on the Rangelands of Borana, Southern Ethiopia

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Abstract

This study focuses on community-based knowledge to analyze the impacts of range enclosures, crop farming, fire suppression and bush encroachment on the communal rangelands of Borana, southern Ethiopia. The knowledge of local herders is the basis for decision making in the utilization and management of grazing lands. We used Borana oral history associated with the period of the *gada* system to reconstruct environmental change that spans a period of 48 years. Our results show that the use of communities' perceptions as a basis for evaluating the impacts of land use change on the environment makes an important methodological contribution. Communities' responses to changing land use resulted in the development of range enclosures, the expansion of crop farming and the fragmentation of the communal rangelands, while the suppression of fire contributed to the expansion of bush encroachment. The overall impact was forage scarcity and greater vulnerability of stock during drought years. We conclude that policymakers could use communities' knowledge of environmental change to improve the use of the rangelands. We propose that sustainable use of the southern rangelands in the future will require a greater focus on regulating the expansion of enclosures, crop farming and ranching, as well as re-introducing fire where necessary, to control the expansion of bush cover.

KEY WORDS: Bush encroachment; community perception; environmental history; fire ban, land use policy, rangeland development

INTRODUCTION

Pastoral communities usually have a detailed knowledge of the environment of the grazing lands. This knowledge is gained through continuous herding (Bollig and Schulte, 1999; Oba and Kotile, 2001; Mapinduzi *et al.,* 2003) and is supplemented by the knowledge accumulated from historical land use (Oba, 1998; Reid *et al*., 2000; Sheuyange *et al*., 2005; Oba and Kaitira, 2006). Despite the existence of such knowledge, researchers and development policy experts previously overlooked community-based knowledge when evaluating the impact of land use change on the environment. Combining community-based knowledge with scientific knowledge may provide a more complete understanding of environmental change from the perspective of those utilizing the resources (Bollig and Schulte, 1999; Oba *et al.,* 2000; Calheiros *et al*., 2000).

The need for incorporating community-based knowledge in assessing environmental change has been widely acknowledged (Berkes, 1998; Berkes *et al*., 1998; Calheiros *et al*., 2000; Fernandez-Gimenez, 2000; Gadgil *et al*., 2000; Olafsdottir and Juliusson, 2000; Mackinson, 2001; Oba and Kotile, 2001; Huntington, 2000). For example, pastoral herders have developed an understanding of the environment in which they manage their livestock and have established distinct systems of grazing landscape classifications that are related to the utilization and management of grazing lands (Fernandez-Gimenez, 2000; Oba and Kotile, 2001). Therefore, the knowledge of local herding communities is a useful source of information concerning the vegetation dynamics, which include changes in the numbers of certain species of plants that are preferred for grazing (Hellier *et al*., 1999). Lykke (2000) reported that local people hold relevant information on vegetation dynamics that could be important for management aimed at the sustainable use and conservation of natural resources. Furthermore, Wezel and Haigis (2000) suggested that the use of community-based knowledge is an important aspect of solving problems related to natural resource management.

According to the World Bank report (1998), community-based knowledge represents a principal component of global knowledge on the development and use of natural resource management. Community-based knowledge could improve our understanding of local conditions and provide useful expertise with regard to activities designed to help the local communities. Additionally, communities' knowledge may provide new insights for improving existing scientific knowledge (Calheiros *et al*., 2000; Oba and Kotile, 2001). This is particularly important where existing literature is scarce. Huntington (1998) also argued that community-based knowledge is more practical and relevant to environmental issues and ecological impact assessments than many other sources of information. Thus, the recognition of community-based knowledge may contribute to an improved understanding of local conditions with regard to reducing environmental degradation, as well as becoming important to scientific research and the development of policies (World Bank, 1998; Calheiros *et al*., 2000). Indigenous knowledge is a tool that can be used to evaluate the impact of development policies and the changed land use systems on environmental management practices. These practices include ecological restorations (Turner *et al*., 2000) and provide the basis for the understanding of environmental impacts and strategies for designing appropriate land use policies.

In this paper, our use of the term "land use policy", when applied to our study (i.e. southern Ethiopia), differs from the usual goals associated with the term that are often aimed at achieving specific development objectives. Without exception, clear policies on grazing regulations is lacking in grazing lands where the traditional pastoral system is the dominant form of land use (e.g. Niamir-Fuller, 1999). Past attempts to implement grazing-pastoral developments were rejected by the pastoralists (e.g. Smith, 1992; Majok and Schwabe, 1996). Thus, when we use the term "land use policy", we are referring to *ad hoc* activities by government departments (e.g. the Ministry of Agriculture) that are intended to promote specific land use (e.g. crop farming). These activities appear to function as policy. Most activities of this type are rarely evaluated to see how the policies affected the traditional system of land use and impacted on the environment.

The alternative is to link land use policies to the knowledge held by local communities in terms of understanding environmental change (see also Scoones and Graham, 1994; Oba and Kotile, 2001; Angassa and Beyene, 2003; Davis, 2005; Mapinduzi *et al.,* 2003; Homann, 2004; Kamara *et al.,* 2004; Ashenafi and Leader-Williams, 2005; Wezel and Lykke, 2006) in response to development-related activities. Such activities include the provision of water, the establishment of semi-private resource tenure in the rangelands (e.g. ranches and semi-private enclosures), crop farming in former communal grazing lands, and banning the use of range fire.

The trend towards the semi-privatization of the communal rangelands through the introduction of alternative land use, such as semi-private and communal range enclosures and crop farming, has fragmented the grazing lands and seriously impacted on traditional grazing systems. Fire is a key environmental aspect that controls the function of savanna ecosystems (e.g. Bloesch, 1999; Hudak, 1999) and performs an essential ecological role in shaping the structure and composition of vegetation (e.g. Walker *et al*., 1981; Kull, 2004; Moreira, 2000; Laris, 2002). The indirect consequence of fire suppression is the increase of bush encroachment (e.g. Sheuyange *et al.,* 2005).

In this paper, our focus is on the understanding of how changes in land use in response to *ad hoc* policies have impacted on the environment of the Borana rangelands of southern Ethiopia. Due to the direct and indirect links between land use policy drivers and changes in resource tenure, as well as shifts in vegetation from open savanna to bush encroachment, we preferred to address the changes in land use associated with the development of semi-private range enclosures, ranches, crop farming and the impacts of the suppression of fire on shifts in vegetation as a single topic. We first briefly introduce the Borana pastoral land use system and then go on to describe the past and present official policies and their implications for the rangelands. We consider the impact the policies have on environmental change before describing the contributions this study makes with regard to the better understanding of community-based knowledge of environmental change.

LAND USE CHANGE IN THE BORANA RANGELANDS

Two decades ago, Cossins and Upton (1987) characterized the Borana rangelands of southern Ethiopia as one of the most sustainable systems of traditional pastoral lands in East Africa. The past success may be related to the traditional system of range management, where the decision-making process on resource management at the local level rests with the *Ardaa* (small neighborhood units) or *Madda* (water sources) (Hogg, 1990). Access to the rich and diverse rangelands comprising of sub-humid, semi-arid and arid ecosystems also accounted for past successes (Coppock, 1994). A functional indigenous institution of resource administration under the responsibility of the *gada* system (Legesse, 1973) ensured equitable access rights to grazing and water sources. More importantly, every eight years, the Pan Borana *Gumi-Gayo Assembly* (Huqqaa, 1996), which is the highest authority among the Borana society for decision-making, developed and revised regulations for the management of grazing lands and water resources (Watson, 2003).

Traditionally, the Borana land use system was based on extensive livestock production (Coppock, 1994; Desta, 1999; Kamara, 2001; Homann, 2004) and the mobility between the *warra*- and *fora*-herds management systems. The *fora*-herds include dry cows, bulls, immature males, oxen and heifers, while the *warra*-herds consist of milking cows and calves. Furthermore, the traditional system of land use is sub-divided into grazing reserved specifically for calves (*laaf seera yaabi*) (Oba, 1998). During the dry season when the availability of forage became scarce in the *warra*-herds' grazing lands, the surplus animals were sent to the *fora*-herds (Oba, 1998). The *warra*- and the *fora*-rangelands were also sub-divided into wet and dry season rangelands. In the dry season rangelands, both the *fora*- and *warra*-herds converged on the deep *tula* well rangelands in the central plateau of Dirre (see Helland, 1980), while in the wet season the *fora*-herds dispersed into the waterless rangelands, relying on temporary rain pools (Oba, 1998). These traditional patterns of land use have been under pressure since the 1960s because of changes induced by the government's official and unofficial policies on land use. Major changes in land use included the development of pond-water, range enclosures, crop cultivation and the establishment of ranches.

Aside from a brief spell of experimentation with crop farming, which oral sources place during the *gada* Morowa Abbay period (1680 - 1688), the Borana rangelands have been used exclusively for livestock grazing. Local history claims that those who conducted crop farming during the *gada* Morowa Abbay period were severely punished for the violation of the *gada* laws that prohibited the digging of land for subsistence (Oba, 1996). During this period, the Borana probably adopted crop farming from neighboring communities who were traditional crop farmers, such as the Konso in the southern highlands of Ethiopia (Watson, 2004). After the *gada* Morowa Abbay period, there were no reports of crop cultivation until Menelik II conquered the Borana region in the late nineteenth century. The settler soldiers ("*Neftanya*"), and later the immigrant farmers from the Ethiopian highlands, introduced the crop farming culture to Borana (Helland, 1997b). The settlers cultivated the humid areas of Borana, where the climate was relatively favorable for crop farming. The sub-humid zones that traditionally served as dry season and drought year grazing reserves were lost to cropping starting from the nineteenth century (Oba, 1998). In the other areas of the rangelands, the expansion of crop farming was gradual, while rangeland development project introduced through donor-funded large-scale projects were sporadic.

The framework for developing the Borana rangelands was laid down in the AGROTEC/CRG/SEDES study conducted from 1972-74. The justification for the proposed rangeland development project was that the traditional land use system was destructive to the natural vegetation. It was wrongly believed that the intervention would promote environmental conservation (Oba, 1998). The modernizing program was expected to increase the productivity of the Borana herds by instituting proper stocking rates. It was argued that the development of infrastructure and pond-water in strategic areas would reduce pressure on the rangelands. The over-stocking of the dry season rangelands and the under-stocking of the wet season rangelands were considered an unacceptable failure of range management (AGROTEC/CRG/SEDES Report, 1974). However, it was recognized that in order to achieve this goal, the natural balance that the Borana pastoral production system maintained would be altered. In the words of the authors of the report:

"…stock-raising, … and agriculture are competing in the utilization of the natural resources…in the framework of a centuries-old ecological balance…(where) mortality, diseases, natural cycles and the calamities were the balancing factors… This ancient balance is soon going to be modified by a series of events; (a) demographic explosion, (b) an external pressure due to higher rate of utilization of livestock and natural resources and (c) the immigration into the area from the…agricultural highlands…(Consequently) "and shifting agriculture could destroy its natural defences and lead to its impoverishment, the taking - over by poorer and poorer vegetal species, [leading] to its slow transformation into [bush encroachment]" (p.17).

Despite this warning, developments in infrastructure were aimed at re-organizing pastoral grazing so that their movements would be effectively controlled and the sedentary nature of the population encouraged. The new grazing model presumed that the availability of water in the wet season grazing areas would ensure rational use of the land and prevent the concentration of livestock in the dry season rangelands. Using heavy earth-moving equipment, the Southern Rangeland Development Unit (SORDU) constructed semi-perennial ponds. The introduction of free water, easier to exploit than the traditional water sources of the labor intensive deep *tula* and shallow wells attracted permanent settlers (Oba, 1998).

These programs were implemented following the 1975 land reform of the socialist government (1974-1991) that established systems of state ranches in the pastoral areas of Ethiopia (Helland, 1997a). Prior to the Land Reform Proclamation, the major land tenure regimes included land under communal use (under the *gada* institution), land owned by the church and state, and the private land distributed by the state to individuals such as officials and loyal servants of the imperial government (Dessalegn, 1984). The radical land reform of 1975, which transformed all rural lands into state property, introduced pre-conditions for access to plots of land that became reliant on membership to peasant associations (Helland, 1999). For the southern rangelands of Ethiopia, the role these development policies played in transforming the Borana pastoral economy has been extensively discussed (e.g. Upton, 1986; Cossins & Upton, 1987, 1988; Coppock, 1994; Hogg, 1997; Helland, 1997a; Oba, 1998; Desta, 1999; Desta and Coppock, 2002, 2004; Kamara, 2001; Kamara *et al*., 2004; Angassa and Oba, 2007). However, the impact on the environment of range enclosures, crop cultivation and the ban on fire have been only sparsely reported (Oba *et al.,* 2000; Tache, 2000; Kamara, 2001).

In response to policy driven land use, the Borana transformed their mode of land use allocations. Their adoption of range enclosures in particular showed the gradual adoption of land use changes, from the traditional communal calf pastures (*laaf seera yaabi*) to the semi-privatization of grazing land. The range enclosures also served as the precursors to semi-private crop fields. Furthermore, the suppression of range burning resulted in the replacement of the historical grasslands with bush encroachment (Oba *et al*., 2000). Two decades ago, 40% of the southern Ethiopian rangelands had been encroached by the bush (Assefa Eshete *et al*., 1986; Coppock, 1994), while recent estimates put the encroachment at 52% (Gemedo-Dalle, 2004).

In understanding the impact of land use on environmental change in terms of the trend in range enclosures, crop farming and the fire ban, we lacked long-term empirical data related to vegetation changes in response to the suppression of fire. Therefore, we used the traditional methods of re-constructing the social environmental history of the Borana, based on the *gada* timelines, to understand the changes (Legesse, 1973). Each *gada* period covers eight years, and is named after the *gada* leader (*abba gada*). A period of 48 years (i.e. six *gada* periods) was used to reconstruct changes in land use and vegetation. The objectives of the study were to understand: (1) the communities' perceptions of general trends of land use including the adoption of (a) range enclosures and (b) crop farming; (2) the history of the traditional use of fire, the banning of fire and its consequences on range vegetation dynamics; and (3) the consequences of the proliferation of bush encroachment on the composition of grass species.

STUDY AREA

The study was conducted in southern Ethiopia in the Borana zone of Oromia Regional State in the districts of Arero, Dirre and Yabello (4 - 4º57.383′N and 36 - 42ºE), and sampling was done across nine Peasant Associations (PAs). Three PAs per district were selected (from Arero we selected Halona, Fuldowa, Kafara, from Dirre we selected Dubluk, Madhacho and Melbana and from Yabello we selected Did-Hara, Daritu, Hara-Wayu). The areas receive a bi-modal rainfall, with the main rains (*ganna*) falling between March and May, and the lesser rains (*hagaya*) between September and November. The rainfall is variable with the coefficient of variability ranging from 18% to 69% (Angassa and Oba, 2007). Droughts occurred every five years (Oba, 1998). The human population of the three districts was estimated at 39,600, divided into 8000 households (Borana Zone Administration, personal comm.). The main economic activities are, in order of importance, livestock production with cattle, small stock, camels and equines (Kontoma, 2000). The total livestock population (i.e. all species) of the nine PAs was estimated at about 156,000 heads (SORDU vaccination census, unpubl.). Crop farming is increasing in terms of the space it occupies (Kontoma, 2000). By the 1990s 2-3% of the grazing lands were already under crop cultivation (Coppock, 1994), but as the current study will show, cropping has since expanded throughout the study area (see the result section).

SAMPLING

The three districts represented different histories of development intervention, settlement patterns, the adoption of range enclosures, the intensification of crop farming, the historical use of fire and the expansion of bush cover. The districts represent the core of Borana pastoralism and the cultural sites of the *gada* system. The establishment of ranches and the development of pond water were also the greatest in these districts. Two stage surveys were conducted between 2002 and 2003. First, region-wide interviews with oral historians and the elderly were conducted in order to reconstruct the environmental history of changes in land use change in Borana (Desta and Coppock, (2002, 2004) report that the use of oral recall among the Borana is a fairly reliable method of data collection). Secondly, in 2003 a sample of 245 households (3% of the total households) was randomly selected from lists of all existing households and was interviewed using structured questionnaires. Desta (1999) considered a sample of 336 households (4.8% of the 7,000-target population) in southern Ethiopia. Of the total respondents, 17% were female-headed households and the rest were male-headed households. The age of respondents ranged from 45 to more than 60 years.

Pastoralists were interviewed in their villages by six well-trained local enumerators. Due to the detailed nature of the questionnaire, each enumerator interviewed 41 households on average, with each interview lasting approximately 120 minutes. The interviews were conducted over a period of 35 days. All the interviews were conducted in *Afaan* Oromo (the Oromo language). Different issues were used to capture the responses of the local people about changes in land use change, the impact on the environment and environmental history (see below).

DATA ANALYSIS

The data was organized under specific responses related to range enclosures, crop farming, the oral history of range burning, the official fire ban and bush encroachments and the impact on vegetation. All data related to enclosures, crop farming and the historical uses of fire were organized by region (i.e. districts), while responses related to bush encroachment and changes in the composition of grass species were organized by local PAs. (1) The data related to the general change in land use was in terms of enclosures (*kalo*), i.e. types of enclosures (communal vs. semi-private), periods of establishment, size of enclosures, trends of communal enclosures (i.e. enclosures managed by community members of one or more villages) and the landscape types (i.e. uplands or bottomlands) used for establishing range enclosures. Relationships were also determined between the size of enclosures and the number of calves in each enclosure. Responses were analyzed in terms of the relationships between enclosures and the traditional calf-grazing reserves (i.e. *laaf seera yaabi*), and the effects of enclosures on communal rangelands and semi-privatization of communal grazing lands. (2) The data on farm holdings for crop cultivation examined the history of crop farming, the allocation of land for cropping and landscape types under crop cultivation. Additionally, the total years involved in crop farming, the reasons for cultivation and the effects on communal rangelands were considered. (3) The data on historical fire use examined the reasons for traditional range burning practices, the specific time of burning, the frequency of burning, precautions taken in range burning practices and the effects of official bans on the use of fire. We analyzed the responses related to pastoralists' comments on the use of fire, changes in vegetation in their lifetimes, reasons for the expansion of bush encroachment, the impact of bush encroachment on livestock productivity and the environmental impact in terms of changes in the composition of grass species.

RESULTS

Change in Land Use Patterns

Two-hundred and forty five households were successfully interviewed about their knowledge of the impact of changing land use on the rangelands in southern Ethiopia. From the interviews, it was apparent that the trend towards semi-privatization of communal grazing areas was increasing (Table I). Among our sample, 98% of the households had access to range enclosures, with more than 94% participating in the management of communal enclosures and the rest participating in semi-private enclosures (i.e. owned by individual families) (Table I). In general, both communal and semi-private enclosures served as the dry season calf-grazing reserves. Communal enclosures were open to all members of the community when feed resources were depleted in communal grazing areas during the long dry season. The semi-private enclosures were owned by individual families but access was granted to their social relations for grazing their calves. Generally, calves and sick or weak animals were allowed to graze in enclosures for a period of 3-4 months during the dry season. On average, the size of enclosures varied between 30 and 300 hectares. The respondents had mixed views on the relationship between the size of enclosures and the stocking rates of calves (Table I).

Generally, 96% of the households reported that the communal enclosures were larger than the semi-private enclosures (Table I). In our sample, approximately 16% of the households had access to communal enclosures in more than one place. Both the communal and semi-private enclosures expanded during the previous decades (Table I). In response to changes in land use, the Borana revised the traditional system of calf-grazing reserves (*seera yaabi*), which were usually open pastures in key grazing landscapes such as hill tops and bottomlands. These were set aside for calf and weak animal grazing through consensus on when they were to be used and by what types of animals (e.g. the age of calves allowed). Among our sample, 55% of the households converted traditional calf-grazing reserves into range enclosures or croplands, while 45% of the households additionally maintained the traditional calf-grazing reserves. According to 87% of the respondents, the management rules for calf-grazing reserves were similar to those of the communal enclosures. The difference was that both the communal and semi-private enclosures were protected by perimeter fences, while the traditional calf pastures were not fenced. There was agreement among the interviewed households (95%) that the expansion of enclosures had had a profound effect on the communal rangelands. The communal and semi-private enclosures were mostly located in the upland landscapes, while the bottomlands were mostly used for crops (see below).

Other sub-divisions of the rangelands were ranches (16,550 ha) and crop farms. Sub-divisions of the rangelands into range enclosures, ranches and croplands disrupted livestock movements, while the remaining communal grazing lands were put under greater pressure (Table I). From the sample population in the nine PAs, it was estimated that about 7,500 ha of the communal grazing lands were converted to range enclosures and an additional 5,600 ha were allocated to crop cultivation. From the sampled villages in the Arero, Dirre and Yabello districts, the adoption of range enclosures was varied (Fig. 1). In the Dirre and the Yabello districts, the enclosures were introduced during the *gada* Jaldesa Liiban period (1960-1968), while those in the Arero district were introduced during the *gada* Gobbaa Bulee period (1968-1976) (Table II).

Crop Farming in Borana Rangelands

Table III summarizes the *gada* periods when crop farming activities were introduced into the districts of Arero, Dirre and Yabello. The pastoralists in our sample group generally began crop farming during the *gada* Jilo Agaa (14%), Boruu Guyoo (22%), Boruu Madhaa (29%) and Liiban Jaldesa (20%) compared to the period of *gada* Gobba Bulee when less than 4% of the households across the region practiced crop farming. A large proportion of the households interviewed were engaged in crop farming (87%), with only a minority reporting no activities related to crop farming (13%). The sizes of farm holdings for crop production were highly variable, ranging from 0.5 ha to 5 ha (Fig. 3b). A greater proportion of the respondents cultivated the bottomlands (90%), as opposed to the uplands (10%), with wheat, maize and teff being the dominant crops grown by the sample households. The ages of crop fields varied from < 10 years old (47%), 10 - 15 years (13%), 16 - 20 years (20%) and > 20 years (20%). The allocation of crop fields was divided by PAs, local institutions (e.g. *Ardaa* elders), PAs in collaboration with the local institutions or was self-allocated by individuals (Fig. 3a). For the communities in the three districts, a common reason for pastoralists' involvement in crop farming was to improve the food security that the declining herds alone could not guarantee. However, the main driver was the agricultural land use policy, promoted by the Department of Agriculture, which was encouraging the semi-privatization of grazing lands.

Oral History of Traditional Range Burning

Historically, fire played an important role in the ecology of the savannas of southern Ethiopia. Fire was used to control the expansion of bush cover and ticks, to remove predator habitats, to improve pasture quality and to facilitate livestock movements. The majority (99%) of the households were involved in traditional range burning in the past. Burning was conducted during the long dry seasons (*bona hagaya*) before the commencement of the main rains (*gana*). Although traditional burning could not be compared to the prescribed and controlled fires practiced by range ecologists, the Borana pastoralists avoided using fire when livestock feed was in critically short supply and they took precautions when using fire in settlement rangelands. The communities also regulated grazing of the post-fire growth. The frequency of fires in individual landscapes depended on past histories. Previously, different villages practiced different fire frequencies, varying between two-year intervals (29%), three-year intervals (49%), four-year intervals (7%) and five-year intervals (10%). Annual range burning was least common (5%). Figure 4 is a summary of the oral historical timeline since the official ban on fire was enforced. The last time the majority of the respondents (94%) conducted range burning was during the *gada* of Gobba Bulee (1968-1976), almost 30 years ago (Fig. 4).

The Impact of Bush Encroachment on the Rangelands

The result of the official ban on fire was a shift in the composition of vegetation from perennial grassland to bush encroachment (100%). At a regional level, the encroached conditions varied across the three districts. At a local level, the intensity of bush encroachment varied according to soil types. The opinion of the herders was that the bush encroachment problem had changed from a localized phenomenon to a broad-scale invasion of the Borana rangelands. The households in the three districts stated that the expansion of bush encroachment began during the *gada* Gobba Bulee (1968-1976), but that the expansion became severe during the *gada* Jilo Agaa (1976-1984), about two decades after the official ban of range fires (Fig. 5).

On a local level, the pastoralists regarded bush encroachment as a major threat to rangeland production. The shift towards bush encroachment changed the composition of the herbaceous layer in favor of annual grasses and unpalatable forbs. According to the households, there were also differences in the composition of invasive species (Table IV). The pastoralists suggested that species that were invasive in some localities might not be a problem in other areas. Thus, the same species could be categorized as either invasive or non-invasive (Table IV). Among the invasive woody species, *Acacia mellifera* (66%), *Commiphora africana* (61%) and *Acacia drepanolobium* (60%) were major threats. Table V summarizes the trends of herbaceous species, particularly perennial grasses. Trends of grass species were divided into those that were increasing, those that were decreasing and those that had disappeared from the local environment. The herders suggested that in terms of grasses, the rangelands were dominated by *Chrysopogon aucheri* (89%), *Pennisetum stramineum* and *P. mezianum* (56%), *Panicum coloratum, P. maximum* and *P. turgidum* (44%), *Heteropogon contortus* (39%) and *Cenchrus ciliaris* (33%). The species that were threatened with disappearance were *Cenchrus ciliaris* (16%) and *Leptothrium senegalense* (20%) (Table VI). The reasons given for the decline in perennial grasses were lack of range burning and bush encroachment (58%), the effects of drought (20%), increased grazing pressure (13%) and the effects of termites (9%). The increasing grass species included *Aristida adoensis* (79%), *Pennisetum mezianum* (90%) and *P. stramineum* (78%) (Table VI).

DISCUSSION

Changes in Land Use Patterns

The use of range enclosures was adopted from the sedentary Guji Agro-pastoralists (Oba, 1998). It has previously been estimated that 90% of the Borana settlements in the Dirre, Arero and Yabello districts have access to range enclosures (Coppock, 1994). Range enclosures are less developed in the arid lowlands, where conditions are too dry, and in the Liban district in the east, where the population is more nomadic (Oba, 1998). According to the households interviewed, the establishment of range enclosures was the communities' way of responding to the scarcity of feed for vulnerable herd classes, such as calves. A similar rule was applied to the managing of the *seera yaabi* system. The traditional calf-grazing reserves (*laaf seera yaabi*) were a communal resource managed collectively, "fenced by rules and regulations" (Oba, 1998). Some traditional calf-grazing reserves have been transformed into range enclosures and farmlands for crop production. Specific rules and regulations exist for the communities' use of range enclosures and traditional calf-grazing reserves, for example, the age of calves was specified as 6-24 months. In the majority of cases, the stocking of the enclosures with calves was not regulated, the assumption being that since the pastures were grazed during the dry season and rested during the growth season, there was no threat of overgrazing.

The decision to establish communal enclosures followed the proclamation of the Assembly of *Gumi Gayo* in 1988 (see Tache, 2000). So far, the amount of land under enclosures is controlled by the general need to limit the loss of communal grazing lands. Among the settlements in the nine PAs, enclosures provide an opportunity to develop a more intensive communal resource management system in which the movements of calves between crop fields (see below), enclosures and the open grazed rangelands mimic the former wet-dry season grazing patterns. By enforcing rules regarding the size of grazing lands allocated to enclosures, encroachment on the communal ranges was gradual (Oba, 1998). The Borana response is cautionary. On the one hand, the Borana have coped well with changes in land use that promote semi-privatization, and on the other hand, they are conscious that the sub-division of communal rangelands could result in loss of viability for the pastoral production.

Thus, despite communities' positive response to changing land use through the gradual semi-privatization of the rangelands, the establishment of range enclosures has fragmented the communal grazing areas. The threat comes from urban residents who have the desire to develop private enclosures for large-scale investments. In the view of the community, the semi-privatization of range enclosures is likely to increase 'land grabbing', a process that has already begun in some areas (Oba, 1998).

Crop Farming in the Borana Rangelands

According to oral historians, the Borana people only began to farm crops in the early 1960s. During the famine of the *gada* Jaldesa Liiban (1960 - 1968), farmers in the sub-humid zones were the principal source of the grain needed by the pastoralists in the lowlands. Drought and civil insecurity during the *gada* Gobba Bulee (1968 - 1976) impoverished a large number of Borana households who needed grain to survive. However, it was not until after the military government's Land Proclamation of 1975 and the droughts of the 1970s that the majority of the pastoralists began to cultivate their own crops. Currently, our Borana informants estimate that < 15% of Borana households rely on the products of their livestock alone. The majority rely on both grain and livestock. Due to unreliable rainfall, however, crop farming in Borana has not been very successful. Generally, successful harvests occur only once every three years. In years of unsuccessful harvests, the Borana rely on the local market for grain or relief food (Kontoma, 2000).

Given the climatic obstacles for crop farming, the pastoralists might be better served both nutritionally and financially by selling their livestock and buying grain rather than directly consuming the protein-rich products of their herds (Behnke and Kerven, 1994). Since the communities' involvement in crop production is a response to food insecurity, the expansion of crop cultivation has transferred parts of the communal grazing lands to semi-private crop farms. The proportion of land used for cropping might still be low, but it is the prime bottomlands that are being converted into crop fields (Coppock, 1994). The loss of the bottomlands to crop cultivation makes livestock vulnerable during droughts when the bottomland areas are in great demand for grazing. Among our sample households, almost 87% were involved in crop farming activities, compared to the earlier figures reported by Holden and Coppock (1992), who estimated that 33% of 108 households in Borana were engaged in crop cultivation. In another study, Coppock (1994) reported that 35% of 77 households were engaged in crop farming. Based on this baseline data, it is clear that crop farming is expanding in the southern rangelands. The findings of this survey showed that the majority of pastoralists involved in crop farming were allocated crop fields by a number of institutions, but that the community's influence varied from one district to another. However, the evidence uncovered the fact that the Borana institutions are losing responsibility for land use allocations to the more formal institutions such as Peasant Associations. These changes have important implications for land use trends, particularly in response to the official land use policy for the rangelands. Until a few decades ago, policy-driven semi-privatization of resource tenure rights was an alien idea to the Borana, whose concept of territorial rights was defined in terms of the right to use the land, but not the right of land ownership by individuals. The land is communal. Such definitions of tenure rights differ from the official definition that places the ownership of land under the state (Oba, 1998).

Oral History of Traditional Range Burning

The Borana oral history of the environment was useful in analyzing the response of the rangelands to periodic burning and the impact of the official banning of range fires. Our informants state that the fire ban began in the early 1970s with the expansion of bush cover. The *gada* period was successfully used to reconstruct historical timelines of changes in vegetation in the southern rangelands over the following decades. The evidence showed that the Borana oral history could be relied upon to understand the role played by fire in the savanna ecosystems of southern Ethiopia. For example, oral sources cite an incident following the rinderpest epidemic of the 1890s, when a fire that was started in Liban crossed the Daua River into Dirre and burned the ritual settlements near the present-day Yabello town, some 280 km from the source (Oba, 1998). The wildfire was caused by an accumulation of fuel that occurred after the reduction of the cattle population. Similar events were reported throughout East African savannas after the decrease in herbivore populations following the rinderpest plague (Kjekshus, 1996).

The reason for the fire ban was the official conservation policy linked to the loss of forest cover in the Ethiopian highlands (Reid *et al.,* 2000). The policy was applied to the rangelands without consideration being given to the ecological role fire played in range management (see also Desta and Oba, 2004). Despite the government's concern about the careless use of fires, this study showed that the pastoralists are knowledgeable and careful about the application of fire. When using fire, the Borana avoided some areas for periodic burning. For instance, the Borana avoided settlement areas, while the "forward grazing areas" (*mataa tikaa*) were periodically burned. Burning removes moribund grass and kills tree saplings. The herders perceived that the post-fire grass growth is nutritionally superior to the unburned grass. The absence of fire for several decades has had a negative impact on the quality of the rangelands (Oba, 1998). Pastoralists' observations suggest that following the official banning of fire, the woodlands have thickened and over-grown the herbaceous layer (see Cossins and Upton, 1988; Mbow *et al*., 2000; Laris, 2002; Natcher, 2004; Sheuyange *et al.,* 2005). The absence of fire also meant that the threat of ticks infesting livestock had increased. The Borana believe that the ban on the use of range fire adversely affected the overall productivity of the rangelands and that fire remains an essential element in sustainable management of the rangelands of southern Ethiopia.

Impacts of Bush Encroachment on the Rangelands

Oral sources suggest little evidence of region-wide bush encroachment before the *gada* Madhaa Galma (1952-1960). The spread of bush encroachment was only noticed after the *gada* Jaldesa Liiban (1960-1968). There is an anecdotal oral historical suggestion that links the cause of bush encroachment with the handing over of power from the *gada* Jaldesa Liiban to Gobbaa Bulee (in addition to other factors already mentioned)[1]. The anecdotal historical event did not preclude the evidence that the Borana linked expansion of bush encroachment to the ban on the use of fire. In the absence of fire, bushes reduce grass production, creating feed deficits for livestock. Across the three districts that were surveyed, bush encroachment was a greater threat in Arero and Dirre than in Yabello. In the southern rangelands, 83% of the rangelands were threatened by a combination of bush encroachment and unpalatable forbs. Only 17% of the rangelands were free from either bush encroachment or invasion by unpalatable forbs. Bush encroachment is in a climax stage in 24% of the

[1] According to the Borana oral historian Borbor Bulle, there was a violation of the *gada* for transferring power (*baali*) from the outgoing Jaldesa Liban to the incoming *abba-gada* Gooba Bulee. According to *aadaa seera* (law), the incoming *abba-gada* takes power in a symbolic ceremonial handling over of an ostrich feather (i.e. *baali*), in an event that is emotionally charged. The concept of an emotionally charged ceremony is related to societies concerns about what the future holds in terms of a better life, peace and political stability. For example, each *gada* class remains in power for a specific period (i.e. eight years), which begins and ends with a formal transfer of *baali*. The group which transferred *baali* to the future ruling *gada* class will not come to power until another 40 years has passed. There is also competition among each *gada* class during the specific time in power that could be evaluated in terms of the peace of Borana society and a better life style. Peaceful transfer of *baali* with a formal ceremony for the Borana society therefore means a bright future, prosperity and stability, while any act against this may create fears about the future. According to the *aadaa seera* (law) of Borana, the outgoing *abba-gada* blesses the *baali* and hands it over to the incoming *abba-gada* who in turn blesses the event for successful achievements in the new era. According to Borana law, the transfer of *baali* is perceived as a transfer of what was good from one *gada* to the next. The transfer therefore symbolically concerns the well being of the entire society. In this particular case, Gooba Bulee refused to take the symbolic power transfer. Not being allowed to stay in power, according to the *gada* laws, the outgoing *abba-gada* placed the symbolic ostrich feather on *Acacia tortilis* (*Dhaddacha*). The transfer of power from *abba-gada* to a tree was unprecedented. In the view of the Borana, Gooba Bulee took the *baali* from the tree and blessed trees, instead of the Borana, which explains the expansion of bush encroachment.

rangelands at the regional scale. In the bush encroachment climax areas, the woody cover exceeded 60%, with the density approaching 2000 trees ha^{-1} (Oba, 1998). Earlier studies (e.g. Bille and Assefa, 1983) suggest that the bush cover expansion might have occurred in phases, first affecting some grazing areas and then expanding to others. For example, a comparison of photographs of the area north of Yabello taken between 1967 and 1984 showed that woody cover had increased from 24.1% to 28.5%. The changes were localized as opposed to being uniform (GRM, 1989). The cycles of bush invasion were probably mediated by episodic climatic events and irregular use of fire. Oral sources suggest that the Borana rangelands have been disturbed by famine, heavy rainfall and disease epidemics that caused episodic shifts in the vegetation structure during previous centuries (G. Oba and A. Angassa, unpubl.).

The Borana pastoralists distinguished the invasive from non-invasive woody species. Our interpretation of herder knowledge was that the invasiveness of particular species varied with specific localities. Species that expanded into new areas where they were not native were considered to be invasive, but the same species occurring in their native habitat were not considered as such. For this reason, the herder response for the same woody species was variable. Furthermore, pastoralists acknowledged other woody species in their rangelands that were non-invasive and therefore valuable as a source of livestock feed.

The loss of key perennial grasses was linked to bush encroachment. It is important, however, to verify the level at which herders made their deductions; plant species loss at local levels might not correspond with losses on a regional scale (Oba *et al.*, 2003). Generally, herders referred to the regional scale. We interpreted pastoralists' responses in terms of the main economic goals of cattle management. The undesirability of bush encroachment is associated with the reduction of the grass layer. Consequently, the attitudes of the pastoralists were determined by the availability of grass fodder. However, this is not to suggest that the present trends in bush cover have not influenced the Borana pastoralists in other ways. As reported recently (e.g. Desta and Coppock, 2002), the Borana responded to the increased bush cover by learning to herd camels, which are mainly browsers.

CONCLUSIONS

The paper focused on the use of indigenous knowledge in understanding, analyzing and evaluating the impact of range enclosures, crop farming, the ban on fire and bush encroachment on the communal rangelands of Borana in southern Ethiopia. The use of communities' knowledge as a basis for understanding how changes in land use have historically impacted the rangelands provided an important methodological approach for evaluating communities' responses to changing land use. In the present study the basic assumption was that any change in traditional land use practices would have an impact on the dynamics of the rangelands. In the last few decades, the establishment of range enclosures and the expansion of crop farming resulted in the fragmentation of the communal rangelands, while the official banning of fire resulted in the expansion of bush cover. These changes resulted in feed scarcity and greater vulnerability of stock, particularly during drought years. The ban on the use of fire has shifted the ecological balance between woody plants and grass species. Following the introduction of the government land use and fire ban policy, vast areas of the savannas of southern Ethiopia have experienced an expansion in bush encroachment and drastic declines in grass cover. Herders suggested that the deteriorating quality of the grazing lands, as a result of bush encroachment, posed a serious threat to livestock production. Given the failure of range development policies to preserve the local environment, the environmental knowledge of the herders may provide a logical guide for redesigning pastoral development policies. Considering that pastoralists are frequently observing and exploiting the local environment, the contribution of the local people to range management may be more efficient than policies imposed from the government. Besides recording traditional land use, studies addressing herders' indigenous ecological knowledge may play a beneficial role in developing a more effective land use policy. In the future, planners and policymakers should consider communities' knowledge in an effort to design effective pastoral development programs. By considering herders' knowledge and involving them in the decision-making process for development, a more sustainable use of the local resources and a better future for pastoralists could be promoted. We suggest that sustainable use of the southern rangelands in the future will require paying greater attention to regulating the expansion of enclosures, crop farming and ranching, as well as re-introducing fire, where necessary, to control the expansion of bush cover. The new policy should recognize the importance of re-introducing fire for the management of bush encroachment and be linked to communities' fodder management strategies. In this regard, future management programs for the control of bush encroachment also need to understand the mechanisms of bush encroachment in relation to land use and the rehabilitation and management of bush-invaded rangelands.

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Table I. Pastoralists' Perceptions of the Different Attributes Related to Range Enclosures in Borana (n = 245)

Attributes	% Av. response	χ^2	District
Had access to range enclosures	98	8	*
Had no range enclosures or access	2	3	ns
Participated in the management of communal enclosures	94	24	**
Participated in the management of private enclosures	6	24	**
Perceived communal enclosures were larger	96	20	*
Number of calves vs. size of enclosure limited	36	91	**
Number of calves vs. size of enclosure unlimited	63	61	**
Access of individuals to communal enclosures in more than one area	7	12	*
Trends of communal enclosures increasing	75	33	**
Trends of communal enclosures decreasing	25	33	**
Enclosures adversely influenced communal grazing lands	58	77	**
Oppose subdivision of rangeland into range enclosures	95	4	ns
Perceived semi-privatization of communal rangeland is increasing	65	4	**

P < 0.05, ** P < 0.01, ns P > 0.05, Chi-square test by District for attribute vs. respondents' perceptions. NB: All responses were rounded to the nearest whole number.

Table II. Pastoralists' Perspectives on the Historical Timeline for the Establishment of Range Enclosures by District (n = 245)

Gada	Years	% Response by district		
		Arero	Dirre	Yabello
Jaldesa Liiban	1960-1968		4	3
Gobbaa Bulee	1968-1976	4	1	1
Jilo Agaa	1976-1984	10	5	26
Boruu Guyoo	1984-1992	31	12	23
Boruu Madhaa	1992-2000	33	37	19
Liiban Jaldesa	2000-2008	18	16	26
No response		5	29	5

df = 2. χ^2 of 87 is significant at the 0.001. NB: All responses were rounded to the nearest whole number.

Table III. Historical Timeline for the Adoption of Crop Farming by Pastoralists in Borana, Southern Ethiopia (n = 242)

Gada	Years	% Response by districts		
		Arero	Dirre	Yabello
Gobbaa Bulee	1968-1976	4	1	1
Jilo Agaa	1976-1984	10	5	26
Boruu Guyoo	1984-1992	31	12	23
Boruu Madhaa	1992-2000	33	37	19
Liiban Jaldesa	2000-2008	18	16	26
No response		5	29	5

df = 2. χ^2 of 55 is significant at the 0.001. NB: All responses were rounded to the nearest whole number.

Table IV. Pastoralists' Perceptions on the Characteristics of 29 Species of Woody Plants in Southern Ethiopia (n = 245)

List of woody plants		% Response				
Scientific name	Local name	Invasive[1]	Non-invasive[2]	No response	χ^2	PA
Acacia mellifera	Saphansa	66		34	2	Ns
Acacia reficiens	Sigirsoo	14		86	27	***
Acacia tortilis	Dhaddacha	2	96	2	10	*
Terminalia brownii	Birreessa	2		98	3	Ns
Grewia bicolor	Harooressa		38	61	88	***
Boscia coriacea	Qalqalcha	27	73		42	**
Commiphora africana	Hammeessa dhiiroo	61		39	41	***
Acacia brevispica	Hammarreessa	24	7	69	88	***
Acacia drepanolobium	Fulleessa	60		40	2	Ns
Acacia nilotica	Burquqqee	19	32	49	67	***
Acacia bussei	Halloo	37	14	49	48	***
Acacia etbaica	Halliqabeessa	10	3	87	1	Ns
Grewia tenax	Dheekkaa	2	22	77	56	***
Rhus natalensis	Daboobessa	4	7	89	17	**
Acacia Senegal	Hidhaadhoo	5		96	3	Ns
Combretum molle	Rukeessa	2		98	8	*
Ormocarpum mimosoides	Buutiyyee			100	2	Ns
Acacia seyal	Waaccuu	9	1	90	35	***
Balanites aegyptica	Baddana		26	74	105	***
Phyllanthus sepialis	Dhiirii	28	1	72	180	***
Pappea capensis	Biiqqaa		23	77	89	***
Acacia nubica	Waangaha	7		93	14	**
Commiphora crenulata	Siltaachoo	5		96	17	***
Commiphora rivae	Agarsuu		2	98	2	Ns
Dichrostachys cinerea	Jirimee	1		99	4	Ns
Lannea floccosa	Handaraka	3	5	99	2	Ns
Cordia gharaf	Madheera		36	63	77	***
Grewia villosa	Ogomdii		34	65	68	***
Boswellia neglecta	Dakkara	14	2	85	11	*

* P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05, 1, 2 = Invasive species are area specific and respondents reported that one species was invasive at one site while not at another site, Chi-square test by PA for woody species characteristics vs. respondents' perceptions. NB: All responses were rounded to the nearest whole number.

Table V. General Trends of Herbaceous Species as Reported by Pastoralists in Borana, Southern Ethiopia (n = 245)

List of herbaceous species	Respondents' comments			
Scientific name	Local name	Increasing	Decreasing	Disappearing
Aristida adoensis	Biilaa	+		
Bothriochloa radicans	Bokkoolaa		+	
Brachiaria species	Unidentified		+	
Chloris roxburghiana	Billaa		+	
Chrysopogon aucheri	Alaloo		+	
Cenchrus ciliaris	Matguddeessa			+
Cymbopogon commutatus	Halchisoo			+
Cynodon dactylon	Sardoo			+
Cyperus species	Buridde		+	
Dactyloctenium aegyptium	Unidentified		+	
Digitaria milanjiana	Unidentified		+	
Eleusine jaegeri	Coqqorsa		+	
Eragrostis papposa	Samphee/samphilee		+	
Eragrostis sennii	Unidentified		+	
Enteropogon macrostachyus	Unidentified		+	
Enteropogon somalensis	Unidentified		+	
Heteropogon contortus	Seerricha		+	
Herbaceous legumes	Hagaggaroo-ree'ee		+	
Hyparrhenia hirta	Gaaguroo			+
Lintonia nutans	Ardaa		+	
Leptothrium senegalense	Ilmogorii			+
Panicum coloratum	Hiddoo qaqallaa		+	
Panicum maximum	Lolloqaa		+	
Pennisetum stramineum	Lu'oo	+		
Panicum turgidum	Hiddoo-dabbasicha		+	
Sporobolus pyramidalis	Bukkicha		+	
Themeda triandra	Marra-saalaa		+	
Pennisetum mezianum	Hogoondhoo	+		

+ Pastoralists' perceptions about species trends

Table VI. Trends of Herbaceous Plant Species Reported by Pastoralists in Southern Ethiopia (n = 245)

Lists of herbaceous species		%Response				
Scientific name	Local name	Increasing	Decreasing	Disappearing	χ^2	PA
Aristida adoensis	Biilaa	79	21		33	***
Cymbopogon commutatus	Halchiisoo		100		8	ns
Cynodon dactylon	Sardoo		88	12	34	***
Cenchrus ciliaris	Matguddeessa		77	16	7	ns
Hyparrhenia hirta	Gaaguroo		91	10	9	ns
Leptothrium senegalense	Ilmogorii		79	20	8	ns
Pennisetum stramineum	Lu'oo	78	22		14	ns
Pennisetum mezianum	Hogoondhoo	90			30	**

P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05, PA = Peasant Association, Chi-square test by PA for species trends vs. respondents' perceptions. NB: All responses were rounded to the nearest whole number.

CAPTIONS FOR THE FIGURES

Figure 1. The Time since Range Enclosures were introduced in the Districts of Arero, Dirre and Yabello in Borana, southern Ethiopia.

Figure 2. The Time when Crop Farming Started in the Districts of Arero, Dirre and Yabello in Borana, southern Ethiopia.

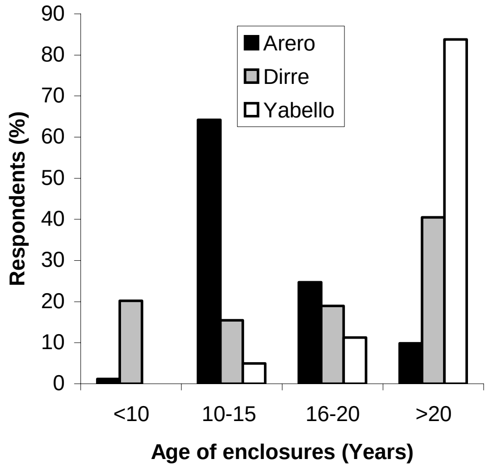
Figure 3a. Institutions for Cropland Allocation in Borana Rangelands in the Districts of Arero, Dirre and Yabello in Borana, southern Ethiopia. PA = Peasant Association, LI = Local Institution (e.g. *Qaaluu* and/or *Gada*), FA = free Access to Cropland and PA & LI = Peasant Association and Local Institution

Figure 3b. Sizes of Plots of Cropland Cultivated by the Sample Households in the Districts of Arero, Dirre and Yabello in Borana, southern Ethiopia.

Figure 4. Historical Timeline for the Official Ban on Traditional Range Burning Practices in the Districts of Arero, Dirre and Yabello in Borana, southern Ethiopia during the *gada* Jaldesa Liiban (1960-1968), Gobbaa Bulee (1968-1976) and Jilo Agaa (1976-1984).

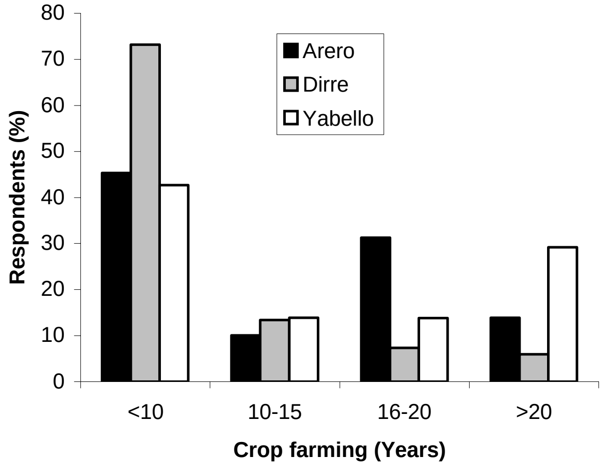
Figure 5. Historical Timeline for the Establishment of Bush Encroachments in the Districts of Arero, Dirre and Yabello in Borana, southern Ethiopia during the *gada* Jaldesa Liiban (1960-1968), Gobbaa Bulee (1968-1976) and Jilo Agaa (1976-1984).

Fig. 1



90
80
70
60
50
40
30
20
10
0
Respondents (%)
Arero
Dirre
Yabello
<10
10-15
16-20
>20
Age of enclosures (Years)

Fig. 2



Arero
Dirre
Yabello
Respondents (%)
80
70
60
50
40
30
20
10
0
<10
10-15
16-20
>20
Crop farming (Years)

Fig. 3a

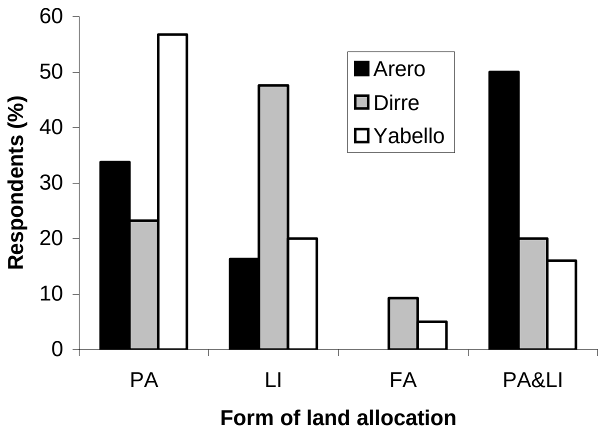

Respondents (%)
0
10
20
30
40
50
60
PA
LI
FA
PA&LI
Form of land allocation
Arero
Dirre
Yabello

Fig. 3b

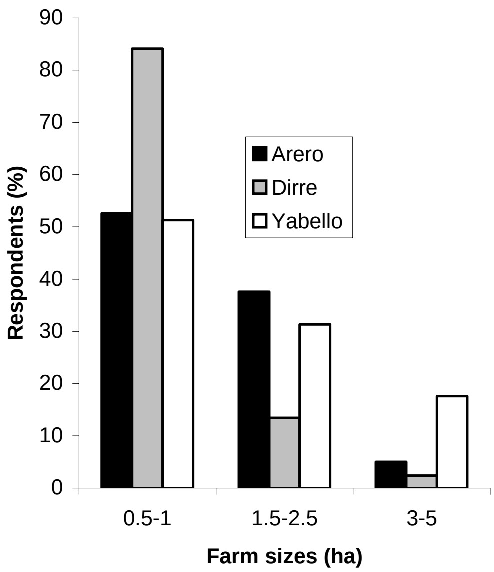
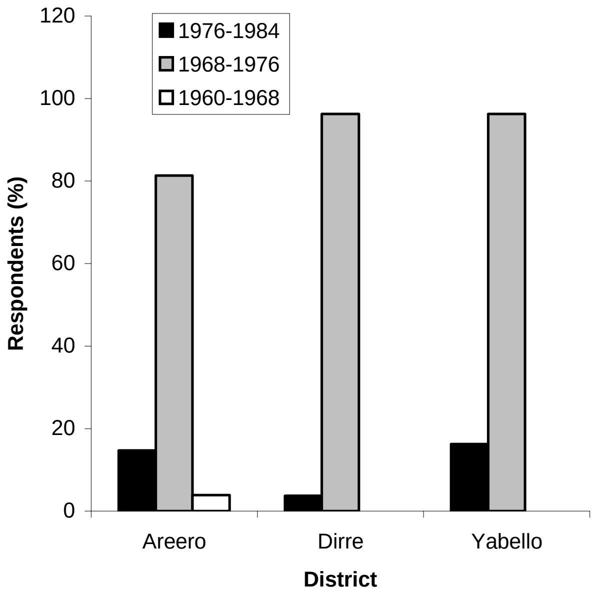
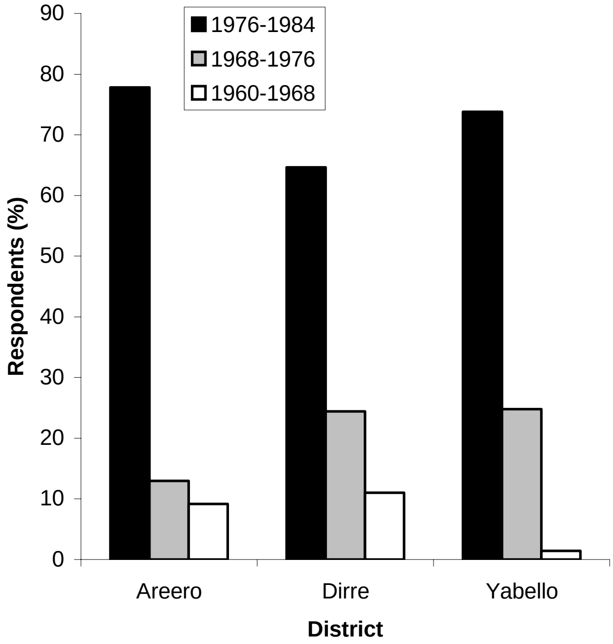

Respondents (%)
0
10
20
30
40
50
60
70
80
90
0.5-1
1.5-2.5
3-5
Farm sizes (ha)
Arero
Dirre
Yabello

Fig. 4



120
100
80
60
40
20
0
1976-1984
1968-1976
1960-1968
Respondents (%)
Areero
Dirre
Yabello
District

Fig. 5



90
80
70
60
50
40
30
20
10
0
Respondents (%)
1976-1984
1968-1976
1960-1968
Areero
Dirre
Yabello
District

PAPER III

Effects of time and grazing on bush encroachment related to age chronosequence of range enclosures in southern Ethiopia

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Abstract

Bush encroachment is a threat to livestock management in southern Ethiopia. However, mechanisms of bush encroachment, which are usually explained in terms of equilibrium between vegetation and grazing pressure, the processes under protection (i.e. enclosures) and the time of protection compared with open grazed rangelands, are rarely investigated. In this study, we used the state-and-transitional model (STT) to investigate mechanisms of bush encroachment in traditional enclosures along age chronosequences of 12 to 14, 17 to 24 and 26 to 30 years. We identified five vegetation states and ten transitions described in terms of densities of mature trees, saplings and seedlings, bush cover, species composition, and the invasive woody species ratio (IWSR). The IWSR is the ratio of density of invasive to non-invasive woody species (i.e. a ratio of 1.0 represents a high invasive threat, while < 1.0 represents a lesser threat). We considered the future responses of invasive species by doubling the age of enclosures. Greater densities of invasive woody species and higher IWSR were found in the enclosures than in the open grazed system, but this was not true of bush cover. Vegetation states differed in terms of tree density, IWSR and species composition, suggesting that the threat of invasive woody species is greater in the enclosures than in the open grazed areas. Doubling the age of enclosures had a negative impact on the majority of invasive woody species, the decline probably being related to self-thinning mortality. The evidence that regeneration of invasive woody species is non-linear in relation to age chronosequence suggests that bush encroachment is probably controlled more by stochastic rainfall events than by livestock grazing.

Key words: Bush encroachment, Invasive woody species ratio, Traditional range enclosures, Ethiopia

Introduction

Bush encroachment is a threat to livestock management in tropical savannas worldwide (e.g. Scholes & Archer, 1997; Oba *et al.*, 2000; Roques, O'Connor & Watkinson, 2001; Augustine & McNaughton, 2004). The dynamics of bush encroachment (Van Vegten, 1983) are usually explained in terms of equilibrium between vegetation and grazing pressure (e.g. Lockwood & Lockwood, 1993). The equilibrium dynamic assumes a linear relationship between bush cover and pastoral land use (e.g. Coppock, 1993). The mechanisms of bush encroachment might, however, be more effectively analyzed using the state-and-transition model (Westoby, Walker & Noymeir, 1989). States are patch mosaics of vegetation types that are usually described by the botanical composition of the dominant species (Iglesias & Kothmann, 1997), which could account for non-linear changes in bush encroachment (Westoby *et al.*, 1989; Iglesias & Kothmann, 1997). The differences between vegetation states are reflected by shifts in age chronosequence (Zavaleta & Kettley, 2006).

Allen-Diaz and Bartolome (1998) argue that the pattern of time dependency in the state-and-transition model is non-linear, exhibiting a significant time dependency that can be described using long-term observations of at least 5 to 10 year intervals. Knowledge about forces that trigger shifts between vegetation states would be useful in understanding the mechanisms of bush encroachment (Sheuyange *et al.*, 2005) in terms of transitions between vegetation states (George, Brown & Clawson, 1992). Additionally, the state-and-transition model can be used to describe threats (i.e. factors that promote bush encroachment) and opportunities (i.e. fodder production for grazing) (Lawson *et al.*, 1999).

In savanna ecosystems in East Africa, the processes of bush encroachment in traditional range enclosures according to different age chronosequence of vegetation states are sparsely reported (Asefa *et al.*, 2003). Traditional range enclosures involving semi-private grazing lands are widely used by pastoralists in the Horn of Africa (Behnke, 1985, 1988) for seasonal grazing by calves and sick or weak animals (Oba, Vetaas & Stenseth, 2001). Range enclosures of different ages may reflect different vegetation states that can be spatially arranged along age chronosequence within the landscape matrix. Among the earlier research studies that evaluated the potential effects of enclosures on vegetation dynamics (e.g. McIntosh, Allen & Scott, 1997; Mengistu *et al*., 2005), a few compared bush density inside enclosures with that in open grazed systems (e.g. Mwaylosi, 2000; Oba *et al.,* 2001). Only in a few of these cases were the effects of age chronosequence of vegetation states even mentioned (e.g. Asefa *et al*., 2003; Zavaleta & Kettley, 2006). Furthermore, little was previously known about the responses of invasive woody species to seasonal grazing, age and doubling of age of enclosures.

We used seasonally grazed traditional range enclosures (i.e. pasture reserves for calf grazing during dry season) compared to full-year grazed communal rangelands to investigate the mechanisms of bush encroachment in Borana, southern Ethiopia. Earlier reports indicate that 40% of the Borana rangelands (estimated at 90 000 km^2) were affected by bush encroachment (Coppock, 1993), while recent estimates suggest a 52% increase in bush cover (Gemedo-Dalle, 2004).

We compared the effects of management systems (enclosure vs. open grazed) with the age of enclosures and vegetation states-and-transitions. The woody vegetation density was investigated, specifically in terms of mature trees, saplings and seedlings, bush cover, species composition and the invasive woody species ratio (IWSR). The IWSR is defined as the density of invasive to non-invasive woody species (i.e. a ratio of 1.0 represents a high invasive threat, while < 1.0 represents a lesser threat of encroachment). We also considered the hypothetical scenario of understanding the possible trajectory of individual woody species in the long-term, by doubling the age of enclosures (i.e. age^2). We expected a linear relationship between the doubling of age of vegetation states and the densities of invasive species (assuming that management systems remained unchanged), while a polynomial, non-linear relationship involving initial increase followed by a decline would have suggested a downward trend following long-term protection (Franklin, Shugart & Harmon, 1987).

Materials and methods

Description of the study area

The study was conducted in Dida-Hara (04^{0} 48.663´N & 038^{0} 19.101´E) in the Yabello district of Borana, southern Ethiopia. The climate is semi-arid with a bimodal rainfall - the main rainy season is expected between March and May and the short growth season during October and November. The two intervening dry seasons are June - August and December - February, when forage resources become scarce. During the period 1980 to 2004, the mean annual rainfall for the nearest stations was 478 mm yr^{-1} (Southern Rangeland Development Unit, Meteorology section, personal communication).

Traditional land use involves seasonal movements of stock across landscapes between the dry and wet seasons (G. Oba unpubl.). The system reflects a long-term history of land use by the mobile (*loon fora*) and the home herds (*loon warra*). During the dry season, the dry and highly mobile animals were sent to the *fora*, while lactating cows are moved back to the home herds and vice versa (Gemedo-Dalle, 2004). Prior to the 1970s, the open grasslands of Dida-Hara were grazed during the wet season by the mobile *fora* herds and rested during the dry season when surface water was exhausted (Fig. 1A). Periodic burning of the rangelands controlled bush encroachment (G. Oba unpubl). The Dida-Hara population settled in semi-permanent settlements (*olla teeso*) following the development of semi-permanent water ponds in the 1980s that changed traditional patterns of land use. The period coincided with the official banning of the use of fire and increased heavy grazing pressure around settlements

(Fig. 1B). These changes in land use created a scarcity of forage near settlements. The response of the community in individual settlements was to enclose large areas (150 - 200 ha) that were protected from livestock grazing during the wet season (WS), in a rotational grazing system (Fig. 1C). Calves were allowed to graze in the enclosures during the dry season (DS) lasting 3 - 4 months, before being moved to the open grazed rangelands with the arrival of the rains.

Traditional range enclosures and site selection

We selected six traditional range enclosures of various ages. The enclosures that were protected with fencing were associated with the settlements belonging to: (1) *olla* Jirmoo Dida with a 30-year old enclosure (200 ha); (2) *olla* Chachuu Halloo with a 26-year old enclosure (150 ha); (3) *olla* Guyoo Jatani with a 24-year old enclosure (200 ha); (4) *olla* Sanqee Dambala with a 17-year old enclosure (150 ha); (5) *olla* Doyo Wario with a 14-year old enclosure (200 ha); and (6) *olla* Tuke Halake with a 12-year old enclosure (150-200 ha). All the enclosures were located in upland landscapes with sandy loam soils. The enclosures were distributed about 0.5-10 km apart, across 225 km^2 (A. Angassa unpubl.). The stocking densities of calves for the six enclosures at the time of sampling were 5.2, 0.5, 5.4, 5.2, 4.6 and 2.3 calves ha^{-1}, respectively. For each enclosure, the immediately adjacent open grazed rangelands were selected as controls. The stocking density of the open grazed rangelands was estimated at 7.2 Tropical Livestock Units km^{-2} (1 TLU = 250 kg bovine).

Vegetation states-and-transitions

Woody cover in the study area was estimated at 56%. The dominant woody species were *Commiphora Africana* and *Acacia*. We used the age intervals between enclosures to identify vegetation states in comparison to the adjacent open grazed areas. We used the composition of the dominant woody species to distinguish between the different vegetation states, while catalogues of transitions were abstracted as the possible responses to management systems (Iglesias & Kothmann, 1997). The traditional range enclosures and open grazed rangelands, as well as the former open grassland states (historical vegetation state) were used to reconstruct five vegetation states and ten transitions. State I was the historical grassland vegetation dominated by perennial grasses, while State II was the open grazed vegetation after settlement. States III, IV and V represented various levels of invasion in enclosures of 12 to 14 years (i.e. younger); 17 to 24 years (i.e. medium) and 26 to 30 years (i.e. older) respectively (Table 1 and Fig. 2).

Assessments of vegetation states-and-transitions

The woody vegetation was sampled in November 2003 by randomly locating 20 plots of 5 x 5 m in each age range of enclosures (young, medium and old vegetation states) (n = 60 plots), i.e. equally 10 plots in each of the six enclosures. The control plots in the open grazed vegetation state were sampled concurrently (n = 60 plots). Tree density was sampled in terms of mature trees (> 2 m height), saplings (0.5-2 m height) and seedlings (< 0.5 m height). Woody cover was visually assessed and expressed as a percentage of canopy cover relative to ground cover. The invasive woody species ratio (IWSR) and species composition of invasive woody and non-invasive species were determined for vegetation States II, III, IV and V (Table 1). Herders determined which of the species were invasive (Gemedo-Dalle, Maass & Isselstein, 2005).

Statistical Analyses

Management system (i.e. enclosure versus open grazed controls) and age of enclosures representing vegetation states were used to group the data. The historical grassland State I was not represented in the current analysis. Different sets of analyses were run to assess the effects of the independent variables (i.e. management and age chronosequence of vegetation states) on the dependent variables (i.e. woody density, bush cover and IWSR). First, woody density and cover were compared between management systems by using the *t*-test. Second, ANOVA was run to test the differences among vegetation states, while differences between individual states were compared using the *t*-test. In the third set of analyses, least square means were estimated for the spatial and temporal responses of woody density and cover across age chronosequence of vegetation states, using the Generalized Linear Model (SAS, 2001). In the fourth analysis, we used the GENMOD procedure in SAS to analyze the effect of age and age^2 on the trends of density of individual species, to determine species trajectories in the future. Positive trajectories of parameter estimates (±SE) would imply increases in species densities, while negative trajectories would indicate reductions. The percentage data was arcsine transformed before analysis. Differences were considered significant at $P < 0.05$.

Results

Effects of management

On average, the total woody density was greater in enclosures (4811 stems ha^{-1}) than in the open grazed areas (3995 stems ha^{-1}) ($t = 2.51$, df = 1, $P = 0.012$). The mean density of mature trees was greater in the open grazed rangelands (989±50 trees ha^{-1}) than in enclosures (800±50 trees ha^{-1}) ($t = -2.65$, df = 1, $P = 0.009$). The densities of saplings (2209±103 saplings ha^{-1}) and seedlings (1802±111 seedlings ha^{-1}) in the enclosures exceeded those in the open grazed rangelands (sapling 1858±103 ha^{-1}, seedling 1148±111 ha^{-1}) (sapling $t = 2.26$, $P = 0.025$, seedling $t = 4.10$, $P < 0.001$). Woody cover did not differ between management systems ($t = 0.02$, df = 1, $P = 0.981$).

In both the enclosures and the open grazed rangelands, we recorded 29 woody species (Table 2). Of the total woody species, 38% were invasive, with *Commiphora africana* accounting for 86% (Table 2). We found greater densities of invasive woody plants (2643 stems ha^{-1}) in enclosures than in the open grazed areas (1179 stems ha^{-1}) and similarly the invasive woody species ratio was greater in the enclosures (i.e. 1.2) than in the open grazed areas (0.42). (Table 3).

Vegetation states- and- transitions

State II represented open grazed rangelands with reduced herbaceous layer (data not shown) following continuous grazing and the ban on fire (T2 in Fig. 2). State II might revert to State I through the Transition T3 if fire were to be introduced in combination with the hand removal of the bush. State III represented greater density of bush encroachment with increased risk of the invasive woody species ratio (Table 1) following protection from grazing (T1 & T4 in Fig. 2), while State IV showed reduced density probably due to the control of woody species by the local community (T6 in Fig. 2). State V represented the secondary recovery phase for woody vegetation density after long-term protection (T7 in Fig. 2). Generally, States III, IV & V could be transformed into State II through disturbances by continuous grazing as indicated by Transition T5 in Figure 2.

The vegetation states differed significantly in terms of total woody density ($F_{3,\,120}$ = 3.88, P = 0.009), but not woody cover ($F_{3,\,120}$ = 0.06, P = 0.980). Significant differences were observed among woody vegetation states in terms of the invasive woody species ratio ($F_{3,\,120}$ = 2.75, P = 0.033). Comparison of total woody density between States II and III showed greater increments in invasive woody species ratio (t = 12.52, P < 0.001), but the ratio was reduced between States III and IV (t = -1.06, P = 0.048). Furthermore, there was a gradual increase in woody sapling density between States IV and V (t = 25.75, P < 0.001, Fig. 3).

The mean density of total woody plants in the 12 to 14 year old enclosures (5369 stems ha^{-1}) was greater than that in the 17 to 24 year old (3297 stems ha^{-1}) and 26 to 30 year old enclosures (4543 stems ha^{-1}). Generally, invasive threats were severe in the younger (12 to 14 years) and older enclosures (26 to 30 years) than in those of medium age (17 to 24 years) (Table 1). There were no differences between vegetation states in terms of woody plant cover ($F_{2,\ 120} = 0.07$, $P = 0.937$). Overall, parameter estimates for age were positive, but negative for age^2, showing that the relationships between age and densities of woody plants are not linear. The densities of individual woody plants showed significant variations along age chronosequence of vegetation states, with the exception of *Acacia mellifera, A. nilotica, Grewia tenax, Lannea floccosa* and *Balanites aegyptica* (F-tests, all $P < 0.05$). The quadratic term (i.e. age^2) for the majority of the invasive woody species was significant (χ^2- tests, all $P < 0.05$, Table 4). The relationship between age chronosequence and densities of 36% of the invasive woody species was positive, while for 56% of the species the trajectory was negative in response to age^2 (Table 4).

Discussion

Effects of management

Our findings showed significant variations in terms of spatial and temporal patterns of vegetation dynamics between enclosures and the open grazed rangelands. Reduced grazing pressure in enclosures compared to the open grazed areas resulted in increased densities of woody plants, suggesting that bush encroachment is a greater threat within enclosures than in the open grazed rangelands. Similar evidence from East African savannas (e.g. Smart, Hatton & Spence, 1985; Western & Maitumo, 2004) suggested that the exclusion of grazing promotes seedling establishment of woody species. In northern Ethiopia, Abebe *et al.* (2006)

reported increased woody species density in area enclosures. Similarly, in northern Kenya, Oba *et al*. (2001) showed that traditional enclosures promote bush encroachment. Other studies (e.g. Lenzi-Grillini, Viskanic & Mapesa, 1996; Mwalyosi, 2000; Mengistu *et al*., 2005) also reported greater densities of woody plants in enclosures than in open grazed rangelands. In Murchison Falls National Park in Uganda, Smart *et al*. (1985) showed that the long-term exclusion of grazing resulted in an increase in woody plant densities, while a study conducted in eastern Kenya reported a greater density of shrubs in enclosures than in open grazed areas (Hayashi, 1996). Comparable evidence from other regions also showed that the absence of livestock grazing results in a marked regeneration of woody species (e.g. Anderson & Holte, 1981; Eccard *et al*., 2000; Augustine & McNaughton, 2004). In the Kondoa region in Tanzania, Mwalyosi (2000) reported that shrubs and trees had greater densities inside than outside the enclosures. In a study of the semi-arid Karoo in South Africa, shrubs were abundant in enclosures and absent in the adjacent open grazed sites (Eccard *et al*., 2000).

Contrary to the earlier studies (e.g. Trodd & Dougill, 1998) our results did not confirm increased regeneration of woody plant density with heavy grazing, rather the opposite. Since there was insufficient evidence that heavy grazing alone contributes to bushy plants in the open grazed rangelands, the observed differences were probably linked to other factors that influence woody plant seed germination in the enclosures as opposed to the open grazed areas. The enclosures probably provide safer sites for the seeds of the invasive species than the open grazed areas, where greater disturbance by livestock trampling might have reduced soil moisture regimes (G. Oba, J. M. Kaitira & R. B. Weladji unpubl.), while the effects of browsing cannot be excluded. In general, there was little evidence that the open grazed rangelands disclose superior regeneration of invasive woody species compared to the enclosures. In contrast to density, woody cover was unvaried between management systems.

Although the driving force behind the dynamics of bush encroachment has not been fully understood, the lack of difference between management systems showed that the growth of bush cover is widespread (Oba *et al*., 2000).

Vegetation states-and- transitions

The dynamics of woody density in the different vegetation states suggests that the mechanisms of bush encroachment might be linked to the ban on fire, inter-annual rainfall variability, the exclusion of browsers, competition and hand clearing of woody species (e.g. States III, IV and V, as well as transitions T1, T4, T6, T7, T8 and T9). The differences in density among States III, IV and V suggest that age differences of greater than ten years may result in the expansion of bush encroachment. The spread of bush encroachment could be hazardous for the herbaceous layer (A. Angassa & G. Oba, unpubl.). Conversely, opportunities could be exploited through the removal of excessive trees, and seasonal land use between the enclosures and the open grazed vegetation states (see Fig. 1, and T4 and T5 in Fig. 2).

The younger enclosures had greater regeneration of the invasive woody species than the older vegetation states. In the older vegetation states the vegetation was probably thinned by hand removal by the local community, while in the younger enclosures improved growth conditions probably promoted regeneration (e.g. T1 and T4). We showed that species composition and the invasive woody species ratio declined in the medium age vegetation states (*cf*. Asefa *et al*., 2003). The decline was probably due to self-thinning mortality among individual species (Grime *et al*., 1987), as well as human disturbance (Iglesias & Kothmann, 1997). According to Franklin *et al*. (1987), tree mortality increases between 10 to 20 years as a result of competition. Our finding is comparable with the findings of Zhang *et al*. (2005) who showed a decline in species composition in medium age vegetation states compared to younger and older vegetation states. The lack of variation in woody cover along age chronosequence is reflective of a general increase in growth of bush cover (Gemedo-Dalle, 2004; Borghesio & Giannetti, 2005).

The data showed that doubling the age of the enclosures would have no significant influence on the trends of seedlings. The effects of rainfall and seed supply are probably more important. Fluctuations in the densities of woody species showed varied patterns in correspondence with the age chronosequence, indicating that changes in the structure of vegetation are unpredictable. We confirmed that doubling the age of the enclosures (i.e. age^2) would have a negative impact on the majority of the invasive woody species. The declining density was probably caused by dieback, which is related to the life history of individual species (Franklin *et al.*, 1987). The species that increased with the doubling of age probably benefited from protection from browsing animals. This was applicable mostly to the *Acacia* species.

Conclusions

We analyzed how enclosures of different age chronosequence might explain temporal variation in bush encroachment. The regeneration of invasive woody species in the enclosures exceeded that in the open grazed rangelands, suggesting that grazing alone has a limited effect in driving bush encroachment. We showed that the seasonal exclusion of grazing did not reduce the problems of bush encroachment compared to continuously grazed areas. Rather, threats in terms of invasive woody species ratio are greater in enclosures than in open grazed areas. Overall, the trajectories of densities of individual woody species showed fluctuations along age chronosequence of vegetation states, suggesting that the relationships are not linear. We confirmed that doubling the age of vegetation states had a negative impact on the majority of invasive woody species and this decline is possibly related to self-thinning. In addition, the evidence that the regeneration of invasive woody species failed to show a linear trajectory in relation to age chronosequence of enclosures showed that the drivers of bush encroachment are controlled more by stochastic events, such as inter-annual rainfall variability (inferred from seedling data), than by grazing by livestock.

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Table 1. Woody vegetation states-and-transitions description for the Dida-Hara range site in Borana, southern Ethiopia

Catalogues of states (see Figures 1 and 2)

State I (Grassland state). Open grassland dominated by perennial grasses – before settlement (before the 1980s)

State II (Grazed rangelands). Woody species composition was dominated by *Commiphora africana* (A. Rich.) Engl. (25.6%), *Acacia tortilis* (Forssk.) Hayne (25%), *Lannea floccosa* (Chiov.) Sacleux (9.2%), *Acacia nilotica* (L.) Willd. Ex Del. (8.9%), *Ormocarpum mimosoides* (Taub.) Engl. (6.5%), *Grewia tenax* (Forssk.) Fiori (6.1%), *Acacia senegal* (L.) Willd. (5.3%), *Boscia coriacea* Klotzsch (2.2%) and others which each contributed < 2.0% of the composition. Estimated total percentage of bush cover was 54.5% of the vegetation state, while the invasive threat (i.e. the ratio in terms of density of invasive woody species to non-invasive species) was 0.42 in the year-round grazed vegetation state.

State III (Early invasion). Increased densities of woody species between 12 and 14 years after rest. The woody species composition was dominated by *Commiphora africana* (A. Rich.) Engl. (48.3%), *Lannea floccosa* (Chiov.) Sacleux (8.5%), *Acacia tortilis* (Forssk.) Hayne (7.1%), *Acacia nilotica* (L.) Willd. Ex Del. (5.5%), *Grewia tenax* (Forssk.) Fiori (5.0%), *Acacia senegal* (L.) Willd. (4.8%), *Acacia etbaica* Schweinf. (4.2%), *Grewia bicolor* (Forssk.) Vahl (2.4), *Acacia bussei* Harms ex Sjostedt (2.3%), *Acacia sp.* (unidentified) (1.6%), *Combretum molle* D. Don and others which each contributed < 1.5% of the composition. Estimated total percentage of bush cover was 57.4% of the vegetation state, while the invasive threat was 1.3 for 12 to14 year old range enclosures.

State IV (Mid invasion). Declining phase of vegetation states between 17 and 24 years of rest due to improved management, i.e. control of woody species. The woody species composition was dominated by *Commiphora africana* (A. Rich.) Engl. (43.7%), *Acacia tortilis* (Forssk.) Hayne (19.6%), *Acacia nilotica* (L.) Willd. Ex Del. (9.4%), *Lannea floccosa* (Chiov.) Sacleux (7.4%), *Grewia tenax* (Forssk.) Fiori (3.9%) and *Acacia drepanolobium* Harms ex Sjostedt (3.6%), *Ormocarpum mimosoides* (Taub.) Engl. (2.6%), *Acacia goetzei* Harms (2.6%) were the dominant vegetation, while others each contributed < 2% of the composition. Estimated total percentage of bush cover was 56.1% of the vegetation state, while the invasive threat was 1.1 for 17 to 24 year old range enclosures.

State V (Late invasion). Risks of re-invasion between 26 and 30 years. Major woody plants included *Commiphora africana* (A. Rich.) Engl. (46.4%), *Acacia tortilis* (Forssk.) Hayne (11.8%), *Lannea floccosa* (Chiov.) Sacleux (6.9%), *Ormocarpum mimosoides* (Taub.) Engl. (5.8%), *Acacia nilotica* (L.) Willd. Ex Del. (4.5%), *Grewia tenax* (Forssk.) Fiori (4.2%), *Acacia senegal* (L.) Willd. (3.7%), *Boscia coriacea* Klotzsch (3%), *Acacia etbaica* Schweinf. (2.3%), *Acacia seyal* Del. (2.3%), *Acacia brevispica* Harms (2.1%), *Acacia bussei* Harms ex Sjostedt (2.1%) and others which each contributed < 2% of the composition. Estimated total percentage of bush cover was 56.6% of the vegetation state, while the invasive threat was 1.3 for 26 to 30 year old range enclosures.

Catalogues of transitions

Transition 1. Increased density of bush as a result of land use changes following the creation of seasonal enclosures (i.e. restoration). Fire ban, full-year grazing as a result of increased sedentary settlements following pond construction over a 12 to 30-yr period (T2).

Transitions 3 and 10. Future bush management scenarios involving range rehabilitation. This transition will take place if control of invasive woody plants is considered through the reintroduction of fire and other control measures such as bush clearing followed by resting.

Transition 4. Increased densities of woody plants leading to more woody density in State III as a result of ban on fire, protection from grazing and inter-annual rainfall variability over a 12 to 30-yr period. Changes in the direction of community trajectory may result in different woody vegetation states due to management dynamics including human disturbance in the form of woody plant control and disturbance by grazing that might lead to State II (T5).

Transition 6. Thinning of woody plants by the local community might reduce woody density. Continued protection from grazing promotes woody densities (T9).

Transition 7. Recovery of woody density with continued protection from grazing after thinning. Removal of woody plants and resting might reverse to the previous state (T8).

Opportunities and hazards

The opportunities involved in the enclosures were reserved dry season fodder for calves, rotational grazing between traditional range enclosures and grazed rangelands, improved range condition as a result of resting and increased soil organic matter through addition of litter. Increase of woody encroachment in the 12 to 14 years represented a threat that will reduce herbaceous forage production leading to the loss of grazing potential of the vegetation states.

Table 2. Percentage composition of individual woody species assessed in enclosures and open grazed landscapes in Borana, southern Ethiopia

Species	Local name	Type	% Composition	
			Enclosure	Open grazed
Acacia brevispica Harms	Hammarreessa	I	0.7	0.2
Acacia drepanolobium Harms ex Sjostedt	Fulleessa	I	1.4	0.3
Acacia etbaica Schweinf.	Halliqabeessa	I	2.2	0.9
Acacia seyal Del.	Waaccuu	I	1.2	0.5
Acacia bussei Harms ex Sjostedt	Halloo	I	1.5	1.1
Acacia mellifera (Vahl.) Benth.	Saphansa	I	0.1	0.1
Commiphora habessinica (Berg) Engl.	Hoomachoo	I	0.9	0.5
Commiphora fluviflora (R. Br. ex Royle) Vollesen	Callaanqaa	I	0.6	0.4
Commiphora crenulata Gillet & Vollesen	Siltaachoo	I	0.2	0.1
Commiphora africana (A. Rich.) Engl.	Hammeessa dhiiroo	I	46.1	25.6
Cordia gharaf (Forssk.) Ehrenb.	Madheera	I	0.2	0.1
Acacia nilotica (L.) Willd. ex Del.	Burquqqee	NI	6.6	8.9
Acacia tortilis (Forssk.) Hayne	Dhaddacha	NI	13.0	25.0
Acacia goetzei Harms	Burra	NI	1.4	0.3
Grewia tenax (Forssk.) Fiori	Dheekkaa	NI	4.4	6.1
Boscia coriacea Klotzsch	Qalqalcha	NI	1.4	2.2
Grewia villosa Willd.	Ogomdii	NI	0.6	0.1
Grewia bicolor (Forssk.) Vahl	Harooressa	NI	1.2	1.8
Acacia senegal (L.) Willd.	Hidhaadhoo	NI	3.0	5.3
Ormocarpum mimosoides (Taub.) Engl.	Buutiyyee	NI	3.0	6.5
Lannea floccosa (Chiov.) Sacleux	Handaraka	NI	7.5	9.2
Rhus natalensis Berah. ex Krauss	Daboobessa	NI	0.7	0.9
Euclea schimperi Hiern.	Mi'eessaa	NI	0.2	0.1
Combretum molle D. Don	Rukeessa	NI	0.5	1.1
Terminalia brownii Fresen.	Birreessa	NI	0.3	0.7
Boswellia neglecta S. Moore	Dakkara	NI	0.2	0.3
Dichrostachys cinerea (L.) Wight et Arn.	Jirimee	NI	0.4	0.8
Acacia sp. (unidentified)	Bokossaa	NI	0.5	1.0
Balanites aegyptica (Van Tiegh.) Blatter	Baddana	NI	0.1	0.1

I = invasive species, NI = Non-invasive species, note: categorization of invasiveness by species was based on herder knowledge.

Table 3. The effect of enclosures compared to open grazed landscapes on the densities of invasive woody plants (plants ha^{-1}) in Borana, southern Ethiopia

Species list	Local name	Management			*t*-test
		Enclosure	Open	±SE	
Acacia brevispica Harms	Hammarreessa	35	9	±5.9	*
Acacia drepanolobium Harms ex Sjostedt	Fulleessa	66	11	±11.4	*
Acacia etbaica Schweinf.	Halliqabeessa	107	36	±18.2	*
Acacia seyal Del.	Waacu	57	18	±9.6	*
Acacia bussei Harms ex Sjostedt	Halloo	70	42	±12.3	NS
Acacia mellifera (Vahl.) Benth.	Saphansa	4	2	±1.6	*
Commiphora habessinica (Berg) Engl.	Hoomachoo	44	20	±7.5	NS
Commiphora fluviflora (R. Br. ex Royle) Vollesen	Callaanqaa	28	15	±5.0	NS
Commiphora crenulata Gillet & Vollesen	Siltaachoo	9	2	±1.5	*
Commiphora africana (A. Rich.) Engl.	Hammeessa dhiiroo	2216	1021	±386.5	*
Cordia gharaf (Forssk.) Ehrenb.	Madheera	7	3	±1.1	NS

* $P < 0.05$, NS $P > 0.05$

Table 4. Parameter estimates and ±SE for the variables age and age^2 showing trends of invasive woody plant densities in Borana, southern Ethiopia

Species list	Age		Age^2		Trends
	Estimate	χ^2- test	Estimate	χ^2- test	
Acacia brevispica Harms	-5.05±4.72	1.14^{NS}	1.72±1.12	2.36^{NS}	Parabola
Acacia drepanolobium Harms ex Sjostedt	13.64±1.76	60.31***	-3.36±0.41	67.34***	Humpback
Acacia etbaica Schweinf.	-9.20±2.64	12.12**	2.23±0.66	11.31**	Parabola
Acacia seyal Del.	4.86±2.33	4.35*	-0.84±0.50	2.83^{NS}	Humpback
Acacia bussei Harms ex Sjostedt	-14.37±5.10	7.93*	3.58±1.27	7.88*	Parabola
Acacia mellifera (Vahl.) Benth.	-1.27±1.52	0.70^{NS}	0.45±0.36	1.56^{NS}	Parabola
Commiphora habessinica (Berg) Engl.	6.10±0.98	38.46***	-1.58±0.25	39.96***	Humpback
Commiphora fluviflora (R. Br. ex Royle) Vollesen	0.41±1.06	0.15^{NS}	-0.19±0.27	0.49^{NS}	Humpback
Commiphora crenulata Gillet & Vollesen	6.74±1.16	33.73***	-1.59±0.27	35.39***	Humpback
Commiphora africana (A. Rich.) Engl.	0.01±1.14	0.00^{NS}	-0.01±0.28	0.00^{NS}	Humpback
Cordia gharaf (Forssk.) Ehrenb.	4.5±1.11	16.38***	-1.04±0.26	15.87***	Humpback

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, NS $P > 0.05$

Captions for the Figures

Figure 1. Schematic patterns of land use in Dida-Hara before the 1970s when the area served as wet season grazing (A) and after the 1980s when grazing patterns changed from seasonal to year-round grazing (B). The current land use involves rotational grazing by calves during the dry season (DS) in the enclosure-management (C) and open range during the wet season (WS).

Figure 2. Schematic representation of vegetation states-and-transitions based on dominant woody species composition representing different age chronosequence in Dida-Hara, southern Ethiopia. Dotted arrows indicate possibilities of change and future scenarios (full descriptions are given in Table 1).

Figure 3. Density of woody plants by age size classes in the open grazed areas (State II) and the three age range of enclosures (States III, IV and V). State I represented the historical vegetation for which the information was not available.

Fig. 1.

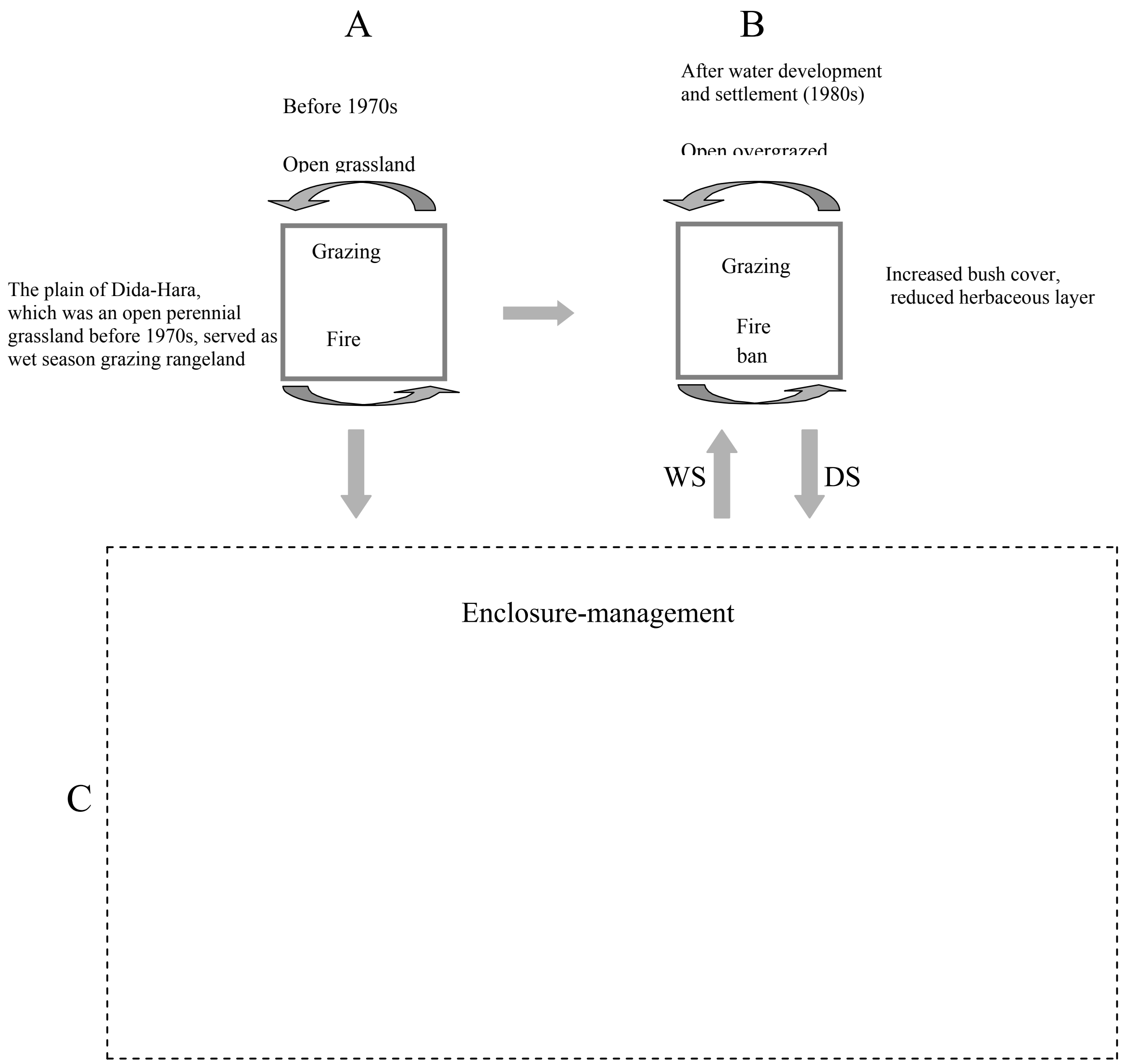

A
B
Before 1970s
Open grassland
After water development and settlement (1980s)
Open overgrazed
Grazing
Fire
Grazing
Fire ban
The plain of Dida-Hara, which was an open perennial grassland before 1970s, served as wet season grazing rangeland
Increased bush cover, reduced herbaceous layer
WS
DS
Enclosure-management
C

Fig. 2.

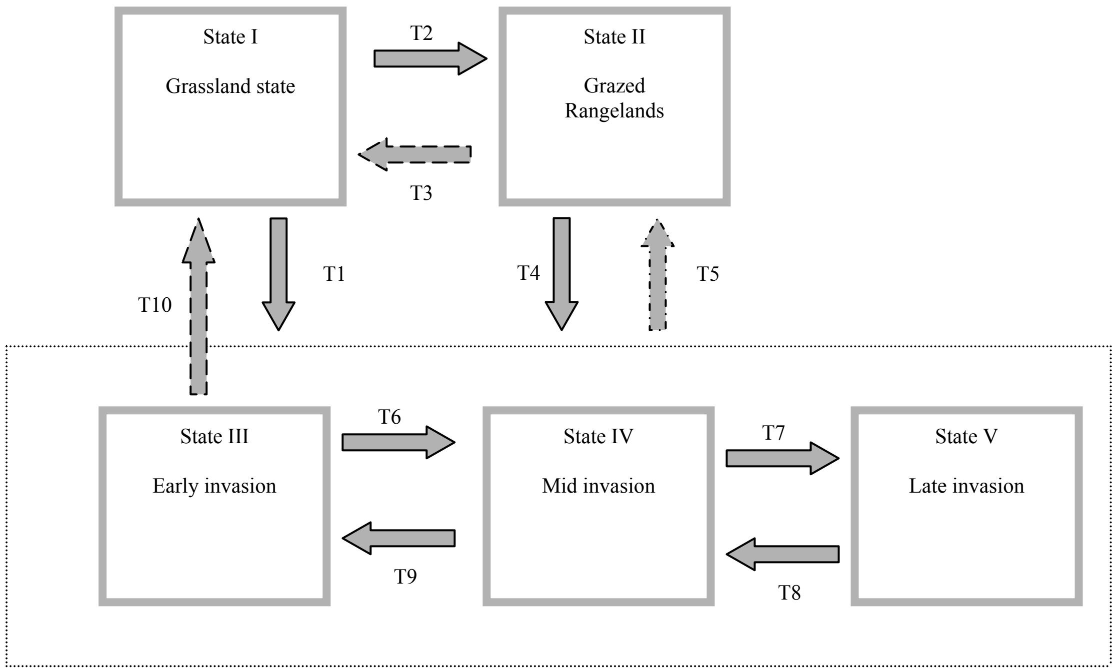
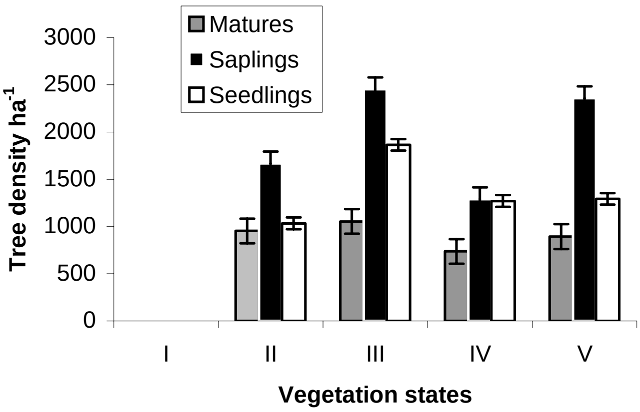

State I
Grassland state
T2
State II
Grazed
Rangelands
T3
T10
T1
T4
T5
State III
Early invasion
T6
State IV
Mid invasion
T7
State V
Late invasion
T9
T8

Fig. 3.


Matures
Saplings
Seedlings
3000
2500
2000
1500
1000
500
0
Tree density ha-1
I
II
III
IV
V
Vegetation states

PAPER IV

Demonstration of bush encroachment control in Borana, southern Ethiopia: 1. Evaluation of tree cutting, fire and grazing on woody plants

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Abstract

Bush encroachment is a serious concern for pastoral production in savanna ecosystems. This study investigated the influence of six bush encroachment control methods (i.e. tree cutting, fire, grazing and their combinations) on the responses of 29 woody plants (38% encroaching species) in the savanna ecosystems of southern Ethiopia, between June 2003 and June 2005. During the post-treatments, we monitored tree stump total kill (TK), partial kill (PK) and the responses of woody plants to disturbances, in terms of coppicing (C) and seedling regeneration (CR). Different woody species had varied adaptation strategies. Protection from disturbance promoted bush encroachment regeneration by 4.6%. The effects of tree cutting and fire greatly reduced the majority of woody species, while tree cutting, fire and grazing treatments were more effective in reducing coppicing. The fire and grazing methods were effective in reducing the regeneration of seedlings, although grazing with bush cover had no effect on seedling regeneration. The effect of the tree cutting method was comparable with tree cutting and fire, as well as tree cutting, fire and grazing. Overall, the bush encroachment control method of tree cutting, fire and grazing was more effective in suppressing the regeneration of invasive woody plants. Some species invested in survival through coppicing, while others invested in seedling recruitment. Disturbance vulnerable species such as *Commiphora terebinthina* and *Boscia coriacea* adapted by increasing seedling regeneration, while coppicing was the most common strategy used by invasive woody species. About 10% of the species adapted relatively to either of the strategies (i.e. ranked between 1 and 10). Only one of the 29 woody species was ranked among the top five in both of the two disturbance-adaptation strategies. The findings were used to discuss management policy and public education for bush encroachment in the savanna ecosystems of southern Ethiopia.

Keywords: bush encroachment control methods, implication for policy, public education, disturbance-response strategy, regeneration of woody plants

Introduction

Bush encroachment in savanna ecosystems is a worldwide phenomenon that has created a serious problem for the pastoral industry (Campbell and Setter, 2002; Wiegand *et al.*, 2005; Ansley and Castellano, 2006). Although the reasons for bush encroachment are diverse and complex (Smit, 2005), the drivers of the phenomenon are the suppression of fire (e.g. Oba *et al.*, 2000; Sheuyange *et al.*, 2005), heavy grazing pressure (e.g. Skarpe, 1990; Coppock, 1993) and climate variability (Scholes and Archer, 1997; Fernandez-Gimenez and Allen-Diaz, 1999). Reduced fuel load also reduces fire frequency, making bush encroachment control difficult (e.g. Archer, 1995; Scholes and Archer, 1997).

In order to control the adverse effects of bush encroachment in savanna grazing lands, various bush encroachment control methods are widely applied including fire (Corra, 1986; Luken and Shea, 2000; DiTomaso *et al.*, 2006) and tree cutting (Smit, 2003) and the combination thereof. While many earlier studies emphasized the effects of woody plant control in terms of reducing woody cover, the short and long-term responses of individual species to different bush encroachment control methods are poorly documented. The effect of fire on woody plants (e.g. Wright *et al.*, 1976; White and Currie, 1983; Menges and Kimmich, 1996; Hoffmann, 1998; Campbell and Setter, 2002; Ruthven *et al.*, 2003; Ansley and Castellano, 2006) suppresses bush growth by killing or reducing the abundance of invasive woody plants, as does cutting, at least in the short-term (Clark and Wilson, 2001). The combined effects of fire and grazing (Salvatori *et al.*, 2001), and cutting inhibit the recovery of woody plants (Scholes and Archer, 1997; Sawadogo *et al.*, 2002; Ruthven *et al.*, 2003; Nolte *et al.*, 1994), while grazing as a form of disturbance played a major role in shaping the composition and structure of savanna vegetation (Hadar *et al.,* 1999).

Depending on the intensity of disturbance and types of woody species, bush encroachment control may either facilitate the regeneration of invasive woody plants by breaking seed dormancy (Oba, 1990), or prevent seedling recruitment by damaging tree seedlings (Kraaij and Ward, 2006). The potential role of bush encroachment control methods on seedling recruitment and coppicing is not well documented. Bush encroachment control methods should therefore focus on the responses of individual woody plants in terms of their disturbance-adaptation strategies related to stump kill, coppicing and the regeneration of woody seedlings. Different woody species may respond differently; however information is lacking on the strategies of individual woody species in response to bush encroachment control methods. Understanding the effects of bush encroachment control methods and the respective responses of woody species may be important for the management of savanna ecosystems (Wright *et al.*, 1976; Masters and Sheley, 2001; Ansley and Castellano, 2006).

In the East African savannas where the suppression of fire is often associated with increased bush encroachment and loss of herbaceous plants (Smit, 2003), the demonstration of bush encroachment control methods has important policy implications. Identifying responses of individual species and their strategies in coping with disturbances may enable policymakers to design appropriate management strategies for bush encroachment control programs. The demonstration of bush encroachment control methods and their implications for policy and public education has not been evaluated in terms of responses of individual woody plants in testing the effectiveness of various management options. Furthermore, there are no public discussions on the demonstration of bush encroachment control methods. Bush encroachment control can be used to create awareness of rehabilitating bush encroached savanna ecosystems. The present study conducted in Borana, southern Ethiopia, was aimed at demonstrating bush encroachment control and using the findings to inform public policy and education.

In the Borana rangelands of southern Ethiopia, changes in land use, such as the official banning of fire in the early 1970s, are perceived to have promoted the rapid expansion of bush encroachment (Oba *et al.*, 2000). Fire was banned as a result of inappropriate management policy. As a result, vast areas of the savanna ecosystems of southern Ethiopia have been put at risk by the growth of bushy plants (Coppock, 1993). By the mid-1980s about 40% of the Borana rangelands had been affected by bush encroachment (Assefa Eshete *et al.*, 1986), while recent estimates put bush encroachment at 52% of the total rangelands (Gemedo-Dalle, 2004). Currently, the adverse effects of bush encroachment on the performance of the pastoral economy are being acknowledged. Local and international NGOs and some government departments are conducting range rehabilitation, involving hand clearing of woody plants along highways and near settlements, on an experimental basis. So far, little is known about the effects of bush encroachment control methods in terms of individual species responses.

The present study evaluated six methods of bush encroachment control (i.e. disturbance control (CO), cutting and fire (C+F), cutting, fire and grazing (C+F+G), fire and grazing (F+G), grazing with bush cover (GBC) and cutting alone (C)) aimed at understanding: (a) how these bush encroachment control methods influenced the responses of woody species in terms of mortality, coppicing and regeneration of seedlings; (b) strategies used by individual species in response to disturbances; and (c) the relationship between changes in population and seedling recruitment strategies. Finally, the implications of the different bush encroachment control measures on management policy and education were investigated.

Materials and methods

Study area

The study was conducted on the government cattle breeding ranch in Dida-Tuyura (04º57.383´N, 38º12.403E´) and the community ranch in Dambala-Wachu (04º29.432´N, 38º16.339´E) in the central Borana region of Ethiopia. The topography of the two ranches varies from uplands (> 1500 m a.s.l.) to bottomlands (< 1400 m a.s.l.). The geology of the whole system is basement complex (Coppock, 1994). According to the FAO soil classification (1986), the soils of the study sites are shallow red sandy loam in the uplands and vertisols in the bottomlands. The climate is variable with the main rainy season from March - May (*ganna*) and the short rains from September - November (*hagaya*). The mean annual rainfall for the period 1980 to 2000 was 513±39 mm for Dida-Tuyura and 359±30 mm for Dambala-Wachu with a high inter-annual coefficient of variation (CV) of 33.3%. In both sites, the dominant vegetation types are *Acacia* species and bush savanna, mixed with perennial grasses such as *Chrysopogon aucheri, Cinchrus ciliaris, Themeda triandra*, and *Sporobolus pyramidalis*. Both ranches had experienced bush encroachment problems.

Prior to the 1980s, the sites were utilized under a communal grazing system. Cattle were the dominant livestock species. The stocking density of the Dida-Tuyura ranch was 12.0 Tropical Livestock Unit km^{-2} (TLU km^{-2}, 1 TLU = 250 kg bovine) compared to 17.6 TLU km^{-2} in Dambala-Wachu (Angassa and Oba, 2007). Before the two range sites were converted into ranches and prior to the official ban on fire in the 1970s, the pastoral community periodically conducted range burning late in the dry season. Currently, bush encroachment poses a threat to livestock production. We selected the ranch sites due to their accessibility to the local communities for extension services. We used the opportunity to demonstrate bush encroachment control methods that extension departments could utilize to communicate with resource users on the management of bush encroachment in the remaining rangelands.

Experimental design

The six bush encroachment control methods were randomly assigned to six demonstration plots replicated across varied topography in the two ranches. We established a total of 24 demonstration plots of 0.25 ha (50 x 50 m), with firebreaks of 10 m width, laid out in the uplands and bottomlands of the two ranch sites. The total number of demonstration plots was limited by both logistical constraints and details of measurements. (1) The disturbance control demonstration (CO) represented the current government policy, which aims at forest cover conservation. The disturbance control demonstration treatments were used as a benchmark against which other management systems could be evaluated. The new management options were combined cutting and fire (C+F), cutting followed by fire and grazing (C+F+G). For these two demonstrations, we hand cleared all trees on both sites in February 2004 to monitor the regeneration potential of individual species. In the demonstrations where we combined tree cutting followed by fire and grazing (C+F+G), the woody plants were chopped up into finer pieces and then piled on tree stumps to create a fine fuel load for burning. The piles of woody plants were allowed to dry for one month before fire was broadcast. The C+F demonstration plots were fenced in June 2003 to allow the accumulation of fuel loads before burning. The third demonstration represented the traditional use of fire (practiced before fire suppression) and grazing (F+G), in which cattle were allowed to graze the burnt plots.

The three burn demonstrations (i.e. C+F, C+F+G and F+G) were conducted late in the dry season. Prior to burning, the herbaceous biomass was clipped to determine the amount of fuel for burning and moisture content. On average the fuel load was 2390±268 kg ha^{-1} on the Dida-Tuyura site while the amount was 2684±268 kg ha^{-1} on the Dambala-Wachu ranch sites (i.e. average of the upland and bottomland plots). Fresh weights of samples were taken to estimate the moisture content of the fuel load, which was 16% for Dida-Tuyura and 10% for Damabala-Wachu.

Burning of the demonstration plots in the upland and bottomland for the Dambala-Wachu ranch was conducted on 12 March 2004 and for Dida-Tuyura on 14 March 2004 between 10:00 and 16:30 hours local time. The weather on the burn days was comparable with air temperatures varying from 26°C and 20.5°C at Dambala-Wachu (Southern Rangelands Development Unit (SORDU) Meteorology station), although the daily temperature at the time of burning was not recorded at the Dida-Tuyura ranch, due to the absence of a weather station. The direction of the wind was determined using plastic balloons tied to upper tree branches outside the burn areas. At Dambala-Wachu the wind direction was westerly with a low speed in the bottomland and easterly in the upland. At Dida-Tuyura, the wind direction was westerly.

In the fourth demonstration, grazing with bush cover (GBC) represented the current traditional system (i.e. after suppression of fire) of rangeland management. On both ranches, grazing was conducted using free ranging animals. For plots in the fifth demonstration (cutting alone denoted by C), all trees were hand cleared followed by fencing to protect the area from grazing. All tree clearings were unselective, involving removal of all trees. This is the method of bush encroachment control commonly used by NGOs through local community participation. In our study we also involved local herders and extension workers to participate in the design of the demonstration of bush encroachment controls.

Sampling

Woody species were identified using the herbarium and checklists collected by the Southern Rangelands Development Unit (SORDU). The classification of woody species into invasive and non-invasive was done by the herders. During the pre-treatment activities, the number of individual trees ha^{-1} was recorded and they were marked using identification numbers on aluminum tags. For the cutting treatments, the tags were placed at the base of the trunk of each tree, below the cutting point. We conducted a species count for all woody species on each plot prior to the demonstrations. Sampling was conducted in June 2003 after the main rains. Following demonstration trials, we monitored the plots in June 2004 and a year later in 2005. During the post-treatment activities, we monitored tree stump total kill (TK) hereafter called mortality, partial kill (PK), coppicing (C), regeneration by seedlings (CR) and change in seedling density in response to the different demonstrations. For the disturbance control demonstration and grazing with bush cover, we monitored woody plant mortality and changes in seedling density. We monitored two main disturbance-response strategies: survival by coppicing and regeneration from seedlings, using the procedures of Otterstrom *et al.* (2006). Species not strongly exhibiting these two mechanisms were identified as being vulnerable. We also recorded the proportion of species that survived at the end of the experiments.

Data analysis

Responses of individual woody species were analyzed in terms of plants or cut-stump percent mortality (number of post-demonstration mortality or total kill/number of pre-demonstration x 100); partial mortality (number of partially killed individuals/number of pre-demonstration x 100); percent of coppicing (number of post-demonstration coppicing/number of pre-demonstration x 100); and percent survival (number of survivals recorded in June 2005/number of pre-demonstration x 100). A chi-square test was used to check for species' vulnerability to the demonstration techniques. Post-demonstration changes in seedling densities were calculated for each species to determine the change in individual population (λ) as the proportion of survived individuals plus mean changes in seedling densities relative to pre-demonstration seedling density (Otterstrom *et al.*, 2006). The Pearson correlation was used to test the association between changes in surviving woody plant populations and seedling recruitments.

Results

Responses of individual species to demonstration treatments

Table 1 provides a list of 29 woody species and their densities during pre-demonstration for the six treatments. Among the total woody species monitored, about 38% were encroachers. The responses of individual species in terms of each of the six demonstration treatments are reported below.

For the disturbance control plots, mortality and seedling recruitments are given in Table 2. *Acacia drepanolobium, Commiphora africana, Lannea floccosa* and *Commiphora habessinica,* but not *Boswellia neglecta,* experienced greater natural mortality under protection (Tables 2 and 3, χ^2-tests, all $P < 0.001$). Seedling recruitment was significantly increased in *Acacia drepanolobium, Acacia etbaica, Ormocarpum mimosoides, Commiphora africana, Commiphora fluviflora, Lannea floccosa, Boswellia neglecta* and *Commiphora habessinica* in response to protection (Tables 1 and 4; χ^2-tests, all $P < 0.001$). Seedling recruitment was greater in *Acacia drepanolobium* (72%) relative to other woody species (Table 2). Protection from disturbance increased seedling recruitment by 4.6% (i.e. 362 seedlings ha^{-1}). Three of the species with greater seedling recruitments (i.e. *Acacia* *drepanolobium, Commiphora Africana* and *Commiphora fluviflora*) were categorized by herders as invasive species (Table 2).

Post-demonstration stump deaths for the tree cutting and fire (C+F) treatment accounted for 64% of the total populations (Tables 1 and 2). Stump total kill (TK) was greater in *Acacia drepanolobium, Acacia etbaica, Acacia mellifera, Acacia tortilis, Ormocarpum mimosoides, Commiphora africana, Commiphora fluviflora, Euphorbia cuneata ssp. spinescens, Lannea floccosa, Dichrostachys cinerea* and *Boswellia neglecta* (Table 3). Total survival for these demonstrations accounted for 36% of the individuals (Table 2). Survival of individual species was greatest for *Rhus natalensis* (100%), *Commiphora schimperi* (71%), *Acacia seyal* (64%), *Commiphora habessinica* (63%) and *Acacia tortilis* (59%), in that order (Table 2). Seedling recruitments were greatly increased in *Acacia drepanolobium, Acacia seyal, Commiphora africana, Dichrostachys cinerea* and *Commiphora habessinica* (Table 4, χ^2-tests, all $P < 0.001$). Among the different woody species, greater cumulative seedling recruitment was recorded for *Ormocarpum mimosoides* (Table 2).

Post-disturbance stump total kill in response to tree cutting, fire and grazing (C+F+G) accounted for 70% of the total number of pre-disturbance treatment individuals (Tables 1 and 2), the effect being highly significant in the majority of woody species (Table 3, χ^2-tests, all $P < 0.001$). *Grewia bicolor* was the only species that tolerated the combined effects of tree cutting, fire and grazing, with survival of 100% (Table 2). We also found significant increases in seedling recruitment by the majority of the woody species in these demonstrations (Tables 2 and 4, χ^2-tests, all $P < 0.001$).

About 60% of the woody plants were significantly reduced in density in response to fire and grazing (F+G) (Tables 2 and 3, χ^2-tests, all $P < 0.001$). Woody plant total kill accounted for 55% of the total pre-disturbance treatment populations (Tables 1 and 2). *Combretum molle* experienced complete mortality in response to fire and grazing (Table 2), whereas three species *Acacia etbaica, Pappea capensis* and *Acacia sp.* (unidentified) did not experience total kill in response to this treatment (i.e. 100% survived) (Table 2). Fire and grazing significantly promoted seedling recruitment in *Acacia drepanolobium, Acacia nilotica, Acacia seyal, Acacia tortilis, Ormocarpum mimosoides, Commiphora africana, Commiphora fluviflora, Grewia tenax, Lannea floccosa, Dichrostachys cinerea* and *Commiphora habessinica* (Tables 2 and 4, χ^2-tests, all $P < 0.001$). The greatest seedling recruitments in response to fire and grazing demonstrations were experienced by *Acacia drepanolobium*, *Ormocarpum mimosoides* and *Dichrostachys cinerea* (Table 2).

Under the grazing with bush cover demonstration (GBC), total mortality for woody species was greater in *Acacia drepanolobium*, *Ormocarpum mimosoides* and *Commiphora Africana* than the other species (Tables 2 and 3, χ^2-tests, all $P < 0.001$). At the same time, greater seedling recruitments were recorded for *Acacia drepanolobium, Acacia nilotica, Acacia seyal, Acacia tortilis, Balanites aegyptica, Ormocarpum mimosoides, Commiphora africana, Lannea floccosa, Grewia bicolor* and *Commiphora habessinica* (Tables 2 and 4, χ^2-tests, all $P < 0.001$).

Tree cutting alone (C) resulted in 59% of total stump deaths (Tables 2 and 3, χ^2-tests, all $P < 0.001$). *Boscia coriacea* experienced total stump deaths of 100% (Table 2). By comparison *Acacia bussei* and *Balanites aegyptica* showed 100% survival in response to tree cutting alone (Table 2). Seedling recruitments were significantly increased in *Acacia seyal, Acacia tortilis, Ormocarpum mimosoides, Commiphora africana, Lannea floccosa* and *Grewia bicolor* (Table 4, χ^2-tests, all $P < 0.001$).

Response strategies of woody species to disturbance

Table 5 lists all the 29 woody species and their post-disturbance survival (coppicing strategy), as well as their seedling recruitment. Mean survival for the woody species was 29.3%. Greater survival by means of coppicing was observed in *Acacia seyal, Acacia tortilis* and *Ormocarpum mimosoides,* while *Euclea divinorum*, *Commiphora terebinthina, Grewia villosa* and *Ozoroa insignis* had the lowest survival rates (Table 5). *Commiphora terebinthina* and *Boscia coriacea* adapted to disturbance by increasing seedling recruitments during the post-disturbance period (Table 5). Although these species ranked within the top five in terms of seedling establishment strategies, their survival ratings were in the lower ranks (Table 5).

According to the disturbance response ranking some species invested in survival through coppicing, while others invested in seedling recruitment (Table 5). Among the 29 woody species only *Acacia seyal* was ranked among the top five in both disturbance-adaptation strategies. Three species, *Commiphora africana*, *Commiphora fluviflora* and *Acacia mellifera*, were ranked relatively low across both disturbance strategies. Most of the species were ranked medium to low in the coppicing strategies but low to medium in seedling recruitment strategies (Table 5). Generally, post-disturbance seedling mortality exceeded seedling recruitment. Among the 29 woody species, about 48% showed negative changes in seedling density (Table 5). There was a weak but significant correlation between changes in total population survival (λ) and seedling recruitment ($r = 0.38$, $N = 29$; $P = 0.041$).

Discussion

Responses of individual species to demonstration treatments

Our results show that only a few of the woody species experienced mortality under protection that could be attributed to natural thinning, probably due to age-related factors. The species that experienced greater mortality also had greater recruitments through seedling establishment. These are the species that are associated with bush encroachment. The evidence suggests that protection would promote bush encroachment (e.g. Pauchard *et al.*, 2003).

The stump deaths in response to tree cutting and fire varied among species. This was probably related to tree sizes (Oba, 1990; Pinard *et al.*, 1999). More than 50% (n = 21) of the species in this treatment showed greater susceptibility to fire, suggesting that fire could be used to control those species, while in the less susceptible species, the effect of fire was short-term. The coppicing species were able to recover between fire intervals (Clark and Wilson, 2001). Of the less susceptible species, about 5% did not experience fire damage to the stumps. Most of the stumps showed successful coppicing (Hoffmann and Solbrig, 2003; Otterstrom *et al.*, 2006). The increase in cumulative seedling by some species suggests that disturbance such as fire does not inhibit the germination of seeds of invasive woody species (Tamene, 1990; Oba, 1990).

We found greater stump deaths among a total of 16 woody species in response to tree cutting, fire and grazing, which may be attributed to the increased intensity of disturbance. Greater damage to some species (e.g. *Commiphora fluviflora, Ozoroa insignis, Boscia coriacea, Commiphora terebinthina* and *Grewia villosa*) as opposed to others (e.g. *Grewia bicolor* and *Ormocarpum mimosoides*) suggests variability in the performance by individual species. Stump deaths in response to multiple disturbances may suggest that changes in management strategy with a combination of disturbance events could greatly reduce the woody populations (Fulbright, 1996). Furthermore, preferences of grazing and browsing animals towards individual species in terms of increased palatability and accessibility of the edible portions probably increased mortality among coppicing woody plants (Sawadogo *et al.*, 2002). The severity of the disturbance generally results in long-term reduction in the density of woody plants (Ruthven *et al.*, 2003; Nolte *et al.*, 1994). From the results, we suggest that combinations of different methods would probably be more efficient in the control of invasive woody species than a single method, particularly where bush encroachment is at climax stage (Gufu Oba, unpubl.).

Tree mortality in response to fire and grazing varied among individual species. The majority of woody species experienced total kill, mostly due to the effect of fire. In the Maasai Mara National Reserve in Kenya, it is reported that fire and grazing shifted vegetation from shrubland to grassland (Salvatori *et al.*, 2001). A similar result was reported by Ruthven *et al.* (2003) who suggested post-fire decline in many woody species. The result of our data analysis shows that the traditional method of using fire and grazing is possibly an efficient way of controlling bush encroachment. Thus, the re-introduction of fire, combined with grazing, would probably sustain the savanna ecosystems of Borana, southern Ethiopia, rather than the current policy of fire suppression.

By contrast, the current method of grazing with bush cover (GBC) did not cause a substantial change in the density of woody plants, although a few individuals perished. The loss of some individuals in response to this control method could possibly be attributed to natural mortality in relation to the life history of individual species. In southern Ethiopia, the expansion of bush encroachment has been attributed to the effect of grazing pressure (Coppock, 1993). Elsewhere bush encroachment has been shown to vary greatly according to the intensity of grazing, climatic conditions and responses of individual species (e.g. Debain *et al*., 2005). We found that under grazing with bush cover, seedling regeneration was greatly increased in some of the species (*cf* Briggs *et al.*, 2002). In another study, however, the control of grazing, rather than continuous grazing, promoted woody plant regeneration (Ayana Angassa and Gufu Oba, unpubl.).

Tree cutting alone reduced woody plant regeneration, while cutting and fire, as well as cutting, fire and grazing promoted woody regeneration in terms of coppicing. It remains unclear why the hand clearing resulted in reduced seedlings. One probable explanation is that cutting disrupts the lifecycles of individuals (Clark and Wilson, 2001), while seed dormancy might have delayed regeneration compared to the fire demonstration treatments. In general, woody plant mortality was greatest immediately after disturbance and declined thereafter in all demonstrations (see also Table 2). A similar finding in Burkina Faso (e.g. Sawadogo *et al.*, 2002) showed that the probability of mortality among woody species is greatest immediately after disturbance. Regardless of the responses of individual species, our findings suggest that four out of the six methods demonstrated seemed to control bush encroachment effectively.

Response strategies of woody species to disturbance

Survival by woody plants probably reflects the capacity of individuals to withstand damage by adapting a coppicing strategy (Vesk *et al.*, 2004; Vesk, 2006) or seedling recruitment strategies (Otterstrom *et al.*, 2006). Our findings show that mortality was relatively lower in some woody species, suggesting that these species were not vulnerable to the overall effects of the bush encroachment control demonstrations in the long-term. On the other hand, we found that a few of the species were highly vulnerable to disturbances. The lowest survival rates observed in some species (e.g. *Commiphora terebinthina, Grewia villosa* and *Ozoroa insignis*) could be explained in terms of damage to vegetative buds in the basal area as a result of tree cutting, followed by the negative effects of fire.

In the current study, all individual woody species were removed to the ground level which probably reduced recovery from coppicing. Earlier studies (e.g. Bond *et al.*, 2001; Vesk, 2006) indicated that woody plant species have different strategies for survival. Woody species with relatively lower survival rates were persistent in using alternative strategies in response to disturbance, for example by investing in seedling recruitment. We found that most encroaching species such as *Commiphora schimperi, Commiphora habessinica, Acacia bussei, Commiphora africana* and *Commiphora fluviflora* were ranked low to medium in the survival strategies, while *Acacia drepanolobium* was ranked among the top species in the survival strategies. In contrast, *Commiphora terebinthina* was ranked among the lowest species in terms of survival (coppicing), but ranked top in terms of seedling regeneration during the post-disturbance period. Our results suggest that the survival strategy by means of coppicing was the most common strategy used by woody plants in adapting to disturbance, as shown by the weak correlation between changes in total population survival (λ) and seedling recruitment.

Implications for management policy and extension

The evaluation of individual woody plants in response to different demonstrations was useful in understanding potential management strategies for controlling the growth of bush cover. By monitoring the performance of individual woody species in response to bush encroachment control methods, we showed that the different methods have varied management and policy implications. The policy of banning the use of fire in the savanna ecosystems has been largely responsible for the expansion of bush encroachment in southern

Ethiopia. Our results confirm that the combined use of fire with other disturbances substantially reduces the abundance of woody species. Overall, four out of the six demonstrations significantly reduced survival of the majority of woody plants. Specifically, the tree cutting, fire and grazing demonstration was the far superior method of reducing bush encroachment. The effectiveness of the different bush encroachment control methods in terms of total kill was in the following order of decreasing significance: tree cutting, fire and grazing (70%), tree cutting and fire (64%), tree cutting alone (59%), fire and grazing (55%), disturbance control (6%) and grazing with bush cover (2%). Similarly, seedling recruitment was greater under tree cutting, fire and grazing (597 seedlings ha^{-1}), followed by tree cutting and fire (515 seedlings ha^{-1}), disturbance control (362 seedlings ha^{-1}), fire and grazing (332 seedlings ha^{-1}), grazing with bush cover (227 seedlings ha^{-1}) and tree cutting alone (133 seedlings ha^{-1}).

The variability in terms of woody plant responses to the different demonstrations probably reflects the capacity of individuals to withstand different types of disturbances. Understanding the reaction of individual woody species to the different demonstrations will assist in guiding the development of appropriate rangeland management policies for the sustainable use of savanna ecosystems. Effective bush encroachment control methods cannot be realised unless policymakers consider the various policy implications, rather than focusing only on the suppression of fire. Further, rangeland management policies cannot succeed unless they are integrated and implemented through extension and public education. We confirmed that excluding the traditional practices of fire and grazing promoted the expansion of encroaching species.

The Borana pastoralists consider bush encroachment control as a priority for the improvement of pastoral production (Oba and Kotile, 2001). Control of bush encroachment requires changes in the overall policy for the management of savanna ecosystems that integrate the use of fire with alternative management options. Bush encroachment control systems should be supported by public education. If herder participation in the different bush encroachment control methods is to be improved, the focus should be more on participatory demonstration and extension. The evaluation of bush encroachment control methods must be based on the priorities of communities and should be integrated with fodder reserves such as range enclosures on a small scale. Extension workers would also require regular in-service training for practical application and effective communication. Finally, we suggest that bush encroachment control demonstrations for public education should focus more on herder participatory research in order to develop appropriate intervention strategies. Participatory research would more effectively promote herder adoption of management strategies for bush encroachment control.

Conclusions

The study evaluated bush encroachment control demonstration methods in the savanna ecosystems of southern Ethiopia. The findings show that four out of the six bush encroachment control demonstration methods substantially reduced the regeneration of invasive woody species, but with varied effects on individual species. The tree cutting, fire and grazing control method greatly reduced the regeneration of woody species when compared to other methods, while the disturbance control demonstration promoted the regeneration of encroaching species. Grazing with bush cover further induced the regeneration of invasive woody species in the absence of fire. The significant finding is that the majority of woody species exhibited greater coppicing as a strategy for survival, in response to disturbance. The evidence suggests that the impact of disturbances on bush encroachment is likely to be short-term and could only be sustained if repeated at appropriate intervals. Responses of individual woody species to the different bush encroachment control methods have important implications for management, conservation policy and public education, which in the future should be promoted through herder participatory research and extension.

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Table 1. Mean density of individual species ha^{-1} in 2003 (i.e. pre-demonstration) in the different demonstration plots in Borana, southern Ethiopia

	Demonstration plots						
	Type	Control	C+F	C+F+G	F+G	GBC	C
Acacia bussei Harms ex Sjostedt	I					4	4
Acacia drepanolobium Harms ex Sjostedt	I	2904	8408	1312	3248	1692	684
Acacia etbaica Schweinf.	I	16	16	12	12	8	16
Acacia mellifera (Vahl.) Benth.	I	8	7				4
Acacia nilotica (L.) Willd. ex Del.	NI	17	73	26	39	33	17
Acacia seyal Del.	I	131	141	86	122	576	70
Acacia tortilis (Forssk.) Hayne	NI	34	85	31	47	41	54
Balanites aegyptica (Van Tiegh.) Blatter	NI	16	130		24	4	4
Acacia sp. (unidentified*)*	NI	4	296	8	40	24	
Ormocarpum mimosoides (Taub.) Engl.	NI	1690	724	366	1326	4456	752
Commiphora africana (A. Rich.) Engl.	I	242	355	171	221	205	700
Commiphora fluviflora (R. Br. ex Royle) Vollesen	I	28	8	6	12	8	10
Rhus natalensis Berah. ex Krauss	NI	4	4	4		31	
Grewia tenax (Forssk.) Fiori	NI	54	16	68	262	99	42
Euphorbia cuneata ssp. spinescens (Pax) S. Carter	NI	160	96	44	22	64	72
Lannea floccosa (Chiov.) Sacleux	NI	125	35	52	71	39	72
Grewia bicolor (Forssk.) Vahl	NI	12	4	4	4	24	
Dichrostachys cinerea (L.) Wight et Arn.	NI	1932	24	220	248	276	176
Euclea divinorum Hiern.	NI				280		4
Commiphora schimperi (Berg) Engl.	I	176	168	148	140	92	220
Boscia coriacea Klotzsch	NI	56	276	48	60	76	32
Ziziphus mucronata Willd	NI	40					
Combretum molle D. Don	NI	20			4		20
Osyris quadripartita Decn	NI	60					
Boswellia neglecta S. Moore	NI	4	40			4	
Cordia gharaf (Forssk.) Ehrenb.	I			8		4	
Commiphora terebinthina Vollesen	I			4		844	
Grewia villosa Willd.	NI			8			
Commiphora habessinica (Berg) Engl.	I	112	180	70	248	116	216

I = invasive species, NI = non-invasive species, note: classification of invasiveness by species was based on herder knowledge.

Table 2. Percentage of individual woody plants in terms of mortality or total kill (TK), partial kill (PK) and coppicing, and cumulative regeneration (CR) of new seedlings ha^{-1} for the six demonstration methods (mean of 4 plots of 50 x 50 m) in Borana, southern Ethiopia.

	Demonstration methods																					
	Control			C+F				C+F+G				F+G				GBC			C			
	M	PM	CR	TK	PK	C	CR	TK	PK	C	CR	TK	PK	C	CR	M	PM	CR	TK	PK	C	CR
Acacia bussei Harms ex Sjostedt																					100	
Acacia drepanolobium Harms ex Sjostedt	1		260	51	12	37	86	57		43	240	56	1	43	110	1		142	44		56	18
Acacia etbaica Schweinf.			6	100				80		20	2			100				2	71		28	
Acacia mellifera (Vahl.) Benth.				100															50		50	
Acacia nilotica (L.) Willd. ex Del.				69	5	26		71		29	5	62	2	36	4				17		83	
Acacia seyal Del.				35	1	64	4	45		55	12	32		68	14	12		4	69		31	7
Acacia tortilis (Forssk.) Hayne				41		59	12	49			7	45		55	2			6	61		39	4
Balanites aegyptica (Van Tiegh.) Blatter				71		29	4					66	1	33				24			100	
Pappea capensis Eckl. & Zey														100								
Acacia sp. (unidentified*)*				73	5	27	24	50		50	20			100	12							
Ormocarpum mimosoides (Taub.) Engl.			2	73		27	204	50		50	78	31	1	68	94	4		6	41		59	20
Commiphora africana (A. Rich.) Engl.	7		24	75		25	25	86		14	116	67	1	32	13	3		24	80		20	34
Commiphora fluviflora (R. Br. ex Royle) Vollesen			61	100				100				67		33	17				58		42	
Rhus natalensis Berah. ex Krauss						100		50		50												
Grewia tenax (Forssk.) Fiori				57		43		68		32	5	49		51					57		43	6
*Euphorbia cuneata ssp. spinescens (*Pax) S. Carter				79	2	19	8	36	3	61		87	1	12					89		11	
Ozoroa insignis Del.								100			8											
*Lannea floccosa (*Chiov.) Sacleux	12		4	70		30		60		40	9	31		69	10			8	48	1	51	4
Grewia bicolor (Forssk.) Vahl				100						100		50		50				12				
Dichrostachys cinerea (L.) Wight et Arn.				67		33	112	65		35	44	33	1	66	32				43		57	28
Euclea divinorum Hiern.												86		14					100			
Commiphora schimperi (Berg) Engl.	5			29		71	32	72		28	44	71		29				12	84		16	8
Boscia coriacea Klotzsch				65		35		100				80		20					100			
Combretum molle D. Don			1									100			8				86		14	
Boswellia neglecta S. Moore	100		2	50		50																
Cordia gharaf (Forssk.) Ehrenb.								50		50	5											
Commiphora terebinthina Vollesen								100										3				
Grewia villosa Willd.								100														
Commiphora habessinica (Berg) Engl.	19		2	37		63	4	86		14	2	84		16	16	14		8	86		13	4
Mean mortality of individuals (%)	6			64				70				55				2			59			
Total cumulative regeneration			362				515				597				332			251				133

Table 3. Chi-square (χ^2-tests) for individual woody species percentage mortality in response to the different demonstrations in Borana, southern Ethiopia

	Demonstration plots					
	Control	C+F	C+F+G	F+G	GBC	C
Acacia bussei Harms ex Sjostedt					0.0^{NS}	NS
Acacia drepanolobium Harms ex Sjostedt	338.9***	12.1**	5709.1***	1442.1***	233.3***	4469.8***
Acacia etbaica Schweinf.	NS	20.6***	NS	NS	NS	4735.0***
Acacia mellifera (Vahl.) Benth.	NS	3417.1***				NS
Acacia nilotica (L.) Willd. ex Del.	NS	0.1^{NS}	4576.2***	7355.5***	NS	4710.2***
Acacia seyal Del.	NS	1.4 ^{NS}	5428.3***	9920.3***	9918.9^{NS}	4622.3***
Acacia tortilis (Forssk.) Hayne	NS	4.8*	5213.2***	6304.6***	NS	5235.9***
Balanites aegyptica (Van Tiegh.) Blatter	NS	0.4 ^{NS}		5361.9***	NS	NS
Acacia sp. (unidentified*)*	NS	4.4*	4981.3***	NS	NS	
Ormocarpum mimosoides (Taub.) Engl.	NS	33.4***	5551.2***	4918.0***	3346.4***	4843.9***
Commiphora africana (A. Rich.) Engl.	4398.8***	6.0*	5920.1***	1936.1***	4549.7***	5596.0***
Commiphora fluviflora (R. Br. ex Royle) Vollesen	NS	77.4***	NS	NS	NS	4938.4***
Rhus natalensis Berah. ex Krauss	NS	NS	NS		NS	3925.2***
Grewia tenax (Forssk.) Fiori	NS	0.32 ^{NS}	5263.3***	9252.4***	NS	5146.1***
Euphorbia cuneata ssp. spinescens (Pax) S. Carter	NS	10.0**	4543.5***	NS	NS	1863.2***
Lannea floccosa (Chiov.) Sacleux	4812.7***	5.5*	5976.9***	7819.0***	NS	4383.1***
Grewia bicolor (Forssk.) Vahl	NS	NS	NS	NS	NS	
Dichrostachys cinerea (L.) Wight et Arn.	NS	24.9***	5329.5***	1064.5***	NS	4917.0***
Euclea divinorum Hiern.						NS
Commiphora schimperi (Berg) Engl.	NS	NS	NS	NS	NS	NS
Boscia coriacea Klotzsch	NS	NS	3448.9***	NS	NS	4207.5***
Combretum molle D. Don	NS			NS		NS
Boswellia neglecta S. Moore	NS	8.8**			NS	
Cordia gharaf (Forssk.) Ehrenb.			4981.3***			
Commiphora terebinthina Vollesen			NS		NS	NS
Grewia villosa Willd.			NS			
Commiphora habessinica (Berg) Engl.	5040.0***	NS	5571.2***	1485.5***	NS	3700.7***

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, NS Not significant

Table 4. Chi-square (χ^2-tests) for individual woody species in terms of cumulative regeneration of seedlings in response to the different demonstrations in Borana, southern Ethiopia

	Demonstration plots					
	Control	C+F	C+F+G	F+G	GBC	C
Acacia bussei Harms ex Sjostedt					NS	NS
Acacia drepanolobium Harms ex Sjostedt	2764.1***	43.1***	1887.3***	273.4***	1174.5***	NS
Acacia etbaica Schweinf.	797.5***	NS	362.6***	NS	NS	NS
Acacia mellifera (Vahl.) Benth.	NS					NS
Acacia nilotica (L.) Willd. ex Del.	NS	NS	1223.1***	266.6***	314.0***	NS
Acacia seyal Del.	NS	3.9*	1315.2***	300.8***	553.6***	1351.3***
Acacia tortilis (Forssk.) Hayne	NS	0.1 NS	856.0***	216.5***	516.1***	828.2***
Acacia goetzei Harms					NS	
Balanites aegyptica (Van Tiegh.) Blatter	NS	3.6 NS		NS	771.9***	NS
Acacia sp. (unidentified)	NS	2.7 NS	1011.7***	254.1***	NS	
Ormocarpum mimosoides (Taub.) Engl.	1604.7***	0.3 NS	2270.2***	304.3***	395.0***	1028.7***
Commiphora africana (A. Rich.) Engl.	2992.6***	3.9*	2894.3***	275.6***	1118.6***	1551.6***
Commiphora fluviflora (R. Br. ex Royle) Vollesen	799.7***	NS	NS	261.2***	NS	0.0 NS
Rhus natalensis Berah. ex Krauss	NS	NS	NS		NS	0.0 NS
Grewia tenax (Forssk.) Fiori	NS	NS	1014.8***	149.1***	NS	886.7***
*Euphorbia cuneata ssp. spinescens (*Pax) S. Carter	NS	0.9 NS	0.0 NS	NS	NS	0.0 NS
Lannea floccosa (Chiov.) Sacleux	961.7***	1.1 NS	1467.6***	265.9***	791.9***	639.3***
Grewia bicolor (Forssk.) Vahl	NS	NS	NS	NS	724.2***	
Dichrostachys cinerea (L.) Wight et Arn.	NS	27.6***	1640.3***	300.8***	NS	NS
Euclea divinorum Hiern.				NS		NS
Commiphora schimperi (Berg) Engl.	NS	NS	NS	NS	NS	NS
Boscia coriacea Klotzsch	NS	NS	NS	NS		NS
Combretum molle D. Don	NS			NS		NS
Boswellia neglecta S. Moore	387.0***	NS			NS	
Cordia gharaf (Forssk.) Ehrenb.			NS		NS	
Commiphora terebinthina Vollesen			NS		NS	NS
Grewia villosa Willd.			NS			
Commiphora habessinica (Berg) Engl.	1546.1***	5.0*	329.6***	180.4***	491.6***	NS

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, NS Not significant

Table 5. Responses of the 29 woody species to fire following tree cutting in the different demonstration plots. Indicators of species strategy are: percent survival (coppicing), and change in seedling densities [mean change = (Δ mean demonstration plots - Δ mean control plots) /mean pre-demonstration density].

Species	No. of individuals observed	Coppicing (%)	Δ seedling density	Rank Survival	Rank seedling	λ	Disturbance tolerant
Acacia seyal Del.	183	55.0	0.21	1	5	55.21	
Acacia tortilis (Forssk.) Hayne	48	51.4	-0.02	2	16	51.39	
Ormocarpum mimosoides (Taub.) Engl.	1411	51.3	-0.09	3	17	51.21	
Acacia drepanolobium Harms ex Sjostedt	3054	47.8	-0.93	4	22	46.87	
Lannea floccosa (Chiov.) Sacleux	65	47.6	-1.67	6	26	45.93	
Dichrostachys cinerea (L.) Wight et Arn.	479	47.8	-1.96	5	28	45.84	
Acacia sp. (unidentified)	60	43.9	0.19	8	6	44.09	
Acacia nilotica (L.) Willd. ex Del.	36	45.0	-1.29	7	24	43.71	
Grewia tenax (Forssk.) Fiori	101	42.2	0.30	9	4	42.50	
Balanites aegyptica (Van Tiegh.) Blatter	51	40.6	-0.58	10	21	40.02	
Rhus natalensis Berah. ex Krauss	16	37.5	0.33	11	3	37.83	
Grewia bicolor (Forssk.) Vahl	9	37.5	0.0	12	7	37.5	
Acacia etbaica Schweinf.	14	37.2	-0.17	13	18	37.03	
Commiphora schimperi (Berg) Engl.	147	36.1	-0.28	14	19	35.82	
Combretum molle D. Don	17	28.6	0.0	15	7	28.6	
Commiphora habessinica (Berg) Engl.	126	26.8	-1.22	17	23	25.58	
Acacia bussei Harms ex Sjostedt	4	25.0	0.0	18	7	25.0	
Pappea capensis Eckl. & Zey	30	25.0	0.0	19	7	25.0	
Euphorbia cuneata ssp. spinescens (Pax) S. Carter	68	27.0	-2.60	16	29	24.40	
Commiphora africana (A. Rich.) Engl.	277	22.9	-0.39	20	20	22.51	
Commiphora fluviflora (R. Br. ex Royle) Vollesen	11	18.8	-1.40	21	25	17.4	
Boscia coriacea Klotzsch	54	13.8	0.50	22	2	14.3	
Boswellia neglecta S. Moore	16	12.5	0.0	24	7	12.5	
Cordia gharaf (Forssk.) Ehrenb.	6	12.5	0.0	25	7	12.5	
Acacia mellifera (Vahl.) Benth.	5	12.5	-1.8	23	27	10.7	
Euclea divinorum Hiern.	142	3.6	0.0	26	7	3.6	
Commiphora terebinthina Vollesen	424	0.0	1.0	27	1	1.0	
Grewia villosa Willd.	8	0.0	0.0	27	7	0.0	
Ozoroa insignis Del.	4	0.0	0.0	27	7	0.0	Disturbance vulnerable

Species are assigned a number based on their rank order for fire responses after cutting in terms of survival and seedling changes. Lambda- λ is the proportion of individuals surviving + changes in seedling density.

PAPER V

Demonstration of bush encroachment control in Borana, southern Ethiopia: 2. Evaluation of tree cutting, fire and grazing on herbaceous vegetation

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Abstract

The rehabilitation of bush encroached rangelands in savanna ecosystems in southern Ethiopia aims at promoting herbaceous vegetation production and increasing biodiversity. Different bush encroachment control methods may indicate different management scenarios that will have practical implications for public education on range improvement. In this study, we demonstrated the effects of six bush encroachment control methods, namely disturbance control (CO), tree cutting and fire (C+F), tree cutting, fire and grazing (C+F+G), the old traditional method of fire and grazing (F+G), grazing with bush cover (GBC) and tree cutting alone (C), on herbaceous species composition, relative abundance of species, biomass, basal cover and species diversity, on two ranches between June 2003 and 2005.

The disturbance control treatment showed no advantage in terms of biomass and basal cover over other treatments, although herbaceous species richness was improved. Bush removal methods such as tree cutting and fire, tree cutting followed by fire and grazing, the traditional method of fire and grazing, and tree cutting alone improved herbaceous biomass, basal cover and species diversity, while grazing with bush cover (the current system of land use) greatly reduced herbaceous biomass. Tree cutting and fire treatments seemed superior in terms of herbaceous biomass, while conservation of herbaceous species diversity was improved more by the traditional method of fire and grazing, and tree cutting. With the exception of species richness, protection from disturbance showed no advantage. The outcomes in terms of herbaceous biomass and herbaceous plant biodiversity have important policy implications for bush encroachment control and public education. We suggest that only fire and grazing methods can reasonably be applied for the control of bush encroachment with the overall objective of promoting biomass production and species diversity. The paper discusses specific policies and public education for future bush encroachment control programs in the Borana rangelands.

Keywords: bush encroachment control, demonstration methods, herbaceous vegetation, policy implication, public education, southern Ethiopia

Introduction

Savanna grasslands are threatened by bush encroachment (Scholes and Archer, 1997; Oba *et al*., 2000; Smit and Rethman, 2000; Sheuyange *et al*., 2005; Wiegand *et al*., 2005) particularly through the suppression of herbaceous biomass production and probably also by reduced biodiversity (Smit, 2003; Hagos and Smit, 2005; Ansley and Castellano, 2006). The threat to the pastoral economy is often the main reason for the control of bush encroachment (Olson and Whitson, 2002). Bush encroachment control methods are disturbance methods that reduce that threat. According to Pickett and White (1985), disturbances are discrete events that disrupt the plant community structure through transformations of biotic environments and habitat conditions in which colonization of the disturbed microhabitat takes place. The shift towards herbaceous species dominance induces succession processes where species that tolerate bush cover are replaced by intolerant species (Clarke *et al*., 2005). Bush encroachment control methods shift the savanna vegetation from dominance by woody vegetation to dominance by herbaceous vegetation (Fulbright, 1996; Hudak, 1999). Disturbances of natural vegetation could cause partial or total reduction of plant biomass (Grime, 1977) and shift vegetation structure and composition (Łaska, 2001). Disturbance can also produce changes in the life history strategies of individual species in response to intensities of disturbance forces (Grime, 1974, 1977). The responses by herbaceous species might vary under different bush encroachment control methods and micro-environmental conditions (Vetaas, 1992).

In savanna ecosystems, different bush encroachment control methods including hand removal of trees (Berlow *et al*., 2003; Smit, 2003, 2004), wildfire (Sheuyange *et al*., 2005), a combination of hand removal and burning (Duggin and Gentle, 1998; Olson and Whitson, 2002), tree cutting combined with fire and grazing (Kobayashi *et al*., 1997; Sawadogo *et al*., 2002, 2005), fire combined with grazing (Fuhlendorf and Engle, 2004; Sawadogo *et al*., 2005) and grazing control (Corra, 1986; Fulbright, 1996; Olson and Whitson, 2002; Smit, 2004; Bates, 2005) are commonly used to increase herbaceous production and species diversity (Smit, 2003; Ansley and Castellano, 2006). Bates (2005) showed that tree cutting and prescribed fire followed by rest from grazing by livestock enhanced herbaceous plant biodiversity. Kobayashi *et al*. (1997) and Sawadogo *et al*. (2005) also studied the effects of tree cutting, fire and grazing on the responses of herbaceous plants. Hutchinson *et al*. (2005) observed changes in herbaceous species richness following prescribed fire, while Fuhlendorf and Engle (2004) reported the importance of fire and grazing in the maintenance and restoration of savanna grasslands. Cutting is effective in increasing herbaceous biomass, cover and diversity (Bates *et al*., 2000). Changes in relative abundance of herbaceous species over time may be a good indicator of species' responses to disturbances compared to pre-disturbance populations. Elsewhere, the importance of bush encroachment control in promoting relative abundance of herbaceous species has been shown (Hadar *et al*., 1999). Relative abundance serves as a proxy of plant populations that could vary in response to disturbances. The effects of different bush encroachment control methods on herbaceous production and diversity can be evaluated in terms of effectiveness of herbaceous species performances (Fulbright, 1996).

Bush encroachment control demonstration methods are management systems (Fulbright, 1996) that might have varied policy implications for bush cover control (e.g. Olson and Whitson, 2002). Understanding the potential role of bush encroachment control methods for promoting herbaceous species composition requires recognition of the objectives of resource users and policymakers. The resource users are interested in livestock production, while the goal of policymakers is environmental preservation. The public is likely to adopt management systems that are more efficient in improving forage for livestock grazing, while official government policy promotes the conservation of biodiversity. Although the effects of bush encroachment control methods on herbaceous plants have been well documented (e.g. Corra, 1986; Hadar *et al*., 1999; Angassa, 2002; Sawadogo *et al*., 2002, 2005; Smit, 2003, 2004; Ansley and Castellano, 2006), information regarding the potential role of such demonstrations in influencing public education policies is limited.

In the Borana pastoral region of southern Ethiopia, which is the focus of the present study, we are not aware of other efforts in which bush encroachment control methods were purposely used to evaluate responses of individual herbaceous species and to recommend public education policy. Researchers and the extension departments concerned with grazing lands rarely design bush encroachment controls to promote the management of bush cover or discuss the educational benefits of different methods in terms of long-term changes in the relative abundance of herbaceous species and biomass for livestock forage. Monitoring the effects of various control methods is useful in highlighting single and combined effects of disturbances on herbaceous vegetation, by providing evidence of changes in species composition over time. We monitored the effects of six demonstration methods including disturbance control (CO), tree cutting and fire (C+F), tree cutting, fire and grazing (C+F+G), fire and grazing (F+G) (which is the old traditional method practiced by pastoralists before the official ban on the use of fire), grazing with bush cover (GBC) (which represents the current method of pastoral land use), and tree cutting alone (C) on: (a) changes in species composition and the relative abundance of individuals of each herbaceous species; (b) trends in the relative abundance of herbaceous species; (c) performances of individual herbaceous species in response to the effects of different demonstration methods; and (d) changes in biomass, basal cover and species diversity between the pre- and post- treatment sampling periods. The findings are then discussed in the light of policy guidelines for bush encroachment control, as well as recommendations for sound public education on the management of the savanna ecosystems in southern Ethiopia.

Materials and methods

Study area and experimental design

We demonstrated bush encroachment control methods replicated across the government cattle breeding ranch (in Dida-Tuyura 04º57.383´N, 38º12.403E´) and community ranch (in Dambala-Wachu, 04º29.432´N, 38º16.339´E) in southern Ethiopia. Through demonstrations and planned educational visits, the extension departments and the communities are expected to repeat the different bush encroachment control methods. Full descriptions of the study area and demonstration treatments have been given (see Ayana Angassa and Gufu Oba, unpubl. Part 1).

Six demonstrations were conducted, including disturbance control (CO) that represented the government policy to exclude fire, grazing and tree cutting, in which grazing was excluded by fencing. The second demonstration treatment combined tree cutting and fire (C+F) and the third method was tree cutting followed by fire and grazing (C+F+G). The fourth demonstration represented the old traditional system that combines fire and grazing management (F+G), for which fencing was not necessary. The fifth demonstration, grazing with bush cover (GBC), represented the current form of land use; for the sixth demonstration, all trees were hand cleared followed by protection from livestock grazing (C). All the six bush encroachment control demonstrations were distributed randomly in the uplands and bottomlands at the two ranches. In this study, we focused on the performances of individual herbaceous species between the pre- and post-demonstration treatments. However, the design of the experiment was not intended to compare directly the performances of different treatments; rather, the results were used to infer what would happen if the recommended management scenarios were adopted for the control of bush encroachment. More importantly, we used the results to inform the lessons that the general public would gain.

For all demonstration treatments in both topographic locations, we randomly distributed 24, 50 x 50 m plots. In these larger plots, we randomly located three smaller 1 x 1 m plots for sampling herbaceous vegetation during pre-treatment in 2003. Sampling was repeated on the same plots during the post-demonstration phases in 2004 and 2005. During each sampling process, all the herbaceous species were identified (where species could not be identified the voucher samples were collected for later identification), and numbers of individuals of each species (i.e. relative abundance) and the species richness were counted per plot per census (i.e. total count of all species per plot). Unidentified herbs and forbs, hereafter referred to as "other herbaceous species" and "herbaceous legumes", were also included in species richness. The species diversity index, $H' = -(\sum (p_i \ln p_i))$ (Shannon, 1948) was calculated using the frequency of each plant species (where pi represents the proportion of individual species in each plot). The basal cover of root crown in relation to the bare ground was estimated for each species or categories of species (i.e. for unidentified herbaceous and leguminous species). All the herbaceous plants in the sample plots were hand harvested. The combined samples of the species were air dried followed by oven drying at 65°C for 48 hours, for the purpose of dry matter estimation.

Data analysis

We report mean values (i.e. by combining data from the two ranches and the two landscape locations), by sampling dates, by demonstration treatments. We used a general linear model to analyze the pre- and post-disturbance mean (±SE) of the relative abundance of individual species. We used descriptive statistics to calculate relative changes (i.e. differences in relative abundance − represented by numbers of individuals of each species between the pre- and post-disturbance) of individual species m^{-2}. A chi-square test was used to analyze changes in the relative abundance of individual species, to determine their susceptibility to the effects of the demonstration, following the methods of Sweet and Tacheba (1984). Least square means were used to analyze changes in biomass, basal cover and diversity between the pre- and the post-disturbance for each treatment.

Results

Disturbance control

Prior to protection, the disturbance control (CO) demonstration had 9 herbaceous species, which after two years of protection increased to 18 (Tables 1 and 2). New species recorded included: *Aristida adoensis, Bothriochloa radicans, Digitaria milanjiana, Enteropogon somalensis, Harpachne schimperi, Heteropogon contortus* and *Panicum turgidum* (Tables 2 and 3). *Cenchrus ciliaris, Chloris roxburghiana, Leptothrium senegalense, Panicum coloratum* and *Sporobolus pyramidalis* increased in relative abundance in response to protection, while *Eragrostis papposa* and *Panicum maximum* were reduced (Tables 1, 2, 3 and 4). We found no changes in the relative abundance of *Chrysopogon aucheri* and *Themeda triandra* in response to protection (Tables 1, 2 and 3). Before protection, the most abundant species was *Eragrostis papposa* followed by *Panicum maximum*, while *Bothriochloa radicans* was the most abundant species after two years of protection (Tables 1 and 2). Protection did not increase herbaceous biomass, basal cover and diversity (Figs 1 a, b, c).

Tree cutting and fire

The tree cutting and fire (C+F) demonstration increased herbaceous species richness from 9 (i.e. pre-disturbance) to 15 (i.e. after disturbance) (Tables 1 and 2). Of the initial herbaceous species, *Cenchrus ciliaris* and *Chrysopogon aucheri* increased in relative abundance, while about 78% of the pre-treatment species showed a decline (Tables 1, 2 and 3). Only in the case of *Sporobolus pyramidalis* was the decline significant (Tables 3 and 4). Generally, the most abundant species was *Sporobolus pyramidalis* followed by *Eragrostis papposa* preceding disturbance, while *Chrysopogon aucheri* was relatively abundant during post-disturbance (Tables 1 and 2). Herbaceous biomass and species diversity, but not basal cover, were greatly promoted during the post-disturbance period (i.e. in 2005) compared to the pre-disturbance period (Figs 1 a, b, c).

Tree cutting, fire and grazing

In response to tree cutting, fire and grazing (C+F+G), herbaceous species richness increased from 9 (i.e. pre-disturbance) to 17 (i.e. after disturbance) (Tables 1 and 2). The species *Bothriochloa radicans, Cynodon dactylon, Enteropogon somalensis, Eragrostis sennii, Heteropogon contortus, Panicum turgidum* and *Sporobolus pyramidalis* were not captured during the pre-demonstration sampling, but were recorded after disturbance (Tables 2 and 3). Among the initial herbaceous species, only *Leptothrium senegalense* was greatly promoted by the combined effects of tree cutting, fire and grazing (Table 3). Hence, tree cutting, fire and grazing reduced relative abundance of most herbaceous species at first, followed later by increases (Tables 1, 2 and 3). The decline of *Chloris roxburghiana, Eragrostis papposa* and *Panicum coloratum* was significant (Tables 3 and 4). The species absent from the post-demonstration period was *Aristida adoensis,* while the species that declined were *Eragrostis papposa* and *Lintonia nutans*. *Eragrostis papposa* appeared to be the most abundant species prior to disturbance, but *Sporobolus pyramidalis* increased in abundance following disturbance (Tables 1 and 2). Herbaceous biomass and diversity, but not basal cover, showed increases during the post-demonstration periods (Figs 1 a, b, c).

Fire and grazing

The fire and grazing (F+G) demonstration promoted herbaceous species richness from 11 (i.e. pre-disturbance) to 21 (i.e. after disturbance) (Tables 1, 2 and 3). *Enteropogon somalensis, Panicum maximum* and *Pennisetum stramineum* increased in abundance (Tables 3 and 4). However, about 82% of the individuals declined in relative abundance during the post-disturbance periods (Tables 1, 2 and 3). Among the species that showed significant declining trends were *Cenchrus ciliaris, Sporobolus pyramidalis* and *Themeda triandra* (Tables 3 and 4). The species most vulnerable to fire and grazing and also absent from the post-demonstration periods were *Aristida adoensis* and *Leptothrium senegalense* (Tables 2 and 3). The two most tolerant species were *Heteropogon contortus* and *Sporobolus pyramidalis*. Herbaceous biomass and diversity, but not basal cover, increased in response to fire and grazing (Figs 1 a, b, c).

Grazing with bush cover

Grazing with bush cover (GBC) promoted herbaceous species richness from 11 to 20 species (Tables 1, 2 and 3). Among the initial herbaceous populations, the species that positively responded to grazing with bush cover were *Cenchrus ciliaris, Hyparrhenia hirta* and *Panicum coloratum* (Tables 3 and 4). Among the key species that showed significant declines in relative abundance were *Chrysopogon aucheri, Eragrostis papposa, Pennisetum stramineum, Sporobolus pyramidalis* and *Themeda triandra* (Tables 3 and 4), while *Lintonia nutans* showed stability in response to grazing (Tables 1, 2 and 3). *Chrysopogon aucheri* was the most abundant species during pre-disturbance, while *Sporobolus pyramidalis* was more abundant after disturbance (Tables 1 and 2). Grazing with bush cover reduced herbaceous biomass and basal cover, while species diversity was promoted (Figs 1a, b, c).

Tree cutting

Compared to the initial populations, herbaceous species richness doubled during the post-demonstration period in response to tree clearing (Tables 1, 2 and 3). Among the newly recorded species, the changes were significant for *Bothriochloa radicans, Heteropogon contortus* and *Panicum maximum* (Tables 3 and 4). Among the initial herbaceous species recorded (n = 10 herbaceous species), about 70% exhibited declining trends (Tables 1, 2 and 3). Overall, *Aristida adoensis*, *Chrysopogon aucheri, Eragrostis papposa, Lintonia nutans* and *Themeda triandra* were greatly reduced in response to tree cutting (Tables 3 and 4). The species most sensitive to the tree cutting treatments were *Leptothrium senegalense* and *Lintonia nutans* (Tables 2 and 3), while the most stable species were *Sporobolus pyramidalis* and *Bothriochloa radicans*. Herbaceous biomass and diversity increased by nearly 50% compared to the pre-cutting period, while basal cover showed no improvement (Figs 1 a, b, c).

Discussion

Disturbance control

The official policy of banning the use of fire was aimed at conserving woody vegetation, but was less concerned with herbaceous vegetation. For the local herders, bush encroachment threatens the production of herbaceous vegetation, which is the feed for the grazing livestock. We were therefore interested to know if the long-term effects of bush encroachment could be reflected by the performances of individual herbaceous species. We showed that species richness under the disturbance control method was comparable to the disturbance treatments (see below). The dynamics of herbaceous species under bush encroachment are likely to have been influenced by environmental conditions associated with bush cover. Bush cover creates microhabitats that favor some species that were less common in the open (disturbed) habitats. Species that were tolerant to bush cover were promoted, while those that were intolerant were reduced in the absence of disturbance (Clarke *et al*., 2005; Osem *et al*., 2002). The dynamics of herbaceous species under bush cover probably reflect the role played by the soil seed bank (Solomon *et al*., 2006), which might account for the new species. We also considered potential competition between herbaceous species and bushy plants. We confirmed herder concerns about the negative role of bush cover on herbaceous biomass production. Our data also showed that herbaceous plant basal cover and herbaceous species diversity are not promoted under bush cover (*cf.* Jacobs and Schloeder, 2003). The evidence might suggest that protection from human induced disturbances, as promoted by state conservation policies, has failed to promote production of herbaceous biomass which is contrary to herder objectives.

Tree cutting and fire

The control of bush encroachment by means of tree cutting and fire increased the richness and relative abundance of herbaceous species during post-disturbance periods. The new herbaceous species that were recorded in response to the tree cutting and fire treatments are probably those that decreased under bush encroachment. These species responded more positively to disturbance, which might suggest that they would be poor competitors under conditions of bush encroachment (Duggin and Gentle, 1998; Berlow *et al*., 2003). Under these disturbance conditions, the bush cover tolerant species became poor competitors. The initial decline in the relative abundance of most herbaceous species to tree cutting and fire was probably related to shifts in the micro-environment following the removal of ecologically important trees. The bush cover tolerant species were reduced, while the intolerant species were promoted. Furthermore, the species that declined were probably more sensitive to fire than the other (fire tolerant) species. We confirmed that combinations of tree cutting and fire promoted herbaceous biomass more than cutting or fire alone (see later section). Woody plant encroachment control followed by resting would improve the restoration of herbaceous biomass and plants biodiversity over time. In terms of management, the C+F demonstration methods created a dilemma between conserving disturbance-sensitive herbaceous species and promoting the disturbance-tolerant species. For the herders, the demonstration showed more beneficial gains in terms of biomass in the long-term, although in the short-term the benefits were less. This demonstration treatment suggests that the management strategy needs to be planned so that treatments are followed by rest, at least for a year or two, before grazing by livestock is resumed. This kind of management strategy has been promoted by the community during previous decades and is more appropriate for range enclosures near settlements (Ayana Angassa and Gufu Oba unpubl.).

Tree cutting, fire and grazing

The combination of tree cutting, fire and grazing (C+F+G) differed from C+F by introducing grazing into the treatment, and evaluating plant performances thereafter. This demonstration method represented active management, and by not excluding livestock grazing, was more likely to be acceptable to the herders. Our data showed that herbaceous species richness was highly promoted. The combined treatments might have improved growth conditions for the species which increased (11%), while the species that declined in abundance (89%) were probably less tolerant to the treatment combinations. The post-demonstration species reflected both seasonal dynamics controlled by climate variability and improved environmental conditions for seed germination. For the most sensitive species, tree cutting, fire and grazing disturbances were initially followed by decline in relative abundance (Kobayashi *et al*., 1997). This decline could be explained either as a result of competition for resources among species (Clarke *et al*., 2005), seasonal fluctuations in relation to the life history of individual species (e.g. Elliott *et al*., 1997; Deil, 2005; Götmark *et al*., 2005) or variations in the soil seed bank (see Solomon *et al*., 2006). Other species declined due to lack of tolerance to disturbance (Osem *et al*., 2002). Our results suggest that tree cutting, fire and grazing treatments were soon followed by decline in herbaceous biomass, basal cover and diversity, but in the long-term the effects were positive on herbaceous biomass and diversity.

The decline in herbaceous biomass soon after disturbance may be attributed to the effect of tree removal that reduced bush cover tolerant species, which were dominant prior to the treatments. It is possible that the treatments reduced the abundance of the bush cover tolerant species and therefore the biomass. After the treatments, the species that tolerated disturbance took a while to build and produce more biomass. For purposes of management, therefore, it appears that grazing might need to be delayed after the hand removal and burning of the woody vegetation. The introduction of grazing after resting might allow a rapid build-up of the biomass. Currently in southern Ethiopia, this type of management has been initiated through the activities of Non-Governmental Organizations (NGOs) that utilize community labor to clear land in limited areas. However, regulations for grazing systems (e.g. rest followed by grazing) have not been put in place, other than those used by the Borana herders, which involves resting of the treated areas during the wet season and grazing the fallow during the dry season by young and old livestock.

Community adaptation of the system would be constrained by a shortage of labor for land clearing. Thus, the use of these demonstration methods would be more viable in areas near settlements, where the community often grazes calves and old animals or saves fodder reserves for the dry and drought periods. The usual practice is for women to travel long distances to collect hay for calves kept at home. The C+F+G demonstration method could easily be incorporated into the traditional system of pasture management, if it is aimed at community management of fodder for the most vulnerable animal classes (e.g. calves and old animals). However, this method is unlikely to be suited to the wider rangelands that are currently suffering from bush encroachment, due to the cost of land rehabilitation. We therefore emphasize the importance of these demonstration methods for pasture management at settlement levels, which could easily be integrated into the existing systems of land use.

Fire and grazing

The fire and grazing combination represents the old traditional system of rangeland management used by the Borana pastoralists. Traditionally, the society burnt areas of the range periodically where bush cover posed a threat or the grass layer was over-mature and losing its nutritive value. The fire killed young woody plants and opened up the under-story vegetation for better growth of herbaceous vegetation. The system of burning was not random, but planned. It is therefore important to understand the responses of herbaceous species to fire and grazing under conditions comparable to the traditional system of fire use. The method of fire management by the community had to be abandoned because of the official policy of forest land conservation (Ayana Angassa and Gufu Oba, unpublished).

The response to the F+G treatment showed that this system of bush encroachment management promotes herbaceous species richness (Sawadogo *et al*., 2005). First, reduced competition from bushy species and increased availability of soil nutrients might have fertilizing effects. Second, fire and grazing could play complementary roles (Fuhlendorf and Engle, 2004). The observed increase in the relative abundance of some species in response to fire and grazing could be interpreted in terms of the removal of old growth and the rejuvenation of disturbance tolerant species. Conversely, the decline of a few species after fire and grazing was probably related to sensitivity to fire damage. The present findings suggest that fire and grazing significantly increase the relative abundance of most species, probably as a result of increased grazing pressure following fire (Fuhlendorf and Engle, 2004). The findings suggest that fire and grazing could play an important role in maintaining herbaceous species richness and diversity. It was also found that the short-term effects of fire and grazing seem to exert considerable influence on herbaceous biomass and basal cover which were promoted in the long-term.

The official banning of fire had previously assumed that the use of fire would be damaging to the rangeland ecosystems. This assumption is not supported when the response of the herbaceous vegetation to fire and grazing is considered in the long-term. Our results suggest that the traditional system is more beneficial from the perspective of biomass production and species diversity, if rest after fire is followed by grazing. Traditionally, the Borana herders utilized the burned areas (called *guuba*) after the growth following the early rains and then shifted grazing to older burned areas. Through the rotational use of landscapes with different fire histories (e.g. Sheuyange *et al*., 2005), they maintained the savanna system in the most productive state.

This demonstration method is widely acceptable to the local communities. It is a system of grazing that can be applied to the wider rangelands without requiring additional labor or other expenses. The difference with our demonstration was that the traditional application of fire was not restricted. Rather, the fire was able to spread beyond the demonstration plots, into those areas where the herders did not intend to burn. The usual practice is to avoid burning of settlement rangelands and of drought fodder reserves (Ayana Angassa and Gufu Oba unpubl.). In the long-term, the demonstration achieved both conservation of biodiversity and increased biomass production. The system appears to meet the objectives of both conservation and livestock grazing. We therefore suggest that the ban on the use of fire in the savanna ecosystem of southern Ethiopia be reconsidered.

Grazing with bush cover

The current system of range management, in which the use of fire has been banned, promotes grazing and bush cover. For the official policymakers, this is the least expensive method of land use, although the exclusion of fire has made the rangelands less productive for the pastoralists in terms of livestock farming. The grazing with bush cover system of management showed that herbaceous species richness could be increased. The probable explanation for the addition of new species could be linked to the performance of bush cover tolerant species that were promoted under this demonstration method. Osem *et al*. (2002) suggested that grazing might favor the recovery of some herbaceous species by suppressing competing species. For example, the observed increase in the relative abundance of a few species under grazing may be attributed to the capacity of individual species to withstand the effect of grazing.

It should be appreciated that bush cover physically constrains livestock grazing, thereby promoting grazing sensitive species that are protected under impenetrable thickets, while in the open areas where the livestock has easier access to grazing, grazing tolerant species were promoted. Similarly, Clarke *et al*. (2005) reported declines in the abundance of herbaceous species under grazing due to selective grazing that promoted disturbance tolerant species over grazing intolerant species. From our results, we inferred that grazing might have negative effects on the relative abundance of some herbaceous species, either in the short- or long-term, depending on the life history of individual species (i.e. annuals and perennials). Fuhlendorf and Engle (2004) suggested that grazing can be sustainable on most rangelands, but the long-term effects may lead to the loss of herbaceous species.

The effect of disturbance such as grazing with bush cover might favor the recovery of some species in the short-term, but in the long-term it may not promote successful establishment. Subsequent failure is probably related to rainfall variability and competition for resources under grazing (Duggin and Gentle, 1998). The significance of the decline in herbaceous biomass may be attributed to the combined effects of grazing pressure and bush cover. Grazing with bush cover reduced the basal cover of herbaceous species, although herbaceous species diversity improved over time.

Tree cutting

The hand clearing of encroached bush should be acceptable to the extension departments, because it suggests benefits to the herders without introducing fire into the environment. Under the tree cutting method, our results showed an increase in the richness of herbaceous species and the relative abundance of a few of the species among the initial population that were intolerant of bush cover. This was probably related to reduced competition for soil moisture in the top layers of soils, and other forms of inhibitory effects following the removal of woody plants (Walter, 1971; Doughill and Trodd, 1999). Conversely, a decline in the relative abundance of some herbaceous species in response to tree cutting might reflect shifts in the micro-environment due to the removal of ecologically important trees, thus exposing sensitive species to increased light intensity (particularly for shade loving species). Our results suggest that reduced bush cover could restore herbaceous plant productivity and biodiversity (Bates *et al*., 2000; Smit, 2004; Ansley and Castellano, 2006). As already indicated, the demonstration method of tree clearing could not be applied to the wider rangelands where bush encroachment is a problem, because of the high costs involved. The local community is more likely to apply this system to local pasture management, such as range enclosures, as opposed to conducting large scale land clearing (Ayana Angassa and Gufu Oba, Part 1, unpubl.).

Implications for management policy and extension

This series of studies (Parts 1 and 2) were broadly aimed at demonstrating effective methods of bush encroachment management. We anticipated that the adoption of these methods by the extension department and the local communities would be dependent on the outcomes, both in terms of meeting the government goal of conservation and the pastoralists' goal of promoting biomass production. We have made suggestions as to how the different systems could be adapted for purposes of range management. Our own experience is that the methods that are more acceptable to communities are those that do not introduce new systems of management. Systems are easier to adopt if they are incorporated into existing community practices of range management.

In order to meet the challenge of broad acceptance, this study evaluated the effects of different demonstration methods on herbaceous vegetation, in order to present various management and policy scenarios. In general, bush encroachment control methods significantly improved the recovery of herbaceous vegetation. The new species recorded during the post-demonstration periods greatly improved the herbaceous vegetation composition and productivity. The cutting and fire demonstration methods were superior to other methods in promoting herbaceous biomass. Sustainable ecosystem management and the restoration of herbaceous plant biodiversity could be achieved if rangeland management authorities consider the traditional use of fire and grazing. This method should be reintroduced through improved extension programs and public education for the effective implementation of bush encroachment control.

Our findings suggest that the integration of fire with other methods has advantages over the current policy of excluding the traditional use of fire and grazing in the management of savanna ecosystems, which tends to promote bush encroachment. The presumed advantage of excluding disturbance, such as fire and grazing, to improve rangeland production was not confirmed. Rather, greater herbaceous biomass and diversity were recorded in response to the disturbance treatments. The combined effects of grazing and bush cover have a tendency to reduce fuel load. Thus, we found no justification for the current policies that promote the exclusion of fire and other disturbances.

Our results suggest that threats to pastoral production and biodiversity can only be reduced if rangeland management policies focus on the use of different bush encroachment control methods and promote sound public education through extension programs. Such improved bush management policies and extension packages would increase public awareness about the sustainable use of savanna rangelands and the conservation of biodiversity. It is imperative that policymakers pay due attention to the threats of bush encroachment on the pastoral industry. In this regard, priority should be given to participatory demonstrations of different bush encroachment control methods and public education through appropriate extension systems to evaluate the effectiveness of each method in terms of increasing forage for livestock production and the conservation of biodiversity. Such extension packages must include training programs on a regular basis to assist extension workers and resource users to improve their knowledge and attitudes required to achieve mutually acceptable management goals. We recommend participatory demonstrations to evaluate the effectiveness of the different bush encroachment control methods in terms of improved herbaceous productivity and conservation of biodiversity under the conditions of the Borana rangelands. Such benefits may be demonstrated on a small scale at the village level, with a particular focus on communal pasture reserves managed by different settlements.

Conclusions

We studied the responses of herbaceous species richness, the relative abundance of species, biomass, basal cover and species diversity in response to different bush encroachment control demonstrations. The results show that protection is comparable to the disturbance demonstrations in terms of herbaceous species richness, while herbaceous biomass accumulation and species diversity were improved by disturbance. Bush encroachment control methods such as tree cutting and fire, tree cutting followed by fire and grazing, and the old traditional method of fire and grazing improved herbaceous biomass, basal cover and diversity, while grazing with bush cover greatly reduced herbaceous biomass. As indicated above, the traditional system of range management is more efficient for improving herbaceous biomass, basal cover and species diversity compared to the current systems of range management used by herders. Thus, future development can use these results to compare benefits in terms of opportunities for the sustainable use of savanna rangelands and conservation of species diversity in southern Ethiopia. Tree cutting also greatly increased herbaceous biomass and species diversity.

Overall, the demonstration methods promoted species richness. The outcomes in terms of herbaceous biomass and the restoration of plant biodiversity in response to the various bush encroachment control treatments have important implications for policy formulation and public education in terms of the future management of savanna ecosystems in southern Ethiopia. By comparing the advantages of various bush encroachment control measures, we conclude that only the fire and grazing method is easy to adopt and reasonable in terms of time and labor required, in order to enhance the control of bush encroachment. The use of fire and grazing seems to be more efficient in promoting forage production for livestock, as well as the conservation of biodiversity of herbaceous plants.

A bush encroachment control method that promotes forage production and the maintenance of ecosystem diversity, while at the same time promoting easily applicable and adopted methods by resource users, is more efficient and has considerable comparative advantages relative to other methods. Defining the comparative advantage of different bush encroachment control methods in terms of forage for livestock and ease of implementation has immediate policy implications. In this regard, priority should be given to the interests of the community rather than focusing on conservation alone. The results of this study clearly show that there is ample scope for policymakers and resource users to improve the management of the savanna ecosystems by focusing on more efficient bush encroachment interventions.

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Table 1. Pre-disturbance mean (± SE) of herbaceous species in terms of abundance of individuals recorded in 2003 in different demonstration plots (mean of 12 plots of $1m^2$) in Borana, southern Ethiopia.

Species list	Demonstration plots					
	Control	C+F	C+F+G	F+G	GBC	C
Aristida adoensis Hochst.			4±2.6	2±1.1		8±3.4
Cenchrus ciliaris L.	10±4.2	14±11.8	12±8.1	43±8.1	3±1.2	6±2.5
Chrysopogon aucheri (Boiss.) Stapf.	9±4.2	25±9.1	18±4.8	14±2.0	45±5.9	21±7.7
Chloris roxburghiana Schult.	3±1.4	3±1.8	2±1.6	1±0.1		6±1.4
Eragrostis papposa (Roem. & Schult.) Stued.	48±17.4	52±11.2	63±14.8	17±8.1	13±10.2	19±7.7
Heteropogon contortus (L.) Beauv. ex. R. & Sch.				78±38.1		
Hyparrhenia hirta (L.) Stapf.					6±5.2	
Leptothrium senegalense (Kunth) Clayton	4±2.7	12±5.8	1±0.6	2±1.2		2±1.4
Lintonia nutans Stapf.		12±5.8	37±5.6		2±1.2	18±13.4
Panicum maximum Jacq.	31±14.7			1±0.1		
Panicum coloratum L.	8±7.4	8±5.8	16±5.6	9±2.0	2±1.2	
Pennisetum mezianum (Vahl) Lanza & Mattei					4±1.2	
Pennisetum stramineum Peter					14±11.2	
Sporobolus pyramidalis Beauv.	14±4.7	63±15.2		78±27.0	41±7.2	24±13.4
Themeda triandra Forssk.	9±4.7	32±15.8	31±18.1	10±7.0	6±5.2	14±9.5
Other herbaceous species (unidentified)					13±10.2	5±3.4

Table 2. Post-disturbance mean (± SE) of herbaceous species in terms of abundance of individuals recorded in 2004 and 2005 in response to the different demonstration methods (mean of 12 plots of $1m^2$) in Borana, southern Ethiopia.

Species list	Demonstration plots					
	Control	C+F	C+F+G	F+G	GBC	C
Aristida adoensis Hochst.	3±2.6	3±1.2			1±0.6	3±1.2
Bothriochloa radicans (Lehm.) A.Camus	43±7.9		8±5.5		17±7.7	22±9.4
Cenchrus ciliaris L.	17±4.0	18±6.5	11±5.2	15±6.0	13±4.9	15±4.7
Chrysopogon aucheri (Boiss.) Stapf.	9±3.2	26±6.5	15±4.4	9±4.8	12±4.1	11±3.3
Chloris roxburghiana Schult.	5±2.6	1±0.6	1±0.5	2±1.5		8±2.4
Cynodon dactylon (L.) Pers.			12±10.5	1±0.5	5±1.8	4±3.4
Cyperus species Vahl.				2±1.5		4±1.4
Digitaria milanjiana (Rendle) Stapf.	1±0.9					
Eleusine jaegeri Pilg.						4±4.4
Enteropogon somalensis Chiov.	12±7.9	5±3.2	6±1.5	9±8.5	12±7.7	6±4.4
Eragrostis papposa (Roem. & Schult.) Stued.	2±1.7	8±3.2	1±0.5	5±1.5	3±1.8	7±4.4
Eragrostis sennii Chiov.			1±0.5	1±0.5		
Harpachne schimperi Hochst. ex. A. Rich.	1±0.9			1±0.5	3±1.8	3±2.6
Heteropogon contortus (L.) Beauv. ex. R. & Sch.	5±4.7		15±10.5	36±9.5	7±5.8	8±4.4
Hyparrhenia hirta (L.) Stapf.					16±10.8	
Leptothrium senegalense (Kunth) Clayton	5±3.6	1±0.9	11±10.5		1±0.8	
Lintonia nutans Stapf.		1±0.7	1±0.5		2±1.7	
Panicum maximum Jacq.	12±7.9			13±13.5	1±0.8	10±9.4
Panicum coloratum L.	11±5.6	5±3.4	14±7.4	7±3.5	13±6.3	5±2.4
Panicum turgidum Forssk.	9±7.9	17±14.5	4±1.5	2±1.5		2±1.5
Pennisetum mezianum (Vahl) Lanza & Mattei				2±1.5	3±1.8	1±0.5
Pennisetum stramineum Peter		18±14.5		9±3.5	11±10.8	
Sporobolus pyramidalis Beauv.	23±4.6	25±6.5	19±7.4	17±5.5	19±6.2	18±3.6
Themeda triandra Forssk.	9±5.6	6±4.2	18±6.1	9±7.9	4±3.7	9±5.4
Herbaceous legumes (unidentified)	7±4.0	6±3.7	13±6.1	17±7.9	8±4.9	4±3.2
Other herbaceous species (unidentified)	6±3.9	18±14.5	12±10.5	18±7.9	6±4.8	9±6.6

Table 3. Trends of individual species and average relative change in terms of abundance in response to the different demonstration methods (mean of 12 plots of $1m^2$) in Borana, southern Ethiopia. Average relative change = average no. of individuals recorded during post-demonstration – average no. of individuals observed during pre-demonstration.

Species list	Demonstration plots					
	Control	C+F	C+F+G	F+G	GBC	C
Aristida adoensis Hochst.	3*	3*	–	–	1*	↓5
Bothriochloa radicans (Lehm.) A.Camus	43*		8*		17*	22*
Cenchrus ciliaris L.	↑7	↑4	↓1	↓28	↑10	↑9
Chrysopogon aucheri (Boiss.) Stapf.	nc	↑1	↓3	↓5	↓33	↓10
Chloris roxburghiana Schult.	↑2	↓2	↓1	↑1		↑2
Cynodon dactylon (L.) Pers.			12*	1*	5*	4*
Cyperus species Vahl.				2*		4*
Digitaria milanjiana (Rendle) Stapf.	1*					
Eleusine jaegeri Pilg.						4*
Enteropogon somalensis Chiov.	12*	5*	6*	9*	12*	6*
Eragrostis papposa (Roem. & Schult.) Stued.	↓46	↓44	↓62	↓12	↓10	↓12
Eragrostis sennii Chiov.			1*	1*		
Harpachne schimperi Hochst. ex. A. Rich.	1*			1*	3*	3*
Heteropogon contortus (L.) Beauv. ex. R. & Sch.	5*		15*	↓42	7*	8*
Hyparrhenia hirta (L.) Stapf.					↑10	
Leptothrium senegalense (Kunth) Clayton	↑1	↓11	↑10	–	1*	–
Lintonia nutans Stapf.		↓11	↓36		nc	–
Panicum maximum Jacq.	↓19			↑12	1*	10*
Panicum coloratum L.	↑3	↓3	↓2	↓2	↑11	5*
Panicum turgidum Forssk.	9*	17*	4*	2*		2*
Pennisetum mezianum (Vahl) Lanza & Mattei				2*	↓1	1*
Pennisetum stramineum Peter		18*		9*	↓3	
Sporobolus pyramidalis Beauv.	↑9	↓38	19*	↓61	↓22	↓6
Themeda triandra Forssk.	nc	↓26	↓13	↓1	↓2	↓5
Herbaceous legumes (unidentified)	7*	6*	13*	17*	8*	4 *
Other herbaceous species (unidentified)	6*	18*	12*	18*	↓7	↑4

↑ = Increase, ↓ = Decline, – = lost, nc = No change, * = indicates species regeneration

Table 4. Chi-square (χ^2-tests) for herbaceous species in terms of performance of individuals in response to the effects of different demonstration plots in Borana, southern Ethiopia.

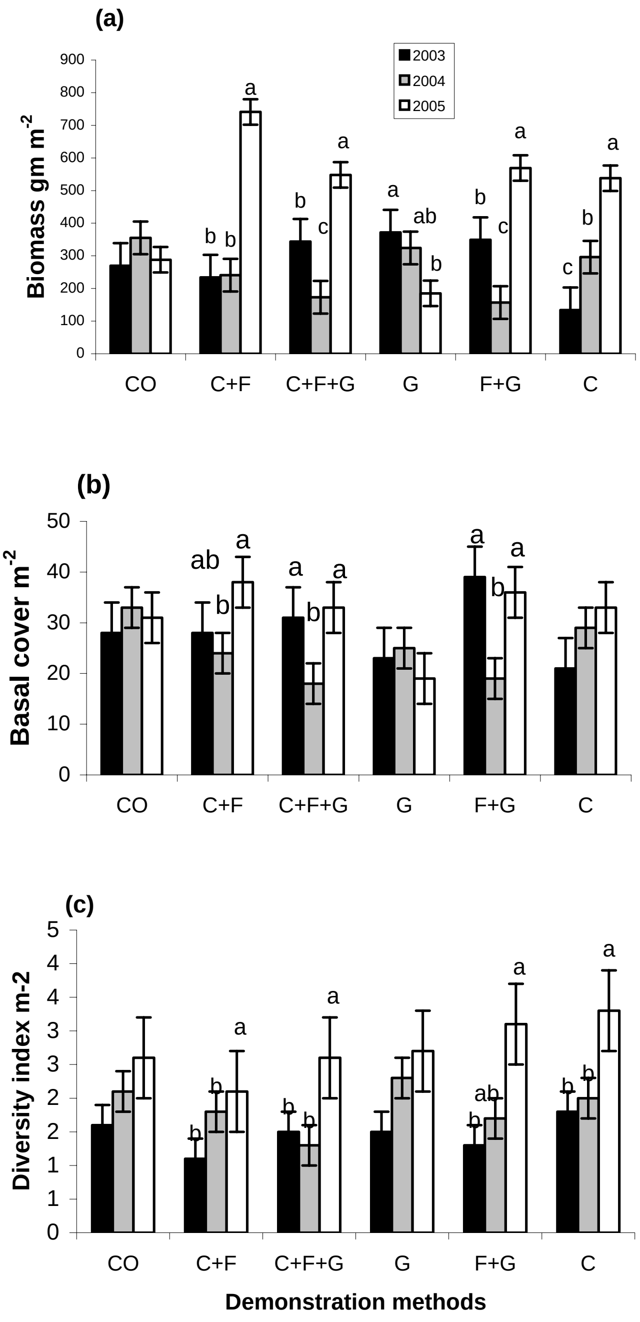
Species list	Demonstration plots					
	Control	C+F	C+F+G	F+G	GBC	C
Aristida adoensis Hochst.	0.81^{NS}	1.07^{NS}	0.71^{NS}	0.77^{NS}	^{NS}	5.40*
Bothriochloa radicans (Lehm.) A.Camus	8.48**		0.13^{NS}		21.73***	6.60*
Cenchrus ciliaris L.	7.07*	0.03^{NS}	0.02^{NS}	15.53***	13.71***	2.06^{NS}
Chrysopogon aucheri (Boiss.) Stapf.	0.02^{NS}	0.49^{NS}	0.21^{NS}	2.74^{NS}	13.38***	8.53**
Chloris roxburghiana Schult.	2.60^{NS}	0.69^{NS}	6.74*	^{NS}		10.36**
Cynodon dactylon (L.) Pers.			0.32^{NS}	^{NS}	^{NS}	0.52^{NS}
Cyperus species Vahl.				^{NS}		0.52^{NS}
Digitaria milanjiana (Rendle) Stapf.	0.06^{NS}					
Eleusine jaegeri Pilg.						2.67^{NS}
Enteropogon somalensis Chiov.	1.62^{NS}	0.87^{NS}	0.20^{NS}	5.99*	0.85^{NS}	1.98^{NS}
Eragrostis papposa (Roem. & Schult.) Stued.	22.07***	1.20^{NS}	8.66 **	4.66*	1.76^{NS}	5.79*
Eragrostis sennii Chiov.				0.84^{NS}		
Harpachne schimperi Hochst. ex. A. Rich.	0.48^{NS}			0.09^{NS}	7.25*	2.88^{NS}
Heteropogon contortus (L.) Beauv. ex. R. & Sch.	^{NS}		0.02^{NS}	1.75^{NS}	12.04**	12.60***
Hyparrhenia hirta (L.) Stapf.					13.48***	
Leptothrium senegalense (Kunth) Clayton	2.34^{NS}	2.37^{NS}	2.93^{NS}	^{NS}	2.80^{NS}	3.63^{NS}
Lintonia nutans Stapf.		2.06^{NS}	^{NS}		2.24^{NS}	12.95***
Panicum maximum Jacq.	18.18***			27.22***	2.48^{NS}	13.98 ***
Panicum coloratum L.	3.48^{NS}	1.21^{NS}	3.86*	11.25**	4.93*	0.28^{NS}
Panicum turgidum Forssk.	3.67^{NS}	0.76^{NS}	1.83^{NS}	^{NS}		
Pennisetum mezianum (Vahl) Lanza & Mattei					2.84^{NS}	
Pennisetum stramineum Peter		0.78^{NS}		14.33**	6.11*	
Sporobolus pyramidalis Beauv.	4.84*	5.64*	1.37^{NS}	12.78 ***	11.65**	1.22^{NS}
Themeda triandra Forssk.	^{NS}	0.17^{NS}	1.10^{NS}	23.84***	43.18***	6.67*
Herbaceous legumes (unidentified)	0.63^{NS}	0.08^{NS}	0.37^{NS}	3.74^{NS}	6.99*	6.68*
Other herbaceous species (unidentified)	0.43^{NS}	1.74^{NS}	0.01^{NS}	^{NS}	5.61*	4.55*

* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$, NS = not significant

Captions for Figures

Figure 1. Responses of herbaceous vegetation variables: (a) herbaceous biomass; (b) basal cover; and (c) species diversity to six bush encroachment control demonstration methods in Borana, southern Ethiopia.

Fig. 1.


(a)
Biomass gm m-2
2003
2004
2005
CO
C+F
C+F+G
G
F+G
C
(b)
Basal cover m-2
(c)
Diversity index m-2
Demonstration methods

Co-author’s statements and Journal permission

Statement regarding article:

Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia

By

Ayana Angassa, Gufu Oba

I, the co-author of the above-mentioned article, hereby accept that the article can be used as part of Ayana Angassa's thesis to be submitted to the Norwegian University of Life Sciences. Also, I confirm that my contribution to the article is limited to a supervisory and advisory role, and that Ayana Angassa is the de facto principle researcher and main author of the article.

21/05/2007
Date and place

Gufu Oba

Statement regarding article:

Herder Perceptions on Impacts of Range Enclosures, Crop Farming, Fire Ban and Bush Encroachment on the Rangelands of Borana, Southern Ethiopia

By

Ayana Angassa, Gufu Oba

I, the co-author of the above-mentioned article, hereby accept that the article can be used as part of Ayana Angassa's thesis to be submitted to the Norwegian University of Life Sciences. Also, I confirm that my contribution to the article is limited to a supervisory and advisory role, and that Ayana Angassa is the de facto principle researcher and main author of the article.

21/05/2007

Date and place

Gufu Oba

Statement regarding article:

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Date and place

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Statement regarding article:

Demonstration of bush encroachment control in Borana, southern Ethiopia: 2. Evaluation of tree cutting, fire and grazing on woody plants

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21/05/2007

Date and place

Gufu Oba

Statement regarding article:

Demonstration of bush encroachment control in Borana, southern Ethiopia: 2. Evaluation of tree cutting, fire and grazing on herbaceous vegetation

By

Ayana Angassa, Gufu Oba, Adugna Tolera

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21/05/2007
Date and place

Gufu Oba

14/05/07, Awassa
Date and place

Adugna Tolera