SPATIALLY EXPLICIT, INDIVIDUAL-BASED MODELLING OF PASTORALISTS' MOBILITY IN THE RANGELANDS OF EAST AFRICA

A Dissertation

by

LABAN ADERO MACOPIYO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2005

Major Subject: Rangeland Ecology and Management

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ABSTRACT

Spatially Explicit, Individual-Based Modelling of Pastoralists' Mobility in the Rangelands of East Africa. (August 2005)

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An agent based-model of mobility of pastoralists was developed and applied to the semi-arid rangeland region extending from southern Ethiopia to northern Kenya. This model was used to investigate temporal adaptation of pastoralists to the spatial heterogeneity of their environment. This dissertation describes the development, structure, and corroboration process of the simulation model, Pastoral Livestock Movement Model (PLMMO). PLMMO is a spatially explicit, individual-based pastoralists-animal foraging and movement model. It simultaneously simulates the foraging and movement behavior of individual pastoralists and their livestock in a rangeland ecosystem. Pastoralists' herd mobility patterns and other measures of movement were compared to data from field studies. Predictions of the model correspond to observed mobility patterns across seasons. The distances moved were found to be significantly correlated (r^2 = 0.927 to 0.977, $p<0.0001$) to drought and non-drought climatic regimes. The PLMMO model therefore proved to be a useful tool for simulating general movement patterns of pastoralists relative to movement range sizes in the pastoral rangelands of southern Ethiopia and northern Kenya.

We then used the PLMMO model to explore the impact of emerging changes in rangeland use in the study area. The ways in which pastoralists' mobility patterns adapt to emerging challenges in the study area were explored by simulating the following four scenarios: 1) climate change with concomitant reduction in forage yield, 2) climate change with concomitant improvement and higher variability in forage yield, 3) increased livestock population densities and 4) improved access to water. The climate induced change scenario with increased and more variable forage production resulted in the shortest distances moved by pastoralists in comparison to all other scenarios. The total search distances under this scenario were only 20% of normal season distances. The improved water access scenario also returned a significant ($p=0.017$) drop in distances moved. There was, however, no significant impact on either increase in livestock numbers or reduction in available forage on mobility. We judged the agent-based model PLMMO developed here as a robust system for emulating pastoral mobility in the rangelands of eastern Africa and for exploring the consequences of climate change and adaptive management scenarios.

DEDICATION

This work is dedicated to my parents and family. I especially dedicate this work in memory of my late father, Stephen Opiyo Omolo who passed on and never got to experience the completion of this work. To my wife Beldinah, daughter Serabi, and my mother Rachel, brother Abisalom, and all my sisters, I dedicate this work for their patience, understanding, support and love for all this time I have been away. The completion of this work would not have been possible without your support. Thank you and I dearly love you all.

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CHAPTER I

INTRODUCTION

Pastoralism and mobility of livestock

Nomadic pastoralism is a form of livestock production that requires constant and periodic movements in search of water and pasture, a factor that differentiates this form of livestock production from that practiced by fenced settled ranchers. The pattern of movement varies widely, ranging from constant roaming to regular and seasonal migrations with semi-permanent settlement. Nomadic pastoralism dominates the vast proportion of arid rangelands of eastern Africa. These rangelands are characterized by intense isolation from development, inaccessibility due to poor infrastructure and inability to support any viable agricultural production. In addition to the torrid natural and neglect conditions, these are regions of intense and prolonged insecurity due to wars between and among clans resulting from competition for the meager resources found here. The conditions existing in this region of the world present enormous survival challenges to the communities living here. Helland (1977) envisages that the pastoral crisis in this part of the world is a result of an increasing imbalance in the ecological systems which are correlated with changes in land tenure system and dramatic increases in human and livestock populations. Combined with recurrent droughts, pastoralists are continually forced to rely on a diminishing and unreliable resource base. For example in the Gezira scheme in the Sudan, land owned primarily by herders is fast disappearing as herders are increasingly being pushed into rapidly shrinking and marginalized areas Markakis (1987).

This dissertation follows the style and format of Ecological Modelling.

In Kenya on the other hand, the government (until recently) has viewed pastoral groups as squatters with no legal claim to either land or water (Timberlake, 1985; Galaty and Salzman, 1981) and in the process weakened pastoralists' rights over resources.

Pastoral and agro-pastoral peoples in the Greater Horn of Africa (GHA) are therefore increasingly trapped in a downward spiral of poverty, recurrent famine, physical insecurity, and environmental degradation (Little, 1983; Webb et al., 1992; Coppock, 1994). External factors such as drought, political instability, and macro-economic adjustment and imbalances have interacted with internal phenomena such as population growth, ethnic tensions, weak financial and marketing systems, and inadequate delivery of support services to exacerbate vulnerability of households and communities.

Background

Our study area traverses an ecologically, ethnically and institutionally heterogeneous transect from Yabello in southern Ethiopia south through Baringo, Marsabit, Isiolo, Wajir, Mandera and Samburu districts in northern Kenya (Appendix 1). The spatial extent of this area is approximately 250,000 square kilometers. Although some animals from southern Ethiopia especially north of Yabello flow northward for grazing and sometimes on to Somalia in the East, principle grazing and marketing areas for livestock in northern Kenya and southern Ethiopia are usually southbound through the Nairobi market chain. Cross-border livestock trade is substantial and seems to be growing rapidly in the Greater Horn of Africa (Little, 1996). Moyale, on the Ethiopia-Kenya border, is a major catchment market for southern Ethiopia, and for small stock from Moyale District, Kenya. Over 90% of the study area is arid to semi-arid with nomadic livestock production and wildlife conservation being the most common form of land use. The livestock production strategies practiced in this region are based on mobile, extensive and subsistence-oriented use of grazing resources. This pastoral production system is a complicated system of utilization of marginal environments by using their seasonally variable forage and water resources which in turn depends on unimpeded access to all grazing areas within feasible reach. Since the growth of vegetation is bound to a seasonal cycle, pastoralists tend to adapt their daily routines to the dynamics of these seasonal changes, in order to meet their animals' requirements for water, forage, and protection. Pastoralists face at least seasonally dry conditions, which result in physical hardships for both livestock and their owners. Traditionally and even presently pastoral livestock production is still almost exclusively subsistence oriented. The main stock types kept are cattle, sheep, goats, and camel. On average, a household has about 45 sheep/goats, 15 cows, 8 camels and 2 donkeys. During migration to access new pastureland only wet (lactating) stock is left in and around the homesteads. About 60%-70% of the population and in particular those with the dry livestock move out.

Pastoral populations live in temporary settlements centered around wells consisting of a semi-circular or circular arrangement of houses built around open space partitioned into pens for the livestock. In each single settlement block, up to 20 households can be found. This is a strategy to enhance security and guard one another in events of external attack.

The migration pattern of settlements varies depending on community groups, but it averages about three to five times a year. Settlements are highly mobile for some communities. During the dry season a dispersion of settlement residents occurs. Settlements may need to move quite often though its annual circuit may be limited to about 160km as it migrates from dry season plains to wet season locations and back to dry season plains again. Nomadic movements of the pastoral communities in the East African rangelands are hardly restricted by either the administrative boundaries, or even the international boundaries and is a cycle that can take as many as six months depending on the situation on the ground. Movement boundaries neither consistently reflect ethnic or cultural boundaries nor do they comprise a viable economic or ecological unit. Every year the distance moved is dictated by a complex set of rules that might include religious rites, forage availability, security concerns and/or water availability. Each administrative district in the region also has a host to several ethnic communities, and clans and sub clans, each of who might move in different directions or cause a general movement of others as the situation may dictate. The general reasons normally noted for the movements include ritual motivation, ecological pressures and security concerns. For example, the Gabra and Rendille community living in northern Kenya but having roots in Ethiopian highlands have been traced to make regular periodic ritual visits to the highlands of Ethiopia about every seven years. Schwartz and Kampen (1992) reported that the journey would take up to 2 to 6 months.

It has been noted however that in the process of movement, pastoral communities usually gear their movement patterns towards friendly communities with whom they share languages and cultural traits. Along the migratory route, there are defined camping sites, determined by the presence of water holes and fallback grazing. These sites which are mainly close to main roads could be as many as the conditions call for, and as long as there is adequate forage and water, grazing takes place per a single group for between one and three weeks. These locations are important spots where household heads trace their stock by making occasional visits or receiving messages on updates sent from the field back to the settlements. Young men accompanying the herds are usually the ones sent to deliver messages back home. Cases of emerging diseases, food needs, status of forage and water access forms the bulk of such messages.

Others include issues to do with rustling and other related dangers. Growth or decline of herd for whatever reason(s) also must be communicated.

Among the pastoralists, the search for pasture and water as dictated by drought oscillations and patterns within the rangelands determine the direction and intensity of migration of the pastoral communities. Droughts are especially common in the more arid rangelands of the region. For instance, in Samburu District of Kenya, 23, 10 and 5 extreme droughts are expected to occur in very arid, arid and semi-arid rangelands, respectively during a 30 year period (Herlocker, 1999). Apart from search for forage and water, pastoralists of the region are also on the migration path to avoid outbreaks of diseases and as well as to avoid social and political instability. Periods of unfavorable conditions may lead to massive emigration to new lands with extensive distance coverage over time. Basic seasonal patterns of nomadic movement are shown in Wajir, Kenya for instance as follows: among the pastoralists grazing is dictated by water needs (specifically the permanent water of the wells), the desire to diversify livestock intake, and the opportunity to capitalize on grass species whose productivity varies seasonally. These movements are usually accompanied by loss of body condition and mortality, the latter which always exceeds net sales especially in times of drought (Desta and Coppock, 2002).

Understanding the factors affecting the distribution of pastoralist movement and grazing may help to recognize heterogeneity in resource use (Coppolillo, 2001), point to areas where water and forage resources conflicts are likely to occur, or provide an in-depth understanding of the long-term factors shaping current landscape structure and ecosystem function (Turner, 1998). Grasping the full extent of mobility and resource use patterns in the arid and semi-arid rangelands therefore has far reaching ecological and managerial implications.

Limited studies however currently exist that have examined broad scale movement patterns and landscape use patterns of pastoralists. This research proposes to develop a landscape level dynamic livestock foraging movement model to simulate the spatial distribution and movements of livestock in East African rangelands in response to resource availability and socio-cultural factors. The dynamic model can be applied by resource managers to help guide decisions regarding placement of resources such as water infrastructure, disease control services, dry season feeding etc. on the landscape not only to respond to needs in times of stress but also to encourage equitable use of resources and increase the pastoralists' asset base. Since resulting interventions may be consistent with seasonal strategies of mobility, they have a higher chance of being utilized and accepted by the pastoral communities. Further, by integrating spatial information of mobility with data on available resources, spatial patterns of community use can be compared with resource availability resulting into a more complete and timely understanding of different dimensions of human conflict arising from competition for limited resources.

This dissertation describes the development and evaluation process of a regional, landscape level dynamic model of pastoral mobility that we developed and call the Pastoral Livestock Movement and Model (PLMMO). The model is a spatially explicit individual based model built using agent-based modeling system. The model demonstrates the use of complex systems science methodology to evaluate rangeland systems dynamics. Our goal was to better understand interactions between pastoralists, their livestock, and the biophysical system they live in so that we could to identify system characteristics and policies that will in the future bestow resilience to these semi-arid rangeland systems. One of the main differences between this model and earlier models is its ability to incorporate pastoralists' behavior into the system modeling process of livestock landscape use patterns instead of simply estimating this pattern through proportional allocation of landscape use through habitat suitability indices. The model is applied to populations in the East African arid and semi-arid rangelands in both Kenya and Ethiopia. Using real data from fieldwork, we were able to compare real system behavior with model prediction and were able to evaluate the soundness and utility of the model. As the simulation results were consistent with field data, we used the model as an extrapolation tool to investigate conditions that have not been tested, or that are not easily amenable to experimentation such as future climate change scenarios.

The model could potentially be a useful tool in managing pastoral mobility for pastoral development in African rangelands by contributing as part of spatially explicit decision support system. The model could be particularly useful in the identification of herd seasonal aggregation regions, monitoring of the variability of herd health, likely marketed offtake in these regions and ultimately, the design of institutional and policy interventions that accommodate the needs of livestock mobility and result in the most optimal use of the forage resources in these regions. Based on the structure of the model, its applicability can be extended to include other pastoral regions depending on the availability of information on livestock populations, seasonal migration behaviors and spatial and temporal distribution patterns of ecological resources.

Recognizing, supporting and empowering traditional grazing management structures through relevant governmental departments is vital. The success of such intervention will come only from expanding the overall understanding of the dynamics of pastoral systems captured formally by utilizing analytical tools such as the individual based model developed here.

CHAPTER II

LITERATURE REVIEW

The case for pastoralism

Pastoralists have adopted mobile or transhumant grazing practices to reduce the risk of having insufficient forage in any one location and therefore as a coping strategy for reducing their exposure to a restricted resource base and to losses from droughts when they do occur. They also adopt opportunistic grazing practices whereby herd sizes and stocking rates are adjusted as the rainy season unfolds to best match available grazing resources (Hazell, 1999).
In response to a harsh and variable physical environment, most nomadic groups in East Africa also use range management techniques, such as pasture rotation and grazing reserves. These techniques are frequently used to save forage for critical periods. For example, the Maasai of East Africa widen their grazing radius and delay entering dry season areas (Jacobs, 1980). Moreover, herd diversity and splitting techniques are also widely practiced to maintain the long-term productivity of the range and to ensure sustainable production at comparatively low cost. The Tigre of Eritrea, for example, frequently separate large ruminants from small ones; calves and small stock are herded near the settlement on reserved pastures, while adult stock are grazed further off within daily travel of the family settlement (Kahsaye, 2002). Jacobs (1980) and Fratkin (1987) also observed a herd splitting method among the Masaai pastoralists that resulted in reduced grazing competition among livestock and dispersion of grazing pressure as each type of livestock was taken to the most suitable pasture. Even though pastoralism in East Africa has evolved over a long period of time as a rational response to the fragile ecosystem, most of the literature emphasizes the failures of pastoral economies, the impact of drought, and the

failed attempts to incorporate herders into large regional and state economies. Arid and semiarid lands exhibit ecological constraints, which set limits to pastoralism and agro-pastoralism. As suggested by Smith (1992) for instance, the major constraints include the inherently erratic nature of rainfall, a high rate of evapo-transpiration, and low organic levels of the soils. Pratt and Gwynne (1977) on the other hand argue that the problem in arid areas is basically one of bad land use, as herders keep very large numbers of poor-quality livestock, and that the only way to resolve the problem is to increase control over the numbers and movement of livestock. Sandford (1983) considered both communal grazing and heavy stocking rates as prime factors for the deteriorating conditions of rangelands and for the subsequent failure of pastoral economies. Even though some of these assertions are based on strong basis, most of works in pastoralism is replete with a wide array of myths and misconceptions.

Theoretical models applying to rangelands

Much of the misconceptions about pastoralism arose from very influential ideas grounded on the range succession theory of Clements' (1916) and Greg Hardin's (1968) 'The tragedy of the commons'. The range succession model assumes that the livestock sector operates in environments that are largely stable, where weather variability is limited to a narrow range and therefore inconsequential for long-term outcomes. The model supposes that a given rangeland continually returns to a single persistent state (the climax) of vegetation in the absence of grazing. By producing changes in the opposite direction, grazing pressure arising from a set stocking rate can slow or halt the successional tendency, producing an equilibrium in vegetation levels. This theory has guided the principles of the western ranching system, principles which were subsequently introduced in many parts of sub-Saharan Africa. These ideas were translated into rangeland policy (Sampson, 1917) and became entrenched in range management (Westoby et al., 1989). Clements' (1916) model assumed grazing management to be a trade-off between the animal crop and the maintenance of stability; stability being a major goal. In the pastoral cultures where most pasture is common property, this ecological model found a partner in the theory of common property resources, associated with Hardin's (1968) 'tragedy of the commons'. Individual pastoralists, Hardin maintained, would maximize profit by fielding as many cattle as possible on common pasture which damaged grazing and jeopardized the collective good (Warren, 1994). The colonial authorities legitimized and re-enforced theses ideas and paradigms and played a major role in the development of a negative image of pastoralists (Widenstrand, 1975). In this view, pastoral economies were driven more by 'ritual' than by 'economic' or 'ecological' motives. Pastoral economies involved the 'worship' of cattle/'cowdolatory' - seen only as status symbols; they were economically irrational (Livingstone, 1977); willfully conservative and ignorant (Bennett, 1988); and they were much less effective than 'rational' ranching systems (Barnes, 1979).

Behnke and Scoones (1993) review of concept in Clements' stability paradigm reveals that very little attention was paid to some crucial environmental and cultural features of African grazing systems when applying this concept to these regions. First among the scientific issues, this stability paradigm ignored the possibility of a nonlinear relation between animals per hectare and animal weight-gain per hectare as reviewed by Noy-Meir (1975), Belsky (1987), Georgiadis and McNaughton (1990). These studies have been able to show there exists non-linearity in many ways and especially for these unpredictable arid systems highly prone to devastating droughts. Its form and intensity varies radically according to plant and animal species, and its position in various life-cycles and seasonal factors. The stability paradigm did not also adjust to some important differences in the culture of management in most of Africa. Among these was the fact nomadic movement of herds is flexible, variable and follows long drawn-out patterns. The stability model was however developed for fenced pastures and in cultures of land tenure rights and capitalization of natural resources in which production per hectare was the concern rather than production per animal as in much of arid Africa. Another aspect that the stability paradigm did not consider is failing to distinguish clearly between different possible objectives of cattle production. It implicitly assumed that the over-riding objective was the production of meat. The stability and range succession ideas of Clements (1916) and Sampson (1917) led to the first general theory being developed by Dyksterhuis (1949) to explain the responses of vegetation to grazing within the range profession. Dyksterhuis (1949) proposed that each rangeland system has a single equilibrium composition in the absence of grazing (the climax or potential vegetation). At each grazing intensity, vegetation composition reaches a new equilibrium, diverging from the climax as grazing intensity increases. It is assumed that these changes are reversible, that is, when grazing intensity is reduced again, the vegetation recovers along the same successional trajectory towards the climax vegetation. Under this theory, any variable of the system is a single, smooth, continuous, and reversible function of grazing intensity.

Even though the range succession model has been widely applied in range management, empirical evidence (Westoby, 1980; West et al., 1984) indicate that rangeland systems do not always behave continuously, and that vegetation can, in some cases, shift toward alternate stable states separated by thresholds (Westoby et al., 1989; Laycock, 1991). Such transitions can be triggered by changes, increases or decreases in grazing intensity, fire regime alterations, types of herbivores or in the spatial and temporal patterns of grazing. The transitions can also be brought about by disturbances such as fire, extreme weather events, or combinations of any or all these factors. Once the transition across the threshold has occurred, it is not a simple reversal when the conditions that triggered it end. It may be practically irreversible, or reversible only at a long time scale or following a different set of events and through a sequence of other vegetation states (Westoby et al., 1989). It is worth noting that the states and transitions model did not intend to completely get rid of the range succession equilibrium model but rather challenged its universality and permitted an integration of continuous and discontinuous dynamics within the same framework (Briske et al., 2003). This model is also being applied to pastoralist semi-arid ecosystems which seldom, if ever, reach equilibrium, while lurching from state to state while being buffeted by fire, drought, insect attack and management (Walker, 1987; Ellis and Swift, 1988). The ecosystem (and the dependent social and economic system) persists at a large scale due to the irregular spatial and temporal pattern of attack of the various disturbances. Patches persist (at various scales) in which better conditions allow the survival of species which can re-colonize devastated areas when good conditions return. Following these models and taking the cultural practices of the communities existing in these arid environments into account, one of the most resilient management strategies is opportunistic, seeking to manipulate states and transitions, according to accumulated wisdom (Westoby et al., 1989).

The value of mobility to pastoralists

Livestock mobility is one of the major ways in which African pastoralists have historically managed uncertainty and risk in arid lands (Bassett, 1986; Scoones, 1994). Grazing patterns in large, heterogeneous landscapes can have both positive and negative implications for animal production. Studies of African grazing systems have consistently identified the importance of large-scale movements for sustaining both domestic and wild herbivores during droughts (Coughenour et al., 1985; Walker et al., 1987). Analysis of mortality patterns has shown that despite a high annual variation in precipitation and plant production, mortality is related to both animal density and to variability in access to available grazing areas with adequate water (Walker et al., 1987; Desta and Coppock, 2002). These empirical results are supported by recent efforts to simulate broad-scale dynamics of plant-herbivore systems, and emphasize the dangers of fragmenting highly variable systems (Illius and O'Connor, 2000). Mobility can address socioeconomic objectives, such as access to a diverse range of markets, symbiotic interactions with farming communities (for example, exchanging manure for feed), and cultural gatherings where livestock are part of the sociopolitical transactions. Mobility is also an adaptive tool that serves several aspects of livestock production simultaneously. One benefit is the provision of fodder to livestock at minimal labor and lower economic cost. Extensive livestock-production, taking livestock to feed and water, is less costly than bringing feed and water to livestock, because of lower labor demand, and lower inputs (Niamir, 1987). Both mobility and dispersion have also been correlated with increasing resistance of animals to diseases, and decreasing their vulnerability to outbreaks (Roeder, 1996). Since the arid ecosystem's productivity is spatially and temporally variable and to a large degree unpredictable, mobility enables the opportunistic use of resources. This includes moving to minimize the effects and impacts of droughts, and being able to use underused pastures distant from settlements, or those that are only seasonally available.

Ecological studies undertaken in the arid lands show that climate appears to be a more significant factor in determining vegetation structure, function, and dynamics than either grazing or internal ecological processes (e.g. Behnke and Abel, 1996; Hiernaux, 1996). Sedentarization is also a more serious problem than overgrazing (Warren and Rajasekaran, 1993). For example, piosphere (vegetal zones related to watering points) studies around agropastoral villages in northeastern Senegal show that undergrazing of distant pastures results in lower palatability of primary productivity, lower phosphorus content of topsoil, lower herbaceous density, and lower biomass production (Niamir, 1987). Thus the prevailing range ecology postulates that, for grazing to have little or no negative impact on arid rangelands, it must follow or “track” climatic variability. The emerging “new ecology” questions the core assumptions of the science of ecology, including that of equilibrium ecological theory (Botkin, 1990; Allen and Hoekstra, 1992).

Recent research (Ellis and Swift, 1988; Behnke, 1997) has provided support for the argument that the scale and magnitude of persistent environmental decline in dryland Africa and the role of livestock grazing in these changes has sometime been overemphasized. The pattern of anthropogenic land degradation is much more severe around permanent settlement sites than it is in open rangelands because of concentration of pressure (deforestation, overcultivation, and overgrazing). In the absence of economically feasible technologies for controlling environmental forces, land-use patterns would have to adapt to the variability and uncertainty of rainfall using strategies that are “opportunistic,” flexible, and mobile (Behnke et al., 1993). Transhumants are well aware of these forces and manipulate the two factors of space and time through their mobility and common-property regimes. Common-pool resources, because of the difficulty or high cost to divide, exclude, or bound them, are often considered as common property (Ostrom, 1990). The drier the ecosystem is, the greater is the incentive to manage the natural resource communally. Secondly, in arid lands, uncertainty is high, and the risks of production and survival are higher. In these communal cultures, the risk burden is too much for an individual to bear; therefore, common-property regimes are devised to share the risk and spread the burden. An opportunistic stocking strategy requires that mobility patterns adapt to both herd sizes and variability in primary productivity. High primary productivity in good years provides an incentive to herders to reduce mobility, but they have to balance that with the needs of a larger herd. The mechanism that allows opportunistic use of resources is the “tracking” of ecological variability, both spatially and temporally. Herders and scouts track the ecosystem by constant monitoring and adjust the behavior of their animals accordingly (Scoones, 1994; Niamir, 1997). Tracking is possible if there is freedom of movement, and specialized labor and talent for tracking and evaluating ecological processes. Scouts must monitor indicators that are sensitive to ecological changes (Niamir, 2000).

If flexible access to different habitats and resources is ensured, higher populations of herbivores can be maintained in any given area (Westoby et al., 1989; Scoones, 1993). For example, studies in Zimbabwe, Botswana, Uganda, and Mali show that overall returns per hectare (counting all products, not just meat) are higher in mobile pastoral systems than in agropastoral or commercial systems (Sandford, 1983; Scoones, 1994). However, productivity per animal is lower, primarily because of the lack of external supplementation and low veterinary input. Recent studies though indicate that dual use of livestock and wildlife can generate greater wealth at lower economic and environmental costs by spreading the economic and financial risk associated with their management, as well as making more efficient use of forage in areas that are less suitable for livestock (Kreuter and Workman, 1994). Another benefit of mobility is its deliberate use for contributing to pasture sustainability and improvement. The mobility of neighboring pastoral herds is a form of spatial and temporal choreography determined by the nutritional needs of the livestock portfolio, informal rules that determine precedence, degree of concentration and length of grazing or effective grazing pressure, and “safe” distance or dispersion between herds. Many examples of macro-scaled movements can be found in the literature, for example, among the Twareg (Winter, 1984), the Tswana

(Schapera, 1940) and the Somali (Rabeh, 1984). These movements are rapidly losing their effectiveness in the pastoral rangelands of East Africa due newer vulnerabilities brought about by recurrent extreme droughts in the recent times (associated with climate change) and by conflicts between communities over land, water or pasture which creates an environment of insecurity for the pastoralists and that of uncertainty for development. Kratli and Swift (1999) postulate that a gradual erosion of elders authority, failure of state to provide security, proliferation of small arms, and a lack of greater integration into the national political and economic sphere are but some of the cause attributed to these conflicts. They further note that what has made the conflicts worse are their qualitative transformation over the recent past from battles among spear wielding warriors into indiscriminate assaults on populations using semiautomatic weapons. This change in the nature of conflict in Marsabit District for example has contributed to a climate of fear and insecurity in the region, and left a legacy of hostility and mutual suspicion (Haro et al., 2005) making sharing of resources among communities utterly impossible.

A holistic and integrated analytical framework is needed that can incorporate all the new developments in each of the contributing scientific fields (economics, sociology, anthropology, ecology, and political science) and provide a sound basis upon which development activities can be designed. Concerted and simultaneous actions are needed on several important aspects of pastoral development including building capacity, determining appropriate forms of service delivery, developing and strengthening rules and regulations for common property management, managing key sites, developing socioeconomic safety nets, and developing drought-contingency measures (Niamir-Fuller, 2000). New means are required to capitalize pastoral assets and protect those assets through innovations such as early warning systems (Stuth et al., 2003), improved market linkages (McPeak, 2003) and potential mortality insurance instruments (Skees and Barry, 1999).

The detailed choreography, or day-to-day dynamic mapping of movements, has not been effectively studied yet. This choreography of movements resembles rest–rotation schemes, albeit less strictly organized, and because of the twin factors of dispersion and frequent movement, contributes to pasture sustainability (Niamir-Fuller, 2000).

Environmental analysts have been prone to characterizing the grazing of domestic livestock as destructive to the environment—but the relationship of grazing to the environment in Africa is much more complex. With the long history of co-evolution of livestock and the African environment, livestock should be seen as an integral part of both conservation and development (Steinfeld et al., 1997).

Coping strategies in the face of unpredictable environment

Two models that seek to explain the herders' coping strategies in the face of unpredictable environment have been proposed. The risk-averse model views pastoral economy as an adaptation of herders and herds to environmental stress caused, for most part, by factors such as variability in rainfall and vegetation types (Roe et al., 2000). This model regards pastoralism as a strategy adopted by herders in ecologically stressful situations caused by exogenous factors. Ellis (1993) presents the risk-averse model from two perspectives. First, the herders try to avoid hazards through moving the livestock to locations of forage and water or minimize the magnitude of hazard by spreading the herd across a large geographical space. The herders therefore escape the worst effects of ecological degradation by searching for a better area. According to Ellis (1993), therefore, the conditions that facilitate herd movement are to be encouraged and those that hinder are to be rejected. The assumption that pastoralism is a risk-averse adaptation to a highly variable exogenous environment was unchallenged for several decades (Swallow 1989).

A newer model postulates pastoralists' behavior in terms of high reliability theory. In high reliability pastoralism unlike in the risk-averse approach, the hazards cannot be avoided; instead they must be accepted and managed because what the risk-averse model treats as external to pastoralism the high reliability model considers internal to the livestock economy (Roe et al., 2000). From the perspective of the new theory, Reckers (1994) argues for the need to diversify herd stocks which allows for a more efficient use of rangeland and facilitates a more reliable supply of food. Therefore, from a risk-averse perspective, pastoralists practice mobility as a strategy to avoid the worse effects of natural stress and to increase the chances of being left with minimum herd survival after that stress. From the high reliability perspective, spatial and temporal diversity of rangeland is managed by herders in general so as to increase the chances of producing and maintaining peak herd sizes, even through drought period. These two perspectives are often presented as mutually exclusive alternatives in the study of pastoralists and their resources.

In summary, the pastoral grazing system is based on scheduled mobility between well-defined seasonal grazing areas. Niamir (1990) noted how micro-mobility is regulated through frequency of grazing, time lapse between each grazing area, distance between grazed areas, and dispersion between herds. Traditional herding is not only a coping strategy for forage but also an art of protecting livestock and minimizing the risk of attack by bandits while positioning herds in landscapes to meet critical water needs and avoid catastrophic losses from disease. The extreme and unpredictable variability in rainfall could be considered to confer a non-equilibrium dynamics by continually disrupting the tight consumer-resource relations that otherwise would pull the components of the system towards equilibrium.

Ecological equilibrium and non-equilibrium ecological models differ fundamentally in the presumed role of biotic versus abiotic elements over the pastoral ecosystem. From a risk-averse perspective, pastoralists practice mobility as a strategy to avoid the worse effects of natural stress and to increase the chances of being left with minimum herd survival after that stress. From the high reliability perspective, spatial and temporal diversity of rangeland is managed by herders in general so as to increase the chances of producing and maintaining peak herd sizes, even through drought period. These two perspectives are often presented as mutually exclusive alternatives in the study of pastoralists and their resources. This research, however, recognizes both as instrumental in understanding the dynamics of rangeland herd mobility in East Africa and the subsequent behavior patterns and rules of pastoral mobility.

Landscape utilization

Animals use landscapes unevenly, with respect to either distance to water or herbivore preferences for different vegetation communities (Senft et al., 1983; Pickup and Chewings, 1988; Stafford Smith, 1988). It is usually the areas much closer to water points that are the focus of much of the grazing pressure. Factors influencing forage production are complex and interrelated. Rainfall infiltration and the spatial redistribution of runoff water are the predominant factors determining patterns in semi-arid vegetation (Friedel, 1990; Maestre et al., 2003), but grazing impacts also contribute to the generation and maintenance of spatial heterogeneity (Adler et al., 2001).

Optimal foraging models

Optimal foraging theory (Pyke, 1984) provides a functional approach for examining grazing behaviors, including diet selection, patch selection, and movements. Optimal foraging theory generally assumes that animal fitness is related to foraging behavior, foraging behaviors are heritable, and that a currency (e.g. energy, protein) can be identified to link foraging behavior with fitness (Pyke, 1984). Theories of optimality involve a mathematical model of cost and benefit analysis that can give quantitative predictions about an animal's behavior. The foraging models can often be used to predict foraging behavior to a reasonably certain degree. To some degree, animals display the ability to modify their behavior so that they receive an optimal balance of benefits and costs, assuming little human intervention to the animal's decision process. Costs can include danger, loss of valuable time, and wasted energy. Benefits are usually counted in terms of net energy intake (consumed calories) per unit time or number of offspring produced. Foraging strategies within landscape therefore seek to maximize daily energy gain. It follows that animals are expected to make decisions about diet selection based on the balance between forage profitability (a function of the satisfaction of nutritional requirements) and the distance traveled to reach this forage. This process is represented by optimal foraging theory (Stephens and Krebs, 1986) which predicts that animals assay the energy balance underlying travel and intake against the profitability of their resource (Bailey et al., 1998). Resource profitability is energy gained in excess of costs, the rate of which is constrained by the logistics of food detection and ingestion. Intake rate constraints depend on the initial locating of food items, the travel between those food items, and, once arrived, the speed of cropping, chewing and swallowing of food (Spalinger and Hobbs, 1992).

Two models are associated with the optimal foraging theory. There is the Contingency Theory and the Marginal Value Theory. Contingency theory, also called the prey choice model, predicts what an animal will do when it encounters a particular food. It determines profitability which is the energy gained divided by the time spent handling it. The Marginal Value Theory, also called Patch Choice Theory, is a form of the economic law of diminishing returns. An animal feeding at a patch must decide when to leave the patch in search of another. The more of the patch the animal consumes, the lower the rate of return will be for the remainder of the patch because the food supply is running out (Bailey et al., 1998). When the profitability of the patch lowers enough to equal the profitability of an average patch, including the time it will take to search or travel to the new patch, the animal should leave. The Marginal Value Theory predicts that animals will remain in one patch longer when patches are scarce or far apart. Like the contingency model, the patch choice model merely serves to approximate the amount of time an animal will spend in any one patch.

Large herbivores usually allocate time spent in different areas of a pasture or habitat based on the resource levels found there when not herded by humans. Senft et al. (1987) applied the term "matching" to this proportional relationship between the time an animal spends in plant communities or large patches and the available quantity of nutrients. Matching is an aggregate response pattern that has been observed in several species including bison, cattle, sheep etc. (Coppock et al., 1983; Hanley, 1984; Pinchak et al., 1991). Patch selection and patch residence time by herbivores has been examined using approaches based on the marginal value theorem (Charnov, 1976). Laca et al. (1993) showed that cattle optimized intake rates from patches that varied in height and spacing, consistent with marginal value theorem predictions. Cattle modified patch residence time in response to a factorial combination of three patch heights and three interpatch distances. Distel et al. (1995) observed that cattle selected feeding stations where intake rate was higher, and time allocated to various feeding stations was at least qualitatively consistent with marginal value theorem predictions.

If all the profitable locations are exploited, it can be said that there has been a degree of matching between animals and their resource, and the resulting spatial pattern of resource utilization is described as the ideal free distribution (Fretwell and Lucas, 1970). Senft et al. (1985) described a matching response pattern where preference by cattle for plant communities could be predicted from relative quantities of preferred species and nutrient abundance.

Stochastic dynamic programming (Mangel and Clark, 1986) and diffusion models (e.g. Farnsworth and Beecham, 1999) imply that a more stochastic mechanism underlies animal foraging behavior. These modeling techniques permit the analysis of behaviors that respond to forage and environmental conditions, animal physiological state, and predation risk over short and long time periods. Newman et al. (1995) used stochastic dynamic programming to investigate diet selection and daily intake by combining a simple mechanistic model of forage intake and digestion with an optimal foraging theory approach. They developed their stochastic dynamic programming model for non-herded sheep grazing on a sward consisting of grass and clover and showed that a variety of behaviors could result from relatively small changes in environmental conditions. Predictions of this stochastic dynamic programming model were consistent with observations of the sheep, and accounted for behaviors not adequately explained by highly detailed, purely mechanistic models (Parsons et al., 1994; Thornley et al., 1994).

In conclusion, optimal solutions to foraging problems are usually assumed to be implemented by rules-of-thumb because animals are constrained in their ability to obtain and process information (Janetos and Cole, 1981; Ward, 1992). Identifying how animals would implement solutions determined by optimal foraging models is important because often the underlying behavioral mechanisms are poorly conceptualized (Senft et al., 1987). Understanding the underlying behavioral mechanisms would improve our ability to develop new, innovative management practices for modifying grazing distribution patterns.

Modeling grazing in heterogeneous landscapes

Over the years, various authors have tried to explain the wide variation in distribution and abundance of African large herbivore populations in terms of relatively simple mathematical models incorporating one or more environmental variable(s). A large number of models have been developed, each an attempt to shed some light on the behavioral response underlying what appears to be a complex grazing pattern. Techniques that have been employed include regression analysis (e.g., Senft et al., 1983), probability densities (e.g. Arnold and Maller, 1985) and GIS (e.g. Wade et al., 1998), random-walk models (Stafford Smith and Foran, 1990). In a regional study of wildlife and pastoral systems in East and southern Africa for example, Coe et al. (1976) demonstrated strong positive correlations between large herbivore biomass, mean annual rainfall and above-ground primary production. Pickup and Bastin (1997) applied models developed in Australian rangelands (Pickup, 1994) to investigate the effects of paddock shape and the locations of water points in influencing cattle distributions. Other studies use unconstrained landscape scale models to examine foraging behavior (Turner et al., 1993; Percival et al., 1996), patterns of searching behavior (Anderson, 1996) and energetics (Moen et al., 1997). Mechanistic models can accurately predict intake rates of hungry animals over small spatial and temporal scales, but selectivity, movement patterns, social interactions, memory, and environmental factors clearly influence the spatial distribution of herbivores and their subsequent use of forages at paddock and landscape scales (Senft et al., 1987; Coughenour, 1991; Bailey et al., 1996). At the largest scales, both statistical and process-based models have successfully reproduced observed patterns of landscape-scale habitat use by non-herded domestic and wild herbivores. When animal movements are largely unconstrained by fences or other barriers, spatial patterns of habitat use by herbivores can often be explained using relatively simple algorithms based on forage quality, topography, snow depth, or other factors that are, in general, relatively intuitive (Stafford Smith, 1988; Turner et al., 1993). In arid areas, water is clearly a dominant influence on movements of domestic livestock. The selection of habitats by domestic herbivores and large-scale patterns of defoliation and ecosystem modification can also be largely accounted for by the location of water (Andrew, 1988; James et al., 1999).

At intermediate scales, regression models have provided some insight to factors that can influence the spatial distribution of animals (e.g. Senft et al., 1983) though the utility of such models may be limited in application outside the range of data used to develop them. On a paddock level a variety of models have been usefully applied to guide management e.g. GRASP (Littleboy and McKeon, 1997), SPUR (Foy et al., 1999).

At large spatial scales, simulation models have made important contributions to evaluating management of grazing lands where competition between domestic and wild herbivores is important (Weisburg et al., 2002), and they have been an integral component of large-scale research in pastoral landscapes (Coughenour et al., 1985). Results from simulation models have supported the hypothesis that environmental heterogeneity has important consequences for large herbivores (Turner et al., 1993; Boone and Hobbs, 2003).

Remotely-sensed Landsat images of vegetation cover have also been used to predict animal distributions through the creation of a filter that accounts for vegetation growth and temporal variation in vegetation cover (Pickup and Chewings, 1988). The filter incorporates growth, natural decline in vegetation cover, and species gradient effects assumed to reduce forage quality under heavy stocking. Animal density is then assumed to be proportional to the depletion of vegetation cover and can be modeled using families of inverse Gaussian distribution functions. The approach is effective in extrapolating information from satellite imagery and linking animal densities to range utilization. It is noteworthy that this remote sensing technique uses defoliation as a predictor of animal distribution. Heterogeneity in rangeland utilization is assumed to be equivalent to spatial difference in the removal of vegetation cover.

Some of the most comprehensive system models that have been attempted to developed so far in Africa on foraging strategies includes Adler and Hall's (submitted) foraging and piosphere development model, Derry's (2004) investigations of animal watering behaviour and travel costs in determining the distribution of spatial impacts around a watering source in semi-arid rangelands of eastern Cape, South Africa and the SAVANNA model predicting animal movement (Coughenour, 1993). In their model, Adler and Hall (submitted.) coupled an individual-based herbivore foraging submodel to a two species vegetation submodel of Lokta-Volterra plant growth and competition. Versions were developed to test four foraging strategies: maximization of forage biomass intake, equivalent to time minimization (TMin); probabilistic movement away from water (MaxDist); maximization of energy intake adjusted for distance from water (EMax-Dist) and energy intake maximization based on forage quality (EMax-Q). Adler and Hall's model (submitted.) produced patterns in grass biomass utilization that were strongest near water and decreased with increasing distance from water. Their responses showed an increase in the extent of the severely degraded sacrifice zone over time. Utilization initially decreased with distance from water and then developed a narrow peak at an intermediate distance that shifted away from water over time.

The SAVANNA (Coughenour, 1993) model is a mechanistic model that attempts to predict animal movement whilst accounting for physiological constraints. The model accounts for energy expenditure in travel undertaken to satisfy water requirements. The iteration interval is a week. Animals are distributed across the grid-based landscape in relation to an index of habitat suitability based upon forage quality and quantity, slope, elevation, cover and the density of herbivores. The Savanna model has been adapted to the Ngorongoro Conservation Area (NCA), in northern Tanzania, a multiple-use area of importance to Maasai pastoralists and wildlife conservation. The model was used to conduct fifteen experiments reflecting potential management questions. Results suggest that the distribution of rainfall throughout the year may have a greater impact on the ecosystem than its forage quantity; increasing survival and reducing disease in livestock yields greater returns than increasing birth rates and allowing livestock to graze in areas where they are currently excluded may lead to a slight increase in livestock populations, but sometimes also leads to large declines in wildlife populations. Whilst, the model has been successfully applied to predicting large-scale vegetation dynamics and animal distributions (Kiker, 1998), an assessment of the model's capacity to simulate dynamics of pastoral mobility has yet to be carried out. In this model the distribution of animals on the landscape is driven not by the pastoralist’s rules and behavior that determine actual movement but by tacit assumptions about the suitability of an environment to accommodate the pastoralists. Forage intake would be for instance balanced against energetic requirements of the livestock something which might not probably encapsulate the subjective pastoralist’s social behavior and desire to move. The model therefore focuses attention on a set of equations that express site habitat suitability. The evaluation of this suitability produces the evolution of livestock foraging and mobility over time. A model that begins with behaviors through which pastoralists interact with one another and or their environment as its starting point would most probably better represent reality on the ground than one that begins with environmental suitability indices. Such a behavioral and complex adaptive model would begin by representing the behaviors of each individual and then turn them loose to interact. Direct relationships among the observables are therefore an output of the process, not its input. Bosquet et al. (1999) and Rouchier et al. (2001) present the only few studies that apply a complex adaptive agent based modeling in Africa. Rouchier et al. (2001) study seasonal mobility among nomadic cattle herdsmen in north Cameroon. The study explored the conditions that determined the access that nomadic herdsmen have to pasture lands. They used an agent-based modeling framework to model the dynamics of the relationships among three agent types: nomadic herdsmen who need both water and grass for their cattle and who seek access to these resources from village leaders and farmers in return for access fees; village leaders who provide herdsmen with either good or poor access to water depending on their order of arrival; and village farmers who own pasture land that they may or may not permit the herdsmen to use for cattle grazing. A key finding is that the grazing patterns and individual relationships established among herdsmen, village leaders, and village farmers tend to be very regular.

Conclusions and gaps in knowledge

Pastoral mobility has been identified as an important factor in determining patterns of rangeland use, and yet very few models of the pastoral mobility exist. Existing system modeling efforts tend to concentrate on the prediction of animal distributions, as a simple function of habitat suitability. Although animal movement may be based on simple rules, complexity evidently exists in patterns of mobility and the consequences that this will have on animal utilization of rangeland and meeting the needs of the livestock. Animal distribution models that do account for habitat suitability to grazing fail to account for behavior of the pastoralists, confining grazing and its impacts to within appropriate limits determined by the suitability indices. Models that do simulate spatial impacts have not investigated the significance of the many other factors that may be contributing to the grazing pattern, including pastoral response to insecurity and disease risk, community differences and assume a gradient of grazing intensity to be a sufficient predictor of rangeland foraging dynamics. Not much work has been reported that accounts for the sequence of events leading to mobility. It is impossible to predict whether developing a model of pastoral mobility will improve its utility and whether increasing the number, and detail, of mechanisms simulated in a model of mobility dynamics will improve its performance. However, we know that such a model will improve our understanding of the dynamics that take place in these pastoral environments and as we improve our comprehension of the factors that drive mobility and the how, where and when it takes place, it will become possible to evaluate the relative influence of mobility on ecology, mechanisms to improve and derive most benefit from it, appropriately guide land reform policies in these pastoral areas, seek ways to better target interventions during periods of need. Perhaps then we may expect improvements in our models of rangeland use.

CHAPTER III

AGENT-BASED MODELLING OF PASTORALIST MOBILITY IN THE RANGELANDS OF EAST AFRICA

Introduction

Pastoralism is a significant but declining component of the livestock economic sector in eastern African countries, including Kenya, Djibouti, Ethiopia, Somalia and the Sudan (Abule et al., 2005). In Africa, indigenous resource tenure systems have evolved to meet the constraints and opportunities of often-difficult biophysical environments, while facilitating the operation of complex spatial and temporal land use patterns (Behnke et al., 1993; Scoones, 1994). However, as seen in Ethiopia and in many nomadic pastoral areas, rangeland-based lifestyles, their associated industries and the rangeland environment are under threat. Some of the reasons attributed to this threat include increasing human population, conflicts, extreme climatic fluctuations, animal diseases, over estimation of the proper stocking rates, land-use changes and the demand from an increasingly important cash-based economy (Roderick et al., 1998). Due to the wide fluctuations in climatic conditions, a household's use of rangeland resources can vary between years and seasons within a year (Ellis and Swift, 1988; Coppock, 1994). The spatial distribution and use of these rangelands has therefore become a major issue facing animal and rangeland managers. Issues are complex, and alternatives are often conflicting (Vavra, 1992). Examples include big game-livestock interactions, game damage on private lands, threatened and endangered species (Holechek et al., 1989) and conflicts due to competition for resources. In some circumstances, uneven grazing exacerbates deteriorative processes such as soil erosion (Blackburn, 1984), and subsequent ecosystem impacts. Livestock grazing in an area may also force indigenous animals to use marginal habitats (Yeo et al., 1993) while human activities may also interfere with animal distribution or preempt access to critical habitat (Williamson et al., 1988; Coughenour and Singer, 1991). Understanding the spatial and temporal dynamics of landscape use by herbivores is critical for ecosystem management (Senft et al., 1987; Coughenour, 1991).

Pastoral systems provide an excellent example of how modeling can assist in understanding the impacts of human resource use. Because most pastoral animals are taken to and from grazing areas each day by humans, it makes monitoring pastoral animals' densities particularly difficult because aerial censuses, which are generally flown in the morning, do not give an accurate picture of cattle distributions at a landscape scale (Peden, 1987).

Secondly, given the difficulties of monitoring the spatial distribution of pastoral grazing, spatial modeling may offer a more useful method for predicting the distribution of grazing and identifying ecological impacts.

Identifying and characterizing the ecological impacts of pastoral production are contentious topics in both the anthropological and biological literature (Lamprey, 1983; Ellis and Swift, 1988; McCabe, 1990; Little, 1996). A key element of these debates is the spatial dimension of impacts and pastoral herding.

Experiments associated with pastoral use of the landscape are usually time-consuming, but behavioral research can make use of simulation studies, which can generate a large amount of data, to test assumptions on the influence of animal or environmental factors on the grazing process. Models are therefore incredibly useful in understanding complicated systems and a computer model allows exploration of a variety of scenarios that would be too difficult, expensive, or even dangerous to allow to happen in reality.

The socio-economic and biological significance of pastoral land use for biological conservation is widely recognized (Western, 1994; Little, 1996; du Toit and Cumming, 1999). As an example, substantial numbers of wildlife use pastoral areas adjacent to Amboseli National Park, Kenya (Western, 1994), Maasai Mara Reserve, Kenya (Broten and Said, 1995), Ngorongoro Conservation Area, Tanzania (Boone et al., 2002). Pastoral land use will likely affect these populations and may strongly influence whether protected areas become insularized. Many studies have explored the negative effects of insularization on East Africa's protected areas (Burkey, 1995; Newmark, 1996, Worden et al., 2003), but far fewer have examined the land use systems potentially leading to it. Therefore, an understanding of pastoral mobility and land use may assist in promoting successful management of pastoral land and conservation efforts in protected areas.

Understanding pastoral mobility may also help to recognize heterogeneity in resource use (e.g. Coppolillo, 2000), indicate areas where conflicts due to resource competition might possibly to occur, or provide a deeper understanding of the long-term factors shaping current landscape structure and ecosystem function (e.g. Turner, 1998).

Landscape physiognomy and composition have been shown to affect grazing distribution patterns. Landscape attributes such as slope and distance to water and biotic factors such as forage quantity and quality affect how individual animals use and move between landscape elements (Turner, 1989). Social-cultural and abiotic factors are the primary determinants of large-scale mobility patterns of pastoralists in the rangelands of East Africa and act as constraints within which mechanisms involving biotic factors operate. To determine temporal and spatial distribution of pastoralists and their livestock, it is necessary to understand how they move through heterogeneous landscapes and the decision rules that drive these movements. Consequently, ecological models should also be spatially explicit. Spatially explicit based models of animal movement and foraging behavior can be helpful in understanding how landscape patterns might affect ecological processes (Walters, 1993).

The approaches that have been used to study livestock and pastoralist foraging behavior patterns of rangelands include algorithmic rule models in combination with habitat suitability models, random walk models, regression studies, and a variety of GIS based approaches (Senft et al., 1983; Turner et al., 1993; Percival et al.,1996; Coppolillo, 2000). Very few, if any individual-based models or artificial intelligence techniques of pastoralists and livestock mobility have been applied to East African environments. Literature of pastoralists' mobility and behavior show that they respond to their environment using a combination of scouting knowledge, ecological and social experience among other factors (Niamir-fuller, 1999). Therefore, rule-based models that encapsulate behavior of pastoralists should be better than habitat suitability models for understanding and making predictions about pastoralist mobility. The use of artificial intelligence in spatially explicit, agent-based behavior models has been successfully demonstrated by several authors elsewhere in Africa (Bousquet et al., 2001; Rouchier et al., 2001). There are no individual-based models of pastoralists' movement applied to East Africa and only a few movement models examine both landscape ecological and social factors influencing movement patterns of pastoralists.

A critical step in a study of herd mobility would therefore be to ensure that behavioral assessments of pastoral mobility and land use are made in terms of mobility behavior of the pastoral communities, an integrated approach, rather than with respect to resource organization alone. Such an approach will provide a method to quantify the pastoralist's perceived assessment of the heterogeneity of the environment.

Ash et al. (1999) suggest that high-level management recommendations in future will be enhanced by support from integrated models that represent rangeland systems as complex adaptive systems, where both the biophysical system and the institutions (people, policies, governance structures) are co-evolving. Integrated models combine simplified versions of expert models of various disciplines (Janssen, et al. 2000). They combine social, economic and ecological sub-systems. One purpose of integrated models is to develop principles for managing and adapting to real complex systems.

The modeled rangeland system presented herein consists of ecological and socio-economic sub-systems. The ecological sub-system is a simplified version of more comprehensive models. Relations are empirically based. The socio-economic sub-system binds the grazing activity pastoralists within several specific fluid and dynamic ethnic community boundaries.

Potential decision rules for pastoralists were developed in discussion with experts on rangeland management and simplified for the model. The decision-making environment and the pastoralists' decision rules addressed the complexities of real systems in a parsimonious approach. The goal of this study was to develop an agent-based model of pastoralist mobility capable of simulating the movements of pastoralists and their cattle.

The objectives of the study were to:

- Simulate pastoralists foraging and movement through heterogeneous semi-arid rangeland habitat.
- Track and generate hypotheses about the influence of the environment on the evolution of simulated mobile populations of pastoralists under different seasonal regimes.
- Demonstrate the utility of ecological modeling in African semi-arid savannas.

Methods

Study area

The study area traverses an ecologically, ethnically and institutionally heterogeneous transect of approximately 750 kilometers, from Yabello in southern Ethiopia south through Baringo, Marsabit, Isiolo, Wajir, Mandera and Samburu districts in northern Kenya. The spatial extent of the study area is approximately 250,000 km^2. This study area was chosen to capture variation in ecological potential, market access, livestock mobility and ethnic diversity. The study area is inhabited by several main pastoral ethnic groups, i.e. the, Boran, Gabbra, Somali, Rendille, Samburu among others. Climatically, Southern Ethiopia is semi-arid to arid. The main pastoral group in this zone is the Boran people who are pure pastoralists. Somali clans are also found in this zone. northern Kenya which is also semi-arid to arid with its major pastoral groups being the Samburu, Turkana, Boran and Somali. All these groups are pure pastoralists and practice transhumance, i.e. the practice of moving between seasonal base camps. They keep cattle, sheep, goats and camels upon which they are greatly dependent on for food security. They move their livestock seasonally in order to exploit areas away from their permanent settlement sites. The animals owned are used for milking, slaughtered for meat, sold for cash or bartered for other commodities. Pastoralism by definition is an extensive system of livestock production in which a degree of mobility is incorporated as a strategy to manage production over a heterogeneous landscape characterized by a precarious climate. Because of the need to take full advantage of the landscape, pastoralism is poorly fitted to the rigid structure of national and international boundaries. The pastoral strategy of mobility therefore underscores the need for a regional perspective, especially since other impacts such as resource access conflict, spread of disease and livestock rustling are side effects of pastoral mobility.

Agent based model

Multi-agent systems offer a modeling method based on the principles of distribution and repetitive competitive interactions (O'Hare and Jennings, 1996; Epstein and Axtell, 1996; Bonabeau, 2002; Gimblett, 2002). To model a complex phenomenon, different interacting entities with specific behavior patterns are represented. The computer entities (agents) perceive their environment and are able to act upon it, are able to communicate by sending messages and to make representations of the world. This structure reflects a bottom-up approach to the representation of reality. Knowledge is represented at the microscopic level and emergent phenomena are observed at the macroscopic level.

The agent based modeling (ABM) presented here is designed to evaluate the dynamics arising from foraging preferences of pastoralists and their livestock specifically cattle.

Variations in forage and water resources, and feedbacks associated with spatial locations of these resources with respect to pastoralist locations are also evaluated. We call this model **PLMMO** (**P**astoralist **L**ivestock **M**ovement **Mo**del). The model involves agents (pastoralists and their herds or herd-herder complex) that locate themselves on a two-dimensional lattice that has a set of heterogeneous attributes with respect to water, forage and ethnic community boundaries. Agents choose their locations based upon these attributes. The model was developed in a Java programming platform and has three major elements: the agents, the environment in which the agents live, and rules governing the manner in which the agents interact with the environment and each other. Since our main goal of building this model was to improve the understanding of the dynamics of the pastoral system, we avoided incorporating too many realistic details in this initial prototype but built a modular structure with the capability allow the introduction of additional agents, attributes, and behaviors as needed in future. The overall flow of information in the model is presented in Fig. 1. A sketch of the Unified Modeling Language (UML) class diagram showing the structure of the relationship between the component classes, attributes and methods identified for each of the classes is presented in Appendix 2. The various attributes and functionalities of each of the Herder agent, Patch and Grid classes and the relationship between them are depicted in this UML class diagram.

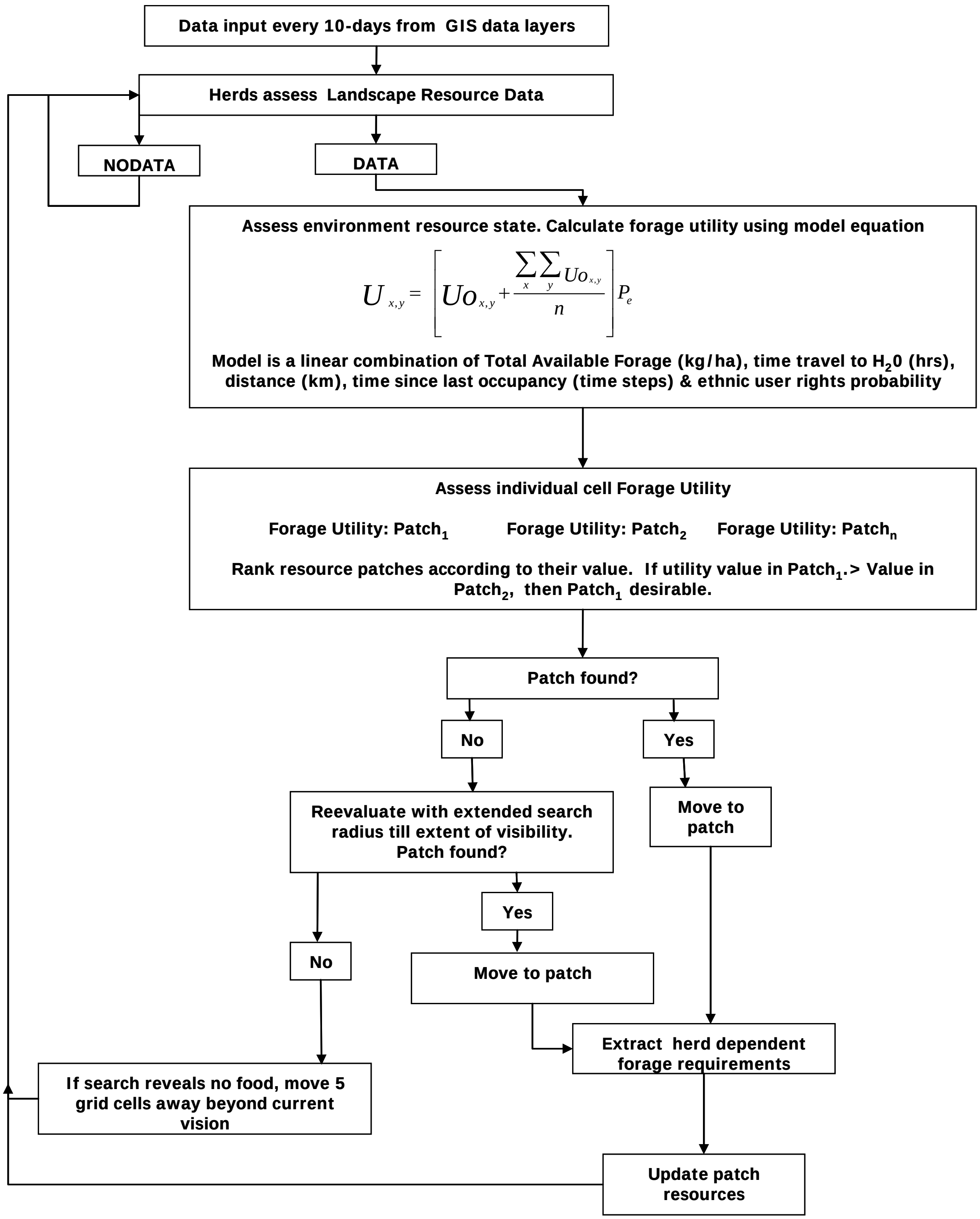

Fig. 1. The flow of information in the agent based PLMMO model of pastoral mobility.

Model structure and components

Our model is a discrete time and state event process representing pastoralist herd/herder agent movement activities and behavior. Events occur discretely every ten days. The rangeland environment is represented by a square grid bounded in a 175 by 87 grid cells rectangle, each grid with an areal resolution of about 21 km^2 representing a total area of approximately 270,000 km^2. The actual area of the simulation runs was however slightly less than this i.e. 246, 448 Km2 due to exclusion from the experiment of regions where there was no data on either livestock population/forage values. This rangeland is represented in PLMMO as a raster-based geographic information system (GIS) in which each location (grid lattice) is an intelligent entity. Each location keeps track of its ecological and ethnic community identification, what resources and cattle herds are present, and a history of events that occurred in the cell with respect to utilization by the herds. PLMMO has graphical user interface that displays data results, such as resident herd population during every time step, location of forage resources and paths of travel for selected individuals. Each herder-herd unit is individually modeled and its movement characteristics output is saved as ASCII output files in a manner that can be imported into a GIS. Behavior can be modified by changing rules, the characteristics of the herds or their environment. The specific parameters that can be modified are: individual animal head consumption rate, radius of visibility of resources, habitat preferences, interspecific relationships with other herds (e.g. competing use of resources at the same location), ethnic community rights of use and utilization algorithm specifications during each time step. PLMMO is written from the ground up in JAVA to provide cross-platform portability and allow for modeling flexibility that might not exist in other pre-constructed agent based software. The basic components of PLMMO are the individual pastoralists' herd/herder units and the resource environment map. These components “talk” to each other through specified rules to create a modeling system.

Herd behavior in the PLMMO

There are three possible actions that pastoralist herds may take: ‘move’ to a neighboring cell; ‘consume’ resources in the cell they are currently occupying; ‘stay’, that is, take no action at all. The borders of the study area are barrier to herd movement and pastoralists are restricted to activity only within these borders. After each action, the herd records where that action was taken and this information is stored in a sequential ASCII text file. The herd forage resource is decreased by a standard, herd-specific consumption rate with each 10-day time step. Movement can only occur in 10-day intervals. This is an interval that corresponds with a principal input data reporting schedule for forage production every ten days (described later in this text).

The flow of information begins by the herder determining whether it needs to move to a new location or not. This process begins by herds determining their internal state (location, how many cattle heads, what ethnic community it belongs to) and also about its environment (water and forage resources available at current location and locations within its “visible” range). Responses to these questions come from data about its environment from the GIS layers and also from other herds in the environment. The single important environmental attribute assessed by the herder:herd agent is termed forage utility ($U_{x,y}$), and is defined below. After the herder:herd agent has acquired all the information it then makes a decision to act accordingly, either move or stay at the same location. The herder:herd agent then updates the entire community what action it has taken and the community then asks the next herd to take action. After each herd has acted in its turn, the community increments the time step by one and the process starts over.

Forage utility model

In order to represent the landscape in terms of consumption profitability to herders and provide a common currency for the mechanisms of foraging encounter, travel and memory, we developed a unit variable which we called “forage utility”. Using this variable, we were able to redefine the environment in terms of profitability to the herder(s). Profitability was determined by known rules of behavior of pastoralist and incorporated into the model to determine the forage utility. Movement was then determined by a utility preference handled by the forage utility value, and herds moved to sites which accorded them maximum forage utility whenever they had a choice.

This expected forage utility is a unit-less value defined by the following equation:

$$(U_{x,y}) = \left[U_{O_{x,y}} + \frac{\sum_x \sum_y U_{O_{x,y}}}{n} \right] P_e \qquad (1)$$

$$(U_{O_{x,y}}) = \frac{\text{Forage}_{x,y}}{\text{Wd}_{x,y}} S_{x,y} \div d(c_{i,j}, c_{current}) \qquad (2)$$

$$S_{x,y} = \frac{(\text{idle days}) \bmod (\text{max Idle days})}{\text{Max Idle days}} \qquad (3)$$

Where:

$U_{x,y}$ is the expected forage utility value associated with cell (x,y)

$U_{O_{x,y}}$ is the initial forage utility value for cell (x, y)

$\frac{\sum_x \sum_y U_{O_{x,y}}}{n}$ is mean directional utility value for cells in the direction of assessment

P_e is the community acceptibility multiplier factor asscociated with current agent

$Forage_{x,y}$ is the forage standing crop (kg/ha) at cell (x, y)

$Wd_{x,y}$ is water distance access factor from current cell

$d(c_{i,j}, c_{current})$ is the total manhattan distance from the current cell

$S_{x,y}$ is a memory decay factor for occupation

(idle days) represents number of days a cell has been idle from occupation

We define forage utility ($U_{x,y}$) as a foraging benefit value that herder:herd agents derive from locations because of a combination of the following factors; the amount of forage standing crop at that location and in its user defined neighborhood, how far the location is from an agent trying to access it, how accessible it is to water source, how long ago the location was previously occupied, and which ethnic community or communities claims rights to its usage. In our model specification, agents care most only about this forage utility value $U_{x,y}$ at a location *x,y*. $U_{O_{x,y}}$ is an initial forage utility value of a single cell location that does not take into account neighborhood forage effects as the final forage $U_{x,y}$ value does. From the equation for the final forage utility, we see that location's utility increases in proportion to the location's forage standing crop quantity (kg/ha) and decreases in proportion to its distance from water location.

Each grid cell location *x,y* has an associated forage utility value. The equation given above for forage utility captures the empirical observation that, although absolute forage standing crop ($Forage_{x,y}$) is an important determinant of utility, it is not considered independent of distance to water ($Wd_{x,y}$), and number of days since last grazing (idle days) which accounts less preference by herders for recently grazed sites. For any specific ethnic community, it forage utility is also determined by rights of usage for resources at any specific location determined by ethnic community acceptability P_e. This model allows agents at a particular cell to consider the tradeoffs between forage, access to water, distance to that forage location and weights near locations much higher using squared distance weighting.

Standing crop ($Forage_{x, y}$), is the forage standing crop for the specific grid cell that the agent is trying to assess. This value is represented in kg/ha. Each cell's standing crop has the ability to receive and evaluate a request for consumption; the cell's assessment of consumption will be a function of how many agents have requested resources from it during each time step. Once it accepts to be "consumed" by agents, it decreases its forage standing crop load at each time step by amount consumed. The cell takes up a new load of reported forage standing crop at the beginning of the next time step from a new GIS forage layer.

Distance to water ($Wd_{x, y}$) is a factor of accessibility to water points calculated using the COST-DISTANCE model in ArcGIS 9.0 (ESRI, 2004) using a friction surface of impedance to get to the water source. Travel costs are represented in terms of travel time (*hours*) to a water source and takes into account factors of size of the water source and its radius of influence (represented by selective weighting), seasonality in availability, slope and terrain barriers, landuse and landcover characteristics. This approach was considered a more realistic representation of distance to a water source than measuring the distance of a road or straight-line connection between two locations. Different types of surfaces present different challenges to get to water and a cost of travel surface was derived from factors of distance, slope, landcover and landuse. Movement across a rangeland would therefore be faster than across a wooded area for instance while a fully fenced protected area presents a challenge to movement as it is some sort of barrier, albeit a permeable one but probably at a higher cost.

Higher slopes and rugged terrain would also present a higher cost for accessing a water source than would flat terrain.

The distance to forage $d(c_{i,j}, c_{current})$ is a variable that describes how accessible a cell location that a herder:herd agent is trying to assay is from the agent's current location. Nearer locations get higher preferences than distant locations due to the reduced cost of travel. This distance from current location is a function of the location of the agent. The distance is measured by summing the Manhattan straight edge distances of cell boundaries ($d = |x1 – x2| + |y1 – y2|$) for the number of cells from agent's location to destination cell.

$S_{x,y}$ is a variable that accounts for the preference by herders to prioritize usage on fresh locations which have not been recently grazed. Cattle via their herders utilize spatial memory to avoid recently grazed areas and when not herded cattle have been shown to avoid locations with depleted food resources for up to 8 days (Bailey et al., 1996). Sites recorded and retained information about the last time a site was utilized or occupied. Using an exponential decay model, these site records serve as the memory of the herder:herd agent's usage for any location and is decayed during each time step until all of the memory of usage was cleared by the end of the third time step (30 days). Areas that were occupied recently received least preference from herder:herd agents bar intervening occupation. However, any site that had not been occupied during the last three time steps clears its memory of any recorded occupation and is viewed by herder:herd agents as a fresh site and therefore most preferred.

In this way, memory about usage of a site was integrated into the assessment of the grid cells to be moved to and thereby influenced the assessment for forage utility value and also therefore the decision as to which cell location to move to next.

The variable $\frac{\sum_{x}\sum_{y} U_{O_{x,y}}}{n}$ represents the mean directional score in the direction of the cell being assessed for utility. This mean directional forage score value is calculated from a roving window average in the direction of the cell being assessed to account for influences of resource density in the specific direction being assayed. This ensures that the assessment of utility is not only restricted to individual cells but also to a neighborhood. Such an assessment ensures that the agent visits as many profitable sites while minimizing the distance traveled. These directional mean values take into account the perceivable profitability for resources at remote locations, beyond the scope of current and a few neighboring cells, out to the limits of the agent's visual range. This directional score is calculated by first calculating the forage utility value at each location and then finding the average forage utility for all the residing within a user defined grid window of size *n* by *n* within which the cell of interest lies at the center (See Figure 2). In our assessment *n*=9.

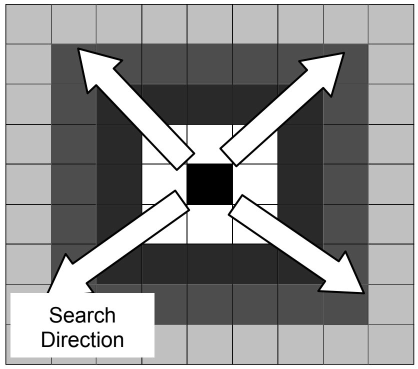

Figure 2. Assessment of the direction with maximum mean forage utility profitability. (If one is assessing the forage value for the dark central cell, one also considers the mean forage utility for all the surrounding cells in this window comprising D_d by $_d$ cells (where d=9) ranging from the central cell location (x,y) out to the limits of the assessment window. A cell selection therefore does therefore not only entail selection of cell with maximum forage utility but also adds to this value the mean of forage utilities for the cells around the destination cell. A single cell might therefore have the highest forage in a herder's search radius but fail to get selected because the cells around it have low mean values which when added to that cell's value might have a lower profitability compared to cells at other sites).

The final forage utility value is computed by the equation:

$$(U_{x,y}) = \left[U_{O_{x,y}} + \frac{\sum_x \sum_y U_{O_{x,y}}}{n} \right] P_e$$

which simply sums up the forage of the cell being assessed to the mean forage utility for the window within which the cell being assessed belongs and adjusts this value by a multiplier factor P_e [0,1] for ethnic community acceptability. Communities grazing within territories where they have absolute user rights will have a P_e value of 1. This value reduces linearly to a minimum of 0 for areas where they have absolutely no user rights.

By representing the landscape in terms of a forage utility value, we are able to redefine it in terms of consumption profitability to herders and provide a common currency for the mechanisms of foraging encounter, travel and memory. From any current location (x,y), therefore the agents' preference is to move to the a cell which accords the maximum utility Max{$U_{x,y}$} defined by:

$$\text{Max}\left[U_{O_{x,y}} + \frac{\sum_{x}\sum_{y} U_{O_{x,y}}}{n}\right]P_e$$

As used here this assessment combines utility at a specific location and within the directional neighborhood of assessment.

Agents

The basic agent types are the pastoralist and their cattle herds each of which has heterogeneous attributes in relation to herd sizes and behaviors in relation to ethnic community grouping. The herd object type is created to represent cattle in a 4.5 by 4.5 km area containing several cohesive herds (approximately 30-50 head each). Pastoralists and water sources enter the world during model initialization through data read from a GIS and each takes up one cell in the grid network. A grid is considered "watered" but multiple water points are not represented in each grid. Water grids have attributes that change seasonally in relation to whether it serves as a permanent or a seasonally water source. Access to water in a grid greatly affects how pastoralists determine where agents will move. Pastoralist agents have three important attributes: (1) forage preference, the weight that an agent gives to the forage resources of a cell. (2) access to water preference, the weight that an agent gives to the cost of reaching a water source and (3) pastoral ethnic community preference, the weight that an agent gives to how friendly/hostile a pastoral ethnic community will be toward the agent making an attempt to move in a grid under their domain of influence.

<u>Agent behavior: site selection</u>

The agent behavior of interest is the location of where the agents move during every ten-day time step. This 10-day temporal scale was chosen to adapt to the availability on forage standing crop data generated by the USAID Global Livestock CRSP Livestock Early Warning System (LEWS) (Stuth et al., 2005) for the study area and also the need to reduce the simulation running time to a manageable time period. This temporal scale is in close agreement with models such as the SAVANNA model (Coughenour, 1993) which employed a weekly time step.

Each time step, pastoralists' agents either move to a new location or stay at the same location, depending on their assessment of their environment. Pastoralists choose their location based on the set of defined preferences and landscape attributes relating to forage utility ($U_{x,y}$). Cattle and herders are simulated as efficient foragers, targeting high forage utility ($U_{x,y}$) locations first before consuming that of a lower value. Field observations and modeling exercises have shown that the maximization of daily energy gain is the rationale for optimal foraging strategies (Fryxell et al., 2001) and the primary determinant of animal movement patterns (Wilmshurst et al*.,* 1999). When forage availability is constrained, they will adjust their consumption habits to match this reduction in forage availability. The Holling type II (Spallinger and Hobbs, 1992) foraging model was used to precisely model how food consumption rates are affected by food availability. (The Holling functional response describes how the intake rate of an animal foraging in a location varies with the amount of food there).

To select a cell to move to, an agent looks at the Moore's neighborhood (neighborhood containing all the 8 adjacent cells to the current cell) and moves into the cell that has the highest utility for forage value (or selects randomly among tied cells). This assessment includes the current agent location and therefore "no move" may prove most profitable. If the search fails to find a profitable cell immediately proximate to the current location, then the search is expanded to the next nearest cells, and so on, until the limits of perception are reached. Furthermore, because visual range may allow assessment of several cell-lengths from the current location, and grid-wide searches extend even further, some herd moves may involve "jumps" from the current location to the destination cell. This mechanism thereby adopts more direct and quicker movement between sparsely distributed forage resources (Etzenhouser et al*.,* 1998). Travel costs are tallied correctly to include these longer movements.

A herder/herd agent's 'move' rule is a derivative of the Marginal Value Theorem (Charnov, 1976), that predicts that animals should move to more profitable sites once resources at the current location have been depleted to the environmental mean (G*). This defines the theoretical 'Giving Up Density' (GUD) for the resource (Charnov, 1976).

The probability of agents moving out of the current cell $_{x,y}$ is then calculated by:

$$\begin{cases} 0 & \text{If current cell } U_{x,y} \geq \text{ local average of } U_{x,y} \\ 1.668 * e^{-0.5117*d} & \text{Otherwise} \end{cases} \quad (4)$$

Where d is the number of time-steps of cell occupation by an agent.

The parameters for the model were derived from calibration using a linear implementation based on literature, experimental data, expert opinion on what we thought to be the order of leaving a cell depending how long an agent stayed at a location. If multiple agents found themselves in the same cell, the order of leaving the cell followed the “first in, last out” or “last in, first out” procedure where *d* is the number of time-steps of residence in a cell. This order is in concurrence of known informal rules of foraging and livestock mobility across African rangelands known to base their foraging activities on a “first come first served” basis and the passive coordination or “choreography” of movements in a desire to avoid other groups (see Niamir, 1999). The scheduler allowed for dynamic scheduling where the cells were updated synchronously but movements were randomized during each run so that no herd had preferential access to resources.

To represent a drought phase, simulation runs were performed during the period April 2002 to June 2004 which was a relatively dry period in the study area. This period represented a meteorological drought defined here by the deficiency/departure of precipitation from normal over an extended period of time. Prolonged drought results in severe shortages of pasture and water. We chose this representative time-period due to the fact that by the time of this study, forage maps had not been created for the drought period between January 1999 to March 2001 for which field data was collected. The post-drought phase was simulated between the dates of March 2001 to March 2002 to correspond to surveys and field data.

Spatial analysis

A nearest-neighbour index analysis (Li and Reynolds, 1995) in ArcGIS (ESRI, 2004) was used to test the distributions of pastoralist activity locations for complete spatial randomness using the animal movement extension for Arcview (Hooge and Eichenlaub, 2000). Nearest Neighbor Analysis (NNA) is a technique for measuring the degree of clustering or regularity in a spatial distribution pattern. NNA involves a comparison of the actual spacing of distribution with the spacing expected if the pattern were random. The value of the nearest neighbor index varies from 0 to 2.1491. A zero index is where all activity is concentrated in one location; a perfect regular spacing of occupation activity gives an index of 2.1491; and a random pattern has an index of 1.

A second analysis was undertaken to evaluate the correlation between forage standing crop availability derived from the GLCRSP LEWS reporting system (http://cnrit.tamu.edu/aflews/) and model run outputs representing herd densities, i.e. values of forage were matched with for herd densities. Correlation coefficients for each dekad were then derived to evaluate if there existed any linear relationship between two variables.

Model parameters and evaluation

The biophysical forage growth model PHYGROW (Phytomass Growth Simulator) (Rowan, 1995) was used to estimate total forage availability (kg/ha). PHYGROW is a hydrologic based plant growth simulation model. PHYGROW produces available forage production for a site, representing complex plant communities (Fig.3a). PHYGROW uses soil characteristics, plant community characteristics, grazing practices and weather data for a particular location to predict the forage production and associated water balance. For soil inputs, the model requires soil layer information including surface features such as runoff curve numbers, surface slope, and surface roughness. Comparisons of forage production to long-term averages can also be made (Fig. 3b). The simulated PHYGROW forage maps in pastoral areas of five countries in the Horn of Africa (Stuth et al., 2003) between 2001 and 2004 (http://cnrit.tamu.edu/maps/) were used for this study. Both rangeland plant communities and associated forage were simulated using PHYGROW. Livestock density maps were derived from a 3rd order administrative livestock survey map for eastern Africa at a 3-arc minute (approx 5 km^2) resolution from the Livestock Early Warning Systems (LEWS) project maps database, Texas A&M University (http://cnrit.tamu.edu/maps/). Maps of existing water sources were compiled from a variety of sources i.e. publications, maps, remote sensing, and fieldwork.

Model parameters were used to emulate fieldwork carried out in a study of pastoral resource use on two locations in the Borana lowlands of southern Ethiopia (Dida Hara and Web) (Homman, 2004). Natural resources and herd movements were mapped using participatory rural appraisal (PRA) tools, official maps and geo-referenced and stored into a GIS database. Socio-economic characteristics of 60 households and their herd movements during and after the 1999-2001 drought were recorded. Surveys performed during the period January 1999 to March 2001 represented a typical drought phase while the post-drought phase was represented by surveys conducted from March 2001 to March 2002. These figures are consistent with representativeness of drought and non-drought phases as can be seen in long term historical ranking for forage and Normalized Difference Vegetation Index (NDVI) conditions under drought and non drought phases (Fig. 3c).

Other model parameters were obtained from literature about pastoral mobility in the East African rangelands.

Field data was used to evaluate the predictive capacity of PLMMO model results with respect to distances moved and number of shifts occurring and during a drought and a post drought phase for two sites in which observed data existed. Validation in the truest sense would have required that livestock movement be monitored through telemetry across the span of the study period and associated factors influencing model variables, pastoral use, directions of movement, number of shifts and distances patterns observed. Since the field data existed only for distance moved and number of locational shifts made by pastoralists across the drought and post-drought period, the performance of the model was evaluated based on these factors and other known facts about mobility of pastoralists in the rangelands in response to climatic regimes. To evaluate the model, predicted distances moved made from representative sites was correlated to observed distances moved by households. A subset of the household survey data were selected and model performance verified using simple linear regression to determine the relationship between the observed and predicted values.

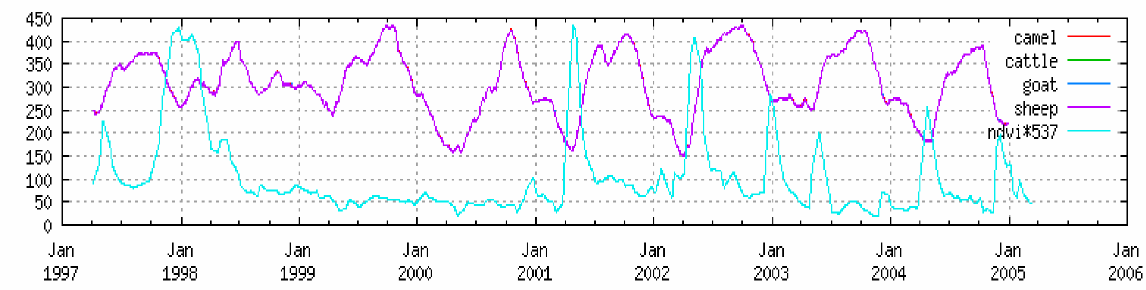

Fig. 3a. Forage and NDVI at Moyale, Kenya (Lat. 3.0012, Long. 38.2008).

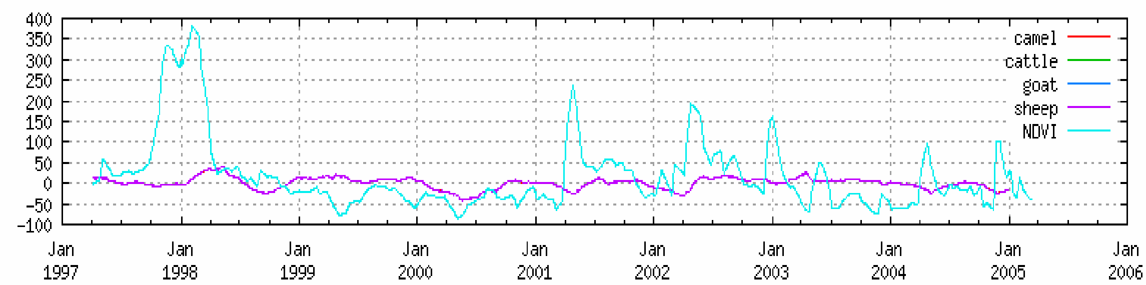

Fig. 3b.Long term deviation forage and NDVI at Moyale, Kenya (Lat. 3.0012, Long.38.2008).

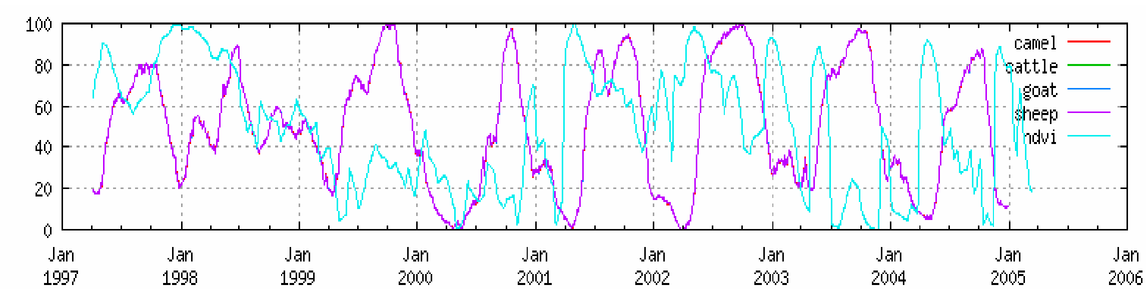

Fig. 3c.Historical ranking of forage and NDVI for Moyale, Kenya Lat. 3.0012, (Long. 38.2008).

Results

Geometry of use of landscape

Nearest-neighbor index analysis of the distribution of foraging locations resulted in values ranging between 0.24 and 0.47 for all cases ($0.24 < R < 0.47$, $N=13320$) The distribution of pastoralists' locations for foraging activities therefore showed a tendency towards clumping, concentrating the duration of activity much more within some study areas than others. Pastoralist densities were therefore not uniform, producing a clustering of their foraging activity. It follows that the cumulative distribution of pastoralists activities reflected in some way the heterogeneity of forage utility distributions. An entirely random distribution of foraging activity would not have been expected to do so, and would imply that foraging locations are not determined by resource distribution. Spatial heterogeneity in grazing was therefore detected.

Testing for the correlation between distribution of forage and herd populations returned low correlation coefficient values for all cases ($-0.2003 \leq r \leq +0.4116$) indicating a weak linear relationship. This implies that the distribution and density of forage resources did not perfectly match pastoralist activity distributions and therefore cannot be used to directly infer the level of herd utilization of a rangeland. This is as a consequence of accessibility to water among other factors that influence the preference to a site by pastoralists. The conflicting need for accessibility to water, forage and to some extent the defined extent of common pool resources for specific communities implied that pastoralists were in most cases unable to perfectly match the spatial distribution of their activities with the spatial distribution of their forage resources.

Model evaluation

Although much of the behavior in each part of the model is based on scientific studies, the performance of the entire system is usually hard to validate due to lack of studies of the pastoral systems. The only way to validate a model is an experiment. It is desirable to perform the model validation for the actual site of interest. However, this is seldom possible. Instead, we often validate the model in principle, i.e., ensuring that it represents the considered phenomena, by conducting controlled field experiments. Perhaps a better way of asking the question about validity of a model is "Is the model actually modeling what we expect?" (DeMers, 2002). Since validation of the model in its truest sense would have been difficult, we performed several runs on the model and analyzed the results to evaluate it and see if the results represented what we expected or what is known in literature. Following are model evaluation results.

Patterns of movement

The analysis of movements of pastoralists reflected heterogeneity in utilization of the arid rangelands. Fig. 4 and Fig. 5 provide model outputs for the simulations showing distribution of pastoralist densities across four sample dekads for the drought and non drought years. Increasing densities are shown with darker shades. These maps produced every ten days indicate that pastoralists utilized the landscape in a heterogeneous manner, as broad areas received fewer visits from pastoralists while others received many visits.

Since the drought and post-drought seasons were different with respect to different lengths and characteristics, we could not do a one to one matching of one season period to another.

However in all cases, we observed a much denser and concentrated utilization of resources during the drought phase than the non-drought phase where utilization was more evenly distributed and thereby showed low density per square kilometer (see comparisons of circled areas). The eight maps therefore illustrate how mobility is limited during the drought phase as more pastoralists tend to concentrate their activities within limited areas than during the non-drought phase when they more evenly disperse their utilization of the resources on the landscape. We suspect that this usage pattern is a result of the fact that the pastoralist herds was unable to spatially expand utilization range during the drought season because there was a weakened watering resource base (fewer locations with water) in comparison to the post drought period. The extent of water availability (and to a lesser extent forage) differentiates a drought and non-drought season. Sandford (1983b) reports that spatially more even distribution of pressure on vegetation and soil can be achieved by increasing the number of water sources which may lead to an overall greater, albeit more evenly distributed, pressure. On the other hand, some livestock, e.g. sheep in mountainous areas, distribute themselves, unherded, more evenly than others, e.g. cattle (Stoddart et al, 1975).

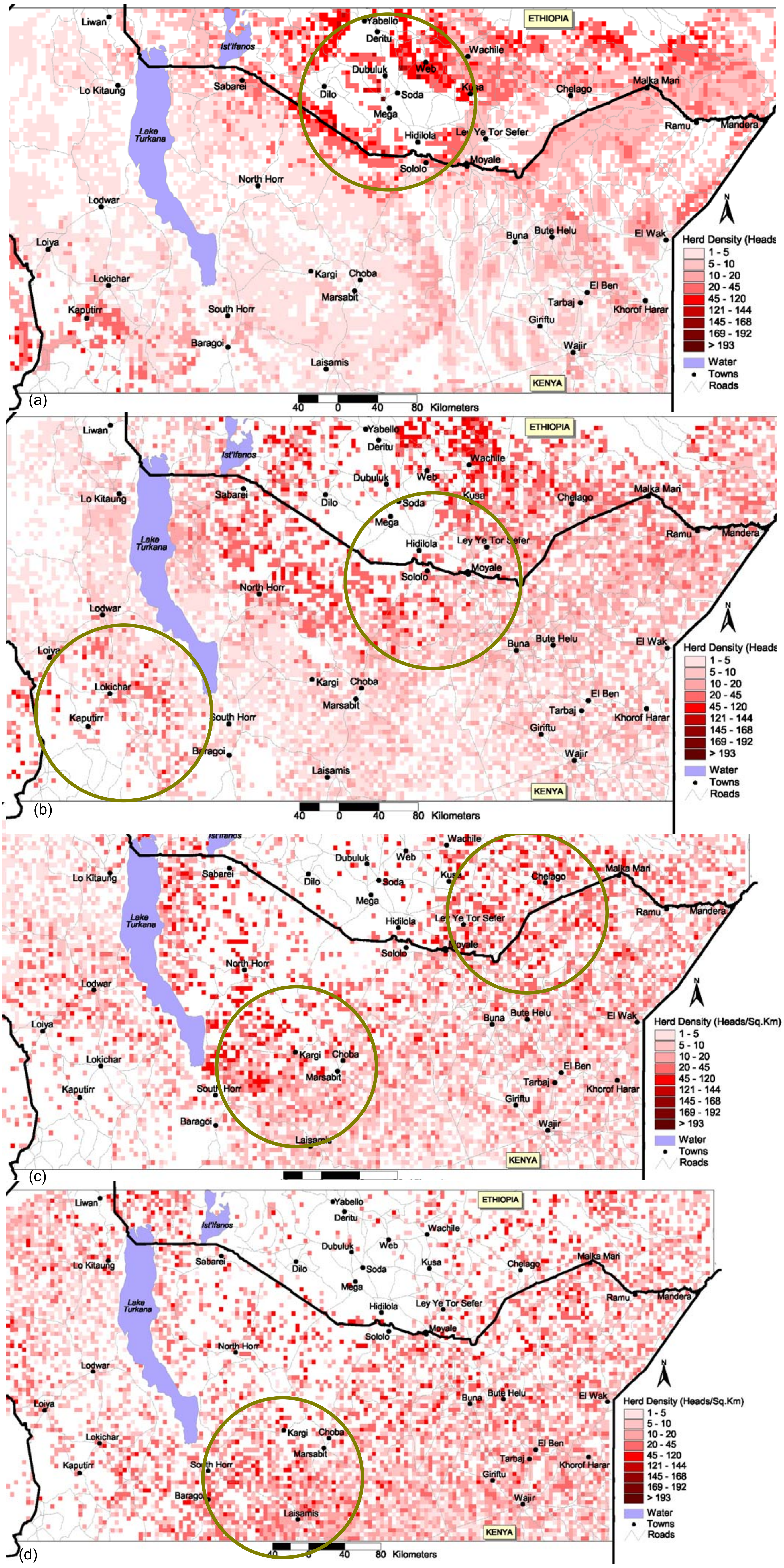

Fig. 4. Distribution of livestock herds during the drought period (a) Dekad 1, Mar 2002, (b) Dekad 2, Apr 2002, (c) Dekad1, June 2002, (c) Dekad 3, Nov 2002. (Circled areas indicate areas of more intense pastoral usage. The figures illustrate a higher aggregation of herds in these drought phase maps than in the post-drought phase maps in the next figure).

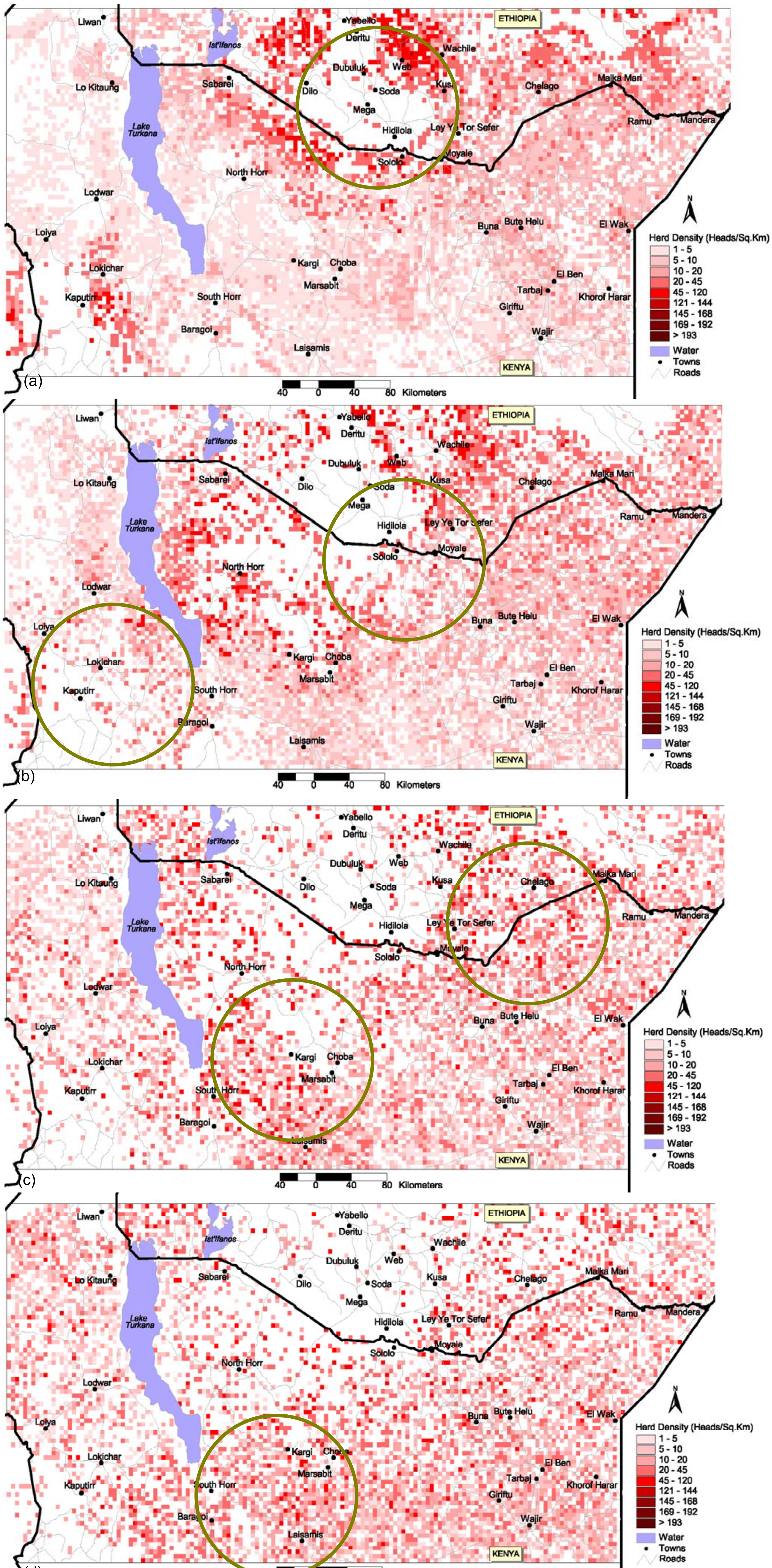

Fig. 5. Distribution of livestock herds during the post drought period (a) Dekad 2, Dec 2003, (b) Dekad 3, Jan 2004, (c) Dekad 3, Apr 2004, (c) Dekad 1, Sept 2004. (Circled areas indicate areas of intense pastoral usage. The figures illustrate less aggregation of herds in this post-drought phase maps than in the drought phase maps in the previous figure).

In all cases, pastoralist activity was concentrated at some intermediate distance somewhere between accessibility to the highest values of access to water and forage. This concentration of activity was constant (with little activity) at a short distance from water then abruptly rose before decreasing linearly with distance from water at the arid study area (Fig. 6). At the furthest point that animals were able to travel before returning to drink, the model predicted a similarly abrupt drop in activity at the outer edge despite substantial forage resources, the unaffected forage being resources that were beyond their mobility range as restricted by water.

The above expectation is reasonable because it compares favorably with published evidence for peak grazing intensity at intermediate distances from water in semi-arid regions. All these studies show that animal densities were highest at intermediate distances from water (Pickup and Chewings, 1988; Adler and Hall (submitted); Worden et al., 2003). This intermediate distance from water and forage seems to be the threshold distance at which pastoralists optimally balance utility.

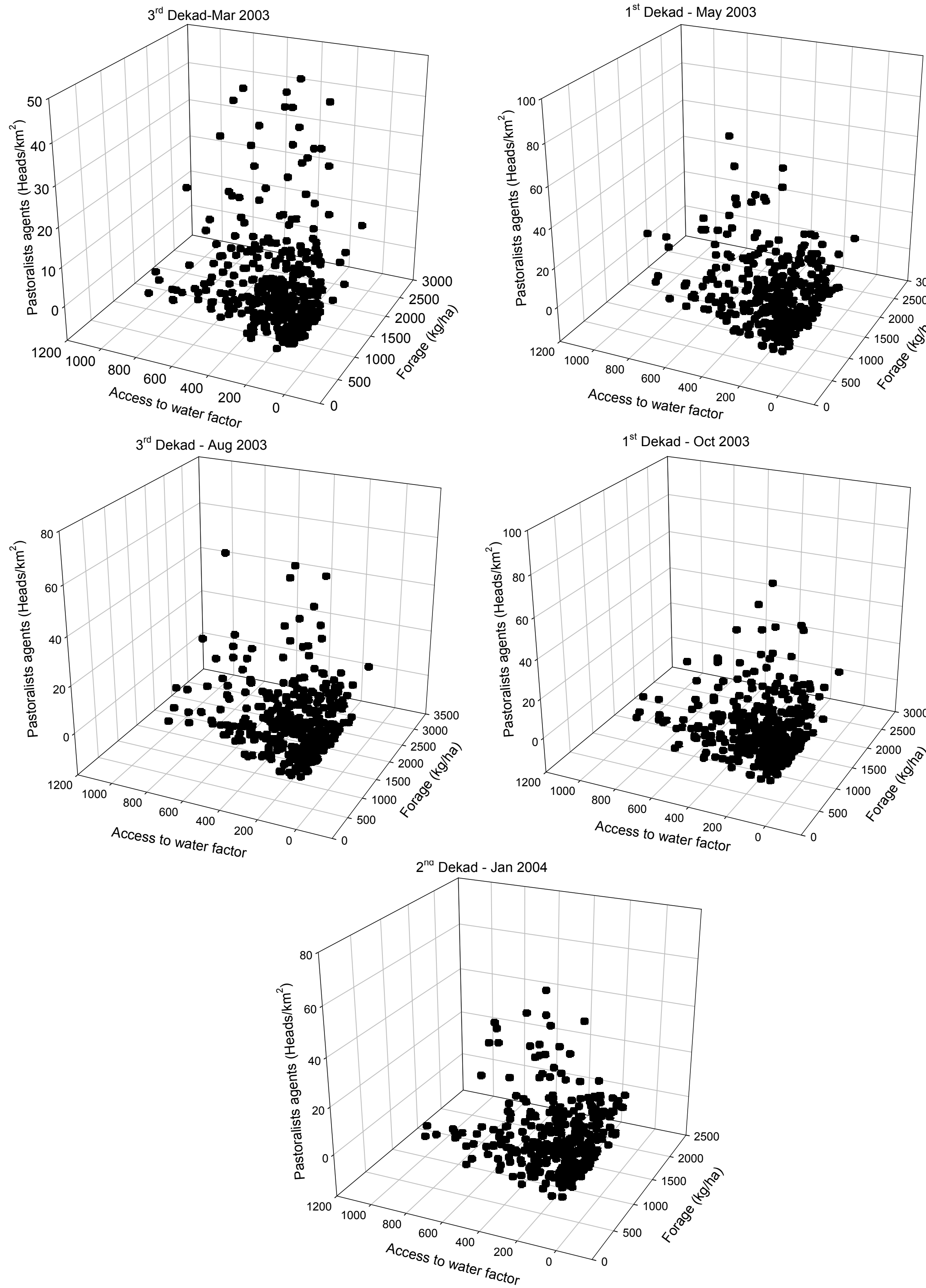

Fig. 6. Patterns of distribution of herds in relation to water and forage. (The figure shows that the region of concentration of herd activity is the intermediate distance from water and from forage).

Influence of climatic regimes on pastoralists' movement

This project was fortunate to acquire movement data of pastoralists within the study area to help compare modeled versus observed (Homman, 2004) distances of movement during the study period. The field study investigated pastoral resource use on two sites in southern Ethiopia (Dida Hara and Web). The study was conducted from September 2000 until July 2002, in co-operation with the Borana Lowlands Pastoral Development Programme (BLPDP) and the German Development Agency (GTZ).

PLMMO model produced 10-day movement patterns and updated populations of pastoralists and distances moved every 10 days for two different seasons that were investigated, drought and post-drought period. Values of distances moved by each cattle herd during a simulation were captured in an ASCII output file and then compared to values reported by the field survey. Results of PLMMO simulation closely approximated reported values. The model predictions were significantly correlated (r^2 values of between 0.927 and 0.977, $p<0.0001$) with observed distances for the three out of the four sites (Figs. 7 and 8) and Table 1. The fourth site did not have adequate field samples to enable a favorable comparison.

Distances collected during fieldwork households correspond to movements predicted by the PLMMO model across the drought and post drought seasons on our modeled landscape. Thus, model results compared favorably to field observations for distances traveled.

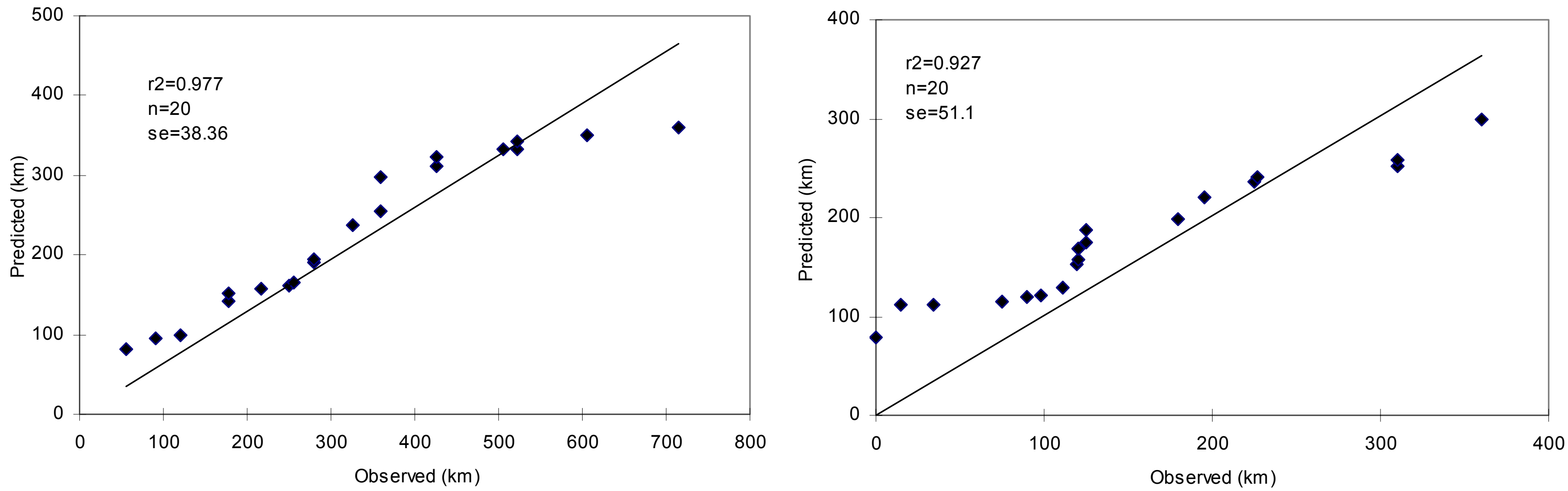

Fig. 7. Relationship between observed and predicted distances moved during drought and post drought in Web.

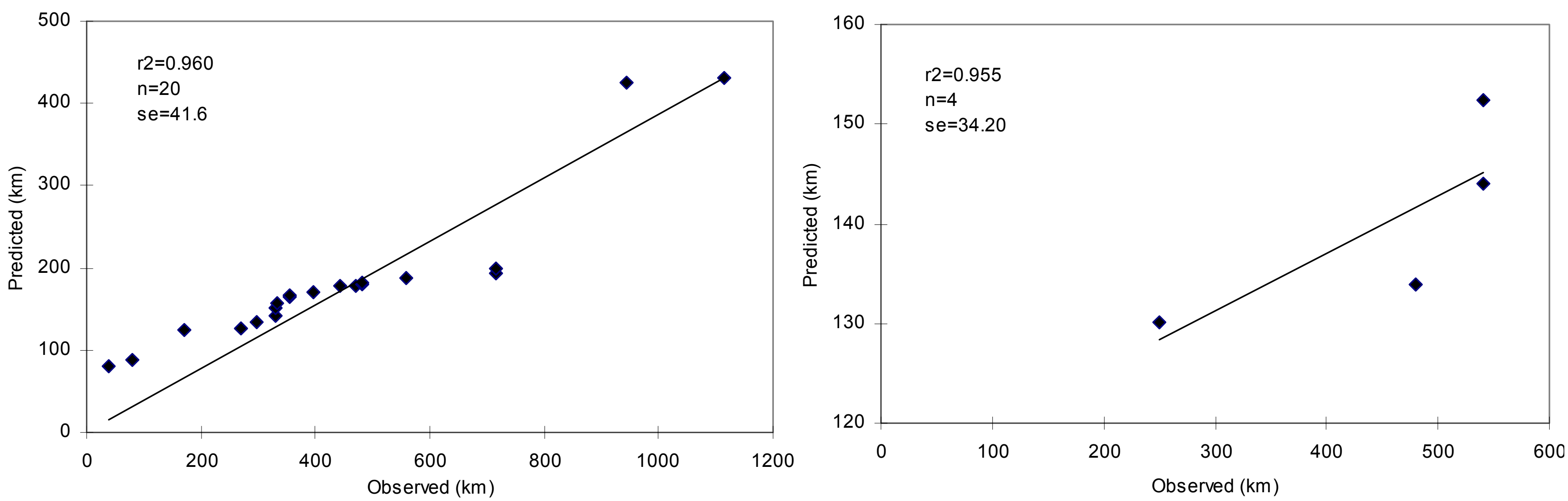

Fig. 8. Relationship between observed and predicted distances moved during drought and post drought in Dida Hara.

Table 1

Summary of relationship between observed and final distances (km) moved by pastoralists for the two study locations during the drought and post drought phases.

	Location					
	Dida Hara			*Web*		
Atrribute	r^2	***P-value***	***Standard error (σ)***	r^2	***P-value***	***Standard error (σ)***
Distance Moved						
Drought	0.960	<0.0001	41.650	0.977	<0.0001	38.368
Post-drought	0.955	*ns*	34.197	0.927	<0.0001	51.100

Movement patterns showed seasonal marked differentiation between the drought and post drought periods. (see Fig. 9). The average distance moved was 206 km in the drought period and 129 km after the drought.

There was a significant ($p < 0.0001$, n= 40, SE= 18.70) difference in the distance traveled during these two seasons. The pastoralists expanded the range for their foraging activity, measured as the distance from the initial location to the destination, during the drought in comparison to post drought with a mean distance of 206 km in the drought period and 129 km post-drought (Fig. 9). This represents a mean difference between the seasons of 77 km and on average, a 60% increase distance gained during the drought period.

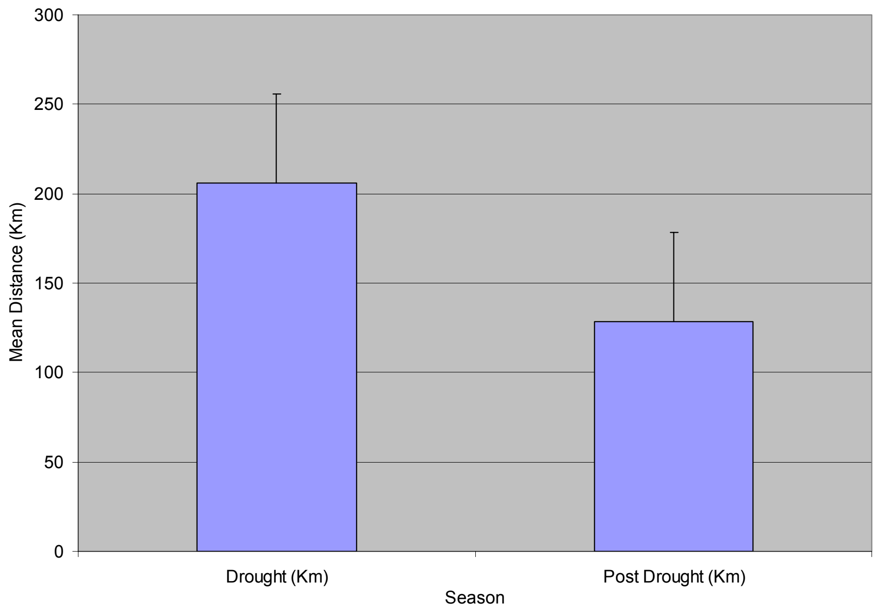

Fig. 9. Comparison of predicted mean distances (km) traveled by pastoralists during drought and post-drought seasons in the Borana lowland study area. The distance moved during drought were significantly higher than post-drought.

Discussion of findings and conclusions

The goal of this research was to develop an agent based model of pastoralist mobility on the rangelands of East Africa. Based on the agreement with observed studies in the region, the model was deemed a successful, first-generation model that mimicked several qualitative and quantitative aspects of known pastoral mobility patterns. The model was able to emulate the utilization of highly heterogeneous landscapes by pastoralists, differentiations in landscape utilization and mobility brought about by variations in seasons' forage availability (quantity), accessibility to water, rights of usage by different ethnic communities, terrain aspects among other factors.

We believe the model is potentially superior to other models of landscape use in the rangelands due to its flexibility and ability to incorporate true non-linear form of individual behavior due to its agent based formulation. Not only were we able to naturally describe the system under investigation; the model also captured movement activities which was a more natural way of describing the system than would a process based system. This system is also quite flexible, allowing addition/removal of agents to this model. ABM structure provides a natural framework for tuning the complexity of the pastoralist agents in the model, their behavior, degree of rationality, ability to learn and evolve, and rules of interactions. We also have the ability to change levels of description and aggregation within the model. Even though we have completed several simulations for this model, it still is a prototype proof of concept whose evaluation is continuing.

The other objective of this research was to track and generate hypotheses about the influence of the environment on the evolution of simulated mobile populations of pastoralists under different seasonal regimes. This objective would facilitate an understanding and examination of a broad range of hypotheses relating to rangeland social-ecological systems. Complex models are difficult or impossible to validate, but corroboration is possible (Caswell, 1976). Using Caswell's criteria for model corroboration, the following questions were asked: (1) Did the model satisfy the purposes for which it was designed; and (2) is it the 'best' of the available alternative models?

The PLMMO model fulfilled the Caswell (1976) criteria in that we believe it is both the best available model of pastoralist mobility behavior in the study area as yet and it best replicates many of the broad patterns exhibited by pastoralist on the ground. The scenario runs we performed on PLMMO matched known concepts about distribution of pastoralists in the arid rangelands and duplicated many of the patterns that were identified both in the field and literature. To explore the relationship between herd distributions and forage quantity alone, a correlation coefficient was determined. In all cases, a weak linear relationship existed, implying that there were other factors that determined this herd distribution, chief among which is water location and stability. The conflicting need for accessibility to water, forage and to some extent the defined extent of common pool resources for specific pastoral ethnic communities meant that pastoralist in most cases were unable to match the spatial distribution of their resources with the spatial distribution of their forage resources. This “undermatching” (Senft et al., 1987) with respect to water-related limitation particularly of dry season foraging is due to the inability of pastoralists and their livestock to travel between resource patches at will. The bulk of pastoral activity was seen to occur somewhere at a point that balances accessibility to factors of forage, cost to water (including terrain, slopes and land use) and pastoral community influence.

In comparing the patterns of distribution of pastoralists across the landscape between the drought and non-drought seasons, the maps indicate that spatially, there was a much more even distribution of pressure of usage during the non-drought phase in comparison to the drought phase where more herds were closely aggregated. Our explanation for this pattern of landscape utilization is that during the drought phase, there were far less water sources in between because many of the water sources have dried up making pastoralists to concentrate their herding activities at locations only pretty close to the few remaining water points. This corresponds to Sandford’s (1983b) contention that a spatially more even distribution of grazing pressure on vegetation can be achieved by increasing the number of water sources which may lead to an overall greater, albeit more evenly distributed, pressure.

The distance which pastoralists graze from a water point is however not simply a factor of the water sources but may vary due a number of factors including species and class of livestock, season, vegetation types, Squires (1978), security issues, user rights on common pool resources, disease etc. However by programming simple rules into individual pastoralist agents, and using a few principal influencing factors, the prototype model used here has been able to fairly accurately capture the configuration of usage of the resources on the landscape as influenced by season.

In comparing model outputs for the distance trekked by pastoralists across two different seasons, the drought and post-drought seasons, PLMMO's results closely mirrored pastoralist mobility patterns with respect to distances moved. Mean distances trekked by livestock to water sources during each of the two climate phases were significantly different. The cumulative distances trekked during the entire season to grazing sites significantly increased during drought, from an average (across zones) of 129 km post-drought to 206 km during the drought. These values were in significant agreement with observed field values (r^2 values of between 0.927 and 0.977, $p<0.0001$). This increase in movement can be attributed to reduced accessibility and availability to water and forage during drought, the key determinants of pastoral movement and migration. Most livestock water sources used across the arid and semi-arid areas zones of study (boreholes, hand dug wells, dug stream beds, ponds, concrete tanks in the ground, concrete tanks above ground, and reservoirs/dams) are recharged by rainfall and the absence of rainfall for extended periods of time due to drought result in the drying up of these sources resulting in a dwindling water supply. Accessibility to a water source is therefore hampered more during drought than in a non-drought season and the increased distances travelled during drought to the water sources is largely accounted for by this difference. Trekking long distances to watering points reduced effective grazing capacity available to pastoralists. It has been reported that when longer trekking distances are necessary the frequency of watering of livestock was reduced to once every three to four days. Coppock (1994) for instance observed that the strategy of restricted watering allows livestock to cover greater radii in search of grazing sites, reduces herding and watering labor and increases the efficiency of water use by the animals.

The PLMMO agent-based model as presented here has been shown to realistically emulate the complex adaptive capacity of pastoral rangeland systems where herders continuously have to adapt to prevailing circumstances, something that would have been hard to achieve using the traditional linear and or differential equation modeling techniques. What brings more confidence into this model is that even though one could have easily applied simple linear/differential simulation techniques to emulate some of the results presented here such as the seasonal differences in distribution and use patterns of landscape resources as shown by the model results, it would be extremely hard for the latter models to achieve the "combination" of results that we have achieved here, where we have quite realistically emulated landscape utilizations patterns of pastoralists across seasons based on a few simple rules and at the same time predicted with a fairly strong relationship their seasonal mobility patterns with respect to distances moved. We believe that this combination result was made possible by application of an innovative agent based framework that we applied to the question at hand.

The modeling framework presented here also permits examination of a broad range of hypotheses relating to rangeland social-ecological systems. The preliminary results from this study demonstrate the ability of the model structure to incorporate processes characteristic of complex adaptive systems, that are central to determining the dynamics of rangelands. We contend that the ABM model presented here provides a much more natural description of a system; and is most natural for describing and simulating a system composed of ''behavioral'' entities. We feel that PLMMO offers a more suitable approach to modeling pastoral movement and more flexible than existing models that try to explain foraging behavior in terms of habitat suitability alone. Simulation of foraging activity in African rangelands should take into account pastoralists behavioral patterns and rules, incorporate these into a model and then observe the subsequent emergent patterns and impacts. Even without full incorporation and complete knowledge of all the factors that influence pastoralist movement, initial PLMMO outputs provided here compare very well to data collected in the field. In addition, the output and predictions appear to be reasonable representations of real-world decision making patterns of pastoralists. The outcomes of the model are in tandem with what is known about the heterogeneity of pastoral resource use and behavior of pastoralists mobility during the drought and non-drought seasons. This application therefore holds promise for future application on other landscapes. Further incorporation of known factors influencing pastoralist movement such as disease quarantine, security issues, market forces, etc. will further improve model input while telemetric field-work about direction of movement of pastoralists, and real time remote-sensing of numbers of livestock mobility involved would be valuable in improving confidence of model results. As the model is refined and expanded, more sophisticated questions about relationships between policy, learning, and ecosystem dynamics can be addressed. Furthermore, the potential exists for application of the PLMMO to other tropical rangelands.

As a conclusion, issues pertaining to movement and migration management need to be addressed given the increasing population and landuse pressures and the subsequent reduction in scope for lateral movement of livestock and humans in pastoral rangelands. These are issues that the PLMMO might aid in investigating and support decision making in relation to practices such as water development, placement of veterinary services on the landscape and disaster relief interventions in times of drought. Knowing the "when, where and how many" of pastoralist herd locations is also crucial in determining strategies to enhance grazing by livestock and wildlife in underutilized areas and also to point to potential conflict regions that arise due to competition for a deteriorated resource base in times of meteorological stresses. Strategies to introduce livestock to areas formerly receiving little use would require decision making tools such as these since benefits attributed to grazing systems can be attributed to improved grazing distribution (Laycock, 1983). Moreover, effectiveness of migration strategies should be examined; for example, are the trekking routes currently in use the most efficient to confer optimum utility to the pastoralists. Tools such as these combined with livestock early warning tools might assist pastoralists to seasonally modify their expectations to account for the reduction in the supply rate of their dry season resources and therefore improve their resource matching within the limits of drought season forage availability. If a means for sufficiently exploiting dry season resources can be found, and ideal matching of resources to pastoralists needs could be achieved.

We have developed a spatially explicit, multi-platform application for studying mobility of pastoralists and their animals in the arid and semi-arid rangelands of East Africa. PLMMO is the first model to use an agent based mechanism to incorporate behavior of pastoralists with respect to mobility in East Africa. PLMMO has the potential to be a useful tool for policy makers, range managers, landscape ecologists, conservation planners and others interested in understanding the impact of ecological and social environment on pastoralists' behavior and livelihoods. With this model, a user can run a variety of ecological, policy-related and land use scenarios and investigate the impact of each on the behavior of pastoralist mobility. While we have focused here only on a few factors influencing mobility to demonstrate PLMMO's utility, the system allows for incorporating a number of other factors and is a significant improvement on similar kinds of rangeland use models in East Africa.

CHAPTER IV

EMERGING INSIGHTS INTO THE PATTERNS OF PASTORAL LAND USE AND ADAPTATION UNDER CLIMATE CHANGE AND SELECT MANAGEMENT SCENARIOS: AN AGENT-BASED MODEL SYSTEMS INVESTIGATION

> *At the dawn of this millennium human use of natural resources is changing the world—its atmosphere and climate, its human and non-human inhabitants, its land surfaces and waters. We face different, more variable environments with greater uncertainty about how ecosystems will respond to inevitable increases in levels of use. At the same time we are reducing the capacity of systems to cope with disturbance. The combination of these two trends calls for a change from the existing paradigm of command-and-control for stabilized 'optimal' production, to one based on managing for social-ecological resilience.*___ Folke et al., 2002.

Introduction

Traditional pastoralism is the dominant form of production in the arid and semi-arid rangelands of East Africa. The Horn of Africa contains the largest grouping of pastoralists in the world: Sudan has the highest pastoralist percentage globally while Somalia and Ethiopia rank third and fifth respectively (Ndikumana et al., 2000). In Djibouti, one third of the population is pastoralist. The semi-arid and arid areas in the Greater Horn of Africa (GHA) make up 70% of the total land area, which provides an average of 20% to 30% of GDP of the countries in GHA. These semi-arid and arid rangelands are generally heterogeneous, due to spatial gradients of climate, soils, landscape and disturbance (Coughenour and Ellis, 1993). As a result of the extremely patchy nature of forage resources in these rangelands, pasture must be exploited opportunistically and the producer with a high level of mobility can maintain a herd in land that is almost unusable for fixed territory or ranch production. Pastoralists exploit spatially distinct areas of vegetation type and productivity by moving species-specific livestock across the landscape. Pastoralism has thus persisted in part due to the fact that environmental variability has remained within the bounds that the pastoralists' management systems can accommodate (Behnke et al., 1993).

Ongoing constraints on some of the strategies employed by pastoralist has increased their vulnerability to natural and human-derived perturbations. The growing human populations along with many land tenure and land-use changes have edged pastoral livestock onto land areas that are too small to be sustainable for pastoral production. A steady increase over recent years in competition for limited land resources, has led to a progressive expansion of the crop-based agriculture and rural settlement into formerly pastoral lands, removing more productive ecological sites from the system and increasing reliance on less productive sites for forage. This trend has led to an untenable situation where pastoralists can no longer depend on their livestock for the sole basis of their livelihood, while opportunities for livelihood diversification remain few. Furthermore, such pressures in combination with weather related perturbations compound the situation further as noted by the marked oscillations of the climate in eastern Africa over the past few millennia. Climate change still remains a subject of numerous investigations (Grove, 1998; Nicholson, 1999). The result is an increasing human population dependent on an unstable or declining livestock population, which leads to a destabilized and an unpredictable productivity regime with obvious implications for such societies. Therefore, despite East African pastoralists being able to track climate variability consistently in the past, these strategies may not be viable now due in part to an inability to implement them in a changing environment. Public adaptation policies to address these multifaceted challenges have been rendered inoperative, with some policies becoming unsuccessful (see Theu, et al. 1996 in Malawi).

Evidence being accumulated from diverse regions all over the world suggests that natural and social systems behave in a non-linear fashion, exhibit marked thresholds in their dynamics, and that social-ecological systems act as strongly coupled integrated systems (Folke et al., 2002). Socio-ecological systems are both complex and evolving and their management is faced with uncertainty and surprise. Complexities in rangelands arise from non-linear responses to grazing and environmental drivers (surprises), unanticipated and counterintuitive consequences of policy, and unpredictable markets together with their effects on decisions by pastoralists.

Many rangeland ecosystems have multiple stable states, sometimes separated by sharp thresholds. Additional difficulties arise from interactions between processes that occur at different spatial and temporal scales, and the need for learning in response to rare events. In periods of rapid transition, the system may evolve faster than forecasting models can be refined, thus predictions may be most unreliable when they are most needed (Walker and Janssen, 2002). Paradoxically, management that uses rigid control mechanisms to seek stability can erode resilience and enhance breakdown of socio-ecological systems (Folke et al., 2002).

To help address these issues, an agent-based model application, Pastoralist Livestock Movement Model (PLMMO), grounded in complex systems science methodology was utilized to evaluate impact of changes occurring in rangeland systems, and address some of the challenges that limit use of linear models. The model holistically addresses interactions between the social and the biophysical system in order to identify system characteristics and policies that would confer resilience to rangeland systems. The integrated agent-based PLMMO for the arid and semi-arid pastoral rangeland was applied to a region approximately 400 by 800 km, from Yabello in southern Ethiopia South through to Baringo, Marsabit, Isiolo, Wajir, Mandera and Samburu districts in northern Kenya.

We review our modeling efforts and explore results in terms of pastoralists' behavioral response to various management and climatic change scenarios. The overall goal was to address the patterns of adaptability by pastoralists to change scenarios that include the effects of climatic change on forage production and hence pastoralists mobility behavior, changes in livestock stocking densities and the effects of improved access by livestock to water sources.

To be able to address patterns of adaptability by pastoralists to scenarios of vulnerability to climate variability and change, changes in livestock stocking densities and the effects of increased access by livestock to water, we addressed the following specific objectives.

The specific objectives of the study were to:

1. To identify the emergent patterns of pastoralist mobility generated under three simulated scenarios;

   a) reduction in available forage as a consequence of climate change,

   b) increase in livestock densities by 50% and

   c) improved access to water source by 50%

2. To investigate the impact of increased seasonal variation in forage yield especially those resulting from extreme weather patterns associated with climate change.

Emergent patterns investigated are those of mobility patterns and distances moved by pastoralists in search of water and pasture as constrained by a number of landscape factors. The consequence of this mobility for pastoralist foraging efficiency is also discussed.

Methods

We used the agent-based PLMMO model (See Chapter III) with modules that represent the biophysical components (vegetation, livestock) and social components (ethnic community pool resource boundaries). A number of other abiotic factors such as terrain, cost-distance to water, landcover integrated together with behavioral patterns of pastoralists with respect to rights of usage of ethnic resources are also represented in the model. The model was designed for simulating pastoralists' movement in the arid and semi-arid pastoral rangelands of East Africa and was previously validated using data from field surveys representative of the structure and patterns of movements by pastoralists during drought and non-drought phases in the northern Kenya-southern Ethiopia study area. Model parameters were calibrated based on field surveys, existing literature on pastoralist behavior with regards to movement and forage standing crop values output from a biophysical plant growth model, PHYGROW (Phytomass Growth Simulator) (Rowan, 1995).

PHYGROW estimates total forage availability (kg/ha) and produces available forage production for a target grazer(s) and associated complex plant community. In addition, PHYGROW uses soil characteristics, plant community characteristics, grazing practices and weather data (RFE/NOAA CPC weather dataset for Africa - ftp://ftp.ncep.noaa.gov/pub/cpc/fews/ - for a particular location to predict the forage production and associated water balance. Using the geostatistical technique of co-kriging, the total available forage data associated with the point-based PHYGROW output was translated into maps of forage standing crop (Angerer et al., 2001) and forage deviation from normal.

The patterns of movement were driven by simple rules that mimicked the behavior of pastoralists' decision making (see Chapter 3). The principal rule set included criteria for selecting target locations for foraging and herd movement. The driving inputs into the rule sets included the following factors: forage standing crop, cost distance to water, livestock density, ethnic boundaries, and movement decision rules. The model operated on a 10-day time step and reproduced movement patterns that roughly matched measurements from the field (r^2 values of between 0.927 and 0.977, $p<0.0001$). Evaluation of what pastoralists' reaction would be in response to changes in management and ecosystem dynamics required a complex adaptive spatially explicit model that would capture the complexity of these rangelands. The PLMMO meets this criteria. The model predicts the change in location and associated distances moved by pastoralists as determined by resource constraints (water, forage, terrain, and usage rules) and socio-cultural boundary limitations.

As seen in Chapter III, forage utility expectation became the index in each grid unit with which a herder and his/her animals used to determine the profitability of a cell. The pastoralist herder agent was programmed with knowledge rules to aid in selecting the behavior with the maximum utility which eventually determined the selection criterion for the destination location to move to. Choices from amongst the possible behaviors are made using a game-theoretic approach based on utilities. Each behavior $B_{i,j,}$ has an associated utility $U_{i,j}$. For example, if an agent wants to relocate to a cell, they have to assess how far that location is, how much forage standing crop exists at the target location, what other competing agents are at that location, what other resources exist in the neighborhood of the target cell, what the cost in terms of effort (travel time -

hours) of accessing water resources is at that location and what level of reciprocal tolerance exist with respect to the ethnic community in the target location. The agent will then compare that utility value to its current location's utility and all the other cells within the agent's extent of "visibility" and choose to move to the location of highest utility. Visibility was the radial extent from current cell location that the agent was programmed to see and incorporate into its assessment. It represented the spatial extent of knowledge that pastoralists have in terms of available resource conditions farther afield from their current positions. For the implementation in the model, this was represented as a symmetrical 360-degree area of assessment. Thus, expected utilities are composed of intrinsic utilities, which correspond to cost and benefits, multiplied by the probabilities, which express the chance of obtaining the utilities through the behavior. Costs and benefits are additive to yield the total expected utility. Therefore, distance is a cost factor (as opposed to a benefit) that reduces the value of benefits at a target location. The expected forage utility is calculated for each cell every ten days. Pastoralists and their associated herd are simulated as efficient foragers, targeting high forage utility before that of a lower value. Of course, there are also tradeoffs between forage, access to water, distance to forage among other factors as considered by the model structure.

All geographic information was generalized to a standard spatial scale of a 4.5 by 4.5 km cell. Livestock density maps were derived from a 3rd order administrative livestock survey map for eastern Africa at a 3-arc minute (approximately 5 km^2) resolution from the Livestock Early Warning Systems (LEWS) project maps database, Texas A&M University (http://cnrit.tamu.edu/maps/). Maps of existing water sources were compiled from a variety of sources such as publications, maps, remote sensing, and fieldwork (see appendix III for a listing of water source information). Projected changes in yield due to climate change were derived from PHYGROW predictions performed at Texas A&M University as part of a climate change study on impact of climate change on food security of Kenya conducted by Angerer et al. (2004). The projected forage yields for that study were performed using data from the Intergovernmental Panel on Climate Change (IPCC) on expected climate change as calculated by as many as seven different climate change models and up to five different increases in atmospheric CO_2. This climate change data is available at the IPCC data site (http://ipccddc.cru.uea.ac.uk/cru_data/datadownload/ . For the purposes of this study, results from the Canadian Global Coupled Model (CGCM1) were chosen to represent the climate change scenarios to be used for assessing impacts.

Simulating change scenarios

A run from a previous post-drought simulation was chosen as a representative of the base or control scenario. This scenario represented a normal, no-drought year which we intended to use to carry out all comparisons against. A series of experiments were then conducted and compared to this post-drought season control scenario. The scenarios were selected to address potential land use change, management and weather related questions and to explore the utility of the PLMMO model for guiding management questions. Departures from the base scenarios by the simulated scenarios were compared against model response in the base scenario. The effect of the change scenarios was investigated using analysis of variance (ANOVA) for a random sample comprising 370 (N=12,827) randomly selected cells at the 95% confidence level and representing a 5% confidence interval. We then used the Random Point Generator Version 1.3 ArcView extension developed by Jennes (2005) to pick out the 370 random observations from the landscape for analysis.

Model output and analysis

Results from climate change scenario I –simulating reduced forage yield

Under CGCM1 climate change scenario, precipitation during the long rain season (February to June) is predicted to decline in southern Ethiopia and the top half of the northern parts of Kenya. These areas were expected to be drier than normal. Under this scenario and assuming no improvements in forage technology (GCGM1 with no forage production technology improvement), cattle forage yields were expected to generally decrease (Angerer et al., 2004). Yields are expected to decline by 14% under this scenario. Therefore, pastoral mobility was explored in response to the reduced forage yields by reducing the normal forage during a non-drought year by 14% and then running the model. The results were subsequently compared to those from the base scenario model. There was a slight decline in the distances moved by the pastoralist during the simulated period, with the average distances moved over the study area (370 sites) experiencing a reduction to 146 from the original 152 Km in the base/control scenario, representing a non-significant decline of 4% (p-value=0.314) (Table 2).

Table 2

Comparison in mean distance (km) moved per season between climate change induced forage decrease (by 14%) scenario and the base scenario.

Scenario	Mean distance (km)	N	Std. deviation	Std. error mean	p-value
Base scenario	152.9	370	104.05	5.41	
Reduced forage yield	146.6	370	101.28	5.27	= 0.314

Results from climate change scenario II – simulating increased forage yield and variability

It is predicted that there would be changes in the distribution and variability of rainfall in response to global climate change (e.g. Hall et al., 1995). To include the effects of climate change-induced variability in season forage patterns and improved yields in pastureland, we modified the seasonal temporal distribution of forage in the study area by first increasing the amounts in forage yield by a modest 14% to match the increment we had observed under the climate change scenario. We then distributed this 14% increment in forage production by randomly increasing available forage in individual dekads across some of the dry and some of the wet months by more than 30%, whilst leaving some of the dekads as they were in a bid to create greater variability (Figure 10).

The total forage as a consequence, increased by only 14% across the season however, variability was very high, with the mean standard deviation of standing crop being nearly twice (224 kg/ha) that of the base post-drought scenario (125 kg/ha). This represented an overall increase of 79% increase in variability of forage on offer to the pastoralists.

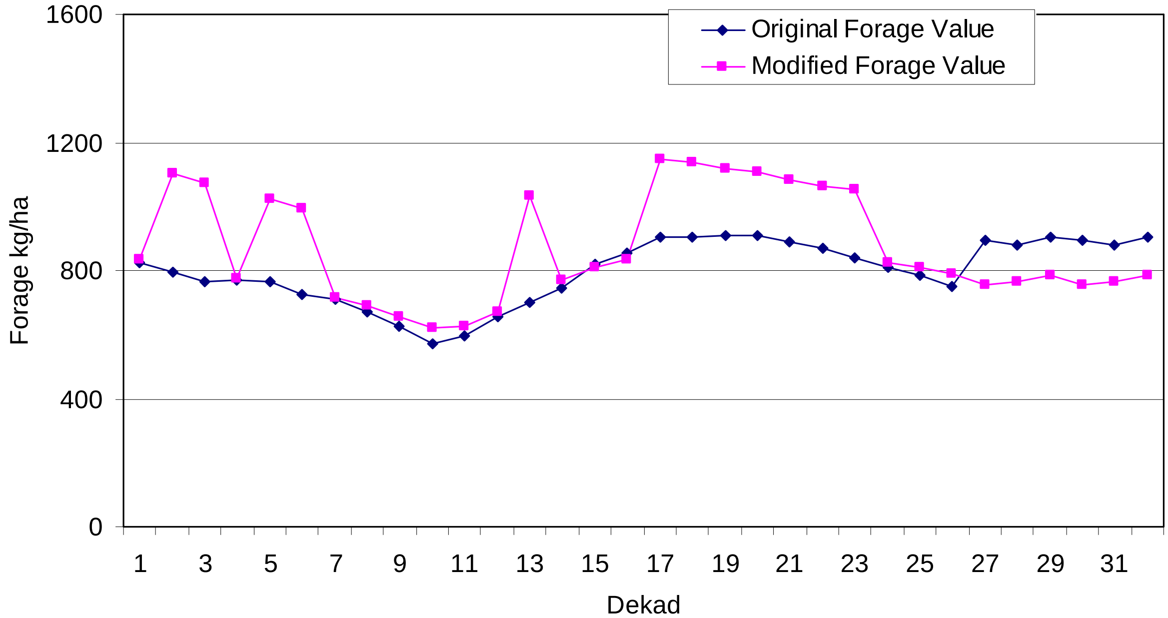

Fig.10. Total available forage (kg/ha) modified for increased variability in the season for a sample site, (Dekad 1, January 2004 – Dekad 2, Nov 2004).

Pastoralist movement decreased markedly under this scenario of increased forage yield with greater variability of yield. The mean distances moved by the pastoralists significantly declined by over 80% ($p < 0.0001$) in comparison to the original distance moved under the base scenario, i.e. 33km in this scenario compared to 152km in the base scenario (Table 3). This scenario represented the largest decline in the distance moved in comparison to all others explored.

Table 3

Comparison in mean distance (km) moved per season between climate change induced forage (kg/ha) increase (by 14%) and variability increase (by 79%) scenario and the base scenario.

	Mean distance (km)	N	Std. deviation	Std. error mean	p-value
Base scenario	152.9	370	104.05	5.41	<0.0001
Increased forage & yield variability	33.4	370	21.35	1.11	

Results from increased livestock densities simulation

The study area is currently in a considerable state of change. For instance in the Borana rangelands of southern Ethiopia, there exists an imbalance caused by a steady growth in the human population in combination with density dependent fluctuations in cattle population (Coppock, 1993). The number of livestock therefore keeps changing over time. We modeled the potential effects of increase in livestock densities by increasing livestock across the entire study area by 50% (similar figure was used in a previous study in Ngorongoro conservation area in Tanzania, see Boone et al., 2002). The distance traveled declined marginally under this scenario, with a mean distance traveled by pastoralists of 140km in this scenario compared to the 152km in the base scenario. This difference represented an 8% decline in mean distance traveled, which was not statistically significant (P=0.052) (Table 4).

Table 4

Comparison in mean distance (km) moved per season between increased livestock densities scenario and the base scenario.

Scenario	**Mean distance (km)**	**N**	**Std. deviation**	**Std. error mean**	**p-value**
Base scenario	152.87	370	104.05	5.41	
Increased livestock density	140.44	370	103.65	5.39	=0.052

Results from improved water access simulation

Water availability is a critical determinant of the distributions of herbivores in East African conservation areas (Western, 1975). The water accessibility grid layers were adjusted to improve the accessibility to existing water sources by 100% i.e. the distance to water source was halved across all seasons for all the water grids across the seasons. The halving of distance to water was done in a bid to simulate management of overall improved access to water for the pastoralists by setting up of more water points, rehabilitation of broken access points, or even improved capture of surface water either through rainwater harvesting or reduction in utilization of stream water by upstream water users. By halving the distance to water resources, the mean distance traveled during the normal season in the study area decreased from 152 km to 137 km, an approximate 10% reduction in mean distance traveled (Table 5). The distribution of livestock and pastoralists were also more evenly distributed across the landscape (Fig. 11) in comparison to the base scenario where they were comparatively more aggregated. This change in water access created a statistically significant drop in distance traveled by pastoralists during the season ($p = 0.017$, SE=6.43).

Table 5

Comparison in mean distance moved between improved water access scenario and the base scenario.

Scenario	Mean distance (km)	N	Std. deviation	Std. error mean	p-value
Base scenario	152.9	370	104.05	5.41	
Improved water access	137.5	370	100.48	5.22	=0.017

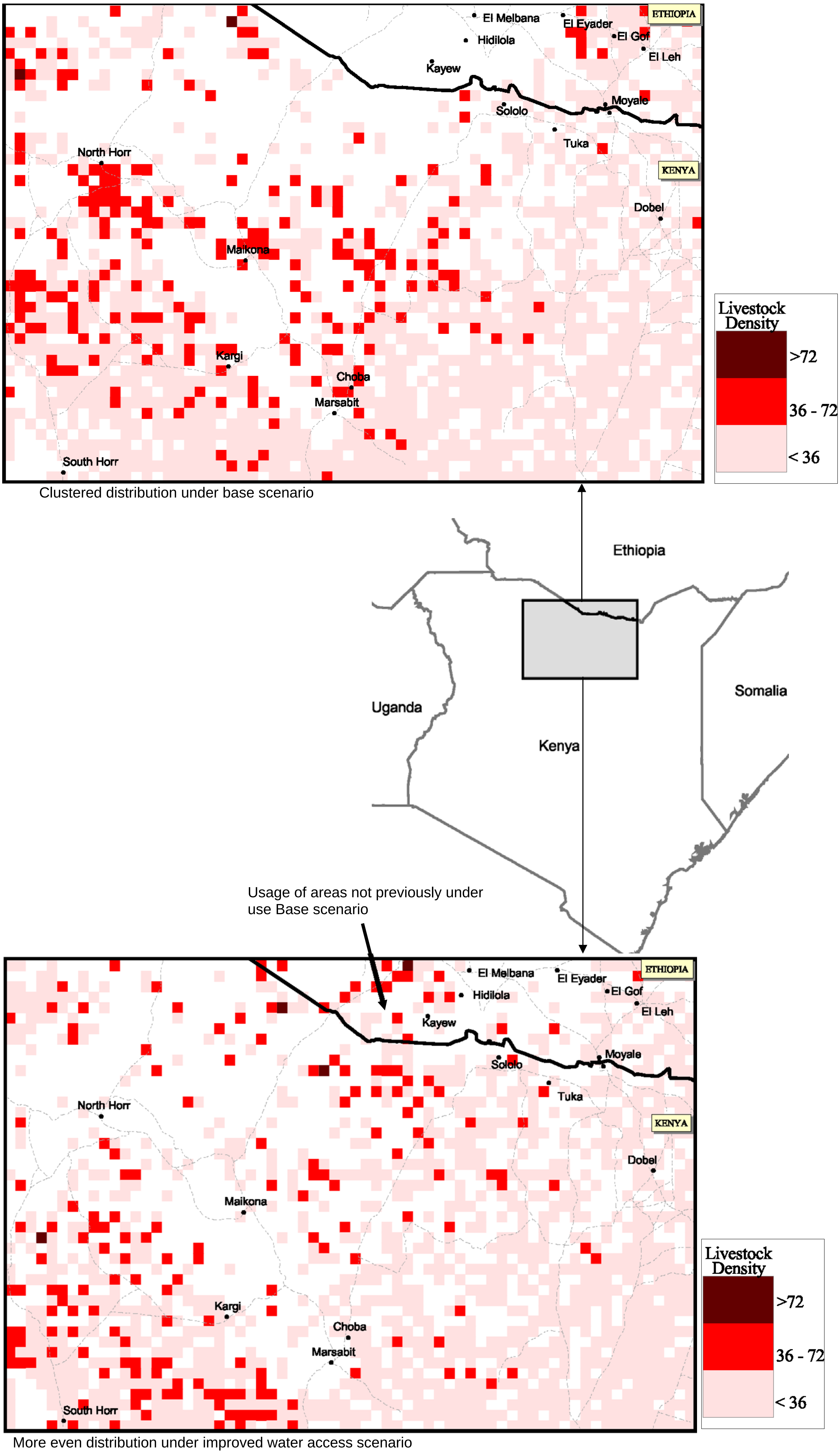

Fig. 11. Comparison of activity distribution patterns between the base scenario and improved water access scenario for sample Dekad 3, June 2004.

Discussion of findings and conclusions

In this study, we demonstrated how the PLMMO model could be used for management purposes to explore “what if” scenarios of management questions and emerging change scenarios. The model experiments conducted were aimed at emulating emerging dynamics that are occuring in the region at present, with the hope that the results of these modeling exercises may be used as a guide for intervention(s) in the pastoral sector in this region. The changes currently taking place include a steady increase in competition for limited land resources that is due to a progressive expansion of agriculture and rural settlement into formerly pastoral lands. These land-use changes have pushed pastoral livestock onto land areas that are too small to be sustainable for pastoral production. This, coupled with the recurrence of extreme climatic events (attributable to climate change or otherwise) in the recent past has made pastoralism a much more difficult enterprise to undertake. By simple adjustments to the data layers, we were able to represent the changes taking place and hence simulate the impact of these changes to the communities. The PLMMO model data requirements are modest yet yielding quite incisive results on the dynamics of pastoral activities in the region.

The summary graph for comparable results is shown in Fig. 12. Results from simulations of pastoral mobility showed that distances moved were lower in all the simulated scenarios in comparison to the base/control scenario. The lowest mean distance moved occurred as a result of an increase in forage yield both during the wet and dry season with concomitant increase in variability in space and time (mean distance of 33 km in comparison to 152 km in the base scenario). This represented a drastic and significant (p-value < 0.0001) drop in distance moved by pastoralists. Improving access to water resource led to the next best impact scenario resulting also in reduced distances moved by pastoralists (mean distance of 137 km). This was also significantly (p-value =0.017) different from the base scenario. There was therefore a 10% decrease in distance traveled in the simulation with improved access to water. However, there was no sufficient reduction in distance traveled in under both the climate change induced forage reduction scenario and the increased livestock density scenario.

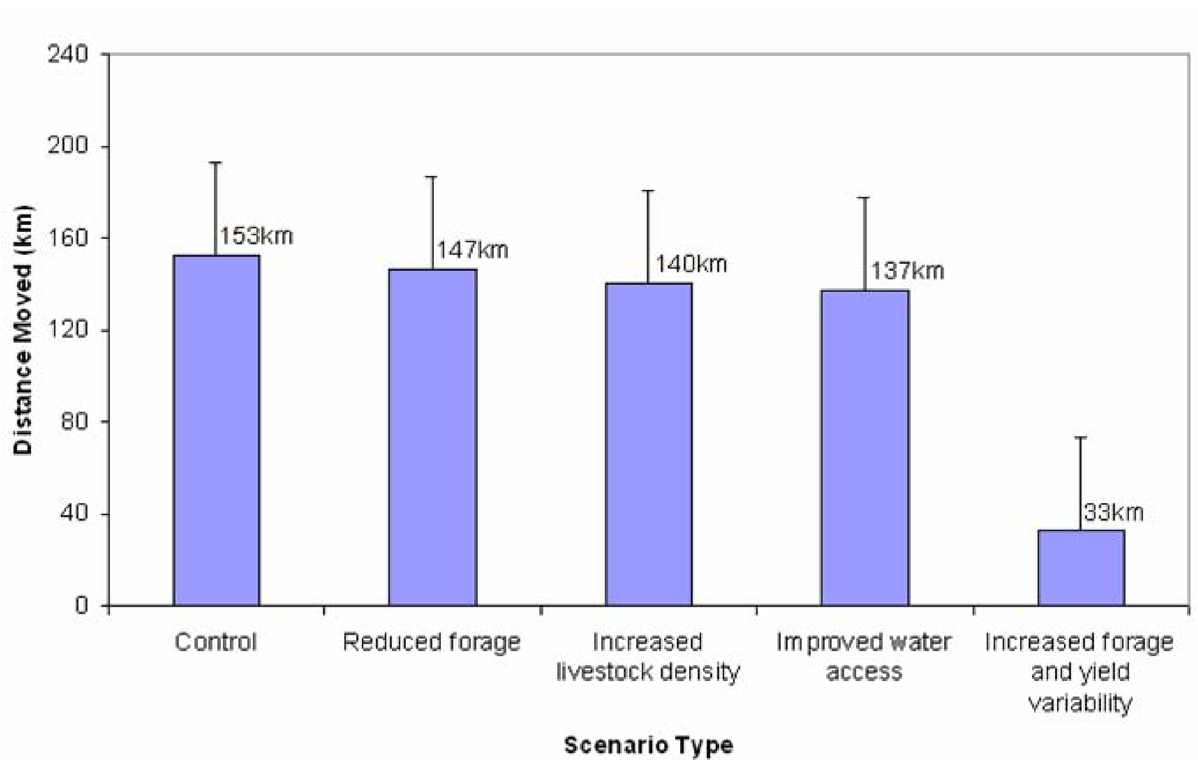

Fig. 12. Comparisons in mean distances moved (km) among the four simulated scenarios plus the base scenario. The increased forage yield and variability had resulted in lowest distances moved.

We observed that potential climatic change with the subsequent reduction in the amount of forage production by 14% did not make a significant difference in the overall mean distances moved by pastoralists in the region. Increased forage across the region with concomitant increased variability of forage across the seasons however resulted in a significant impact on the mobility patterns of the pastoralists. It decreased the distances pastoralists moved by over 80%. The minimal increase of (14%) forage on offer to animals and associated increased variation (79% overall) resulted in substantial decreases in distances moved by pastoralists. These indicate that variability in forage resources across the season could have greater impact in pastoralists mobility than the total reduction/increase in forage brought about by climate change and resonate results from similar work carried out in the Ngorongoro Conservation Area in Tanzania by Boone et al. (2002) whose simulations using the SAVANNA model found climate variability to result in large increases in dry-season green biomass.

The results also suggest that access to water is crucial; pastoralists were possibly able to utilize a larger spatial extent that was previously unavailable due to the lack of water resources, as highlighted by the results. Shorter distances were now traveled to get this commodity due to improved access. Therefore, there was a significant drop in distance traveled under this scenario of improved water access. The distribution of resource utilization over the landscape in comparison to the norm was also much more uniform, exhibiting an equitable and much more even utilization of the available forage resources. Sandford (1983b) reports that spatially more even distribution of pressure on vegetation and soil can be achieved by increasing the number of water sources which may lead to an overall greater, albeit more evenly distributed, pressure. On the other hand, some livestock, e.g. sheep in mountainous areas, distribute themselves, unherded, more evenly than others, e.g. cattle (Stoddart et al, 1975, p. 285).

Improving access to water is therefore a crucial aspect of management of rangelands.

Scenarios of improved access to water are anticipated to likely result in a decrease in conflict between the pastoral communities competing for limited forage and water resources due to its ability to indirectly bring more land under usage. A more comprehensive, integrated assessment is a necessary to incorporate and further explore whether market access would be required to produce an outlet and avoid a system collapse. Incorporating more rules into the PLMMO model to take into account socioeconomic relationships will make the model much more robust. Consideration of other important policies issues e.g. disease outbreak and quarantine/movement restrictions would offer a greater opportunity to see the movement responses in a more holistic framework.

The question remains however, whether specific locations can be identified that effect the greatest return for investment by government or donors, while at the same time ensuring that the overgrazing of the local environment associated with most of the installed water sources in these arid and semi-arid rangelands is avoided. Tools such as the PLMMO could guide such assessment if the resolutions of the datasets are improved (currently approx 21 km^2) and ecosystem grazing impact explicitly incorporated into the model.

The last two simulations were for increased livestock densities and reduced forage availability. These scenarios represented emerging increases in competition for limited forage resources due to progressive expansion of agriculture and rural settlement into formerly pastoral lands, conflict etc. We tried to emulate the situation in which there was intense competition for limited resources thus reducing available forage per herd; or a situation where pastoralists were forced to congregate in limited areas thus increasing the density of livestock in that area.

The increase in livestock populations though expected to increase mobility, due to the existence of limited resources for this increased number of “mouths to feed,” did not perform as excepted. There was no significant difference in the distance moved by pastoralist in comparison to the base scenario (152 km for baseline versus 140 km for the increased density scenario). For any given area, increasing the animal density was anticipated to reduce the resources available to the individual herds. Hence, the distances traveled whilst foraging by pastoralists within each cell were marginally expected to scale negatively with a larger stocking rate in order to meet the collective nutritional requirements of larger herds, more cells would be visited with each time step, thereby increasing commuting distance. This however did not occur in PLMMO. A possible explanation for this could be that the model restricted the boundary of movement for the agent herds (they were programmed not to leave the boundaries of study area) and therefore the competition among the agents forced them to adapt to the reduced resources and hence stabilized their movement patterns as if they were under the base scenario, since the stocking density was increased across the entire region.

A similar occurrence was noted in the scenario of reduced forage availability, where there was no significant difference in distance moved by the pastoralists in comparison to the base scenario (mean distance of 152 km for baseline versus 146 km reduced forage scenario). As per the rule sets, these two scenarios i.e. reduced forage and increased livestock stocking rate scenarios could have been simulating closely associated phenomena.

Future enhancements of the model need to introduce outlets from where the pastoralists can escape in case of intense competition for resources. In fact, current field conditions indicate that under extreme drought, the pastoralists have been known to escape into ranching and other sub-humid agricultural regions (Niamir-Fuller, 1999; Mkutu and Marani, 2001) or even into urban centers (BBC, 2000).

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This study sought to develop a model of pastoral foraging and movement in the pastoral rangelands of northern Kenya and southern Ethiopia. Pastoralist spatial herding behavior and associated grazing pressure, arising as a direct consequence of a need to forage, find water and adhere to respected ethnic community boundaries were integrated into the model. Pastoralists and their herds were modeled as agents with complex behavior in the Pastoral Livestock Movement Model (PLMMO). The observed emergent properties in terms of pastoralist movement were not only the result of the behavior of individual agents, but the interactions among them as well. We focused on the emergent properties of pastoralists' mobility to illustrate the value of agent-based modeling framework for evaluating policies which minimize the impact of long distance mobility by pastoralists and their herds.

The movement range of pastoralists was constrained by the distribution of their forage and water availability especially during the drought season, when forage becomes much scarcer and the temporary surface water dries up resulting in limited supplies to more persistent sources. Water dependency constrains the home range of free-ranging animals during the dry season and thus dictates the availability of their food (e.g. Weir, 1971). The impact upon pastoralists is the extensive distances traveled in search of these two principal resources. There therefore exists a marked difference in mobility patterns and distances covered during the drought and a normal year. The specific distances moved during each of these seasons was simulated in this study and compared to field values; they were found to be correlated.

As a preliminary step to investigating pastoralists' response to resource heterogeneity, characterization of mobility patterns using non-linear agent-based modeling was carried out. The process involved integrating a "bottom-up approach", programming into individual agents, factors representing pastoralist behavioral rules that corresponded to their cultural practices as well as contemporary ecological theory, followed by observation of collective emerging patterns of landscape utilization. This approach is reminiscent of individual insects who though relatively small and weak on their own, are collectively capable of finding food, building sophisticated shelters, division of labor and defending their territories.

The fitness of the agents rule base in response to water, forage and socio-cultural boundary constraints was corroborated with a data set collected by Homman (2004), and provided a high correspondence between observed movement and modeled moments in two locations in the study area in a drought and non-drought year (r^2 values of between 0.927 and 0.977, $p<0.0001$).

Several scenarios representing ongoing landuse and climate change dynamics were then tested in order to explore emergent adaptive capacity of the pastoralists under these changes. The response of the pastoralists in PLMMO resulted in no significant impact under the increased livestock density and decreased forage yield scenarios. However, the increased forage yield with concomitant increase in variability during both the wet and dry season and improved access to water scenarios significantly reduced the distance moved by pastoralists. This was possibly achieved by making available more area for animal grazing in addition to resources for animal intake. At the core of this investigation were also questions about the response of animals to the heterogeneity of their resources. A more uniform distribution and better utilization of resources was observed under the improved water access scenario.

The notion of optimal foraging, resource matching, and laws governing use of common pool resources were also applied. On a larger scale, pastoralists' mobility dynamics were found to be determined by a combination of key resources, and an optimal threshold point lay somewhere between a number of these resources. The model behavior and results bore close resemblance to what is understood about fine-scale movement influenced by foraging, where species maximize their energetic return through foraging behavior (Hobbs, 1999). This raises the viability of the effectiveness of using the model to assess mobility across multiple spatial scales.

Typical recommendations include use of interventions such as those that enable watering distribution across the seasons thus avoiding seasons of extreme scarcity, utilizing livestock early warning tools with the ability to track and show the amount of available forage in as near, real-time as possible (as well as customized dissemination of such products) etc.

In addition to the insights provided by the model, it has several other advantages. At the basic level, the fact that the results generated by PLMMO concur with field results provides an elevated level of confidence in the model. Secondly given that the agent-based model was dynamic and in a higher dimensional space when compared to a linear model suggests that such an innovative methodology applied here might offer more insights into causal factors explaining observations made in the complex systems of rangelands. The results that arise as a consequence are of great scientific interest.

Justification for this second point was illustrated when we incorporated the effect of climatic change induced variability in forage yields on movement by pastoralists. The model showed a marked drop in distance moved by pastoralist despite our expectations that such variability may result in an increase in distances moved due to the existence of an unstable forage regime. This result echoes a classic character of emergence under agent-based models which is that these emergent properties may sometimes be counterintuitive. This counterintuitive phenomenon can only be predicted by agent-based modeling framework and may not be easily explained or instinctively anticipated without looking at how all parts behave and interact to make the whole.

The results from the ABMs illustrate the value of agent-based models for evaluating policies in situations where multiple agents interact to produce collective outcomes that might need to be managed in a particular way. The flexibility of the agent-based model offers other advantages. Their ability to explore the interesting complex behavior is one of its much-touted strengths, especially since reality is more likely to be represented by that complexity, something not aptly captured by linear models that are limited by the relatively simple assumptions that that have to be made. The ABM, on the other hand, can be extended to include a two-dimensional landscape representation, can involve agents with heterogeneous preferences and incomplete information, can take into account real or designed patterns of landscape properties, and can incorporate complex interactions like the effect of climate change on movement patterns of pastoralists. These extensions all improve the realism of the model and its applicability for evaluating alternative mechanisms to achieve the desired rangeland development patterns.

Conclusions and future research

No study to date has investigated in detail the rates and density of pastoralists movement patterns in the study area. Also to date, there are no complete surveys that have been carried out to quantify the number of pastoralist and their herds at any particular location in the pastoralist area under study. Most aerial surveys have only been conducted around wildlife management parks for purposes of wildlife management, while livestock density maps are restricted to estimations along administrative units. The model developed here therefore fills a big conceptual and data gap in relation to patterns of movements of pastoralists, real time distribution patterns and locations of pastoralists and response of pastoralists to various social and ecological transformations. Although simulation studies such as those in this thesis are able to predict mobility dynamics, future work should be directed at validating these predictions with respect to densities of livestock at specific locations, and relating changes in forage and water use gradients to changes in stocking pressure, subsequent vegetation and animal response. Furthermore, since the future scenario simulations we carried out were based on a model of existent factors responding to non- existent ones, there is now a need for collaboration with field experts who will in turn utilize the results from the model to investigate its applicability in a field setting, as we do not have real data to back up our models. Future versions and applications of this model should explore the feasibility of

- coupling it with quarantine and disease situations to help governments explore animal health policy and interventions and guide and expanded capacity for disease control
- investigating the effects of dynamic and tenuous insecurity and conflict regime boundaries

- incorporating the effects of market pull and trade through interactions such as imitation, information diffusion, buying and selling with subsequent impact on economics

The major finding of this work is that the agent-based model, PLMMO developed here is a robust system for emulating pastoral mobility in the rangelands of eastern Africa.

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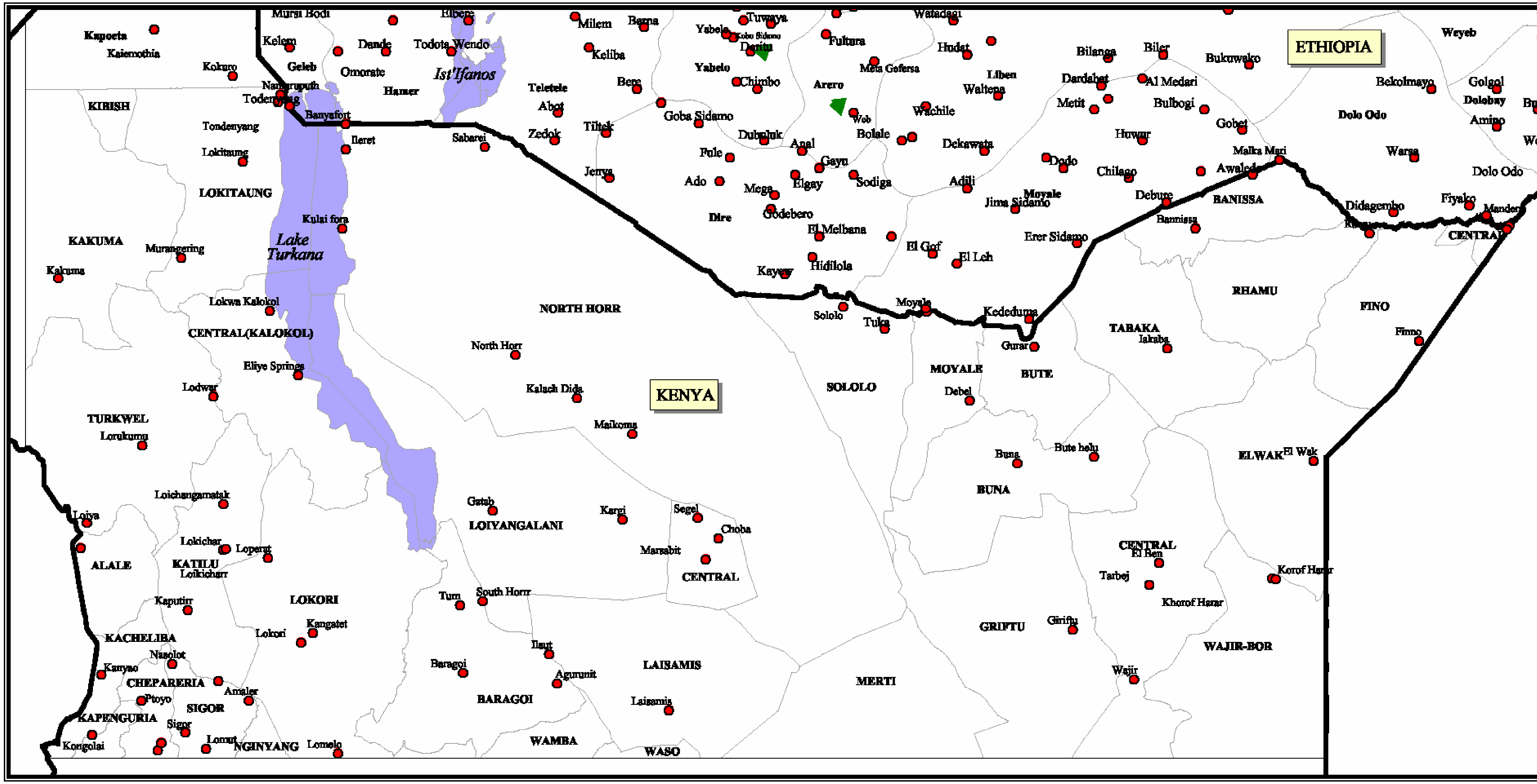
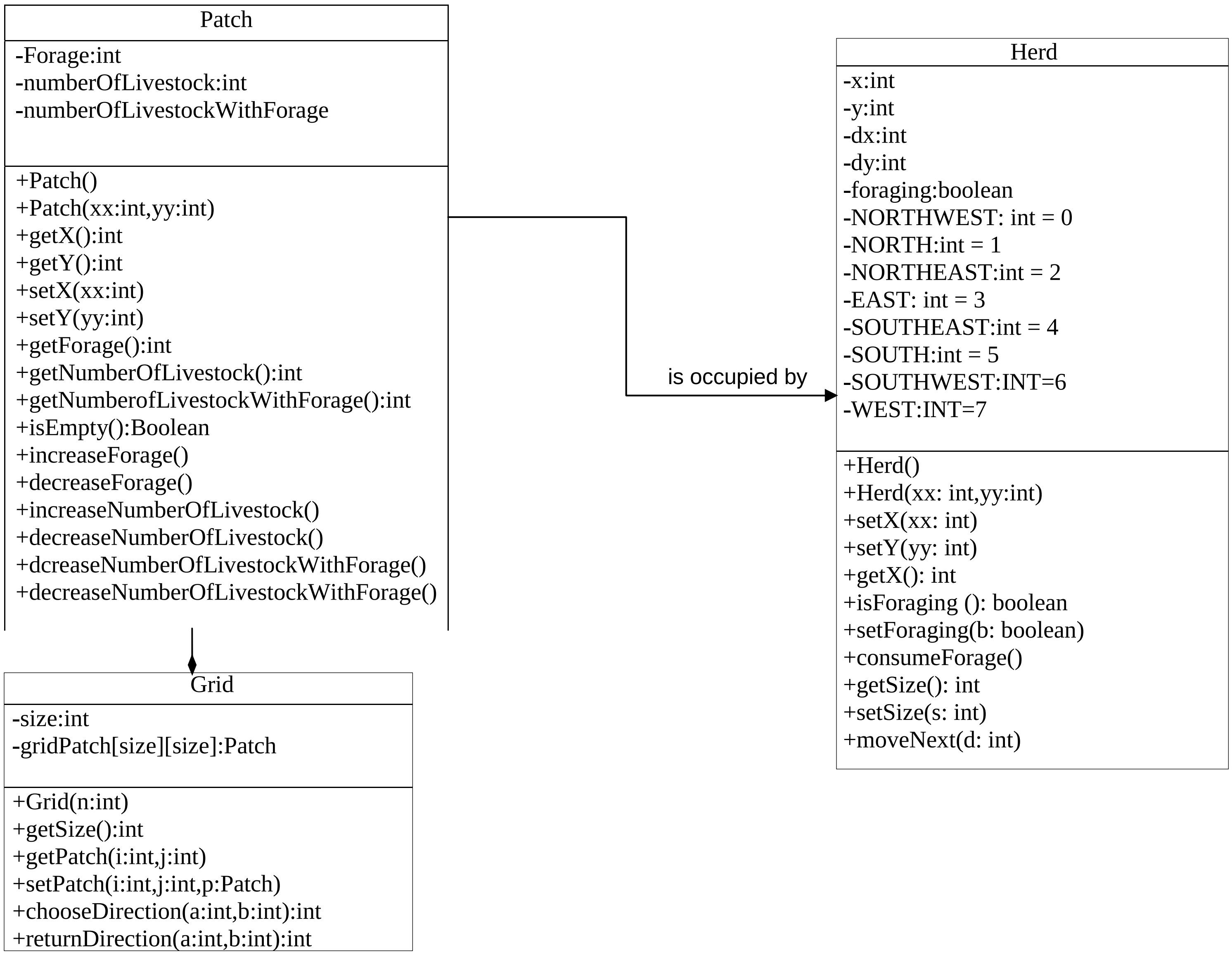
APPENDIX

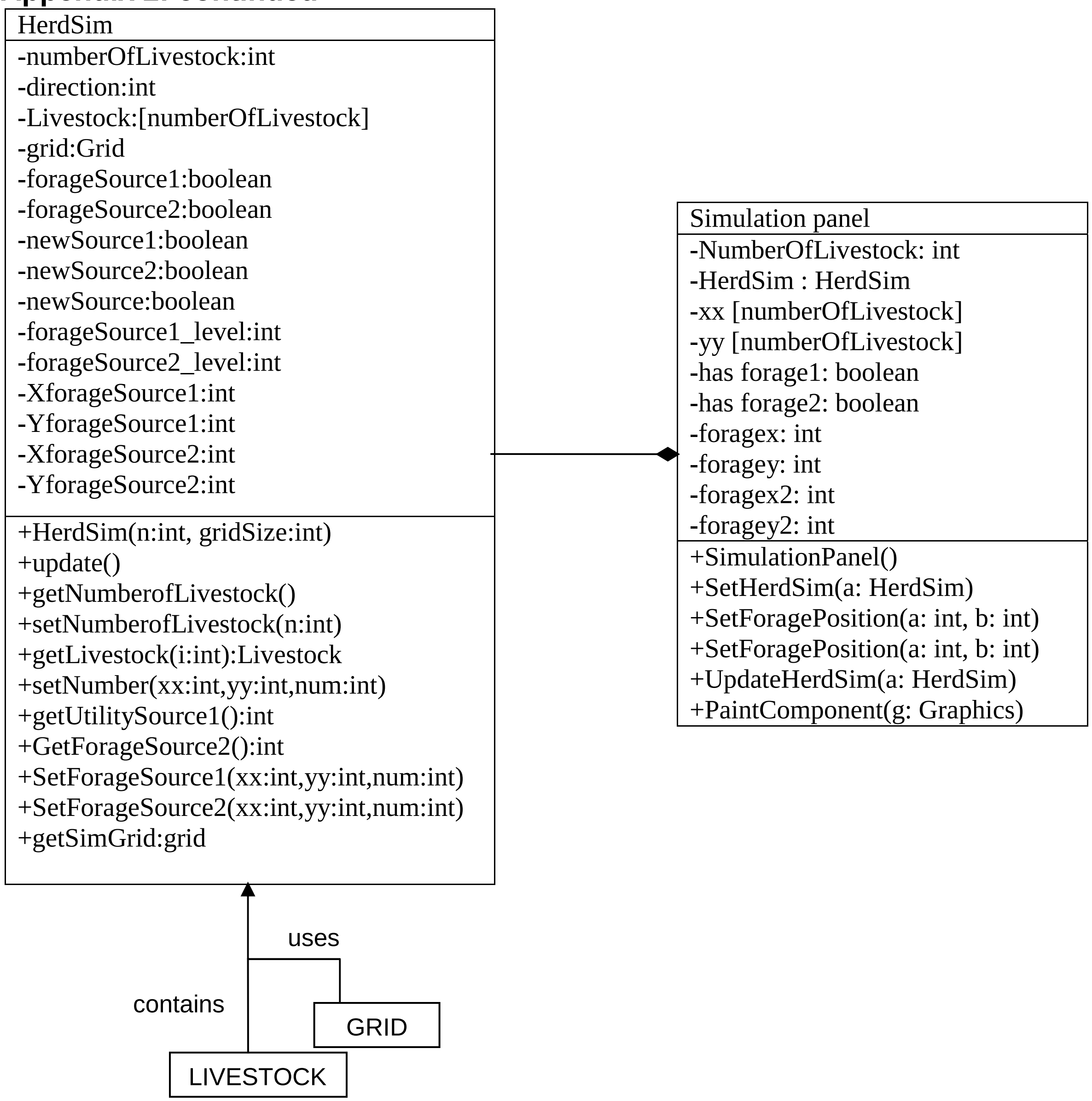
Appendix 1: Study area urban and administrative locations



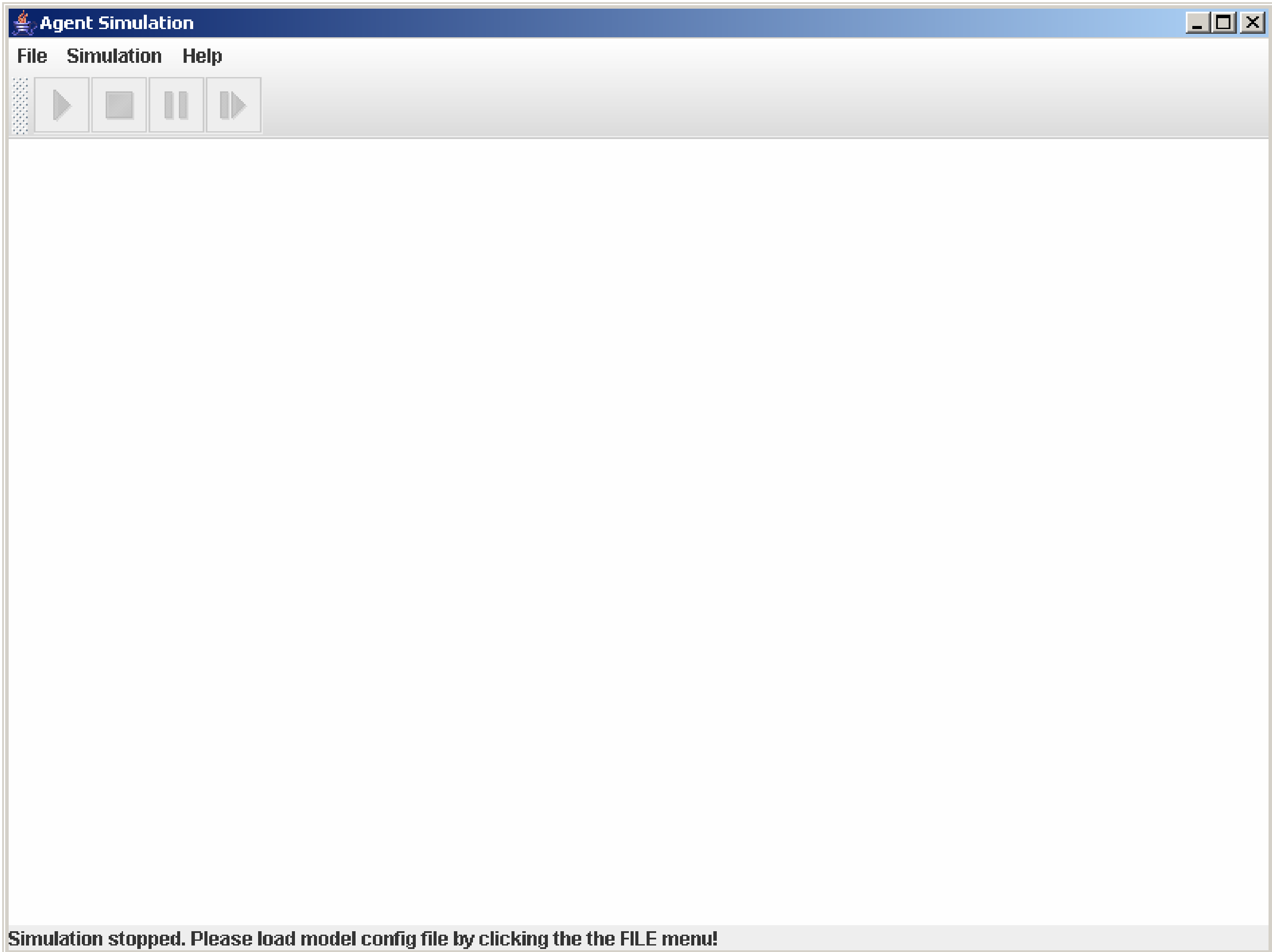
Appendix 2: PLMMO conceptual UML diagram sketch



Appendix 2: continued



Appendix 3: PLMMO user interface



Appendix 4: Surveyed pastoralists movement data during drought

DIDA HARA		**Drought (Jan1999-Mar2001)**					
Location		IDHH	distance moved (Km)	#of shifts	head of Cattle(begin)	km	months
DH	DAC	1	470	9	514	255	16
DH	DAC	9	270	2	48	75	7
DH	DAC	11	332	4	41	132	9
DH	DAC	14	170	2	134	85	4
DH	DAC	15	170	2	66	85	4
DH	DAC	21	170	2	32	55	10
DH	DAC	24	297	4	74	137	8
DH	DAC	40	716	5	57	212	17
DH	DAC	43	330	3	35	135	7
DH	DAC	50	716	5	39	212	17
DH	Dikale	56	481	2	219	74	13
DH	Dikale	57	481	2	18	74	13
DH	Dikale	63	560	5	357	200	14
DH	Dikale	64	80	1	17	40	2
DH	Dikale	77	135	1	34	45	3
DH	Dikale	78	330	1	57	30	11
DH	Dikale	81	211	3	64	63	9
DH	Dikale	89	80	1	33	40	2
DH	Dikale	91	0		16		
DH	Dikale	99	0		1		
DH	Dambi	102	945	4	60	93	24
DH	Dambi	105	86	3	53	48	6
DH	Dambi	106	395	6	30	178	14
DH	Dambi	109	443	6	86	148	15
DH	Dambi	119	0		39		
DH	Dambi	120	1116	7	739	226	24
DH	Dambi	121	355	3	6	135	7
DH	Dambi	123	355	3	21	135	7
DH	Dambi	129	45	2	40	30	3
DH	Dambi	135	38	2	26	23	3
DH	Dambi	144	200	1	125	40	5

DH=Dida Hara
DAC=Danballa Abba Chana

Appendix 4: continued

WEB		**Drought (Jan1999-Mar2001)**					
Location		IDHH	distance moved (Km)	#of shifts	head of Cattle(begin)	km	months
Web	DG	146	0		87		
Web	DG	147	0		81		
Web	DG	150	0		36		
Web	DG	151	426	4	5	146	12
Web	DG	153	426	4	28	146	12
Web	DG	154	0		89	146	12
Web	DG	155	1016	10	31	393	24
Web	DG	156	1016	10	55	393	24
Web	DG	159	90	1	22	15	6
Web	DG	162	250	3	47	70	11
Web	DG	164	715	2	14	105	11
Web	KY	166	120	3	54	55	8
Web	KY	167	216	2	57	46	9
Web	KY	169	890	5	48	338	15
Web	KY	174	605	4	46	145	14
Web	KY	178	326	7	16	179	13
Web	KY	179	256	4	22	90	13
Web	KY	180	522	8	20	176	23
Web	KY	181	522	8	49	176	23
Web	Nana	183	995	3	47	151	18
Web	Nana	184	280	2	36	130	5
Web	Nana	186	178	4	57	63	11
Web	Nana	187	280	2	55	130	5
Web	Nana	188	995	3	40	151	18
Web	Nana	190	55	1	45	11	5
Web	Nana	191	505		41	90	23
Web	Nana	193	360	4	114	64	21
Web	Nana	195	360	4	30	64	21
Web	Nana	196	178	4	33	63	11

DG=Daka Guracha
KY=Kukub Yaa

Appendix 5: Surveyed pastoralists movement data during post-drought

DIDA HARA		**Post Drought(Mar2001-Mar2002)**					
Location		IDHH	distance moved (Km)	#of shifts	head of Cattle(begin)	km	months
DH	DAC	1	0		250		
DH	DAC	9	0		1		
DH	DAC	11	0		6		
DH	DAC	14	0		18		
DH	DAC	15	0		11		
DH	DAC	21	0		11		
DH	DAC	24	0		10		
DH	DAC	40	0		3		
DH	DAC	43	0		7		
DH	DAC	50	0		2		
DH	Dikale	56	0		24		
DH	Dikale	57	0		1		
DH	Dikale	63	60	1	334	60	1
DH	Dikale	64	0		0		
DH	Dikale	77	0		5		
DH	Dikale	78	0		1		
DH	Dikale	81	0		24		
DH	Dikale	89	0		5		
DH	Dikale	91	0		7		
DH	Dikale	99	0		4		
DH	Dambi	102	540	1	15	45	12
DH	Dambi	105	0		4		
DH	Dambi	106	0		2		
DH	Dambi	109	0		18		
DH	Dambi	119	250	1	13	50	5
DH	Dambi	120	480	1	450	40	12
DH	Dambi	121	540	1	1	45	12
DH	Dambi	123	0		7		
DH	Dambi	129	0		4		
DH	Dambi	135	0		4		
DH	Dambi	144	0		24		

DH=Dida Hara
DAC=Danballa Abba Chana

Appendix 5: continued

WEB		Post Drought(Mar2001-Mar2002)					
Location		IDHH	distance moved (Km)	#of shifts	head of Cattle(begin)	km	months
Web	DG	146	119	1	26	17	7
Web	DG	147	0		23	0	0
Web	DG	150	34	1	7	17	2
Web	DG	151	120	2	7	45	5
Web	DG	153	120	2	6	45	5
Web	DG	154	120	2	40	45	5
Web	DG	155	90	2	15	50	3
Web	DG	156	75	1	14	15	5
Web	DG	159	15	1	17	15	1
Web	DG	162	111	2	10	47	5
Web	DG	164	0		2		
Web	KY	166	0		14		
Web	KY	167	98	2	36	23	7
Web	KY	169	360	2	25	90	8
Web	KY	174	225	3	12	60	12
Web	KY	178	0		7		
Web	KY	179	0		1		
Web	KY	180	195	1	10	55	9
Web	KY	181	180	2	22	40	9
Web	Nana	183	310	2	46	85	6
Web	Nana	184	0		2		
Web	Nana	186	0		7		
Web	Nana	187	840	1	17	70	12
Web	Nana	188	310	2	14	85	6
Web	Nana	190	227	2	20	87	4
Web	Nana	191	0		6		
Web	Nana	193	0		5		
Web	Nana	195	125	1	14	25	5
Web	Nana	196	125	1	13	25	5

DG=Daka Guracha
KY=Kukub Yaa

Appendix 6: List of ethnic communities in study area

1. Abdwak
2. Ajuran
3. Aulihan
4. Bajun
5. Boni
6. Boran
7. Burji
8. Degodia
9. Gabbra
10. Garreh
11. Kalenjin
12. Korokoro
13. Leisan
14. Murulle
15. Oromo
16. Pokomo
17. Pokot
18. Rendille
19. Sakuye
20. Samburu
21. Somali
22. Turkana
23. Merehan

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