CHAPTER 9A

LARGE-SCALE MOVEMENTS OF LARGE HERBIVORES

Livestock following changes in seasonal forage supply

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Abstract. Large-scale movements allow large herbivores to cope with changes in seasonal forage supply. Pastoralists use mobility to convert low-value ephemeral forage into high-value livestock. Transhumant pastoralists may move livestock less than ten to hundreds of kilometres. In semi-arid tropical sites, water and forage shortages in the dry season cause pastoral livestock to move to water or key resource areas. In temperate summers, livestock may be moved to higher-elevation snow-free meadows. In winters, animals may be moved lower to warmer sites, or to mountain valleys protected from steppe winds. Despite the recognised value of mobility, pastoral mobility is being reduced around the world. Changes in the mobility of three pastoral groups are reviewed, the Aymara of the South-American highlands, Mongolians, and the Maasai of Kenya and Tanzania, for which quantitative results are given. The Maasai of Kajiado District, Kenya are subdividing some group ranches into individually owned parcels. In subdivided Osilalei Group Ranch, herders moved an average of 5.6 km per day, whereas in undivided northern Imbirikani, herders moved 12.5 km per day. Residents of northern Imbirikani accessed more green vegetation the more they moved, whereas those in subdivided southern Imbirikani did not. Maasai selected areas with more heterogeneous vegetation during the dry season than found at their permanent households. In modelling, subdividing to 100-ha parcels allowed Eselengei Group Ranch to support 25% fewer livestock by mass, even though the area remained the same. For any pastoralist, the costs of mobility must be weighed against benefits, but pastoralists have demonstrated flexibility in their mobility, if constraints such as human population growth and limitations in land access are not too great. We show that pastoralists have successfully evolved methods of herding livestock to access adequate forage in areas of variable climate.

Keywords. Aymara; fragmentation; Kenya; Maasai; Mongolia; pastoralism; subdivision

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INTRODUCTION

Semi-arid and arid rangelands that are generally too dry to support rain-fed agriculture but have vegetation comprise about 25% of the landscapes of the world, excluding Antarctica (reviewed in Groombridge 1992). Twenty million or more households make their living as pastoralists on these lands, and ten times as many obtain a significant source of income from raising livestock (De Haan et al. 1997). Some form of pastoralism is practiced in every continent, excluding Australia and Antarctica, and a diversity of pastoral cultures and subcultures have evolved, especially in Africa, the Near East and West Asia, and the Indian region (FAO 2001). Most of these groups must contend with rainfall that is more variable within years, between years and across space than in more mesic regions (Ellis 1994). At its most basic, pastoralists have had to develop means of converting a spatially and temporally variable resource of little intrinsic value (grass) into a more stable, mobile resource of greater nutritional, economic and social value (livestock) (Swift 1977; Goldschmidt 1979). Adaptations allowing pastoralists to use areas with spatially and temporally variable rainfall are varied, but a central adaptation is through movements of livestock to make use of ephemeral forage resources. Livestock herders move their animals to different degrees (Box 9.1). This chapter focuses on transhumance and the effects of seasonal movements on livestock.

Movement of livestock is a crucial adaptation allowing pastoralists to use areas with spatially and temporally variable rainfall

Box 9.1. *Livestock and pastoral movements*

Livestock herders move their animals in ways that may be broadly categorised into three classes (FAO 2001), although a continuum exists. Some movements are nomadic, using a given foraging resource, then moving on to other pastures following variable rainfall, with movement patterns notably different from year to year. Other movements are transhumant, where animals and people move between locations where forage is available seasonally. Movements may be short (< 10 km) or long (hundreds of km), and may be absent in years of very good rainfall (Kavoori 1999) or extreme in years of severe drought (Bekure et al. 1991), but movements in years of typical rainfall follow a predictable pattern. Agropastoralism is practiced by those that cultivate lands and raise livestock. Their livestock movements tend to be short, allowing family members to remain close-by and to work their agricultural plots.

In rangelands around the world, the mobility of pastoralists has been, or is being, reduced. Reductions are due to exogenous sources, such as increased transportation costs, land subdivision and changing government policies, as well as endogenous sources reflecting the pastoralists' desires, such as to be near schools, hospitals and other services, or to work agricultural plots. The literature of the past 15 years includes pleas for the mobility and land access of pastoral peoples to be maintained (e.g., Behnke and Scoones 1993; Scoones 1995; Niamir-Fuller 1999; Chatty and Colchester 2002). However, mobility has been reduced, as evident in the case studies we present. Today an important research focus is on quantifying the effects of sedentarisation and on adaptive strategies pastoralists may invent or adopt that allow them to lessen the negative effects of sedentarisation and improve decision making in the face of uncertainty.

We briefly discuss some general principals in transhumant pastoralism. We then seek to introduce transhumance patterns, but transhumance is as variable as the pastoralists the literature describes (Dyson-Hudson and Dyson-Hudson 1980). To limit our contribution, we review traditional patterns of livestock movements in three groups inhabiting three continents, selected to represent short-, long- and medium-range seasonal movements: the Aymara of the South American Andes, the Mongols of Mongolia, and the Maasai of Kenya and Tanzania, where we focus upon southern Kajiado District, Kenya. Some effects of fragmentation and other interventions on the seasonal movements of Mongolian and Aymara pastoralists are briefly cited, and the status of Maasai transhumance in Kajiado is reviewed. We then present quantitative effects of declining access of livestock to a diversity of forage patches due to profound land tenure changes in Maasailand. Maasai herders' selection of seasonally available green forage patches is quantified, and modelling results quantify the effect of declining parcel size on livestock production and human welfare. We conclude by reviewing some effects of fragmentation and emphasise the flexibility of pastoralists to adapt to stressors, if limitations are not too extreme.

Most pastoral systems have evolved responses that entail moving livestock seasonally

SEASONAL MOVEMENTS OF LIVESTOCK

Most pastoral systems have strong seasonality, with extremes in temperature (summer and winter), precipitation (dry season and wet season) or both. Forage quality and quantity vary through time in any pasture, but in semi-arid and arid lands, seasonal changes in forage quality and production can be extreme. In many regions, pastures cannot support livestock throughout the year, and water may be unavailable for portions of the year. Access to forage may be limited (e.g., because of snow depth), production may be inadequate, or the nutrient content of forage may be low (Bokdam and WallisDeVries 1992; Turner 1998; Schareika 2001; Kerven 2002; Mishra et al. 2003; Mishra et al. 2004). Pastoralists have evolved responses that entail moving livestock seasonally, so that the aggregate access to forage is the sum of access to forage 'pulses' within grazed landscape patches (Pickup and Stafford Smith 1993). Rotational movements also allow grazed pastures to rest between uses, reduce the likelihood that diseases or pests will become a severe problem (Kavoori 1999), and can help maintain biodiversity in some pastures (Zervas 1998). Pastures may be burned to reduce insects and encourage new growth (e.g., Bassett and Koli Bi 1999; Van de Vijver et al.1999). Large herds are apt to be moved longer distances, in part because large herds require more forage, and in part because the costs per animal are too high when moving small herds (Humphrey and

Sneath 1999; Kerven 2002). Herds may be moved several times throughout the year, or even throughout a season, and if labour is available herds are split into groups (Evans-Pritchard 1940; Stenning 1959; Swift 1986), such as young and milking animals that stay near the households and heifers and steers that are taken far afield. Transhumance should not be viewed solely as livestock and people moving about on foot. Transhumance can be improved or made possible using vehicles, concrete loading bays, watering troughs, etc. (Chang 1993; Karoovi 1999; Kerven et al. 2003); we provide an example from Mongolia. In tropical systems, high-quality forage and water are generally most plentiful during the wet season (e.g., Prins 1989a; Prins and Beekman 1989). Areas where permanent water is not available are often used in the wet season, leaving areas with year-round water as reserves for use in the dry season (Bernus 1979; Galaty 1980). Livestock may be moved closer to temporary or permanent households to reduce travel costs and allow families easier access to lactating livestock. In temperate systems, summer months are times of plenty. In mountainous areas, livestock are typically moved to higher elevations, to make use of snow-free high mountain meadows and to prolong milk production (Chang 1993; Jina 1999; Mishra et al. 2003).

In the tropical dry season, forage availability and quality, rainfall, humidity and water availability decline (Stenning 1957). Some livestock species (e.g., goats, camels) may remain on landscape patches used in the wet season, relying upon woody vegetation. However, typically livestock are moved to areas where forage remains greenest and water is available (e.g., Evans-Pritchard 1940). Dry season sites may be highland slopes that receive more rainfall, areas with soil properties that lead to better plant growth (Schareika 2001), grazing reserves intentionally avoided other times of the year, areas free from insect pests (Stenning 1957, 1959), heavily grazed areas around water sources that are the only remaining options (e.g., Schareika 2001), or drainages, wetlands or other key resource areas (Box 9.2) that provide forage even in dry periods. Crop residue can be a key resource for some pastoralists (Jina 1999; Kavoori 1999; Turner 2003). Livestock may be trekked long distances to forage on residues left after crops have been harvested, often in formal arrangements that benefit both the pastoralist (access to residue and perhaps payment) and agriculturalist (manure and urine deposited on the cultivated plot) (Heasley and Delehanty 1996).

In temperate regions, winters bring cold, snow, and reduced quality and access to forage. Grasses may be covered by accumulated snow, and crusted snows make access to forage difficult or impossible. Herders move animals to sheltered valleys and lower elevations with less snow and higher temperatures (Jina 1999; Mishra 2003), although access to areas swept free of snow by wind may be valued. In some systems, such as those of Inner Asia and the Andes, pastoralists move from their autumn pastures to higher elevations, locating sites in mountain valleys that are protected from strong winds on the steppe or plains (Humphrey and Sneath 1999).

Box 9.2. *Key resource areas*

Many semi-arid and arid grazing areas are expanses of rangelands with low or episodic vegetative productivity, with smaller areas of higher, more reliable, or extended primary production. Drawing from his work in Zimbabwe and examples from elsewhere, Scoones (1991) documented the importance of small wetlands in livestock management, and coined the term key resources, or key resource areas, for the wetlands. Primary production within key resources may limit the number of ungulates that can occur in an area (Illius and O'Connor 1999, 2000), and may be limiting factors (Blackman 1905), but are generally small and can be delineated from the surrounding landscape. Examples of key resources include wetlands, lake and river floodplains, and high-elevation grasslands that stay green longer than lowland rangelands (see also chapter 10a).

Key resource areas in semi-arid and arid areas throughout Africa are threatened due to land-use intensification and human population growth. For example, in Kajiado District, Kenya, the margins of the swamps outside Amboseli National Park are being converted to cultivated plots by agropastoralists, with water from the swamps used in irrigation and their livestock grazed nearby year-round (BurnSilver et al. 2004; Worden et al. 2003). Stakeholders are concerned about the effects that loss of swamp area, access to water and continuous grazing by livestock have on Maasai food security and area wildlife.

Seasonal movements of livestock are not solely associated with forage quality or quantity or water availability. Traditionally, movements were constrained or altered by social, tenural, labour or political restrictions, military or other security threats, large rivers or disease (e.g., Stenning 1957; Dahl and Hjort 1976; Frantz 1978; ILCA 1979; Turner 1999b), and those constraints and others exist today. Increasingly, it is a combination of socioeconomic and political factors that strongly influence the ability of pastoralists to continue using mobility as an adaptation to seasonal resource heterogeneity in dry rangelands.

TRADITIONAL RESPONSES TO SEASONAL FORAGE AVAILABILITY

The Aymara of the highlands of South America provide an example of short-range seasonal movements of livestock in a temperate system. The Aymara raise llamas and sheep for meat and alpaca for wool, with other species (e.g., cattle, horses, pigs) less common (Orlove 1977). The environment is extreme; the Bolivian area studied by Buttolph and Coppock (2001) was 3,900 m in elevation, with 260 days with frost in an average year and large swings in diurnal temperature. During the summer wet season, families move to houses at lower elevations to make use of productive grasses and herbs. In the dry winter, families return to the highlands, which remain relatively moist (Orlove 1977). Households use designated landscape patches within lands owned communally. These landscapes include *bofedales*, which are natural or man-made high-elevation peatlands with more than 60 species of perennial grasses, herbs and sedges (Moreau et al. 2003). *Bofedales* are an important grazing resource in the dry season. Llamas tend to graze in upland habitats during the wet season, but alpaca and sheep are regularly moved between upland habitats and *bofedales*, conserving forage in the *bofedales* while maintaining an adequate nutritional state for the livestock. In the dry winters, alpaca and sheep predominately use *bofedales* for forage and water, and llamas use these resources somewhat more than in the wet season as well (Buttolph and Coppock 2001).

Mongolians have adopted complex movement patterns in response to extreme climatic conditions (Enkhtuvshin and Tumujav 2002). This system provides an example of some groups making short seasonal movements, and some very long movements. Mongolian growing seasons are brief, with most of the annual rainfall in the summer, with rainfall totals of less than 300 mm annually, except for the northern zones. Sheep, camels, goats, cattle, horses and yaks are herded for meat, milk, wool and transport – mostly indigenous breeds that can withstand the low winter temperatures without housing and restore body condition quickly during the short growing season. Seasonal movements are made to access some or all of the desert, desert steppe, mid-altitude steppe, mountain steppe and forest steppe (Mearns and Swift 1995). Movements span from 10-km shifts two to four times a year between protected valleys used in winter to nearby summer pastures, to 300-km treks between open mountain passes used in the summer, autumn in lowlands, with a return to mountain passes in winter (Fernandez-Gimenez and Allen-Diaz 1999; Enkhtuvshin and Tumujav 2002), seeking snow as a water source for livestock and shelter for livestock and people from strong steppe winds (Suttie 2000). In general, four seasonal grazing areas are used (Fernandez-Gimenez and Allen-Diaz 1999; Enkh-Amgalan 2002). Winter and spring pastures are most important to the survival of livestock and are in limited supply, whereas summer and autumn pastures are often understocked (Suttie 2000).

Pastoralists have adopted complex movement patterns in response to extreme climatic conditions

The final example of seasonal movements is for our focal pastoral group, the Maasai of southern Kajiado District, Kenya. Within the district, and elsewhere in Maasailand, herders make medium range movements throughout the seasons to access green forage. Traditionally, Kajiado herders used lands communally, and movements were subject to complex use rights, within large Maasai sections (Figure 9.1a) (Galaty 1980). The short and long wet seasons brought highly nutritious forage that was readily available (Bekure et al. 1991), and many Maasai grazed their cattle, goats and sheep near their permanent households. Others moved their herds to temporary households within wet-season grazing areas. As forage was consumed or dried, livestock were moved farther away from the permanent settlement areas, to nearby areas of remaining green forage, with herds ultimately occupying dry-season zones. The timing of return to permanent households for those that migrated to dry-season grazing areas was often determined by water shortages, as well as by forage availability.

RESPONSE TO SEASONAL FORAGE AVAILABILITY UNDER INTERVENTIONS

Buttolph and Coppock (2001) provide an example of a negative effect of intervention on behalf of transhumant Aymara people – in this case, the pastoralists' own production association. In 1993, Project Alpaca was begun by the Asociación Integral de Granaderos en Camélidos de los Andes Altos, comprised of Aymara herders. They sought to improve alpaca wool production. Among the interventions made, the association provided credit and barbed-wire fencing for herders to fence the *bofedales* that they used, so that grazing could be controlled seasonally and land-use conflicts reduced. There were some benefits to fencing *bofedales*, but the effect of interest was that *bofedales* that were once managed communally were fenced for private use. In one site, about half of the accessible *bofedales* were fenced within two years. Instead of land-use conflicts being reduced, they had been intensified. More importantly, this magnitude of loss of access to key resources does not bode well for the Aymara in drought (Buttolph and Coppock 2001).

In Mongolia, intervention came in the form of profound political change. Under socialism, the livestock sector was collectivised in 1950, although some stock remained privately held. Families were required to raise single-species herds under relatively intense management, including increased hay and fodder production and use of government-provided mechanised transport, boreholes and simple livestock shelters. Unlike in the past, households were associated with management units, called *negdels*, which restricted their opportunities to move to access forage relative to their historic seasonal movements (Suttie 2000). Livestock were using pastures for longer periods than under the traditional system. The centralised government also attempted to avoid overstocking, although stocking rates were elevated and degradation did occur (reviewed in Kerven (2002) for areas to the west). In 1990, the centralised system of government ended and efforts were put in place to create a market economy (Mearns and Swift 1995). Much of the subsidised support for livestock production ceased, including most hay production and mechanised transport, and many wells failed. In the years since, the degree to which traditional transhumance patterns have re-emerged is mixed. Many families owned too few animals to maintain a transhumant, or even pastoral, lifestyle – in 1995, more than 40% of households had fewer than 50 head of livestock, which is the poverty line (Suttie 2000). In some areas, land-use rules are now absent or weak, with new (ex-urban) or displaced herders using lands not traditionally theirs to use (Mearns and Swift 1995). Many pastoral families have re-established mixed-species herds and have resumed some seasonal movements, although distances travelled are shorter than what was traditional (Humphrey and Sneath 1999). In general, although control of grazing and movements have persisted or has re-emerged among family units, such control is at a spatial scale too small for efficient management of the variable and extensive grazing resources of the region (Humphrey and Sneath 1999; Suttie 2000).

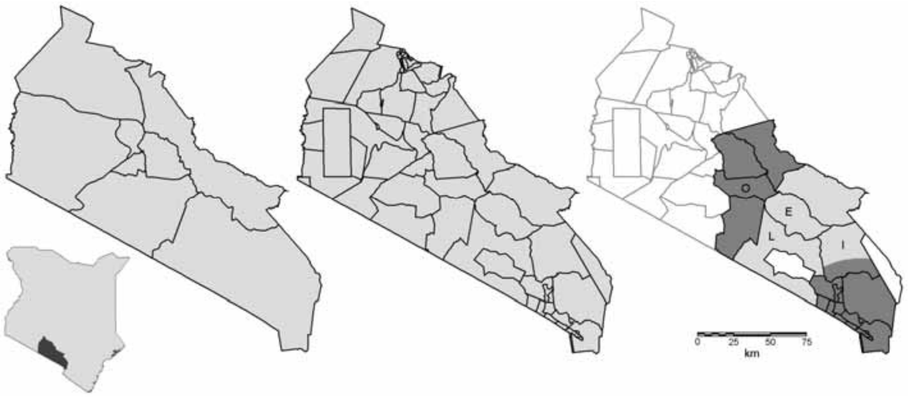

Figure 9.1. *(a) Maasai sections within Kajiado District, south-western Kenya (Ole Katampoi et al. 1990), (b) Kajiado group ranches and (c) the state of subdivision of ranches within the area we modelled are shown. Areas in (c) that are dark grey are subdivided, those that are light grey remain communally held, Amboseli National Park in the southwest is white, and West Chyulu Game Conservation Area to the east is in white. Group ranches cited include Imbirikani ("I" in c), Eselengei ("E"), Olgulului/Lolarashi ("L"), and Osilalei ("O") (Group ranch boundaries are ill defined; approximate boundaries are shown)*

In Kajiado District, Kenya, land tenure has changed markedly in the last 30 years after a series of economic and political interventions instituted for the most part from outside the pastoral system. The Kenyan government, in cooperation with the World Bank, began dividing Maasai sections (Figure 9.1a) into group ranches (Figure 9.1b) in the late 1960s and early 1970s (Galaty 1980). Group ranches were formed to improve livestock production, ease the provision of services, and secure land ownership. In general, group ranch formation failed to meet its original goals (Galaty 1994; Heath 2000), although ranch formation has allowed lands to stay largely in Maasai hands. From 1965 to 1975, Kajiado District was adjudicated, and the district was divided into 52 ranches (Figure 9.1b) that are used somewhat exclusively by group ranch members (Kimani and Pickard 1998). Members graze their livestock within their own ranches throughout the year, but in years of drought, agreements can allow herders to move between group ranches. In 1983, the government sanctioned subdivision of ranches (Kristjanson et al. 2002), and today subdivision continues, with group ranches being further subdivided into parcels held by individual herders or families (Figure 9.1c). There have been many social and institutional effects of subdivision in Kajiado (e.g., Galaty 1980; Bekure et al. 1991; Rutten 1992; Galaty 1994; Kristjanson et al. 2002; BurnSilver et al. 2004); in the next section, we focus upon effects on livestock and household status.

REDUCED ACCESS TO FORAGE HETEROGENEITY

We turn to qualitative and quantitative analyses that reflect the importance of access to heterogeneous forage patches in livestock production and the associated costs of fragmentation for herders under land subdivision. In analyses relating to biocomplexity, we are assessing the effects of fragmentation on ungulates and human welfare. Theoretically, we hypothesise a humped-shaped relationship between the importance of landscape fragmentation to livestock and system productivity (Box 9.3). Here we focus upon the middle portion of that hypothesised curve where loss of access to heterogeneous forage patches can reduce herbivore capacity (Figure 9.2), the range of productivity represented by southern Kajiado, Kenya. We use satellite images in analyses to represent the strength of selection for green vegetation by Maasai, or alternatively, the cost of sedentarisation due to landscape fragmentation. Process-based ecosystem modelling is used to quantify the effects of landscape fragmentation on livestock stocking rates.

Reduced access to heterogeneous forage patches in livestock production under land subdivision results in costs for herders

Box 9.3. *Primary production and effects of fragmentation*

We hypothesise a quadratic (humped-shaped) relationship between the importance of landscape fragmentation to livestock and system productivity. Very arid systems with low primary productivity and low stocking rates, where livestock travel costs cannot be increased and primary and secondary productivity are weakly linked (Ellis and Swift 1988), may be insensitive to fragmentation at broader scales. Conversely, at exceedingly productive sites, forage production may be adequate to supply livestock their needs, and stocking is limited by other factors (e.g., behavioural restrictions because of crowding, disease transmission risks, etc.); fragmenting the landscape into small units may have little effect upon livestock production. In turn, livestock inhabiting homogeneous pastures are less sensitive to fragmentation than those inhabiting heterogeneous pastures. For heterogeneous pastures in a moderately productive system (i.e., near the top of our humped-shaped curve), fragmentation can reduce the foraging choices available to livestock.

Images and modelling tools

Satellite images have often been used to represent vegetation greenness. Ratios of the near-infrared and infrared bands are termed Normalised Difference Vegetation Indices (NDVI), and reflect vegetation biomass and vigour. The images cannot represent all relevant aspects of semi-arid lands, such as the prevalence of unpalatable or exotic vegetation, but NDVI values are correlated with ungulate stocking rates (Oesterheld et al. 1992; 1998; Ottichilo et al. 2000b), and have been used in research extensively (e.g., Tucker et al. 1985; Eklundh 1998; Boone et al. 2000; Skidmore, Chapter 4). Satellite images were acquired from the SPOT program, Earth Observation System, which was developed by the Centre National d'Etudes Spatiales of France, with cooperation from the governments of Sweden and Belgium. Recent SPOT satellites have included a vegetation sensor, which has a coarse resolution (1.15 km square pixels). Vegetation NDVI images are freely available at full resolution (1 km pixel) for entire continents (VITO 2003), with the earliest images from April 1998. These are 10-day (i.e., decadal) composite images, where the best NDVI value available (based on sun and sensor angles, etc.) is selected for the 10-day period. We acquired the NDVI images for Africa from 1999 and 2000.

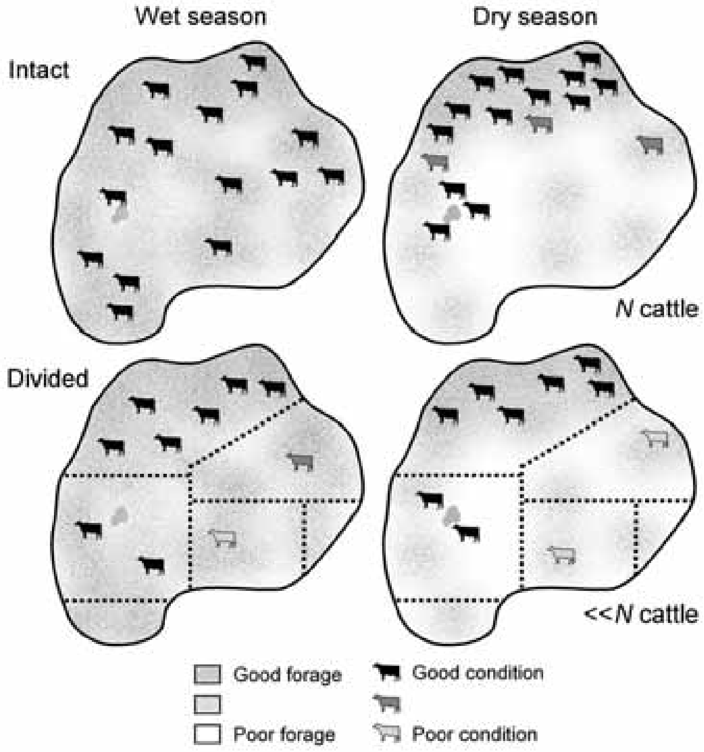

Figure 9.2. *A schematised view of movements by livestock in an area of heterogeneous forage patches of moderate productivity. Animals move about freely (a) in an intact landscape, shifting to high-elevation grazing areas and a key resource in the dry season. If the landscape is divided into parcels (b), some parcels contain adequate forage through the dry season and livestock prosper, but other parcels cannot support livestock or support animals in poorer condition*

Two models were used in the analyses, the SAVANNA ecosystem model and a pastoral-household decision model called PHEWS (Pastoral Household Economic Welfare Simulator). A full description of these models is beyond the scope of this review, but more detail is available (Ellis and Coughenour 1998; Boone 2000; Boone et al. 2002; Thornton et al. 2003). In general, SAVANNA is a series of interconnected computer programs that model primary ecosystem interactions in arid and semi-arid landscapes, simulating functional groups for plants and animals. SAVANNA is spatially explicit and represents landscapes by dividing them into a system of square cells that have spatial data associated with them. The model predicts water and nitrogen availability to plants using rainfall and soil properties, for each of the cells. Based upon water, light and nutrient availability, products of photosynthesis are calculated for plant functional groups, using process-based methods. The carbohydrates are distributed to leaves, stems and roots using plant allometrics, yielding estimates of primary production and from that, plant populations. A habitat suitability index is calculated for each cell in the landscape, at weekly intervals and for each animal functional group, based upon forage quality and quantity and physical attributes of the cell. Individuals in the population are distributed in the landscape based upon these indices. Animals will feed upon the available vegetation, and energy gains and losses are tracked, as well as changes in populations. Summaries of the status of vegetation, herbivores and climate are produced at monthly intervals.

The PHEWS model simulates decision making in Maasai households (Thornton et al. 2003). A series of rules that reflect decision making in Kajiado were incorporated, determined from interviews and published sources. Families seek to meet their caloric needs, while simultaneously seeking to build livestock and monetary holdings. Calories are gained from milk, tea with sugar, and livestock slaughtered due to disease or for occasional ceremonies. More calories are needed, so available maize and other crops are eaten. If there remains a caloric deficit and the family has money or animals to sell, grains and other crops are purchased. Finally, if a deficit remains and livestock cannot be sold, the families' needs are met through supplemental food. The PHEWS model is tightly linked to SAVANNA. For example, SAVANNA reports to PHEWS livestock populations, and PHEWS reports back to SAVANNA the numbers of livestock sold so that population dynamics may be tracked.

Grazing-area analyses

Based on survey results, we have shown that the daily pathways (i.e., grazing orbits) were shorter in a completely subdivided group ranch than in unsubdivided ranches (BurnSilver et al. 2004). BurnSilver and Worden conducted surveys in 6 communities within four group ranches: Imbirikani, Olgulului/Lolarashi, Eselengei and Osilalei Group Ranch (Figure 9.1c). Osilalei Group Ranch is fully subdivided, with ranch members each owning individual parcels of approximately 40.5 ha (100 ac). The other group ranches are not subdivided, but the wetlands of southern Imbirikani Group Ranch are being subdivided for cultivation. 61 daily grazing pathways from 32 herds were recorded during a wet and dry season, using global-positioning technology. Herders in subdivided Osilalei moved 5.6 km per day in the wet season, whereas herders in communally held northern Imbirikani moved 12.5 km. These movements may be additionally affected by differences in vegetation productivity between the ranches (Osilalei is more productive than Imbirikani), but the differences in distances travelled are large, and 86% (18 of 21 people surveyed) stayed on their own parcel in Osilalei during 1999.

As part of the surveys, BurnSilver and Worden asked Maasai herd owners to identify areas where they had grazed livestock. For 46 herds, locations were recorded each month for a calendar year of average rainfall (1999) and an extremely dry year (2000); here we present results from the average year. The approximate centres of the seasonal grazing areas were later identified using geographic-positioning instruments, and grazing areas are assumed to be circular, with radii defined using summaries from daily grazing orbits cited above. Whether each location was associated with a permanent or temporary household was noted. Two spatial data sets were generated from these lists: the locations of herds as they moved in reality, and the location of herds if they remained near their permanent households, emulating sedentarisation through subdivision. The differences between mobile and simulated-sedentarised herd locations in communal northern Imbirikani Group Ranch were large, whereas the differences were small for southern Imbirikani, where most pastoralists are engaged in agriculture and typically do not move their animals long distances.

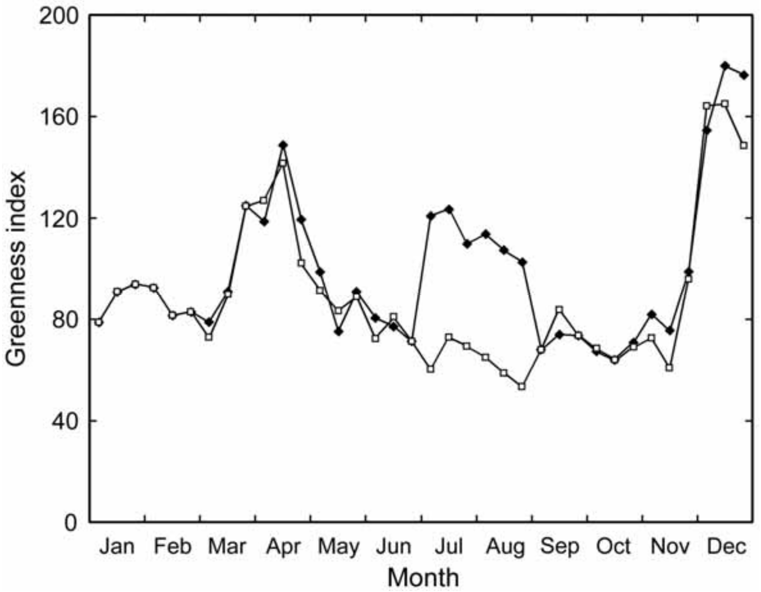

Figure 9.3. *Greenness indices, from 1999 NDVI, tracked by pastoralist "98" in Imbirikani Group Ranch in reality (solid diamonds) and if forced to graze only near permanent settlements (open boxes). In 1999, the herd was moved 6 times, and access to green forage improved in the stressful long dry season, relative to if the herder used only the permanent settlement area. Here the difference in access to green forage was large (380 units), but on average integrated greenness accessed by Maasai herders of northern Imbirikani that moved was 61 NDVI units higher than when those same herders were simulated to be sedentary. NDVI indices are based on greenness measured by satellite images, and are a good indication of primary productivity (e.g., Tucker et al. 1985; Paruelo et al. 1997)*

Integrated (i.e., summed) greenness profiles were generated from NDVI based upon seasonal movements, and compared to greenness profiles based on the locations of permanent settlements. Pastoralists improved their herd's access to green forage by moving, compared to if they remained around their permanent settlements (e.g., Figure 9.3). Access to greenness improved (Figure 9.4) as inhabitants of northern Imbirikani moved more ($R^2 = 0.59$, $P < 0.001$, with one herd that left Imbirikani Group Ranch excluded) with up to 6 movements made, whereas inhabitants of subdivided south Imbirikani did not move more than three times and showed no improvement in access to green forage as movements increased ($P > 0.1$).

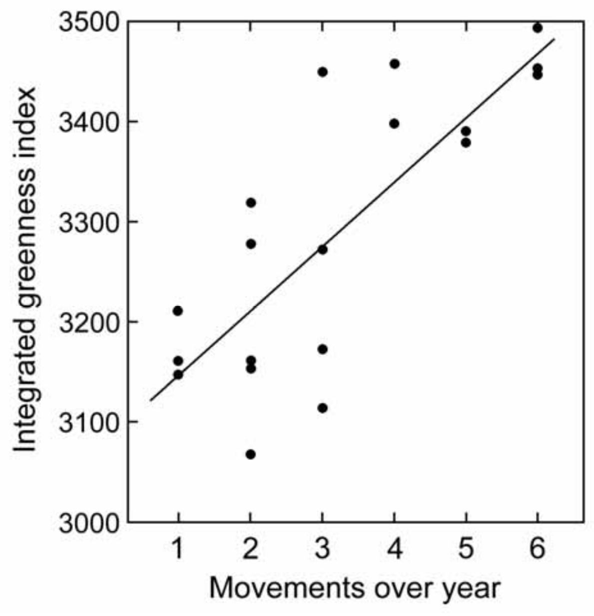

Figure 9.4. *Pastoralists in northern Imbirikani Group Ranch accessed more green forage if they moved, as reflected in integrated greenness indices from NDVI. NDVI indices reflect primary productivity, as cited in the legend of Figure 9.3*

We hypothesised that areas used for seasonal grazing by Maasai would be more temporally and spatially variable in vegetation greenness than areas around their permanent settlements. Measures of vegetation heterogeneity were created by calculating standard deviations in changes in greenness across images within wet seasons (combined short and long seasons, i.e., last image in October, November, December, March, April, May) and dry seasons (i.e., January, February, June, July, August, September and the first two images of October). Standard deviations were used rather than coefficients of variation to avoid standardising the variation by the mean; a 50-g increase in forage production is of similar value to livestock whether in a pasture with 100 or with 350 g standing biomass. The mean of the standard deviations within a 2-km moving window around each pixel in the image was then calculated using Arc/Info (Environmental Systems Research Institute, Redlands, California, USA). This created heterogeneity indices (Figure 9.5) similar to those in BurnSilver et al. (2004), except that elevation and soils were not incorporated. Monthly grazing areas used by Maasai in Imbirikani Group Ranch and neighbouring northern Chyulu (Figures 9.1 and 9.5) were overlaid upon the seasonal heterogeneity indices and mean heterogeneity indices calculated.

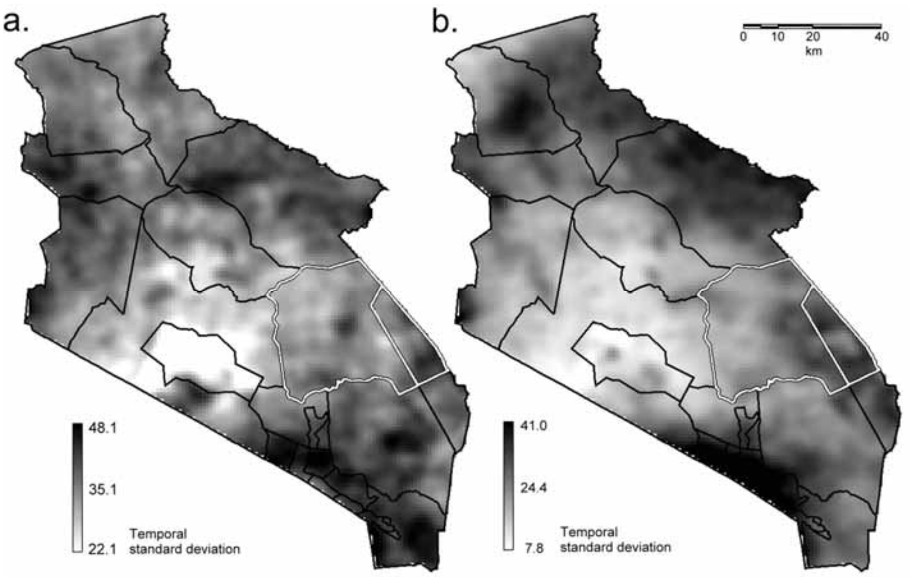

Figure 9.5. *Vegetation heterogeneity indices in the (a) wet seasons and (b) dry seasons. Indices reflect the standard deviation in NDVI across time, smoothed across space. The areas bounded in black and white are Imbirikani Group Ranch and the northern portion of Chyulu Hills, the area used in the analyses*

Maasai in communal northern Imbirikani Group Ranch selected more heterogeneous landscape patches in the dry season (Figure 9.6) than when we simulated herders remaining at their home settlement year-round. Mobility allowed more access to heterogeneity in the wet season as well, although the differences were small. Maasai in southern Imbirikani rarely move between seasons, and if simulated to be entirely sedentary, showed no difference in selection for vegetation heterogeneity (Figure 9.6). Maasai of southern Imbirikani occupy swamp margins – subdivided key resources that are highly heterogeneous, yielding large indices for their permanent settlements.

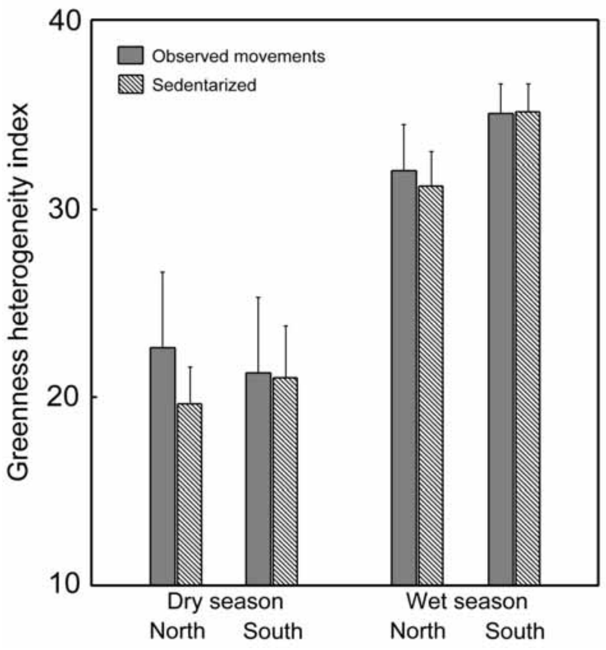

Figure 9.6. *Heterogeneity indices of areas grazed by Maasai herders (grey bars) in the wet and dry seasons in northern and southern Imbirikani Group Ranch, and indices if herders used only their permanent households (hatched bars). Northern Imbirikani residents selected heterogeneity differently in the dry seasons (N = 126 movements; P < 0.001) and the wet seasons (N = 89; P = 0.012). Heterogeneity indices were calculated from NDVI images, which reflect primary productivity, as cited in the legend of Figure 9.3*

SAVANNA / PHEWS *modelling*

In a theoretical setting emulating a semi-arid ecosystem, the SAVANNA model was adapted to include only cattle in a 300-km^2 landscape, and to disregard effects of water supply (Boone and Hobbs in press). Simulations were then run for each parcel with the block fragmented into two 150-km^2 parcels, three 100-km^2 parcels, ..., fifteen 20-km^2 parcels and thirty 10-km^2 parcels (Figure 9.7a). Fragmenting the system into 10-km^2 parcels caused a significant decline in the livestock population that could be supported across the entire block of land (Figure 9.7b); 19% fewer animals could be supported when entirely fragmented.

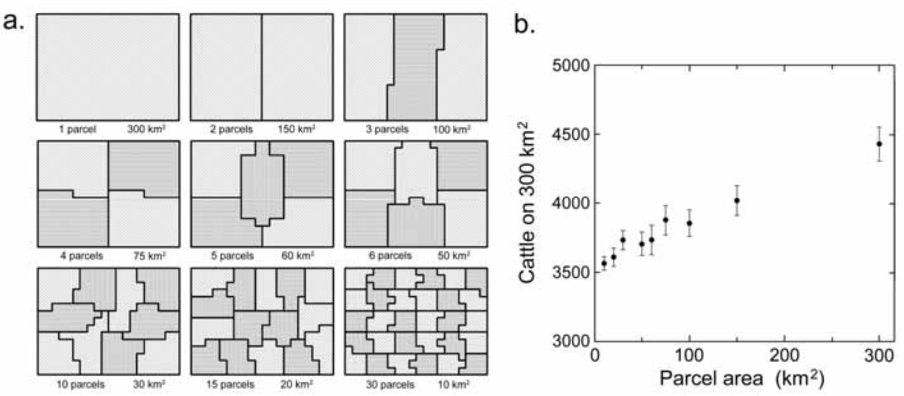

***Figure 9.7**. Parcels of different areas (a) were used in SAVANNA simulations in a hypothetical landscape. Cattle that could be supported over the entire 300 km^2 block over the long term (b) declined by 19% when fragmented to 10 km^2 parcels*

We may ask what the effect of subdivision into small parcels in Kajiado may be on livestock and human welfare, or alternatively, what level of external inputs will be required to maintain human welfare under subdivision. The joined SAVANNA/PHEWS model was adapted to southern Kajiado District, and included three livestock and eight wildlife populations (Boone et al. in review). Using replicated simulations, the effects of fragmentation on livestock and household welfare were quantified. For Eselengei Group Ranch, livestock populations for the entire ranch declined by 25% as the ranch was fragmented into 1-km^2 (250 ac) parcels (Figure 9.8) (Boone et al. in review). Incidental to boding poorly for Maasai food security, these results highlight the inappropriateness of assigning a 'carrying capacity' to an entire landscape, regardless of patch size. When simulated with PHEWS, effects of these losses on human welfare were extreme. As livestock holdings declined and food security lessened, Maasai sold animals to purchase grain, which further reduced food security and led to the sale of more animals. In analyses, Maasai households at their current density that were forced to graze their animals on 196-km^2 parcels in Eselengei Group Ranch could not persist without massive economic support from outside the system or dramatic changes in pastoral economic strategies.

Fragmenting the system into small parcels caused a significant decline in the livestock population that could be supported across the entire block of land

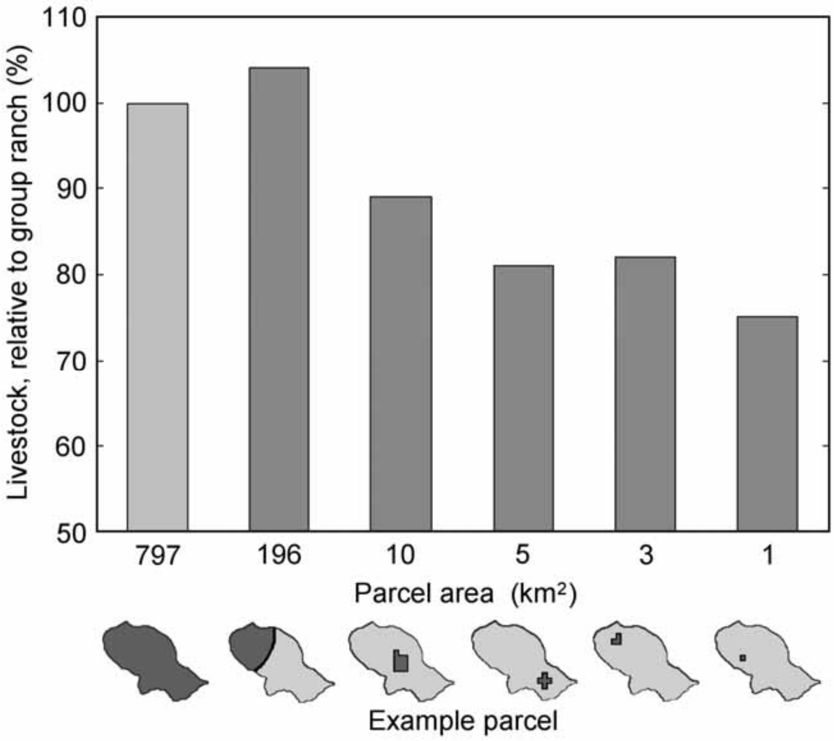

***Figure 9.8**. In a SAVANNA/PHEWS application to southern Kajiado District, livestock (in tropical livestock units: TLU = 250 kg) declined significantly as Eselengei Group Ranch was fragmented from its full area (797 km^2) to 1 km^2*

SYNTHESIS

Lane and Moorehead (1994, p. 123) put it plainly, that "settlement of nomadic pastoralists is the greatest single transformation of pastoralism as both a production system and a way of life". Sedentarisation has been pursued as a specific goal of policy reforms, a secondary outcome of governmental administration or neglect, and as a philanthropic goal of non-governmental organisations to ease the provisions of services (Niamir-Fuller and Turner 1999). But what was once a laudable goal and remains a frequent outcome of fragmentation is now discouraged, as one of the three hard-earned lessons Sandford (1994, p. 179, emphasis added) cites "My personal opinion is that we social scientists have not yet structured our views rigorously enough to have any clear message for policy makers and practitioners except that everything is very complex, that Hardin (1968) was wrong *and that livestock mobility is to be encouraged*". Dramatic examples of improved survival in herds that moved relative to sedentary herds have been reported (e.g., Scoones 1992; Kavoori

1999). We have cited negative effects of reduced mobility in three areas on three continents, quantified the positive effects of greater mobility in Maasailand, and provided modelling results that quantify losses under increasing fragmentation.

That said, the costs of moving livestock, especially for small herds, must be weighed against the benefits (Dyson-Hudson and Dyson-Hudson 1980; Schareika 2001; Kerven et al. 2003), and the benefits of other adaptations to fragmentation, such as changes in herd structures, production systems or intensification (e.g., Dahl and Hjort 1976; Swift 1977; Dyson-Hudson 1980). There are real costs associated with movement, such as transportation and labour costs, plus costs associated with the maintenance of complex social networks. Transhumant pastoralists cannot simply move about seeking the greenest pastures, irrespective of social constraints (Evans-Pritchard 1940; Stenning 1959). Areas may be set aside as grazing reserves, to provide late-season forage or to rest the vegetation. Beyond that, societal relationships can be very complex, changing throughout the season, affected by social norms, religious views and politics (Dyson-Hudson and Dyson-Hudson 1980; Lane and Moorehead 1994; Sylla 1994; Niamir-Fuller and Turner 1999; Turner 1999b), and the social networks to which pastoralists must appeal have sometimes themselves been fragmented, such as by emigration, diversification or disease (e.g., HIV/AIDS). Competition for land is high, especially for key resources and access points (Prins 1987b; Turner 2003) – indeed, some key resource areas are individually controlled and are no longer in competition, such as the fenced *bofedales* of the Aymara (Buttolph and Coppock 2001) or the riverine trees privately owned by Turkana families or controlled by well-armed rivals (Lind and Sheikh 2001; Mbogo 2003), a de facto privatisation. Areas used by livestock that are marginal for agriculture are now being converted to cultivation, and herds are in closer proximity to cultivated lands (Ottichilo et al. 2000b; Turner 2003). In regions such as West Africa, areas used seasonally by transhumant pastoralists are favoured for cultivation, because of the build-up of manure (Heasley and Delehanty 1996), although livestock make use of some cultivated lands (Kavoori 1999).

The importance of maintaining transhumant patterns has gained acceptance, but benefits gained from transhumance may be outweighed by changes in land tenure systems – private property and intensification as a foundation of investment and economic growth pervade economic policy (Stenning 1959; Oxby 1982) – and rapidly expanding human populations. The Aymara studied by Buttolph and Coppock (2001) had not emigrated to pursue non-pastoralist lifestyles, and the population was high, increasing rates of trespass. In Mongolia, even though livestock numbers had been fairly stable from 1950 to 1996, the numbers of livestock per person had dropped by two-thirds due to human population growth (Suttie 2000). Similarly, in the well-studied Maasai system of Ngorongoro (Kijazi et al. 1997; NCAA 2000; see Prins 1992), livestock biomass has been relatively stable for 40 years, but livestock-to-person ratios have declined dramatically (Figure 9.9), a pattern that is similar for Kenya (Ottichilo et al. 2000b) and much of semi-arid East Africa. Land subdivision within Kajiado District may be inevitable, given the value of subdivided land in securing loans and maintaining control of group ranch resources. We do, however, encourage those holding lands individually within group ranches to avoid fencing their properties, and retain open access.

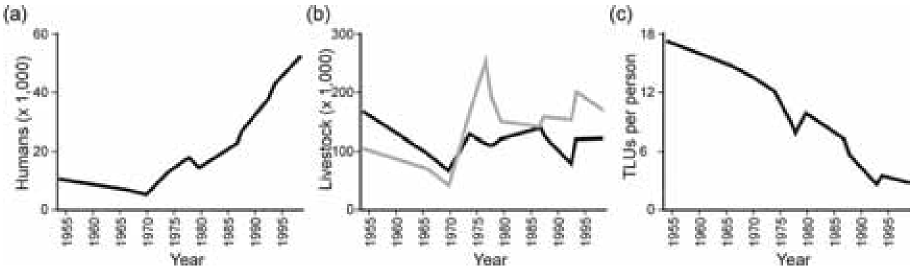

Figure 9.9. *(a) Human and (b) livestock (cattle – black line; small stock – grey line) populations in Ngorongoro Conservation Area, Tanzania. Livestock populations have been relatively constant (b), but increasing human population has led to a dramatic decline in Tropical Livestock Units (TLUs) per person (c), a unit of standardised livestock biomass, where cattle is 180 kg, goats and sheep 18 kg, and 1 TLU = 250 kg*

Pastoralists have successfully evolved methods of herding livestock to access adequate forage in areas of variable climate. Environmental, political, demographic and socioeconomic relationships are altering these long-term movement patterns, necessitating further adaptations or leading to insecurity, and spawning new research questions (Box 9.4). From local changes such as fencing of parcels to regional changes in climatic variability due to global climate change (Fowler and Hennessy 1995; Mason et al. 1999), pastoralists will have to adapt to new conditions. Calls for returns to historic patterns of transhumance are likely unrealistic because of human population growth and socioeconomic changes, and indeed may be detrimental to pastoral well-being – there are advantages to moving families shorter distances, such as access to hospitals and schools. That said, evidence to-date reflects well on mobility as a strategy allowing pastoralists to find new and creative ways to adapt to changing conditions, provided that political and socioeconomic restrictions on flexibility are not extreme.

Pastoralists have successfully evolved methods of herding livestock to access adequate forage in areas of variable climate

***Box 9.4.** Testable hypotheses for future research*

Many questions remain about livestock seasonal movements, and management and policies that apply to the resources the livestock use.

Hypothesis 1. Sedentarisation of families and reduced mobility of livestock herds will cause declines in livestock productivity, but these may be offset by external inputs. At some point, declining mobility in moderately productive areas will cause populations to collapse. The area available to herbivores at that point of collapse should be related to measures of vegetative heterogeneity, from simple counts of land-cover types to more complex heterogeneity indices. If heterogeneity is related to minimum viable herd sizes, it will have important implications for stakeholders and policy makers, as well as implications under global change.

Hypothesis 2. Theory and model simulations have demonstrated that key resource areas can influence the number of livestock an area can support to such a degree that livestock populations may not be related to primary productivity in areas outside key resources (Illius and O'Connor 1999, 2000). Such a response would emulate non-equilibrium dynamics relative to the region, but in reality would represent equilibrium dynamics relative to the key resource (Illius and O'Connor 2000; Cowling 2000), although others disagree (see Sullivan and Rohde 2002). The simulation results have not been demonstrated in reality. An assessment of the theory would be an important contribution to a continuing debate (Briske et al. 2003).

Hypothesis 3. As mobility is reduced for livestock and human populations increase, a research focus has been on diversification of pastoral people, as they cultivate, start small businesses and work as wage labour. Recent research results (BurnSilver unpublished data) suggest that for Kenya, although diversification is occurring, economic returns are variable, and intensification is a dominant change in the system – livestock continue to bring the vast majority of income to Kajiado Maasaii. The relative importance of intensification to diversification is not well known elsewhere.

ACKNOWLEDGMENTS

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