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Multiple Methods in the Study of Driving Forces of Land Use and Land Cover Change: A Case Study of SE Kajiado District, Kenya

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This landscape-scale study combines analysis of multitemporal satellite imagery spanning 30 years and information from field studies extending over 25 years to assess the extent and causes of land use and land cover change in the Loitokitok area, southeast Kajiado District, Kenya. Rain fed and irrigated agriculture, livestock herding, and wildlife and tourism have all experienced rapid change in their structure, extent, and interactions over the past 30 years in response to a variety of economic, cultural, political, institutional, and demographic processes. Land use patterns and processes are explored through a complementary application of interpretation of satellite imagery and case study analysis that explicitly addresses the local–national spatial scale over a time frame appropriate to the identification of fundamental causal processes. The results illustrate that this combination provides an effective basis for describing and explaining patterns of land use and land cover change and their root causes.

KEY WORDS: Kenya; land use change; patterns and processes; remote sensing; methodology.

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INTRODUCTION

Concern with the identification and remediation of processes contributing to global environmental change is widespread. A variety of environmental issues, often codified in international conventions, are the focus of contemporary scientific inquiry and of international and national policy. Land use and land cover change (LULCC), a central component of global environmental change with direct implications for the Earth's climate, ecology, and human societies, is of great concern to national and international policymakers. Policymakers seek from scientists information on the root causes of LULCC in order that policy may focus not on symptoms, but upon the fundamental processes that require remedial action. However, processes that drive LULCC are complex and require the use of multiple methods of analysis and critical interpretation of social data in order to understand the drivers and impacts of change through time and across spatial scales (Jiang, 2003; Nightingale, 2003; Rocheleau, 1995)

Kajiado District has experienced rapid and extensive land use and land cover change over the past 30 years in response to a variety of economic, cultural, political, institutional, and demographic processes (Campbell et al., 2000). This landscape-scale study employs a combination of analysis of multitemporal satellite imagery spanning 30 years and information from field studies extending over 25 years to assess the extent and causes of LULCC in the Loitokitok area, southeast Kajiado District, Kenya (Fig. 1). The study describes patterns of LULCC and examines the intersection of social driving forces creating this change. These driving forces are reflected in the transformation of farming and herding systems along the Mount Kilimanjaro ecological gradient. Political ecology is used as a conceptual approach to identify local and exogenous driving forces of change (Blaikie and Brookfield, 1987; Peet and Watts, 1996). They reflect ecological and societal conditions and the interactions between them over space and time (Campbell and Olson, 1991). Policy-making will continue to influence land use and have implications for the land users. Identification of past and ongoing patterns and processes can assist planners in coping with the uncertainty associated with planning for future developments in the area.

In addition, the study addresses methodological issues that have emerged in integrating different kinds of data on LULCC in analyses that seek to identify underlying driving forces of change. The discussion of methodology highlights the benefits and limits of integrating analyses of remotely sensed data and social science fieldwork. The study suggests that the use of multiple methods can contribute to the development of integrative assessments of the evolution of the driving forces of LULCC within the study area and the implications for different societal groups.

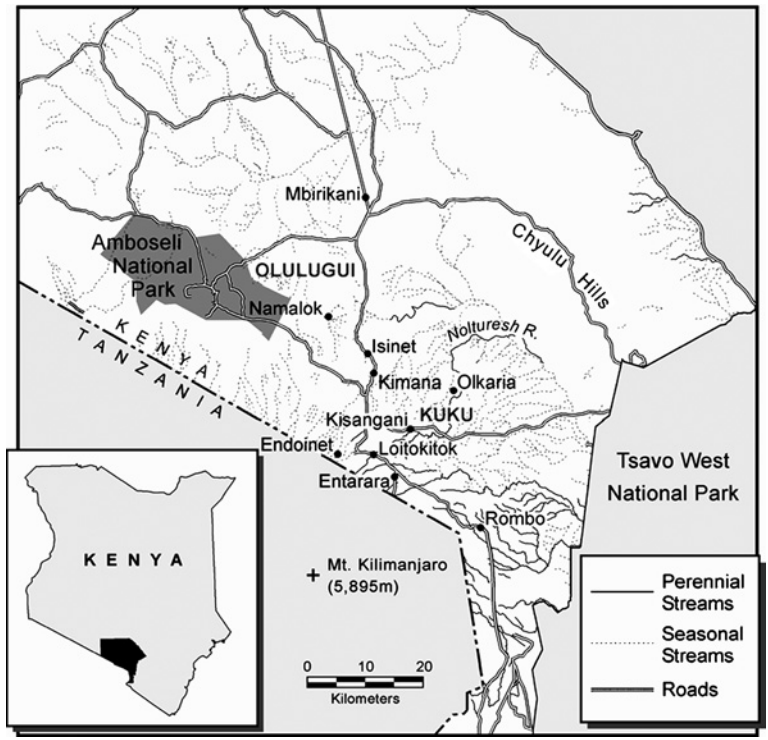

Fig. 1. The study area.

PEOPLE AND PIXELS: CRITICAL LINKAGES IN SOCIETY–ENVIRONMENT ANALYSIS

The science of global environmental change has expanded rapidly in the last two decades. Increased funding and greater availability of both social and environmental data have contributed to the proliferation of research on the dynamics of LULCC as an important component of the global change agenda (Turner *et al*., 1995). Given the overlapping interests of social and natural scientists in this area of research, new strategies for combining social and environmental data have emerged which include geographic information systems (GIS) and remotely sensed imagery in the analysis of questions of interest to social scientists (Fox *et al*., 2003; Guyer and Lambin, 1993; Homewood *et al*., 2001; Liverman *et al*., 1998; Rindfuss and Stern, 1998; Turner, 2003; Walsh and Crews-Meyer, 2002). Many such efforts have focused on the development of quantitative and conceptual models that seek to identify the driving forces of LULCC (Geoghegan *et al*., 2001).

Census and household survey data have been the most prevalent type of social data employed in this research (e.g., Stéphenne and Lambin, 2001). The objectives are twofold: 1) to identify the social and biophysical driving forces of LULCC in order to evaluate policies that address emerging environmental problems; and 2) to project future changes in land use and land cover under different political and economic scenarios (Turner *et al*., 1995).

Methodological and theoretical dilemmas often render the above objectives difficult to attain. A central issue that has created difficulties in integrating remote sensing and social science field research is the concept of interactions among processes acting at multiple scales. Scale issues come into play in several contexts. For example, the spatial resolution of remotely sensed data affects which land cover changes are recorded and analyzed. Within smallholder systems that characterize much of rural Africa, changes in land use and land cover with major impacts on the social system may be difficult to detect with the imaging systems most commonly used in LULCC research. Thus, recognition of the limitations of the changing patterns observed within remotely sensed datasets is crucial to contextualizing the interpretation of land use change within the study area.

A recent development in efforts to link social processes to LULCC is the use of spatially referenced household survey data. In addition to issues of research ethics and the confidentiality of human subjects (Rindfuss *et al*., 2003), the use of household survey variables as proxies for social processes unfolding in the study area presents important scale questions. First, the notion that social phenomena and environmental change find an explicitly spatial expression within the landscape may be problematic for a number of reasons. Where common property resources exist, identification of the spatial correspondence between household characteristics and land use decision making may be problematic (e.g., BurnSilver *et al*., 2003). Furthermore, processes that affect household land use decision making are driven by both internal and external forces, which cannot be discerned from household-level data. Therefore, it is appropriate to consider the context of changes in household socioeconomic characteristics and activities as a means of understanding the effectiveness of household-level variables as surrogates of LULCC processes. This requires a broader investigation into the changing social dynamics of resource use within the study area that encompasses the interaction of various groups in society who are differentiated by gender, ethnicity, wealth, and power. The role of power within households, communities, regions, and countries is often central to understanding patterns of LULCC, unexpected outcomes, and the local framing of environmental problems and their social impacts (Rocheleau, 2001; Taylor, 1997).

Although cultural, political, and socioeconomic forces may not lend themselves easily to quantification and use in modeling frameworks, it is

nonetheless essential to interpret survey data and modeling results in the broader context of the complexity of human–environment relations in the study area. Such interpretations should be sensitive both to national and international political economy and local differentiation. While the implications of environmental changes are often discussed in terms of global and regional consequences, there is growing recognition that many of the critical causes arise from interactions between societal and biophysical processes at the local level (Geist and Lambin, 2002; Lambin *et al*., 2001; Rocheleau, 2001; Rocheleau *et al*., 1996; Schroeder, 1993; Smucker, 2003; Turner, 1999).

In short, the driving forces of land use and land cover change are many-faceted. They may change in relative influence over time, and their impact will vary as the local context changes. Analysis of LULCC at multiple scales demands conceptual frameworks and analytical methods that are both comprehensive enough to capture the dynamics of society–environment interactions at different scales, and flexible enough to accommodate the temporal dynamics of these processes (Campbell, 1998; Ewel, 2001; Kinzig, 2001). It is essential that analyses of LULCC processes be carried out in reference to the complexity of the human-environment systems within the study area. As such, without dismissing the utility of spatially referenced data to specific research questions, we suggest an approach that provides "socially referenced" interpretations of various kinds of data that assist in characterizing LULCC processes and their underlying driving forces. Such socially referenced interpretations would be concerned with the local and regional mediation of environmental change via cultural, political, and economic relationships.

Evaluating the driving forces of change and projecting future changes requires a commitment to methodological pluralism and critical interpretation of social and environmental data (Norgaard, 1989). While remotely sensed imagery provides information on the patterns of land cover change, understanding the underlying causes of change requires a critical interpretation of different kinds of field data and an awareness of social differentiation within the study area. Furthermore, in considering changes in driving forces through time, categories central to the analysis may change in meaning and significance. Multiple field methods can be used to both confirm interpretations, delineate the way in which such categories have changed, and identify the impacts on land use decision making. The decisions that lie behind the actions that create environmental problems are influenced by a wide variety of interrelated factors that emanate from both local and external circumstances, cross boundaries between societal and environmental systems, and are driven by the exercise of power in the interests of particular objectives (Campbell and Olson, 1991). An assessment of the role of

political and economic power, as manifested in land use and tenure policies and the evolution of access to the resources essential to local livelihood systems, is central to developing a more nuanced understanding of linkages between standard categories of driving forces and outcomes as observed in patterns of land use and land cover change.

METHODS

The strengths of triangulation through the use of multiple research methods are well established in case study research methodology (Yin, 2003). This study employs a variety of methods to describe changes in land use and land cover patterns and to identify the driving forces of these changes. Pattern and process are explored through a complementary application of satellite imagery interpretation and case study analysis that explicitly addresses the local–national spatial scale over a time frame appropriate to the identification of fundamental causal processes. The results illustrate that a combination of imagery analysis and detailed field study can provide an effective basis for describing and explaining patterns of LULCC cover change and their root causes.

Interpretation of Remotely Sensed Imagery

In order to cover the maximum time span and in light of the difficulty of obtaining cloud-free imagery in the study area, three different image types were obtained for this study. For 1973 (December 20) and 1984 (December 17), Landsat MSS images (80 meter pixels) were used. On February 7, 1994, the study area was imaged by SPOT; the resulting 20m, multispectral scene was interpreted. The Landsat 7 ETM+ sensor imaged the study area on January 29, 2000 (path 167) and again on February 21, 2000 (path 168), providing 30m multispectral imagery of the entire study area. Once all four dates of imagery were interpreted, their boundaries were simultaneously displayed on the higher-resolution 1994 and 2000 images to reconcile the small, splinter polygons that were formed. Where the image evidence supported it, the arcs creating these problem areas were made coincident. After all the arc segments were edited using this process, they were exported as arc coverages, combined with the Kenya-Tanzania border coverage, and cleaned and built into a polygon coverage in ArcInfo. The polygon attribute table created by the build process listed polygon area as one of its fields. This table was edited to isolate the various land use–year combinations and the areas of the three land cover categories were tabulated. Air reconnaissance in 1996, documented with oblique color slides, and a field

visit in 2001 that focused upon locations where imagery interpretation was proving difficult, assisted in the delimitation of the land cover categories. Land cover categories were identified and mapped for each image. Land cover change was mapped for 1973–1984, 1984–1994, and 1994–2000.

Household Surveys

Household surveys were conducted in 1977 and 1996 using the same sampling methodology and similar questionnaire. The 1977 survey interviewed 225 farmers and 166 herders and that of 1996 involved 332 farmers and 227 herders. The surveys were conducted along ecological transects that descended from the Tanzania border into the semiarid rangelands. Four transects were surveyed—from Endoinet to Namalok, from Loitokitok to Kimana, from Isinet to Imbirikani, and from Entarara to Kuku (Fig. 1). Interviews were also conducted in Rombo. The sampling along the transects was stratified by major land uses to include rain fed agriculture, irrigated lands, and rangeland areas. The information has permitted comparison of responses between the surveys on a number of issues, including perceptions of agricultural conditions, household responses to drought (Campbell, 1999a), competition over access to resources between farmers and herders (Campbell *et al.*, 2000), and human-wildlife interactions (Campbell *et al.*, 2003a). An overview of the survey results is provided by Campbell *et al.* (2003c).

Community Workshops

Subsequent to initial analysis of the survey data, meetings were held in the communities where the surveys had been conducted to present and discuss results of the household surveys and to assess interpretations. The workshops held in 1978 are reported in Campbell (1984a, 1987). To ensure a balanced coverage of farmers and herders, in 1996 workshops were held in six market centers Rombo, Illasit, Kisanjani, Isinet, Namalok, and Imbirikani). The results of the 1996 workshops and an assessment of the community dynamics that influenced the results of the workshops are reported in Smucker *et al.* (2004). The survey team presented the principal findings specific to each area and also stated the major problem identified in each area. The workshop participants were then asked the following questions: (i) Is this the problem? (ii) What are the causes? and (iii) What can we do about it? There was lively and pointed discussion at each of the workshops. The issues raised by the research findings were discussed critically

and this contributed to a more focused interpretation of the information from the survey.

Key Informant Interviews

Interviews with individuals who have particular knowledge of various dimensions of land use change issues in the study area provided additional information, particularly about the impact of external forces. Such key informants included chiefs, representatives of non-governmental organizations (NGOs), government officials, and others.

LAND USE, DEMOGRAPHIC CHANGE, AND DEVELOPMENT POLICY 1973–2000

Background

The study area has a bimodal rainfall regime, with peaks from March to May and October to December. Lower elevations between Amboseli National Park and the Chyulu Hills receive less than 500 mm and higher rainfall occurs on the Chyulu Hills and on the slopes of Mt. Kilimanjaro (Jaetzhold and Schmidt, 1983). The rainfall is however irregular in time and space and drought is a recurrent problem in the area. During the twentieth century droughts were recorded in 1933–35, 1943–46, 1948–49, 1952–53, 1960–61, 1972–76, 1983–84, the early 1990s, and 2000. The soils on the hills are derived from volcanic rocks, those at lower elevations from the basement complex, while along rivers and swamps there are alluvial soils.

Agricultural potential is highest on the slopes of Mt. Kilimanjaro due to reliable rainfall and fertile volcanic soils. The savanna lowlands are of relatively low productivity and their dominant land uses are livestock herding and wildlife. Within the lowlands are relatively small, localized areas that, due to the existence of permanent water and fertile soil, are potentially more productive than the surrounding savanna. These include the swamps at Namelok, Isinet, and Kimana, and the valleys of the perennial streams that originate on Mt. Kilimanjaro, such as at Rombo.

Prior to the arrival of the British at the end of the nineteenth century, the Maasai were the dominant group in the area, and they tolerated the presence of a large and diverse wildlife population. The Maasai were mostly transhumant pastoralists whose livelihood was based upon the herding of cattle, sheep, and goats. These animals formed the basis of their social and economic system, and their primary goal was to maintain sufficient livestock in the face of an unpredictable physical environment in which periodic drought and disease jeopardized their survival. Maasai grazing patterns

reflected the seasonal and annual variations in the availability of water and grazing. During the wet season the herds dispersed as resources were abundant and widespread, but during the dry season they congregated where reliable supplies of water and grazing existed on the slopes of hills and around the swamps. The land was communally owned, while the livestock belonged to individual families (Spear and Waller, 1993).

While the area around Loitokitok is one of recent agricultural settlement, some Maasai groups have been farming in Kenya and Tanzania since the nineteenth century. Spear (1993, p. 131–32) identifies long-established areas of Maasai farming, oases in the savanna plains, including the Arusha on Mt. Meru in Tanzania, a Maasai society (Spear, 1993, pp. 122 ff), and at Taveta to the east of Mt. Kilimanjaro where a number of groups including Maasai had farmed and provisioned trading caravans originating in Mombasa. The northern slopes of Mt Kilimanjaro around Loitokitok were not cultivated at this time. The caravan routes ran from Mombasa to Taveta and along the south side of the mountain, so generated no demand for agricultural products on the northern slopes. These slopes were however important as dry-season and drought-retreat areas for Maasai herders.

Treaties between the Maasai and the British colonial administration in 1911 and 1912 established the Masai Reserve that restricted the Maasai to the southernmost of their former grazing lands and deprived them of some of their most important dry-season and drough-retreat areas (Great Britain, 1934; Huxley, 1935; Low, 1963). These losses were compounded as alienation of land for European settlement affected farmers in adjacent areas (Kitching, 1980), and the consequent land shortage led many to look for land to cultivate elsewhere, such as the better-watered locations in neighboring dry lands, including the slopes of Mt. Kilimanjaro. Later, the National Parks Ordinance of 1945 led to the establishment of national parks and reserves that formerly provided water and dry season pasture for the Maasai livestock.

Population growth in Kajiado District has been rapid since Independence (Table I). In the Loitokitok area it reflects natural increase as well as migration of large numbers from the congested central highlands of Kenya to farm the slopes of Mt. Kilimanjaro and other hills. The dominant livelihoods are herding and farming. In recent years many herders have begun to farm, both under rain-fed conditions on the mountain slopes, and in the plains where horticultural production has expanded around swamps and along perennial streams (Krugmann, 1996). Wildlife-based tourism, however, is the most important activity in terms of the national economy.

Since Independence in 1963, national policy has contributed to the diversification of the area's economy to include farming and wildlife-based tourism alongside herding. Land adjudication in Maasai areas ostensibly

Table I. The Population of Kajiado District 1969–1999

	Kajiado District			Kenya
Census year	Population	Inter-census growth (%)	Avg. annual growth (%)	Avg. annual growth (%)
1969	85,093*			
1979	149,005*	75.1	5.76	3.8
1989	258,659*	73.6	5.67	3.4
1999	405,000**	56.6	4.58	2.9

* Kenya, Central Bureau of Statistics, Population Census 1969, 1979, 1989.
**Ministry of Finance and Planning, February 2000. Provisional Results of the 1999 Population and Housing Census.

designed to reduce land degradation has been an important policy instrument. High potential land on the mountain slopes was allocated to prominent individuals as Individual Ranches (IR), and most were quickly subdivided and sold to immigrant farmers. The majority of the Maasai remained in the savanna lowlands where Group Ranches (GRs) were created that were based on traditional grazing areas and boundaries drawn to enclose sufficient wet and dry season water and grazing resources (Table II). While the ranches have met peoples' needs in years of good rainfall, in bad years movement beyond the ranch boundaries remains necessary (Campbell, 1999a).

The Maasai accepted the concept of GRs, not to improve resource management and economic conditions, but because they viewed legal title to the land as a means of securing their land from encroachment by immigrant farmers. This objective has proved elusive. In the Loitokitok area farming began in the 1930s with the establishment of a District Office. The administration employed staff who came from farming areas elsewhere in Kenya, and who began to cultivate. The numbers were few and the cropped area was limited. The extensive rain-fed cultivation present today

Table II. Group Ranches in the Study Area

Ranch	Date incorporated*	Area (HA)*	Number of parcels*	Number of members 1987***	Number of members 1999**	Number of members 2001***
Mbirikani	1981	122,893	922	922	4650	4585
Kimana/ Tikondo	1972	25,120	169	167	843	843
Lolarashi/ Olgulului	1975	147,050	1380	1300	4000	3418
Kuku 'A'	1984	48,600	NA	1400	A+B	1996
and 'B'	1975	96,000	604	417	4401	5516
Rombo	1973	38,365	512	366	3565	3665

Sources: *Ole Katampoi *et al*., 1992. **Mbogoh *et al*., 1999. *** Ntiati, P., 2002.

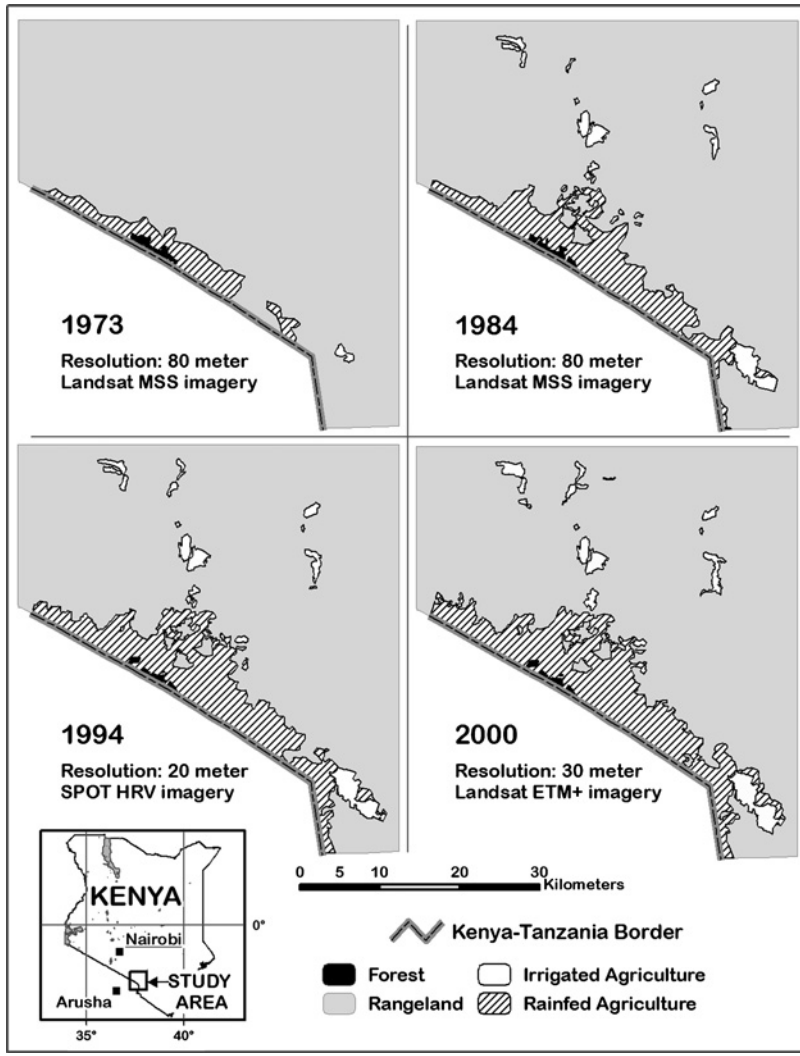

Fig. 2. Patterns of land use change in southeast Kajiado District, Kenya, 1973–2000.

originated in the 1970s with the demarcation, and subsequent subdivision, of IRs on the mountain slope. Irrigated agriculture also began in the 1970s along streams at Rombo and Kimana. Some farmers were Maasai who, as in other areas, married women from farming groups. Additional migrants were relatives invited by these wives. Once the land market developed many migrated from areas of Kenya where land was in short supply.

Table III. Changes in Area of Major Land Use Categories

		Area in Hectares (Ha)			
ID	Land use	1973	1984	1994	2000
1	Forest	646.34	595.88	416.69	416.69
2	Irrigated Agriculture	245.17	3,512.48	4,043.39	4,766.18
3	Rainfed Agriculture	7,211.47	17,762.31	22,032.66	24,911.04
4	Rangeland	160,846.76	147,094.63	142,473.97	138,871.08

The changes in land use that were initiated in colonial times, and which have continued since Independence, resulted in the Maasai herders losing access to vital water and grazing resources, in an expansion of the area under crops, and in changes in wildlife both gaining access to resources due to the creation of national parks and losing such access as cultivation has encroached on the areas where they found water and vegetation. More recent patterns of land use change and their driving forces are discussed in the following sections.

Land Use Change Patterns and Processes: 1973–1984

Between the mid-1970s and mid-1980s, the processes encouraged by government policy on agriculture and land tenure, and readily bought into by farmers and herders, accelerated. These external drivers combined with local ones to contribute to a transformation in the land use on the northern, lower slopes of Mt. Kilimanjaro. These slopes receive over 800 mm of rainfall annually and a number of perennial streams flow down them to the plains. They offered, therefore, considerable opportunities for cultivation and by the mid-1980s almost the entire area between the Tanzania border and the semiarid plains had been cleared and planted by immigrant farmers, mostly from Central and Eastern Provinces, and by Maasai themselves.

The primary change in land use and land cover was the expansion of irrigated and rain fed agriculture into rangelands comprised of Acacia woodland near the mountain and bushland and grassland savanna at lower elevations (Fig. 2; Table III). Land adjacent to permanent water sources, e.g., along rivers at Kimana and Rombo, and around the swamps at Namalok and Isinet, had been cleared for cultivation. This expansion of agriculture was supported in government plans, and as opportunities expanded for grain production on the mountain slopes and vegetable production for export around swamps, agriculture attracted the attention of land speculators and business people. The impact was to reduce the availability

to herders of the most reliable of their water resources. The general pattern of agricultural expansion between 1973 and 1984 (Fig. 2) matches the distribution of rainfall that follows a concentric pattern conforming to the slopes of Mt. Kilimanjaro (Jaetzhold and Schmidt, 1983). An uneven expansion extended farther down slope around the district headquarters town of Loitokitok and along the main road from the town to Nairobi.

This expansion of agricultural activity coincided with a sustained increase in the population of Maasai herders, with the implication that more livestock were needed at a time when resource availability was declining. From the perspective of the Maasai herders, the change in land use to farming from herding in these better-watered locations added to the losses incurred when Tsavo and later Amboseli National Parks were established. The drought of 1972–76 revealed the impact of these changes in land use on the herding system (Campbell, 1984b), though concern among herders with the loss of access to the resources on the mountain slopes was balanced by the importance of crops in offsetting the losses of livestock during the drought. Some herders began to cultivate plots on the GRs and, by the mid-1970s there was widespread discussion over subdivision of GRs to accede to demands for individual land ownership from the growing population, and particularly from younger Maasai who had not been registered as GR members (Campbell, 1986, 1993; Galaty, 1994; Kimani and Picard, 1998; Ntiati, 2002; Rutten, 1992).

The change in land use patterns also had an impact on the area's wildlife-based tourist activities. Tourism is among the leading three earners of foreign exchange in Kenya. The study area plays a central role in the wildlife-yiewing sector of tourism. Tourists come to look at the wildlife, particularly the elephants, in Amboseli National Park, view Mt. Kilimanjaro, and visit Maasai communities. The cultivation of mountain slopes and around swamps reduced the access of wildlife to browse and water resources, fragmented habitats and altered seasonal dispersal patterns. In the process, damage to crops by wildlife has increased (Campbell *et al*., 2000).

The issue of competition or complementarity between, herding, farming, and wildlife tourism is complicated and politically sensitive. Since the 1970s, wildlife managers have attempted to develop and implement strategies that would encourage people living adjacent to wildlife parks to accept the costs, and benefits, associated with the parks and the wildlife. A major strategy has been to return some of the revenues from wildlife-viewing activities to the adjacent landowners as compensation for the losses they incurred due to wildlife grazing and damage to crops during their wet season dispersal (Emerton, 1999; Lusigi, 1981; Norton-Griffiths, 1996; Norton-Griffiths and Southey, 1995; Western, 1976, 1982, 1994). These strategies have not been effective in reducing people's concern about wildlife damage

and have not therefore provided the political benefits of greater popular support for wildlife conservation policies (Campbell *et al*., 2003a).

Land Use Change Patterns and Processes: 1984–1994, 1994–2000

Since the mid-1980s, the pattern of expansion of the area under rain-fed agriculture on the slopes of Mt. Kilimanjaro has altered from down-slope expansion to that of intensification of land use in, and infilling of, areas at the edges of established rain-fed cultivation. However, expansion of irrigation around swamps and along rivers has continued (Fig. 2; Table III) largely because of increased opportunities for commercial horticulture arising from market liberalization, abandonment of controls on currency exchange, and improved transportation linkages, including those to European markets using commercial aircraft.

The change in distribution of land use, particularly the expansion of cultivation around the critical water sources, has resulted in many Maasai herders taking up cultivation. While 20 years ago the majority of Maasai were herders, and most farmers were immigrants to the area, a more complex pattern has emerged. Calls for subdivision of group ranches have gained momentum as significant numbers of Maasai have informally claimed well-watered land on the GRs and leased it to farmers (Ntiati, 2002). This has led to disagreement among GR members and to more frequent disputes between farmers and herders, whose animals frequently damage crops.

Further, many Maasai have taken up cultivation and are herder-farmers. They have diversified their economy thus providing flexibility that is important in mitigating drought (Campbell, 1999a). Their success is illustrated by their having herds of comparable size, if not larger, to those of the herders who continue to occupy the rangelands. The latter have fared less well due to the loss of critical dry-season water sources. At the same time, many farmers around swamps and rivers have also accumulated livestock. Thus, the Maasai are no longer dominant ethnically, herding is being replaced by mixed livestock-cropping enterprises, and the better-watered margins of the rangelands are extensively cultivated (Campbell *et al*., 2000).

This increased agricultural activity among herders is reflected in the expansion of cultivation between 1994 and 2000 (Fig. 2) in areas that had hitherto remained as grazing land, for example to the west of Loitokitok. The reasons for the relative delay in these areas being brought under cultivation could not be inferred from the imagery, but were clarified by field interviews. These revealed that there were no edaphic constraints to cultivation in these areas and that the delay was caused by the decisions of individual landowners to maintain them under grazing until very recently.

There are additional areas where cultivation is taking place but the impact on land cover is insufficient to be readily visible in the imagery. These include 'expeditionary' activities on the lowest slopes of the mountain and to the north of the irrigated area at Rombo. The rainfall in these locations is highly variable and in many, if not most years, is insufficient for a harvest. Such fields are scattered in the rangeland and do not establish a distinct land cover pattern. Field reports also indicated the beginnings of cultivation at swamps near the Chyulu Hills, but their extent is insufficient to be apparent in the 2000 imagery of the area.

These findings illustrate the importance of combining field study and satellite imagery analysis. Field verification was needed to explain anomalies in general patterns of LULCC, it was useful in identifying where future changes might be observed, and it was necessary to describe land use changes that were not revealed in the patterns observed in the imagery. These included intensification of cropping activities in established areas of cultivation such as that occurring in those areas on the slopes of Mt. Kilimanjaro that were brought under crops prior to 1984, and the impact on rangeland vegetation of reduced grazing pressure implied by the change in the herding economy from livestock-dominant to one that is more mixed herding/farming, and more sedentary.

The imagery also did not easily reveal implications for wildlife of the altered cropping and herding systems. Field study established that the patterns of expansion of cultivation shown in the imagery are associated with fragmented habitats and disrupted wildlife movements, reduced access to water in riparian zones, and altered livestock grazing patterns. These have also affected the distribution of vegetation and opportunities for predation. Competition and disputes have increased over access to reliable water between wildlife managers, livestock herders, and farmers (Campbell *et al.*, 2000, Compbell *et al.*, 2003a).

The Drivers of Land Use Change

The preceding discussion has illustrated the complexity of local and exogenous forces that have been driving the land use changes that were clearly illustrated by the imagery (Campbell *et al.*, 2003b). The drivers that have altered over time in importance and intensity from the colonial period to the present are illustrated in Table IV. Wildlife and Maasai herding dominated the precolonial land use of the study area. During the colonial period and since Independence, a number of processes were set in motion that had immediate and cumulative impacts upon society and resource use. The Maasai land use system was altered by excision of vital dry-season

Table IV. Societal and Biophysical Drivers of Land Use Change in the Study Area

ECONOMIC DRIVING FORCES

International

Market forces.

Trade policy and agreements.

Structural Adjustment; resumption/suspension of aid.

National

Economic policy – Agricultural pricing, transport, exchange rates.

Land use policy – Coherent land use plan often lacking. Individual sectoral bureaucracies implement strategies in uncoordinated manner & with perhaps conflicting goals.

Land tenure policy – explicit and perceptual.

Land tenure laws

Customary tenure: continuity and change; National *land ethos* often based on ethnicity,roots in colonial land alienation and post-independence land acquisition by political class.

Dynamics of primary production

Modified subsistence – dynamics of cropping and livestock systems.

Structural Adjustment Programs (SAP) and economic liberalization.

Exports: meat, vegetables, flower growing.

Cash crops–chemical pollution of water.

Irrigation policy–chemical pollution, salinization.

Urbanization–urban demand for meat and vegetables encourages commercial production, pollution of air and water.

Local

Markets.

Herding-diversifying to include agriculture at perennial water sites (swamp edges; streams; mountain slopes).

Rain fed agriculture–immigration, intensification/extensification.

INSTITUTIONAL/POLICY DRIVING FORCES

International

International Conventions: Biodiversity, Climate Change etc.

Bilateral and multilateral governmental and commercial interests; NGOs.

Warfare, political instability, refugees.

National

Centralization versus decentralization.

Uncoordinated policy framework – no land use planning.

Land tenure policy.

Political & economic power: Intersecting interests of government policy, commercial institutions, NGOs, and individuals.

Structural Adjustment Programs and economic liberalization.

Contraction of government input provision, extension, & marketing infrastructure.

Local

Land tenure – communal versus individual rights to land, trees & water.

Social differentiation in land rights – gender, young/old, tenants& squatters.

Informal land claims: tenants/renters/squatters claim land rights.

Local NGOs.

BIOPHYSICAL FACTORS

Rainfall

Variability of rainfall: long-term, inter-annual, seasonal, within growing season.

Surface Water

Swamp margins/riparian zones/hillsides-occupied & crops vulnerable to damage by livestock and wildlife.

Irrigated agriculture-market demand, wholesalers.
Economic differentiation–options in land, labor and capital.

SOCIAL/CULTURAL DRIVING FORCES
National
Urbanization.

Immigration.
Leadership–past interference from influential men.
Local
Population dynamics: growth, migration (gender and age specific), decline (AIDS)–intensification/extensification; maintenance of erosion control measures, cropping patterns, health & food security.
Diversification of herders into agriculture changes mobility & settlement patterns. Altered vegetation complex under reduced grazing pressure in rangelands; removal of riparian & swamp-edge vegetation for cultivation.
Cultural change - leadership issues debated (age, gender). emigration.
Violence in inter-ethnic conflict situations in all areas with heterogeneous populations–disruption of production,
Ethnic heterogeneity - ethnic self-identification changing, particularly in farming areas.
Less trust in and recourse to traditional institutions. Disputes formerly settled by discussion; now more recourse to chiefs, police, courts and violence.
Redefinition of cultural and economic categories–e.g. herders become herder-farmers; farmers become farmer-herders; changes in gender roles and divisions of labor.

Water quality–chemical pollution of water in irrigated areas–implications for the health of people, livestock and wildlife.

Water quantity–irrigation water in reduced supply.
Access to water more difficult for domestic use, agriculture, livestock & wildlife.

Change in hydrological cycle.
Land Cover and Soils
Vegetation–dry savanna on plains, riparian forest, gradient on Mt. Kilimanjaro.
Soils
Fertility decline–evidence of land being taken out of production; enforced fallow.
Management–stall fed cattle–application of manure; chemical fertilizer.
Soil erosion–increased runoff, siltation, wind erosion- dust.
Woodland–change in species mix, change in spatial pattern–biodiversity of flora; potential for trees to replace grasses under less extensive grazing.

Habitat depletion and fragmentation–biodiversity and distribution of fauna.

Source: After Campbell, 1999b.

resources to protect wildlife, and cultivation has been promoted in other such areas. While limited in area, these permanent sources of water and grazing were essential to the much more extensive land use systems of herding and wildlife.

The altered accessibility and use of these vital water sources has resulted in competition between the major land use systems that can be explored through the interrelated impact of local drivers, each of which is associated with both local and external processes—wildlife conservation, population growth, and economic opportunity in agriculture. Local circumstances were altered as colonial restrictions on ethnic distributions were removed, and as the economy responded to national and international opportunities after independence. National policies on economic issues, agricultural strategies, wildlife management, and land tenure reform have all influenced the pattern of LULCC.

In the contemporary setting, it is the ongoing process of subdivision of the GRs that has the most significant implications for future land use and LULCC (Ntiati, 2002). It has resulted in a political debate with economic, environmental, and social implications at both the local and national levels. The motivation for subdivision came from the sons of original GR members. By the mid-1970s many found themselves owners of livestock, but without legal rights to the land on which to graze them (Campbell, 1993). Nearly all GR committees in the district were forced to consider the issue, and politicians and administrators joined the debate in support of subdivision. The government welcomed subdivision and in 1981 enacted a policy to promote it.

Anticipating subdivision, many group ranch members have claimed land that has access to water—the vital resource areas for all land users. Some rent to immigrant farmers, some hire seasonal labor, and others have taken up cultivation. The diversification of the herding economy to include farming is thus related not only to a need to increase flexibility to mitigate climatic risk, or to take advantage of the recently developed trade in vegetable production for urban markets and for export, but also to the process of transformation of land tenure from "communal" to individual title.

Awareness of the economic potential of the rangelands has altered national-level approaches to development in the area. National policy is no longer merely seeking to resolve the problems of population pressure or overgrazing in Kajiado District. The recognition that areas that have been consistently characterized as "marginal" have substantial economic potential has contributed to the stimulus to subdivide the GRs. The majority of Maasai will obtain too little land to practice a viable livelihood based primarily on livestock herding and may be forced to sell the land

they are allocated. In addition, there is concern that with the break up of the GRs, land may be fenced accentuating the existing disruption of the seasonal movements of wildlife, and their access to water and grazing.

The discussion of the linkages between drivers of change illustrates that they are responsive to the development context. Some have effects over the long-term, such as population growth and immigration, though these may in future reflect the impact of HIV/AIDS. Others are strongly influenced by external events and policy changes. Examples include the growth of horticulture facilitated by improved transportation, market liberalization and removal of currency controls, and the uncertainty in the tourist industry reflecting political conditions in Kenya, civil unrest in Africa, and the fluctuations in the international economy influencing tourist travel. It is possible to anticipate the impact of established trends, such as human population growth, and to examine implications of processes based on past experience, such as the environmental implications of irrigation. However, political and economic events, such as changes in government, devaluation of currency, and building of infrastructure, are by definition unpredictable.

This brief discussion of the driving forces of change highlights some of the most important among those portrayed in Table IV and elaborated in Campbell *et al.* (2003b), and illustrates the complexity of interactions among and between societal and biophysical systems across scales and over time, and their importance to understanding the processes that contribute to the dynamics of LULCC. A number of conceptual frameworks are now available that can guide researchers as they seek explanation of the driving forces of LULCC including political ecology (Blaikie and Brookfield, 1987; Zimmerer, 1994; 2000), landscape ecology (Farina, 1993;Wu and Hobbs, 2002), and other approaches to issues of complexity (Gunderson and Holling, 2001; Kinzig, 2001).

MULTIPLE METHODS IN THE ANALYSIS OF LAND USE CHANGE PROCESSES THROUGH TIME

A growing literature provides description of changing patterns of land cover at the landscape scale (Petit *et al*., 2001; Serneels *et al*., 2001). Relatively few studies have sought to combine analysis of multitemporal satellite imagery with longitudinal information on the drivers of land cover change at the landscape scale. Such analyses are important because they enable an understanding of the underlying processes that transform land use practices and create new trajectories of land cover change.

Complementary Use of Remotely Sensed and Field Data

This study has used analysis of satellite imagery to describe the pattern of land cover change between 1973 and 2000 at the landscape scale in southeast Kenya. These changes have been interpreted in terms of broad land use categories based upon information from detailed field surveys conducted in 1977 and 1996, and additional reconnaissance visits to the field between and since the detailed surveys. The surveys also facilitated the identification of the local drivers of these changes and the impact upon them of exogenous national and international forces.

The patterns of land cover change revealed by the imagery provide little information on the drivers of change, but they enable the investigators to better assess the findings of the results of the field surveys. For example, the period between 1977 and 1996 was not one of continuous and constant change. Rather the pace and direction of expansion of agriculture varied over time. The most rapid conversion of rangeland to cultivation on the slopes of Mt. Kilimanjaro, and the expansion of irrigation along rivers and around swamps, occurred between 1973 and 1984. After 1984 the areas of both rain-fed and irrigated agriculture continued to increase, but at a less rapid pace.

The findings of the 1977 household survey identified many of the fundamental driving forces behind the land use changes occurring at that time. However, in terms of future scenarios, those findings were shown by the imagery analysis and the 1996 survey to have had varying success in anticipating future outcomes. In general terms, the respondents to the 1977 study expected expansion of rain-fed agriculture on the mountain slope but there was little sense that it would extend down slope where the rains were variable in amount and duration. Irrigation was at first seen as experimental and of uncertain economic viability. There was little expectation among those interviewed in 1977 that this would become a significant activity as the streams and swamps were considered essential to the herding economy. While general patterns of change were anticipated by respondents, details of these patterns were foreseeable, as the subsequent field studies demonstrated the importance of individual decisions in remaining land use practices on specific areas.

The 1977 study did not indicate potential for either the growth of tourism-related activities outside the parks or the intensification of cultivation activity on the mountain, and the anticipated establishment of livestock-based industries did not occur. These outcomes would not have been indicated by significant changes in patterns of land cover and thus imagery analysis would not have informed the 1996 survey. In some cases, however, the availability of the results of the imagery analysis would have

illustrated LULCC that could then have been better investigated in terms of causes and implications in the 1996 field survey. The extent and pattern of expansion of rain-fed and irrigated agriculture is an important case in point. Had the analysis of patterns of change up to 1994 been available, the research team could have focused more explicitly on a number of the 'unpredicted' patterns including the uneven extent of cultivation down the slope of the mountain, irrigation far from the road network along the Nolturesh River, and the extent of irrigation at Rombo and Isinet.

Similarly, for the research reported in this study, prior analysis of landscape patterns could have contributed to the definition of pattern-related questions to be addressed in the 1996 survey. However, analysis of imagery cannot reveal the complexity of driving forces that contribute to land use decisions. These include social and cultural, economic, and institutional processes together with the responses of people to changes in the availability of land and in the biophysical environment (Table IV).

The 1977 study was able to identify a variety of sociocultural processes that continued to influence the livelihood systems of the area, including population increase, immigration, changes in the relationship between older and younger Maasai, and land tenure change through the subdivision of group ranches. The advent and impact of externally-driven institutional and policy changes were not foreseeable. These included the impact of economic liberalization consequent upon the implementation of structural adjustment programs promoted by the IMF, the diversification of tourist activity, and the impact on tourism of global economic conditions. The study did anticipate the weakening of traditional institutions of governance, and the greater involvement of powerful external interests to take advantage of economic opportunities, but the associated rise in importance of local civil institutions and NGOs in determining land use was not foreseen.

The 1977 study anticipated a variety of environmental consequences of the predicted patterns of economic and land use change. These included increased conflict over water resources for agriculture, herding, wildlife, and domestic use; problems of chemical pollution of the irrigation water; and soil fertility decline, increased soil erosion, and deforestation. However a policy decision to divert over 60% of the flow of the Nolturesh River to a pipeline serving areas near Nairobi was not a predictable event.

Many of these issues were examined again in the 1996 survey, and a number of processes and issues were found in common with the 1977 results. Concern with the impact of drought remained (Campbell, 1999a), as did conflict over crop damage and predation by wildlife (Campbell *et al.*, 2003a), and the comparison of the two surveys allowed discussion of the processes contributing to conflicting demands for resources among the livelihood systems of the area (Campbell *et al.*, 2000). Many survey

respondents in 1996 perceived with apprehension a decline in the quality and quantity of water available for irrigation, watering livestock, and domestic consumption, and removal of trees and bushes that were important as building materials, fuel, and medicines. In addition, wildlife managers were anxious about the implications for the expansion of cultivation for habitat fragmentation and wildlife access to water and food.

The 1996 survey was conducted without the benefit of the analysis of remotely sensed imagery. Such information has subsequently indicated the extent and trends of changes in land use over the period since 1973. For example, while the irrigation activities along the Nolturesh River were investigated, the survey could have been better targeted in terms of location, and questions about the experience of the farmers over time could have been more precise had we known that these areas had been cultivated since the early 1980s. A second example is provided by the uneven extension of rain-fed cultivation down the side of Mt. Kilimanjaro. Had this pattern been known, specific attention could have been paid to the reasons for the emergence of this pattern. Subsequent visits to the area in the wake of the analysis of the imagery revealed that the unevenness was not a result of edaphic factors as we had hypothesized but rather of decisions made by individuals that were different from those of the majority.

The experience of the 1996 survey provided an opportunity to more effectively integrate remote sensing into the work of the subsequent Land Use Change Impacts and Dynamics (LUCID: http://www.lucideastafrica.org/) project. For example, remote sensing analysis facilitated definition of the spatial distribution of likely water problems, losses of vegetation, and habitat fragmentation, information that other methods were unable to provide. The identification of the locations where these issues were prominent allowed researchers to better focus and structure analyses of vegetation change, water quality and quantity, and implications of land use change for wildlife distribution and management (Githaiga and Muchiru, 2003; Maitima *et al*., 2003; Norton-Griffith and Butt, 2003; Worden *et al*., 2003).

Longitudinal Study of "Changing Environments"

In conducting long-term studies, interpretation of the survey data must reflect the fact that change has occurred in the "research environment" over time. In this study socioeconomic information was gathered from household surveys, community workshops and from key informants. In order to maintain confidentiality the respondents to the surveys were not identified either by name or by location. The result was that the 1977 respondents were not

identifiable in 1996. This reflects the concept of what Rindfuss *et al.* (2003) refer to as the "ephemeral household," the characteristic of sampling over time when people die, move in, within, or out of an area, and the land they own may change through sale, purchase, or subdivision. In our study comparability between surveys was maintained by employing an identical stratified random sampling method, and aggregating the household-level information to livelihoods such as farming, herding, and mixed herding/farming, as socioeconomic categories, and to land use zones as spatial categories. Discussion with key informants and at feedback workshops also focused on the community/landscape scale.

The outcome was that the socioeconomic information and the land use and land cover patterns were interpretable not at the fine resolution of household and field, but at the coarser resolution of community/livelihood and landscape. Explanation of the driving forces of LULCC thus focused on linkages between broad exogenous drivers such as national policy and variability of rainfall, and landscape/community scale processes such as demographic, institutional, infrastructural, and land cover changes, rather than household level decision making, and field-level biophysical processes. Discussion of landscape-scale processes identified important questions that required finer-scale analysis. Some of these have been addressed in subsequent studies including the impact of gender relations on land use decision making at the household level (Wangui, 2003), issues of water quality and quantity (Githaiga *et al.*, 2003), and the impact of the location of homes on the distribution of wildlife (Worden *et al.*, 2003).

Current conditions reflect the interaction of social and environmental processes through time. Interactions are dynamic in that they are modified as people respond to different opportunities and constraints. For the researcher, this is important as fundamental analytical categories themselves change over time, resulting in the need for flexibility and critical approaches to understanding changing categories. For example, our study found that it is not only households that are "ephemeral" but that some of the fundamental analytical categories also change their meaning over time. One of these is the changing definition of "Maasai" that reflects the dynamic relationship between ethnicity and the land use system in the study area. Among Maasai pastoralists, crop agriculture became accepted between 1977 and 1996. During that time, Maasai communities have diversified and, as in other areas, many households no longer fit the classical description of pastoral herders. They can equally be considered herders, herder-farmers, and even farmers. Herder-farmers are least vulnerable to drought, reflecting the notion of diversification and flexibility as a basis for successful herding observed in other pastoral societies in transition (Campbell, 1999; Campbell *et al.*, 2000; Spear and Waller, 1993;). As land use diversifies, many of the

meanings associated with "being Maasai" are also disappearing (Fratkin, 2003; Fratkin and Mearns, 2003). Institutions and local social organization in Loitokitok, once structured primarily around pastoralism, now reflect more complex and diversified livelihoods. Thus, ethnicity as a category that differentiates groups based on cultural affinity is difficult to interpret and relates little to actual land use practices, social organization, and socioeconomic characteristics that were previously assumed to be typical of Maasai individuals and households.

One example of the changing institutional context relates to the organization of local societies into age-sets whose power, authority, and social obligations change through their lifetime. Within sections of Maasai society, age-set affiliation has not retained its central importance to determining local power for several reasons. First, ethnic affiliation has become more complex in the context of marriages of mixed ethnicity. In some cases, children of Maasai fathers take the ethnicity of their mothers, who often belong to ethnic groups such as the Kikuyu, Kamba, and Chagga. There are also new hierarchical dynamics in the local context. Intersections of education and wealth have emerged in many communities as important dimensions of power, thus undermining customary structures of authority in Maasai society (Southgate and Hulme, 2000). This has led to disagreements within Maasai society, and the emergence of new factions that are active in the debate over allocation of land, and in negotiations with wildlife managers over the local implementation of policy on wildlife and tourism.

The prevailing political and economic "world view" of people in the study area has also changed significantly since the 1977 field research was conducted. This was a time of optimism in post-colonial Kenya. Representatives in the national government were successful in directing state resources toward Kajiado District. Furthermore, non-Maasai settlers on the slopes of Kilimanjaro were not noticeably wealthier than their Maasai counterparts. By the mid-1980s, optimism had begun to dissipate. The political scene had changed and the influence of Maasai leadership from the area had diminished significantly. Locally, land use competition had intensified with the expansion of irrigated and rain-fed agriculture into the drier zones of Loitokitok. There was further change and interaction of Maasai with Kikuyu and other ethnic groups. By 1996, the most recent period of field research, there was a deep cynicism about local prospects for improvements in basic human development. By this time, many Maasai had diversified into crop cultivation, while elites had invested in irrigated farming. The proliferation of patron-client relationships, irregular allocations of land, and the misuse of government funds for development further reinforced this cynicism. To the extent that government and parastatal funds were available for

rural development, programs emphasized agricultural development over pastoralism.

As central categories in society change, so does the meaning and significance of environmental characteristics. As farmers acquire technology, such as plows and irrigation, soils may change in terms of their economic and subsistence potential for local people. With long-term use of land, fertility may decline with rapid effects on farmers' agronomic and economic strategies. Thus the Cartesian geographies of agroecological potential as displayed discretely on soils and rainfall maps are not immutable; rather the perception of them and their significance within social and economic systems changes through time.

Such changes in locally held worldviews have implications for the research process itself. In 1977, one community denied us permission to survey because a previous research group had failed to report back to the community the results of their study. Local communities had begun to use strategies of seeking accountability on the part of government and NGOs. In their relationships with researchers, many communities have insisted on forms of participation from the research community. By the end of the 1990s, participation in forums at which local people could hear, discuss, and scrutinize the results of research was regularly demanded of researchers throughout Kenya. These community workshops have proven to be a significant method for comparing and contrasting the perspectives and understanding of issues held by local people and the research team. They permit the results of the research and the interpretation of the external research team to be shared, their validity assessed, and their implications discussed (Smucker *et al*., 2004).

In both 1977 and 1996, such community "feedback" workshops were held in areas where the research was conducted to discuss the research results and their interpretation (Campbell, 1984a, 1987). Open and critical discussions were held that provided insights to the issues under consideration, and sometimes made explicit the importance of the "changed categories" discussed earlier. In some cases, the forums reinforced the interpretation of the information and in others clarified a number of issues that might otherwise have been misconstrued or underrated. Important among the latter was the high rate of reporting of predatory activity of hyenas, and the apparent decline in mutual support during time of food shortage that was indicated in the survey data. This decline was explained in the workshops as an artifact of the timing of the field survey that coincided with food distribution by an NGO, and thus people emphasized external assistance over mutual support in their responses to the enumerators' questions. This saved the research team from the embarrassment of developing a plausible but inaccurate thesis that greater integration into the external system had undermined

local networks of mutual assistance, often referred to as social capital, and replaced it with a dependence upon external sources of relief.

An important difference between the two time periods was that while in 1977 the format was open and inclusive, by 1996 we were faced by a more politically authoritarian situation illustrated by an absence of women from the workshops. This is a reflection of the bureaucracy that emerged under KANU that altered local political structures and the political engagement of women in Kenya (Haugerud, 1995; Rocheleau, 2001). Southgate and Hulme (2000) have examined this process in the study area, and Wangui (2003, 2004) has documented the impact upon roles of women. This raises the question of authority and representation. Who was speaking? Whose views were excluded? What may have been the implications for the interpretation of the survey data? Such questions are often left out of discussions of participatory research methodology; yet they remain crucial to the interpretation of data collected through methods such as household surveys and key informant interviews, and they provide insights into complex community power dynamics that are central to the political ecology approach.

CONCLUSION

This landscape-scale study analyzed patterns and processes of LULCC using multitemporal satellite imagery and information from field studies over a period of three decades. Satellite imagery was used to assess the spatial extent and patterns of change, and the social science field research was employed to identify the underlying endogenous and exogenous driving forces of change and the implications for changing human–environment interactions and rural development in Loitokitok Division.

National level policy on land adjudication and ownership reinforced sustained immigration that contributed to rapid population growth. Economic policy provided incentives to horticulture and tourism as opposed to livestock production. Crop agriculture expanded in the study area, particularly where perennial water supplies supported horticulture. As crop production, livestock, and wildlife are all water-dependent, the livelihoods dependent on them came to compete over access to water. Resolution of such competition reflected local socioeconomic conditions, particularly the power of different producers to access desirable land and water. Over 30 years the ability of the Maasai herders to maintain their long-established livestock system has been curtailed and many now combine livestock and cropping. Immigrant farmers have contributed to expansion of agriculture, and the extensive enclosure of riparian land along rivers and around swamps has reduced the access of wildlife to water, forcing changes in their

distribution and movement. The landscape reflects these changes induced by a combination of local and external driving forces.

This case study provides examples of methodological issues that are of increasing importance to scientists engaged in research on the driving forces of LULCC, particularly as higher-resolution remotely-sented imagery becomes available. Such imagery will provide greater detail about the land surface and a variety of biophysical attributes, thus facilitating questions related to biophysical processes, land cover patterns and distributions, and their implications for ecological systems, and peoples' livelihoods. Pixel pattern will still have to be interpreted with care to ensure that external driving forces are understood in a more nuanced way that reflects the complexities of local contexts. Explanation of the drivers of change will require conceptual frameworks that integrate complexity in interactions between and among societal and biophysical process, effectively address the issues of temporal and spatial scales, and explicitly consider the role of power in human systems. Further, implementing research within such frameworks requires a variety of methods of information gathering, analysis, and interpretation.

The identification of driving forces through time challenges social science field research to come to terms with the transformations in the central categories of concern to the researcher. For example, understanding the implications of changes in the meaning and importance of ethnicity and local institutions proved essential to interpreting the local dynamics of resource access and use. Furthermore, such changes raise questions about the nature and limitations of participatory forums, such as the "feedback seminars" described above.

Reflection on the process of identifying patterns of LULCC and their causes leads to the conclusion that while remotely-sensed information by itself provides little information on the drivers of change, autonomous field surveys can be made more effective by using information from the analysis of imagery. In combination, these two approaches contribute both a descriptive and an analytical understanding of patterns and processes of LULCC, and can thus better inform both policymakers and scientists developing modeling approaches that seek to extrapolate from the landscape-scale to the regional-scale.

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