Untangling Mechanisms of Land-Cover Change:

A Rapid, Policy-Relevant Analysis of Human-Environment Interactions at the Forest-Grassland Interface in Uganda

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Abstract

Rapid population growth, unsustainable land use, and a pervasively degrading landscape are components of a dominant paradigm regarding African development. While recent work articulating the 'misreading' of the African landscape have begun to challenge this paradigm, much work remains regarding the pervasiveness and character of this misread. Here we argue that instead of one or two pervasively operating mechanisms resulting in woody biomass change across African landscapes, there may be several mechanisms of human-environment interactions operating simultaneously. Here we present a more rapid method, of use to development practitioners, subnational planners, and scientists, for identifying patterns woody biomass change and characterizing the prevailing mechanisms in a way less influenced by dominant paradigms. We combine remotely sensed products, collected at multiple spatial scales, archival data, and rapid rural appraisals to describe alternative mechanisms of woody biomass accumulation (both forest and tree-cover) in south-central Uganda than those currently understood.

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Introduction

Significant attention has focused on the fate of the African environment in light of ongoing and complex relationships between population, agriculture, and natural resource use (e.g., Anglesen and Kaimowitz, 2001; Benjaminsen, 2001; Cleaver and Schreiber, 1994; Fairhead and Leach, 1996; Lee and Barrett, 2001; Place and Otsuka, 2000; Tilman et al., 2001; Turner et al., 1993). A great deal can be learned from these relationships in Africa, where they have been underway longer than anywhere else and have led to highly modified landscapes. Currently, population change makes these relationships increasingly important as food and livelihood security priorities merge with concern about broad-scale resource degradation on the continent.

While paradigms and policies rooted in assumptions of a pervasively degrading African landscape due to population growth and unsustainable land use persist, some studies have challenged a strictly deterministic relationship between population, land use, and resource degradation (Agrawal, 1995; Batterbury and Bebbington, 1999; Benjaminsen, 2001; Blaikie and Brookfield, 1987; Lambin et al., 2001; Reenberg, 2001). Recent evidence has challenged paradigms of pervasively degrading landscapes by exposing cases that apparently were “misread” by colonial forestry officials (Fairhead and Leach, 1996; Gray, 1999; Howorth and O’Keefe, 1999; Leach and Mearns, 1996; Tiffen et al., 1994). To see beyond these paradigms, Batterbury and Bebbington (1999) summarized Leach and Mearns’ work (1996) and called for more “penetrating interpretations of the social and institutional dynamics that structure access to and use of resources” (p. 279). Most of the cases that describe this misreading have focused on portions of West Africa where new tools for addressing landscape change (primarily remote sensing) have documented an increase of forest islands in savanna locations due to the human relationship with the landscape. Fairhead and Leach (1996) have argued against the assumption that the forest-savanna mosaic in Africa is a result of forest loss and a process of savannization. Rather, they argue that human land use and humidification may be causing an expansion of forests into savanna lands. They describe how farmers encourage forest growth through their choices of agroforestry, transplantation of trees, fire management strategies, and unintentional activities such as changes in livestock grazing or location of the community and orientation of households within the community (Fairhead and Leach, 1996). However subsequent studies have pointed out that the existence of particular cases in confined locations do not necessarily lead to an assumption of a pervasive "misread" of what was considered to be a degrading landscape (Gray, 1999; Howorth and O'Keefe, 1999; Nyerges and Green, 2000).

While these contrasting scenarios of change outline specific mechanisms regarding how the "African landscape" might function over long periods of time, this paper presents evidence that *multiple, simultaneously acting* mechanisms of human-environment interactions are more likely than a few pervasively operating mechanisms, such as those described by Fairhead and Leach (1996) and colonial resource managers. For example, the mechanisms we observe for woody-biomass accumulation are quite different from that reported under the misread construct, which focuses more on the biophysical outcomes of forest expansion or regrowth than on the institutional mechanisms (sets of rules) that prompt land-cover change. The broader question then becomes how many dissimilar mechanisms might reside in the human-environment mix that lead to similar patterns of reforestation, afforestation or, deforestation. Also, how can the understanding and identification of these multiple mechanisms be of utility to development practitioners, subnational planners, and local-resource users? The number and character of mechanisms is important in the development context, where government and donor understanding of the subnational population–land use–environment mix determines particular development policies and forms of assistance. Subnational planners often use participatory methods to bring local voices to subnational and national policy making, basing these policies on the mutual assessments of the impacts of land use on land cover, and conversely, the impacts of land-cover change on local livelihoods. However, both planners and local users are often biased by the pervasive and enduring myths described in the "misreading" construct that have been presented to them for several decades. The resulting assessments often conclude that a singular mechanism of gradual degradation in vegetation cover occurs over time, with population growth. We believe that assessments may be improved in a low-cost way if planners and local users can readily identify and characterize the multitude of change mechanisms occurring not only across the "African landscape," but across landscapes within each nation.

Scientists may also use this methodology when investigating human-environment interactions in either causal direction. For example, the method could be used to identify particular patterns of land-cover change (i.e., deforestation, reforestation, or afforestation) when investigating land cover as an independent variable driving human decisions of land use, resource management, or evolution of institutions regulating resource use. Or, it could be used to identify the above patterns to stratify a region or landscape to investigate the diverse mechanisms leading to the patterns of land-cover change observed in a particular area of interest.

In this paper, we demonstrate the use of a rapid, multi-disciplinary method suited for the latter type of investigation. We use this method to describe a case in East Africa where tree cover has increased over recent decades, concurrently with population growth. We articulate historical and institutional factors, legacies of the Buganda Kingdom in Uganda, which have influenced land-use decisions and resulted in an expansion of tree cover onto shallow soils that favor grasslands.

Subsequent to describing the study site, we demonstrate how this method may be used to rapidly identify and characterize the different human-environment interactions that are likely to exist across a landscape. We then describe the different mechanisms of the observed biomass accumulation of this study area in the context of land tenure, population change, and shifts in resource use. Finally, we consider the policy implications of multiple mechanisms of land-cover change acting simultaneously on the landscape with regard to development and conservation.

Study site/background

Our study site is located in the northern portion of Bugala Island, the largest island in the Ssese archipelago, which lies in the northwestern section of Lake Victoria (Figure 1). Land-cover changes in this area illustrate broader patterns across the island as a whole. Bugala Island is located between 0º13’ and 0º32’ south latitude in the District of Kalangala in southeastern Uganda. The island is covered with tropical high forest that comprises 221.5 km^2 (about 49%) of the district’s total land area. Average annual rainfall in the district exceeds 2 m and is distributed in two wet seasons (NEMA, 1998). On highly productive sandy clay loam soils, this bimodal rainfall supports two agricultural seasons. Generally, the forests on the island are in good condition with only 6.2 km^2 affected by human activities (NEMA, 1998). The archipelago lies within the traditional boundaries of the Buganda Kingdom, which historically was organized under the *kabaka* (king). Today the land is governed by the district land board as outlined in the Ugandan Local Government Act of 1997.

The majority of forests on Bugala Island are in *mailo* land tenure, while a small fraction exist as either central or local forest reserves under the central government. The *mailo* tenure system is a well-established and enduring tenure system in Uganda based on traditional kinship institutions (Bikaako, 1994; Place and Otsuka, 2000).

Mailo land tenure is the holding of registered land in perpetuity, but in restricted allotments. It was introduced by the Buganda Agreement of 1900 between the colonialists and the *kabaka*, giving the *kabaka* and other notables defined tracts of land. The *kabaka* also could allocate a mile of land (*mailo*) on a freehold lease to other members of the kingdom. Those receiving land in this way often lacked the means to farm the area and initiated arrangements with tenants, who received eviction protection in 1928 and could not be removed forcibly without compensation. While only the owners of *mailo* land can acquire titles, tenants (the majority today) continue to have strong land rights (Place and Otsuka, 2000). Early in the twentieth century, the *kabaka* instructed the Buganda people of Kalangala to wage war against his enemies who had taken refuge on the islands. Those who were victorious were rewarded with land, and their ownership is still recognized today (conversation with William Gombya-Ssembajwe, April 2002).

<Figure 1 near here>

Thomas (1942) estimated the population of the Ssese Islands near the turn of the nineteenth century to be approximately 20,000, mostly fisherman, farmers, and cattle keepers (Figure 2). In 1902 there was an outbreak of sleeping sickness caused by an infestation of tsetse flies that killed all of the cattle. As a result, the island residents were evacuated to the mainland in 1909 (NEMA, 1998). People were allowed to return to the island in 1920. Many did not return but maintained ownership of their land, and population recovery has been gradual until recently (Figure 2). Since 1980, the population has increased from 5,979 to 17,312, and during the past decade, the population in Kalangala Town Council (the settlement adjacent to the study site) increased from 1,376 to 3,063 inhabitants (UBOS, 1980, 1991, 2002). Eighty-one percent of the population is Buganda, and the majority of these belong to one clan: the Mamba (lungfish) clan. Their occupation is primarily fishing, with limited sedentary agriculture and cattle keeping (Gombya-Ssembajwe et al., 2000a, 2000b).

<Figure 2 near here>

Methods

Data collection

A combination of fieldwork and remote-sensing data was assembled as part of a rapid assessment to determine the patterns and processes of landscape change over time on Bugala Island. Fieldwork was carried out in June–July 2001. Brief interviews were conducted with a group of key informants, including farmers and the chairman of the Buyinja village council. Rather than conducting household-level studies and linking to specific pixels, we first identified the different patterns of directional change observed in remotely sensed products, occurring over recent decades, and conducted interviews with informants who interact with the area over which the change is observed. In Buganda, an enduring local administrative structure exists, so informants include local elders and administrators familiar with resource-use histories for the administrative unit where the land-cover change has been observed. Key informant interviews elicited information on land tenure, agricultural practice, and social trends over time. The few interviews we were able to conduct are supported with archival research and more in-depth past studies, including the long-term community-level monitoring studies of the island conducted by colleagues at Makerere University in Kampala using the International Forest Resources and Institutions (IFRI) Program protocol (CIPEC, 1994–1999; Gombya-Ssembajwe, 1996; Gombya-Ssembajwe et al., 2000a, 2000b, 2000c, 2000d). Information from the interviews and earlier studies allowed us to describe the environmental history of this area from the late nineteenth century to present. A combination of site visits with geographic positioning systems and the use of topographic maps (1:50,000 scale) depicting the 1955 forest extent (derived from aerial photographs) and a composite produced from 1986 and 1995 Landsat images allowed observation of patterns in land-cover change over time (from 1955 to 1995) and to locate the places where each is occurring.

Our analysis of the remotely sensed images provided a detailed accounting of the pattern and direction of landscape change. Care was taken to choose imagery from the same season for each date.[1] There are two dry seasons in south-central Uganda: December to March and July to August. Landsat images from the first dry season were collected whenever possible, because this season is longer and woody species are more easily distinguished, spectrally and visually, from annual herbaceous vegetation when smallholder fields are cleared or are in initial stages of crop growth. An advantage of using Landsat products is that the acquisition times for a particular area have been held fairly constant over the past 30 years. This consistency reduced misinterpretations of land cover caused by differences in sun angle.

An image-processing strategy was adopted that provided the information for a qualitative analysis of land-cover change for the study area. To support this analysis, a multi-temporal color composite was created from 1986 and 1995 Landsat 5 Thematic Mapper images (Figure 3). The composite reveals areas of change within a nine-year time frame and the direction of that change (loss or gain of forest). Used in conjunction with a vector coverage produced from topographic maps depicting 1955 forest boundaries, the recent nine-year land-cover change was compared to 40-year trends of forest boundary recession from or advancement into natural grasslands (Figure 3). Sussman et al. (2003) provide a more detailed explanation of how multi-temporal color composites are constructed and how they are interpreted (and used with three image dates).

<Figure 3 near here>

Aerial photography, taken from an overflight of the study area in 2001, enhanced our analysis of field and remote-sensing work. Three-dimensional models consisting of the 1995 TM imagery, the 1955 forest boundaries, and a digital elevation model (DEM) were created and used with aerial and ground photos to better understand the relationship between time, land use, and topography (Figures 4A–F and 5A–B). These three-dimensional models proved to be especially valuable because we could create views from any perspective, allowing us to nearly duplicate the perspective of the aerial photos. Spatially linking these data sources provided the means to identify the subtleties of forest boundary transition zones and better understand their complexities.

<Figures 4 and 5 near here>

Image processing

Vector Coverage and Subset Images

Four vector coverages were produced from the scanned and registered topographic map: forest boundaries, contour lines, streams, and point elevations. We used Erdas IMAGINE to complete the vectorization process and ArcInfo to attribute the coverages.[2] Two subset images of the island study area (Figure 1) were created from the 1986 and 1995 Landsat 5 TM scenes. Both scenes were rectified in an image-to-image fashion using the registered topographic map as the coordinate reference source. A lack of infrastructure in the study area created a less-than-ideal situation for geometric rectification and prompted the use of natural features such as ridgelines, rivers/streams, and shoreline points as ground control points. Sixty to seventy points were gathered for each subset image.[3]

Multi-temporal color composite

A multi-temporal color composite, representing land-cover change between 1986 and 1995, was produced by selecting and stacking band 3 from each image (Figure 3). During the dry season, soil and senesced grass tend to exhibit high reflectance within the spectral band pass of band 3 of the TM instrument, while photosynthetic leaves on trees produce low reflectance. The difference in spectral information was used to indicate changes in land cover—forest to non-forest and non-forest to forest.[4]

Digital elevation model and Landsat image drape

Three-dimensional models of the island study area were rendered by draping a multi-spectral color composite generated from the rectified 1995 subset image over the DEM (Figures 4A and 5A). Three components of the coverage—contour lines, stream lines, and elevation points—were incorporated into a single digital elevation grid.[5] The model was then rotated to visually match the view angle and elevation of the aerial photographs (Figures 4B and 5B), thus allowing us to combine the satellite imagery, the 1955 topographic map, the DEM, and the aerial photos into a single model. The detail provided by the aerial photos also allowed us to identify the locations of the ground photos.

Tree cover expansion

The most noticeable observation drawn from Figures 3, 4, and 5 is the overall stability of many of the forest-grassland boundaries from 1955 (yellow line) through 1995 (the year of our most recent imagery) to 2001 (the year aerial photos were taken). Much of the grassland shown in Figures 4B and 5B (which correspond respectively to boxes 4B and 5B in Figure 3) has been stable since 1955. Such boundary stability over decades is strong evidence for a natural, topographically driven distinction between these forest and grassland areas. Figures 4A and 5A show that many of the grasslands on Bugala Island are located on ridges or hilltops; this is also evidence for edaphic influence on their distribution.

The primary changes observed in the forest-grassland boundaries are woody species encroaching onto the grasslands, in spite of the population growth on the island during the last several decades (Figure 2). Figure 4 shows that this movement of trees onto grasslands occurs in areas where agriculture also has advanced onto grasslands and general utilization of grassland has increased. In most cases, these areas were not used for agriculture in the past. Thus, in locations where human use of the grassland is limited, such as the location shown in Figure 5B and box 5B in Figure 3, the grassland-forest boundary remained largely the same from 1955 to 2001. But in locations where we observed greater human activity on the grassland, such as in Figure 4B and box 4B in Figure 3, there is a significant advance of trees into the grassland areas, e.g., purposefully planted trees on field boundaries and other forms of agroforestry (figures 4C, D, and F) and the advance of self-seeding trees from a forest patch on disturbed grassland soil.

Mailo land tenure, in particular, has played a key role in the advancement of trees onto the grasslands of Bugala Island in recent decades. According to local residents, this land tenure system excludes the more fertile forest areas from agriculture and limits land utilization to the currently occupied lands and the grassland savannas. Access to *mailo* land in this region depends on kinship-based institutions that govern property rights arrangements (Bikaako, 1994). Both forests and grasslands on Bugala Island are governed by the *mailo* institutions, but access is restricted only in forest areas, not in grasslands, due to the marginal productivity of the latter (conversation with William Gombya-Ssembajwe, April 2002). Since precolonial times, production has largely occurred on the fertile hillside areas between the hilltops and streams, traditionally called the *mutala*. Hilltop grasslands and areas under fallow on the *mutala* were grazed communally (Richards et al. 1973). In precolonial Buganda, local administrative chiefs (now councilors) allotted individual holdings on the *mutala* and permitted communal grazing on hilltop grasslands and fallows to members of the village (Mukwaya 1953). Thus, land tenure and strong, enduring local institutions enforcing rules-of-use and access constitute the primary components of the mechanism that has led to the increase in woody biomass on grassland savanna, not simply the expanse of agroforestry onto grasslands and increased disturbance of those soils as a function of population growth.

Discussion

The paradigm regarding pervasive, unidirectional degradation in land cover from increasingly unsustainable land uses has been enduring. In 1998, each district in Uganda submitted a report to the National Environment Management Authority (NEMA) enumerating various environmental issues, including land use. In Kalangala District, particularly on Bugala Island, a number of studies were conducted for this report. Soil samples were collected in the grassland areas to demonstrate past human activities, but no historical analyses of community land-use/cover change were conducted to show actual processes of interaction between people, soils, and woody vegetation over time. The basic conclusions of this report are: (1) the island was once entirely covered by forest, (2) the savannas of today were derived from forest by cattle grazing and unsustainable cultivation, and (3) the forests of today are secondary forest regrowth (NEMA, 1998). These conclusions were based on evidence of human activities in the grasslands and the assumption that this meant the areas were converted from originally forested land. They state that at the end of the nineteenth century there were numerous farms with large cattle herds. They postulate that the grasslands were a result of a process of forest clearings followed by unsustainable cultivation and grazing, and finally abandonment due to poor resource management.

Our multi-disciplinary approach, which employs multiple products that cover a range of scales, allows us to investigate the actual processes of land-use change across soil types (differentiated by topography) and how these affect, and are affected by, land-cover change. Our investigation shows that the island was in all likelihood not entirely forested at any time, but rather a dynamic, natural forest-grassland mosaic. Between 1909 and 1955 the island was first abandoned and then lightly repopulated. If climatic and all edaphic conditions had favored forest regeneration within a 50-year interval, then we would expect to observe more complete forest cover in the remotely sensed products of 1955. Instead, we observe a forest-grassland mosaic. Intervals between subsequent land-cover observations are shorter than this, and we did not observe complete reforestation at any time after this, but rather we saw shifts in the forest-grassland mosaic. Oral histories and past descriptions of land-use patterns also support this postulation. While the population has grown over the past 50 years to approach that of the late nineteenth century, we do not observe an increase in conversion of forest to grassland. Instead, we observe a process of increased application of agroforestry methods on the long-occupied fertile lands, and the expansion of those practices that generates an increase in woody biomass on soils that predominantly supported grassland. Expansion of agriculture onto grasslands, and other human activities, may also disturb soils, allowing self-seeding trees from neighboring forest patches to also colonize these grasslands. Thus use of the NEMA report for policy and development planning would be significantly problematic, assuming as it does a pervasive degradation of woody biomass.

We can better understand the process of land-use/cover change by looking at the land-cover configuration of 1955, which was very much the same as it is today. If the island were cleared for agriculture and cattle in the early 1900s, it would have had to regrow to its current configuration within 50 years but remain stable thereafter and regrow no further. Today's grasslands adjacent to the human settlements are not expanding. Instead, we find agriculture, with a tree component, expanding into the grassland as a result of *mailo* tenure rules. Smallholders have persisting access rights to these grasslands though not to the fertile forest soils. The nature of the resource—a naturally low-productive grassland—rather than the conversion of forest to grassland in the late nineteenth century, most likely prompted the continuance of access rights similar to those granted by administrative chiefs in precolonial Buganda (Richards et al. 1973).

Other evidence, gained in IFRI studies conducted by researchers at Makerere University, also support our interpretation that the majority of current Bugala grasslands are not derived from human activities. First, IFRI studies in Uganda indicate that closed forests are not used significantly for grazing (Gombya-Ssembajwe, 1996; Gombya-Ssembajwe et al., 2000a, 2000b, 2000c). However, cattle may be brought to the seasonally inundated, closed valley forests for water or for brief grazing during the dry season. Second, animal husbandry has never been so extensive in the tropical moist agro-ecozones of Uganda for farmers to clear large tracts of forests for pasture as is reported in Brazil or Indonesia. Most cattle in this agro-ecological zone are kept in small numbers (five to ten heads) for subsistence and typically grazed in existing patches of grassland by the young boys of the households. Historically, the few large cattle-producing estates (kept by members of the upper echelons in the Buganda Kingdom) used large areas of natural grasslands rather than clearing forests to create pastures. Currently large herds are kept primarily in the semi-arid regions of the Buganda Kingdom that form part of the Uganda "cattle corridor" (such as Luweero, western Mubende, western Mpigi, Maska, Nakasongola, and Sembabule districts). Also, most keepers of large herds have been nomadic rather than sedentary pastoralists (conversation with Abwoli Banana and William Gombya-Ssembajjwe, July 2003)

Our investigation in this agro-ecological zone, have revealed that once a piece of land that was intensively used for cultivation is left for three to five years, advanced growth of colonizing species is observed. After 25 to 30 years, the colonizing species are replaced by advanced succession species of a typical high tropical forest. On Bugala Island, colonizing species such as *Maesopsis eminii, Polycias fulva,* and *Trema orientalis* are replaced by dominant species such as *Celtis spp.*, *Albizia spp.*, *Piptadenia africanum*, and *Uapaca guinense*. With advancing succession one observes an increase in basal area in these species, the presence of epiphytes and lianas, and a decrease in understory (herbaceous plants, shrubs, and colonizing woody species). These patterns were observed in the Najjakulya and Katebo IFRI sites of

Mpigi District and at the Busowe and Kabunja IFRI sites on Bugala Island (Gombya-Ssembajwe, 1996; Gombya-Ssembajwe et al., 2000a, 2000b, 2000c, 2000d). All these sites fall within the same agro-ecological zone.

One specific case of how the "African landscape" functions, with multiple mechanisms of woody biomass accumulation, does not mean that these particular mechanisms of human-induced landscape change operate pervasively across Africa, or even across Uganda. What it does imply, particularly when considered together with different mechanisms that operate elsewhere, is the existence of numerous mechanisms that can lead to increases in woody biomass on a previously treeless landscape. These mechanisms are now more rapidly observable through this application of a suite of multi-disciplinary and multi-scalar analytical techniques (integrating remote sensing, GIS, and social science studies). The variety of mechanisms that effect local changes in vegetation cover challenge us to reconsider paradigms of an overall, continentwide degrading or aggrading landscape. Not only does the integrative use of these analytical approaches allow the untangling of historical and dynamic human-landscape interactions, they improve and accelerate the examination of processes of landscape change, providing important understanding for development practitioners, planners, and local-resource users to identify land-use policies that lead to mutually preferred outcomes among stakeholders.

Implications for policy making and development

National and donor policies in Africa are confronted with the dual and often conflicting objectives of agricultural development and environmental conservation. While attempts to integrate the two are laudable, they are significantly problematic, particularly when both poverty reduction and environmental conservation are central concerns. At the same time, general policy application based on broad paradigms about the direction of environmental change in Africa has not produced desired outcomes.

Broad, generalized assumptions regarding how smallholder resource use decisions are impacting the environment run the risk of marginalizing the poor and increasing resource degradation as policies based on these assumptions unnecessarily reduce access rights or help promote an inappropriate land-use plan. With government, donor, and scientific interest in many parts of the African continent focusing on issues of agricultural growth, poverty reduction, resource conservation, and the intersection of these, the simultaneous occurrence of multiple mechanisms of afforestation/ reforestation and agricultural change has significant policy relevance. Fortunately, advances in methodologies and their integration have lead to an ability to investigate specific cases of in a timely and effective manner, and can facilitate future policy making and development planning. A cross-disciplinary and multi-scalar approach to policy derivation is relevant to both development and resource conservation agendas (Batterbury and Bebbington, 1999; Gray, 1999; Harriss, 2002; Reenberg, 2001;

Schimel et al., 2001; Scoones, 1998). Such an approach to the historical analysis of landscape transformation can more readily reveal the interactive relationship between humans and their environment through time. This in turn can move our understanding of the human-environment relationship regarding a particular location beyond the singular interpretations deduced from more deterministic models. Of particular importance is policy specificity with regard to conditions present at particular subnational locations, as opposed to continentwide, or even countrywide policy approaches to development and conservation.

List of references

Anglesen, A. and Kaimowitz, D. (2001) *Agricultural Technologies and Tropical Deforestation*. Center for International Forestry Research, Jakarta, Indonesia.

Batterbury, S. P. J. and Bebbington, A. J. (1999) Environmental Histories, Access to Resources and Landscape Change: An Introduction. *Land Degradation and Development* **10**, 279–289.

Benjaminsen, T. A. (2001) The Population-Agriculture-Environment Nexus in the Malian Cotton Zone. *Global Environmental Change* **11**, 283–295.

Bikaako, W. (1994) *Land to Tillers or Tillers to Land: The Existing Forms of Land Tenure Systems in Mpigi District*. Centre for Basic Research, Kampala, Uganda.

Blaikie, P. and H. Brookfield (1987) *Land Degradation and Society*. Methuen and Co., New York.

CIPEC (Center for the Study of Institutions, Population, and Environmental Change) (1994–1999) *International Forest Resources and Institutions (IFRI) Research Program Field Manual* (versions 7.0–9.5, updated annually). CIPEC, Indiana University, Bloomington, Ind., 47405 USA.

Cleaver, K. M. and Schreiber, G. A. (1994) *Reversing the Spiral*. The World Bank, Washington, D.C.

Fairhead, J. and Leach, M. (1996) *Misreading the African Landscape*. Centre of African Studies, Cambridge University, Cambridge, U.K.

Gombya-Ssembajwe, W. (1996) Analysis of institutional incentives for sustainable management of tropical moist forests: a case of Mengo Forests, Uganda. Ph.D. diss., University of Wales, Bangor, U.K.

Gombya-Ssembajwe, W., Bahati, J. and Banana, A.

(2000a) *Busowe Forest Reserve Site Report: First Visit, 2000*. Uganda Forest Resources and Institutions Center, Kampala, Uganda.

(2000b) *Kabunja Private Forest Site Report: First Visit, 2000*. Uganda Forest Resources and Institutions Center, Kampala, Uganda.

(2000c) *Katebo Cultural Forest Site Report, 2000*. Uganda Forest Resources and Institutions Center, Kamapala, Uganda.

(2000d) *Najjakulya Private Forest Site Report, 2000*. Uganda Forest Resources and Institutions Center, Kampala, Uganda.

Gray, L. C. (1999) Is land being degraded? A Multi-Scale Investigation of Landscape Change in Southwestern Burkina Faso. *Land Degradation and Development* **10**, 329–343.

Harriss, J. (2002) The Case for Cross-Disciplinary Approaches in International Development. *World Development* **30**, 487–496.
Howorth, C. and O'Keefe, P. (1999) Farmers Do It Better: Local Management of Change in Southern Burkina Faso. *Land Degradation and Development* **10**, 93–109.
Lambin, E., Turner, B. L. II, Geist, H., Agbola, S., Angelsen, A., Bruce, J., Coomes, O., Dirzo, R., Fischer, G., Folke, C., George, P., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E., Mortimore, M., Ramakrishnan, P., Richards, J., Skanes, H., Steffen, W., Stone, G., Svedin, U., Veldkamp, T., Vogel, C. and Xu, J. (2001) The Causes of Land-Use and Land-Cover Change: Moving Beyond the Myths. *Global Environmental Change: Human and Policy Dimensions* **11**, 261–269.
Leach, M. and Mearns, R. (1996) *The Lie of the Land: Challenging Received Wisdom on the African Environment*. James Currey, Oxford, U.K.
Lee, D. R. and Barrett, C. B. (Eds.) (2001) *Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment*. CABI Publishing, New York.
Mukwaya, A. B. (1953) *Land Tenure in Buganda: Present Day Tendencies*. The Eagle Press, Kampala, Uganda.
NEMA (National Environmental Management Authority) (1998) *The State of the Environment 1998*. Kampala, Uganda.
Nyerges, A. E. and Green, G. M. (2000) The Ethnography of Landscape: GIS and Remote Sensing in the Study of Forest Change in West African Guinea Savanna. *American Anthropologist* **102**, 271–289.
Place, F. and Otsuka, K. (2000) Population Pressure, Land Tenure, and Tree Resource Management in Uganda. *Land Economics* **76**, 233–251.
Radwanski, S. A. (1960) *The Soils and Land-Use of Buganda*. Kawanda Research Station, Kampala, Uganda.
Richards, A. I., Sturrock, F. and Fortt, J. M. (Eds.) (1973) *Subsistence to Commercial Farming in Present-Day Buganda: An Economic and Anthropological Survey*. Cambridge University Press, Cambridge, UK.
Reenberg, A. (2001) Agricultural Land Use Pattern Dynamics in the Sudan-Sahel: Towards an Event-Driven Framework. *Land Use Policy* **18**, 309–319.
Schimel, D., House, J., Hibbard, K., Bousquet, P., Ciais, P., Peylin, P., Braswell, B., Apps, M., Baker, D., Bondeau, A., Canadell, J., Churkina, G., Cramer, W., Denning, A., Field, C., Friedlingstein, P., Goodale, C., Heimann, M., Houghton, R., Melillo, J., Moore, B., Murdiyarso, D., Noble, I., Pacala, S., Prentice, I., Raupach, M., Rayner, P., Scholes, R., Steffen, W. and Wirth, C. (2001) Recent Patterns and Mechanisms of Carbon Exchange by Terrestrial Ecosystems. *Nature* **414**, 169–172.
Scoones, I. (1998) *Sustainable Rural Livelihoods: A Framework for Analysis*. IDS Working Paper No. 72. Institute of Development Studies (IDS), Brighton, U.K.
Sussman, R. W., Green, G. M., Porton, I., Andrianasolondraibe, O. L. and Ratsirarson, J. (2003) A Survey of the Habitat of *Lemur catta* in Southwestern and Southern Madagascar. *Primate Conservation* **19**, 32–57.

Thomas, A. S. (1942) The Vegetation of the Sesse Islands, Uganda. *Journal of Ecology* **30**, 330–353.

Tiffen, M., Mortimore, M. and Gichuki, F. (1994) *More People, Less Erosion: Environmental Recovery in Kenya*. John Wiley and Sons, Chichester, U.K.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W. H., Simberloff, D. and Swackhamer, D. (2001) Forecasting Agriculturally Driven Global Environmental Change. *Science* **292**, 281–284.

Turner, B. II, Meyer, W. and Skole, D. (1993) Global Land-Use/Land-Cover Change: Towards an Integrated Program of Study. *Ambio* **23**, 91–95.

UBOS (Uganda Bureau of Statistics)

(1969) *Population Census 1969*. Kampala, Uganda.

(1980) *Population Census 1980*. Kampala, Uganda.

(1991) *Population Census 1991*. Kampala, Uganda.

(2002) *Population Census 2002*. Kampala, Uganda.

Endnotes

[1]For this study we used a subsection of Path 171/Row 60 for the TM images (Worldwide Reference System 2) and Path 184/Row 60 for the MSS images (Wordwide Reference System 1).

[2]The topographic map was scanned at a resolution of 300 dots per inch using an 8-bit (256) color palette. These scanning parameters produced a 75 MB file with an image resolution, approximately 4.25 meters, sufficient for delineating forest boundaries, streams, and contour lines for digitization. The calculation for image pixel resolution is as follows: The map was registered in Erdas IMAGINE software using its "Geometric Correction" tools; a first-order polynomial model was selected.

The projection parameters for the model were as follows: Eight ground control points were selected to solve the model and register the map. The points were positioned on the UTM graticule intersections, and coordinates were entered by keyboard. The point selection produced a total registration error of 0.0075 pixels. The map was then resampled at a cell size of 4.25 m using the Nearest Neighbor method.

[3]Twenty-five to thirty points, evenly distributed, were retained as ground control points producing a registration error of less than 1 pixel for both subsets. A visual accuracy assessment was performed using the "Utility" functions of Erdas IMAGINE (flicker, swipe, and blend). Once subpixel accuracy had been confirmed, both subset images were resampled at a cell size of 30 m using the Nearest Neighbor method.

[4]The composite was created by assigning band 3 of the 1995 registered subset as the red layer and band 3 of the 1986 registered subset as the green and blue layers. Since it was optimal to view areas exhibiting no change as black or white, either bright in both dates or dark in both, band 3 from the 1986 registered subset was used twice to

account for all primary colors. The colors were then normalized by stretching the bands to distribute values over the entire 8-bit data range (256).

[5]The individual components were assembled into a DEM using the "topogrid" functions in ArcInfo. The process of draping the image over the DEM was completed in ArcScene by assigning base heights provided by the DEM to the image. Once the elevation data had been assigned and the band combination selected, the image was enhanced by stretching the data, for each band being viewed, over the entire 8-bit data range. This stretching process was repeated any time the band combination was altered.

Figure captions

Figure 1. Map of the study area, showing Bugala Island, the largest of the Ssese Islands in the Ugandan waters of Lake Victoria. Bugala Island is located within Kalangala District, less than 50 km southwest of the city of Kampala.

Figure 2. Graph of the human population of Bugala Island between 1890 and present. The plot shows a sharp drop in population when a disease outbreak forced the evacuation of the islands inhabitants. People were allowed to return in 1920, and the island's population has increased since then. It has more than doubled since 1980. (Data taken from UBOS, 1969, 1980, 1991, 2002)

Figure 3. Multi-temporal color composite showing areas of stable land cover, forest loss, and forest gain on a portion of Bugala Island (see "Figure 3" in Figure 1). These composites are generated using Landsat 5 Thematic Mapper (TM) images acquired at red wavelengths (band 3) on two dates: January 19, 1995, and December 28, 1986. The composites are constructed such that the 1986 image drives the blue and green colors and the 1995 image drives the red colors. Produced in this way, shades of gray (plus black or white) indicate little or no change in land cover, while the presence of color indicates change. Dark areas indicate stable forests, bright areas indicate stable grasslands, red areas indicate a loss of woody cover, while cyan (green plus blue colors) areas indicate areas of woody growth. Vector coverages delineating the forest/non-forest 1955 boundaries are shown by yellow lines. Red boxes depict areas shown in Figures 4 and 5. The red arrows show the direction of view. The aqua blue areas within the yellow lines in box 4B show areas of woody growth between 1986 and 1995. The savanna area, covered largely by box 5B, shows forest boundaries that have been fairly stable since 1955. The small red area at the southern end of box 4C reveals an area of forest loss.

Figure 4. A: A Landsat 5 Thematic Mapper image, acquired January 19, 1995, is draped over a 30-meter DEM. The multi-spectral color composite is produced by setting band 3 (red wavelength) to drive the blue colors, band 5 (mid-infrared wavelength) to drive the green colors, and band 4 (near-infrared wavelength) to drive the red colors. Forests are shown as areas of orange color, while grasslands are associated with greenish-blue colors (darker areas show recent burns). Vector coverages delineating the forest/non-forest boundaries in 1955 are shown by yellow lines. The red box (B) frames the extent of the aerial photograph B. The orange-colored areas within the yellow lines depict areas that have experienced woody plant growth between 1955 and 1995. **B:** An oblique aerial photograph, taken from the

north in August 2001, which corresponds to box B in A and box 4B in Figure 3. This 35 mm photo was taken at approximately 500 feet above ground level from a Cessna 172. Forest is shown by dark green colors, and areas of grass cover are shown by light green tones (recent burns are gray). This photograph shows that woody growth has continued to expand into the grasslands in this area since 1995. Areas with many small trees might be colonized by continuous forest in the future. **C:** An oblique aerial photograph, taken from the south in August 2001, that corresponds to box 4C in Figure 3. Forest growth in the background corresponds to areas of blue within the box, and the human settlement in the foreground corresponds to the small area of red in the same box, which is associated with loss of woody plants. Red arrows indicate the views of photos shown in D–F. **D:** Oblique aerial photo, taken from the south in August 2001 at lower altitude, shows an area of agriculture expansion into the grasslands. **E:** A ground photo taken in 2001 of the edge of forest that has colonized the grassland since 1955. Another grassland area that is experiencing woody invasion is shown in the background. **F:** A ground photo that shows the edge of a newly cultivated field that has been established in an area that was grassland in 1955. (Aerial and ground photos were taken by Nathan Vogt.)

Figure 5. A: Landsat 5 Thematic Mapper, images acquired January 19, 1995, is draped over a 30-meter DEM. The multi-spectral color composite is produced by setting band 3 (red wavelength) to drive the blue colors, band 5 (mid-infrared wavelength) to drive the green colors, and band 4 (near-infrared wavelength) to drive the red colors. Forests are shown as areas of orange color, while grasslands are associated with greenish-blue colors (darker areas show recent burns). Vector coverages delineating the forest/non-forest boundaries in 1955 are shown by yellow lines. The red box frames the extent of an aerial photograph (B). Many of the forest grassland boundaries shown in the 1995 Landsat image correspond to the forest/non-forest boundaries of 1955. Thus, it is shown that these boundaries have remained fairly stable since 1955. **B:** An oblique aerial photograph, taken from the northeast in August 2001, that corresponds to the red box in A. The area covered is also shown by box 5B in Figure 3. This 35mm photo was taken at approximately 500 feet above ground level from a Cessna 172. Forest is shown by dark green colors, and areas of grass cover are shown by light yellow and green tones (more recent burns are brown in color). This photograph shows that woody growth has remained fairly stable since 1955. (Aerial photo was taken by Nathan Vogt.)