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INTEGRATING REMOTE SENSING DATA AND RAPID APPRAISALS FOR LAND-COVER CHANGE ANALYSES 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. A method is presented for investigating mechanisms of land-cover change that combines remotely sensed data, archival data, and rapid appraisals in a way less influenced by dominant paradigms. We present a case where increasing human activity is resulting in accumulation of woody biomass on edaphic grasslands of a forest–grassland mosaic, rather than the expansion of grasslands at the expense of forests as is currently understood in that area. These increases in biomass are stimulated by anthropogenic influences that are shaped by institutional and edaphic factors. We do not claim that resources are being pervasively enhanced across sub-Saharan Africa under conditions of population growth, but that there may be many mechanisms of change, resulting in both degradation and enhancement, occurring simultaneously across sub-Saharan Africa or even intra-regionally within a nation under these conditions. The integration and application of these methods serve to improve applied analyses of land-cover change to better characterize these mechanisms, and avoid the wrong policy prescriptions. Copyright © 2005 John Wiley & Sons, Ltd.

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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

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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 of different mechanisms of human–environment interactions occurring other than through the few pervasively operating mechanisms described by Fairhead and Leach (1996) and colonial resource managers. Accurate and specific characterization of these 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.

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. For example, in our Uganda case, we find two different mechanisms whereby woody biomass is accumulating on existing grasslands under conditions of population growth and increasing activity, rather than the replacement of forests by grassland with population growth as is currently understood in the study area. By analyzing human–environment interaction under the assumptions of the prevailing paradigms, as per the analysis by the Ugandan National Environmental Management Authority (NEMA) in our study area, there is risk of developing the wrong policy prescription. We believe that assessments may be improved, and appropriate policies prescribed, if planners and local users have a method that is less biased by prevailing paradigms to more readily identify and characterize the mechanisms of vegetation change occurring not only across the 'African landscape,' but across landscapes within each nation. In this paper, we demonstrate the use of a multi-disciplinary method suited to this type of investigation.

Subsequent to describing the study site, we demonstrate how the method may be used to 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 the study area in the context of land tenure, population change, and shifts in resource use. Finally, we consider the policy implications of the application of this methodology, and findings it produced, 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 0°13′ and 0°32′ South latitude in the District

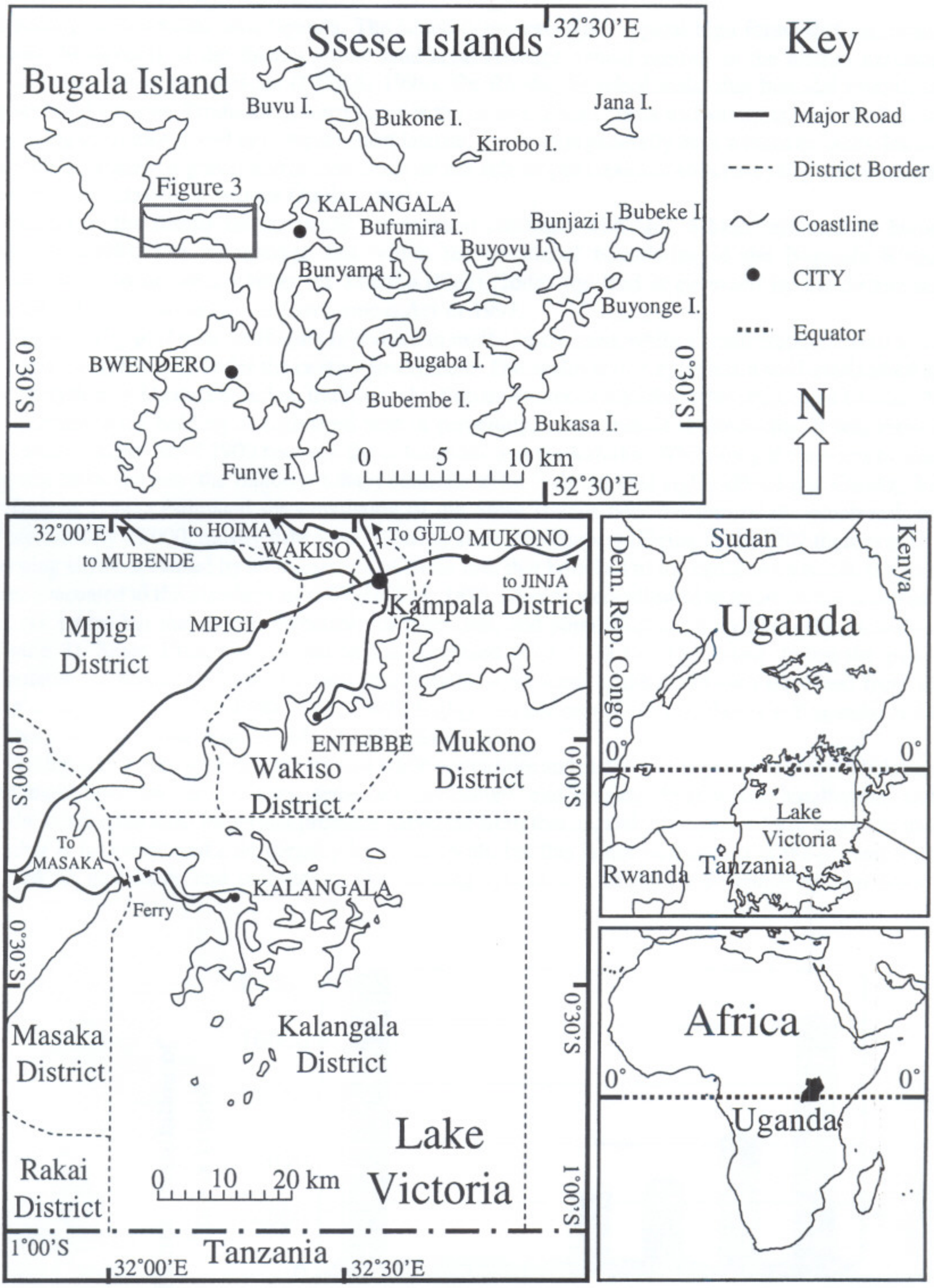

Figure 1. Map of the study area, showing Bugala Island, the largest of the Ssese Islands in the Ugandan waters of Lake Victoria. Bugala Island is located within Kalangala District, less than 50 km southwest of the city of Kampala.

of Kalangala in southeastern Uganda. The island is covered with tropical high forest that comprises 221·5 km^2 (about 49 per cent) 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 Rhodic Ferralsol soils, this bimodal rainfall supports two agricultural seasons. Productivity varies across the catena. Broad crests and summits have shallow subsoils with overlying quartzose gravel or compact sheet laterite. These soils generally have a loam or sandy-loam texture with varying quantities of gravel and stones. Soils on the side slopes (residual soils) are deep and well drained. These have a sandy-clay loam texture (Aniku, 2001).

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 exists 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**. While only the owners of **mailo** land can acquire titles, tenants (the majority today) continue to have strong land rights (Place and Otsuka, 2000).

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 5979 to 17 312, and during the past decade, the population in Kalangala Town Council (the settlement adjacent to the study site) increased from 1376 to 3063 inhabitants (UBOS, 1969, 1980, 1991, 2002). Eighty-one per cent of the population is Buganda, and the majority of these belong to one clan: the Mamba (lungfish) clan.

Fishing is the main form of cash income while agriculture and cattle keeping are primarily subsistence activities. The main land uses are forestry, sedentary agriculture, and grazing. Fuel wood, handicrafts, and traditional medicines are the most important products harvested from forests, and all residents have access to these products. Timber is harvested and sold illegally by some youth, but this is not widespread at the present time. Cattle are grazed on grasslands and in fallows. The farming system is a sedentary perennial system based on banana

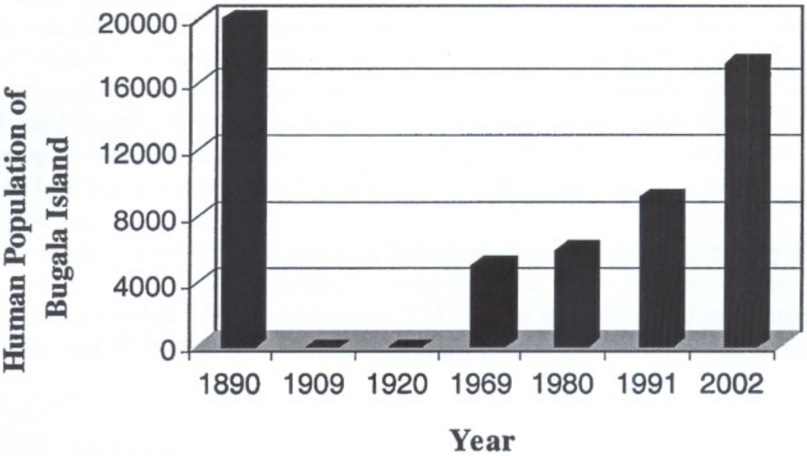

Figure 2. Graph of the human population of Bugala Island between 1890 and the present.

(plantain) production. Subsistence crops include banana, cassava, and potato. Fruit trees are found interspersed among crops and in the home-garden. Common trees found on land used for agriculture and home-gardens are jack fruit (*Artocarpus heterophyllus*), avocado (*Persea americana*), orange (*Citrus reticulata*), and papaya (*Carica papaya*) (Gombya-Ssembajwe *et al.*, 2000a, 2000b).

METHODS AND ANALYSIS

Data Collection

A combination of fieldwork and remote-sensing data was assembled as part of an assessment to determine the patterns and processes of landscape change over time on Bugala Island. Fieldwork was carried out in June–July 2001. Brief, unstructured interviews were conducted with a few farmers and the chairman of 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 members of the administrative unit encompassing the study area were interviewed. We also attempted to identify elderly members who might have been familiar with resource-use and cover histories in the study area over longer time periods.

Key-informant interviews elicited information on land tenure, agricultural practice, and social trends over time. These were conducted outside so as to relate the land-cover materials on the landscape with those observed in the remotely sensed product. The few interviews that we were able to conduct were 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). Studies using the IFRI protocols also rely on open-ended rapid appraisals (Chambers, 1992; Freudenberger, 1994) with individuals or groups of individuals who use the forests in various ways, but not with remotely sensed images of land-cover change patterns around which to focus discussions about resource use and cover that are more spatially and temporally explicit.

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 the location of the places where each was 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. These composites are generated using Landsat 5 Thematic Mapper (TM) images acquired at red wavelengths (band 3) on two dates: 19 January 1995, and 28 December 1986 (Plate 1). During the dry season, soil and senesced grass tend

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[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).

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.[2] The composite reveals areas of change within a nine-year time frame and the direction of that change (loss or gain of forest). 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).

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 (Plate 1). Vector coverages delineating the forest/non-forest 1955 boundaries are shown by yellow lines. Red boxes depict areas shown in Plate 2, Figure 3 and Figure 4. The red arrows show the direction of view. The aqua blue areas within the yellow lines in box Plate 2B show areas of woody growth between 1986 and 1995. The savanna area, covered largely by box 3B, shows forest boundaries that have been fairly stable since 1955. The small red area at the southern end of box 4A reveals an area of forest loss.

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 (Plate 2A–B, Figure 3A–B and Figure 4A–D). 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.[3]

RESULTS

The most noticeable observation drawn from Plates 1, 2, Figure 3 and Figure 4 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 Plate 2B and Figure 3B (which correspond respectively to boxes Plate 2B and 3B in Plate 1) 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. Plate 2A and Figure 3A 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). Plate 2 and Figure 4 show that this movement of trees onto grasslands occurs in areas where agriculture has also advanced onto

Figure 3. (A) Landsat 5 Thematic Mapper, images acquired 19 January 1995, is draped over a 30-meter DEM.[4] 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 3B in Plate 1. 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 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.).

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[2] 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 on both dates or dark on 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). 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.

[3] Please contact the first author for more information regarding image processing.

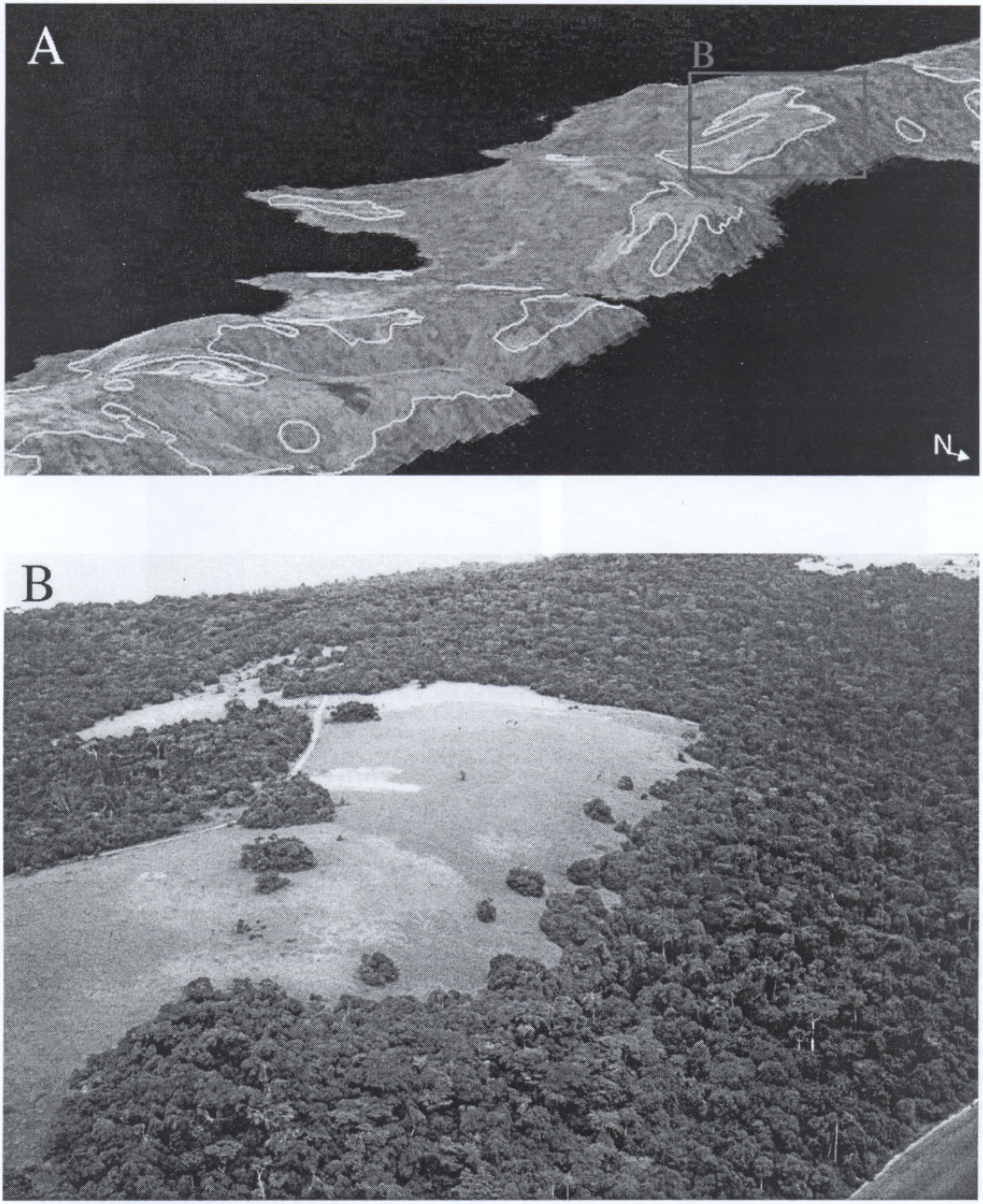

Figure 3.

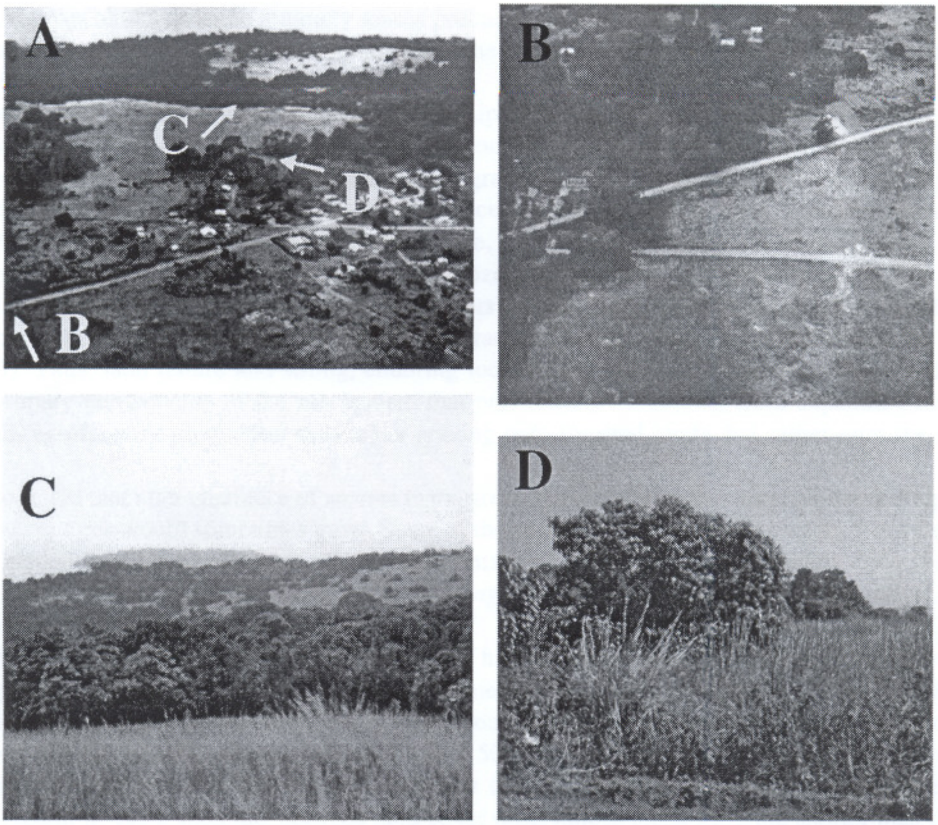

Figure 4. (A) An oblique aerial photograph, taken from the south in August 2001, that corresponds to box 4A in Plate 1. Forest growth in the background corresponds to areas of blue within the box, and the human settlement in the foreground corresponds to the small area of red in the same box, which is associated with loss of woody plants. Red arrows indicate the views of photos shown in B–D. (B) Oblique aerial photo, taken from the south in August 2001 at lower altitude, shows an area of agriculture expansion into the grasslands. (C) 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. (D) 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.).

grasslands and general utilization of grassland has increased. In most cases, these areas were not used for agriculture in the past. Through visual interpretations of the multi-temporal composites and aerial photographs, we observed an apparent increase of trees on the long-settled areas (lands used for agriculture and home-gardens since re-settlement) and the slight expansion of land used for sedentary agriculture onto grasslands, which results in an increase of woody biomass on soils that predominantly supported grassland (Plates 1, Figure 4A, B, and D). We also see the advance of self-seeding trees from a forest patch onto grassland adjacent to the settlement, which is more heavily utilized than other grasslands (Plates 1 and 2B). Thus, in locations where human use of the grassland is limited, such as the location shown in Figure 3B and box 3B in Plate 1, 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 Plate 2B and box Plate 2B in Plate 1, there is a significant advance of trees into the grassland areas through two processes.

Interviews with key informants were conducted on location where both stability and change were observed in the remotely sensed images. **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 key informants, this land tenure system limits land utilization by smallholders to the currently cultivated lands and the grassland savannas. Walking with them through land-cover types observed in the remotely sensed products—forest, grassland, crops—they stated that the preferred soils for sedentary production was on lands within the **mailo** forests. However, they are not permitted to cultivate within the **mailo** forests in this study area.

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. Since pre-colonial times, production has largely occurred on the fertile soils, typically found areas between the hilltops and streams in this agro-ecological zone, which is traditionally called the **mutala**. Hilltop grasslands and areas under fallow on the **mutala** were grazed communally (Richards *et al.*, 1973). In pre-colonial Buganda, local administrative chiefs (now councilors) allotted individual holdings on the **mutala** and permitted communal grazing (shared access) 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 constitutes the primary components of the mechanism that prevented smallholders from expanding land used for agriculture (an agroforestry production system) or grazing onto forested lands, but rather onto the savanna grasslands.

Informants also stated that after clearance of an area in the grasslands for agriculture or grass harvesting (by fire or physical clearance) trees would sometimes grow. Some of the species identified when visiting these areas with key informants, guided by GPS to locations where woody material on grassland was visually observed in the remotely sensed images, were *Canarium schweinfurthii*, *Harungana madagascariensis*, *Maesopsis eminii*, *Sapium ellipticum*, and *Vernonia* spp.

Our investigation shows that in all likelihood the island has not been entirely forested (primarily void of grasslands) at any time since the onset of colonization (late nineteenth century), as suggested in the NEMA report (see below). 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 found that both forests and grasslands were present in 1955. Intervals between land-cover observations since 1955 are shorter than this, and we did not observe complete reforestation at any time after this. 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 as is currently understood. Instead, we find woody biomass accumulating on existing grasslands through the mechanisms described above under conditions of population growth.

Other evidence, gained in IFRI studies conducted by researchers at Makerere University, also supports 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, or individual fallows, 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 semiarid 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.

Other investigations in this agro-ecological zone, have revealed that once a piece of land that was intensively used for cultivation (typically on fertile soils of the **mutala**) 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*

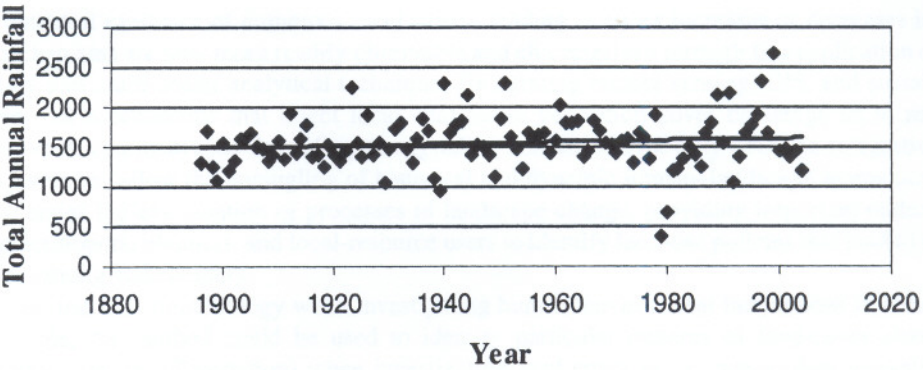

Figure 5. Graph of total annual rainfall at Entebbe collection station (45 km NNE of study area) between 1896 and 2004.

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.

We also tracked the trend in total annual rainfall between 1896 and 2004 (Figure 5) at the Entebbe station (approximately 45 km NNE from the study area) to confirm that the advance of woody vegetation on grasslands was largely due to anthropogenic influences rather than from increasing rainfall in the region. The slope of the trend line was not significantly greater than zero ($p = 0{\cdot}2541$).

The patterns of changes and mechanisms characterized here differ from those currently understood and characterized in a recent NEMA report. In 1998, each district in Uganda submitted a report to NEMA enumerating various environmental issues, including land use. In Kalangala District, particularly on Bugala Island, a number of studies were conducted for this report. Soils were analyzed in the grassland areas to find evidence of past human activities on the grasslands, 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. No systematic, over-time studies have been conducted to determine empirically if there is any change in soil fertility on grasslands.

DISCUSSION

The mechanisms characterized in this study are contrary to those in the NEMA report. 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, and expansion of grasslands from increased human activity as a function of population growth.

The paradigm regarding pervasive, unidirectional degradation in land cover from increasingly unsustainable land uses has been enduring. One specific case of how the 'African landscape' functions 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 potential existence of numerous mechanisms leading to either increases or decreases in woody biomass. These mechanisms are now more readily observable and characterized 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, but it improves and accelerates 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.

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 on land use, resource management, or the 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.

When integrating remote sensing and rapid rural appraisal, we found that interviews with informants of different stakes, or interests, in the area under investigation may make the narratives of mechanisms richer and more robust. Thus identification of these stakeholders is an important first step. For example, the socio-political structure traditionally had great influence over land allocation and use. Current and past administrators at multiple levels in the hierarchy can provide greater insights into changes of rules of use and access and impacts of state (colonial and post-colonial) policies. Likewise, agriculture and forestry agents assigned to the area can provide insights into broader-scale planning and management efforts in the area. In the integrated studies, we only interviewed members of the socio-political unit within the study area, but in IFRI investigations they identify user groups that graze or harvest from the study area but who may reside outside of it. This is useful in capturing change in pressure on resources in the study area from non-local stakeholders, but challenging to identify. It takes a longer time to identify these informants. Subsequent studies on the mainland also used this approach of interviewing informants with longer-term experiences on the landscape, but including those with very local experiences, such as groups of smallholders, to broader scale experiences of regional chiefs or district forest officers.

Also, in our experience, informants could more readily orient themselves on a topographic map by finding key roads, administrative boundaries, and natural features than on a geo-rectified Landsat image. To aid in orienting them on the Landsat products, we overlaid the same roads and administrative boundaries found on the topographic map onto the most recently collected Landsat image. Once informants located themselves on the topographic maps in relation to roads and boundaries, they were asked to locate their current position on the Landsat image using these corresponding roads and administrative boundaries as references. Multi-temporal composites were very confusing to informants, more so than multi-spectral composites. It was discovered that multi-temporal composites could be a useful way for investigators to cross-check the statements by informants about changes in land-use practices occurring at specific times and places in the study area.

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 the 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 occurrence of different mechanisms of afforestation/reforestation and agricultural change than currently understood, has significant policy relevance.

Fortunately, advances in methodologies and their integration have lead to an ability to investigate specific cases 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.

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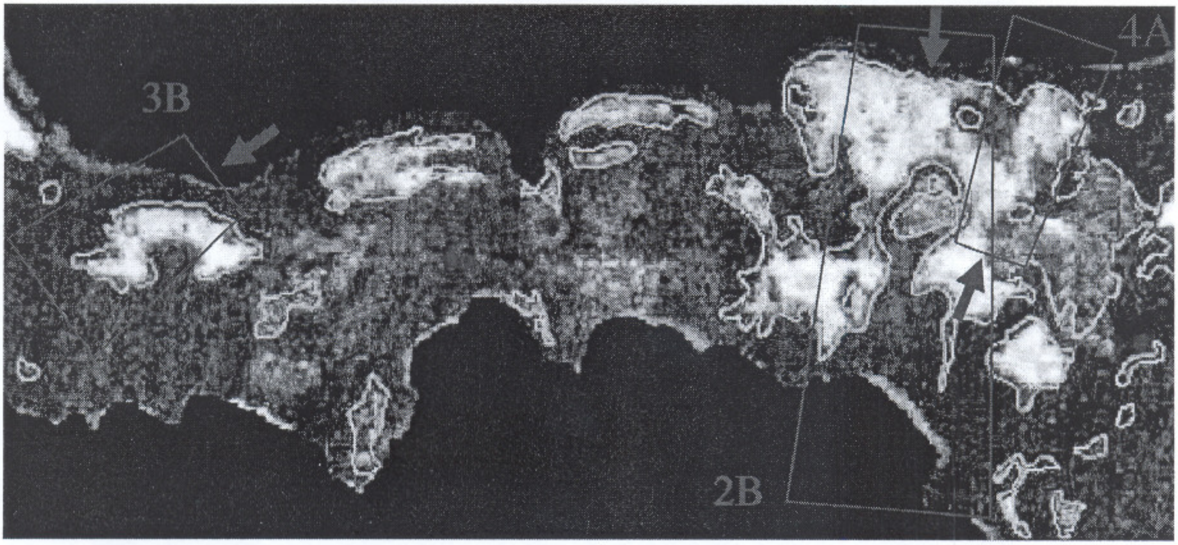

Plate 1. Multi-temporal color composite showing areas of stable land cover, forest loss, and forest gain on a portion of Bugala Island (see 'Figure 3' in Figure 1).

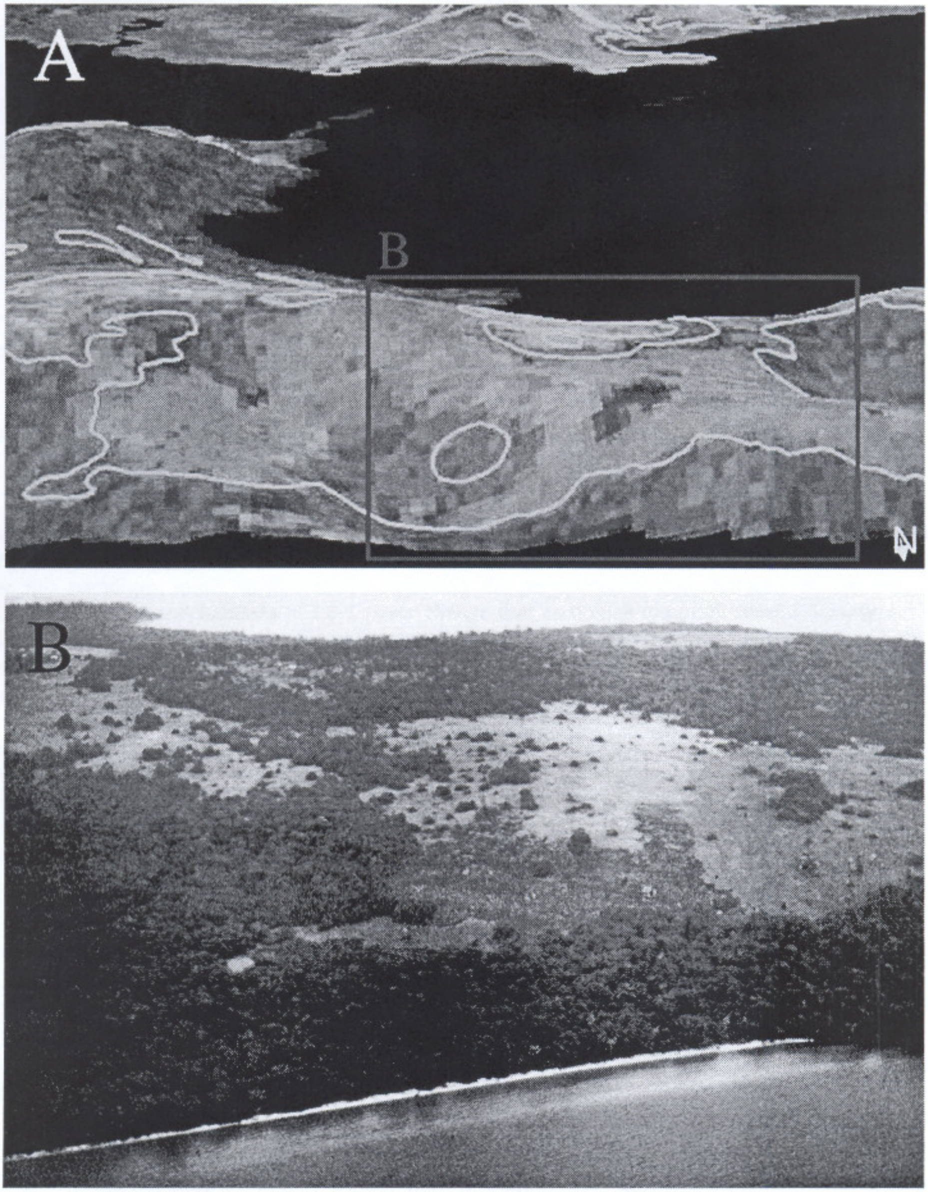

Plate 2. (A) A Landsat 5 Thematic Mapper image, acquired 19 January 1995, is draped over a 30-meter DEM.[4] The orange-colored areas within the yellow lines depict areas that have experienced woody plant growth between 1955 and 1995. The red box (B) frames the extent of the aerial photograph B. (B) An oblique aerial photograph, taken from the north in August 2001, which corresponds to box B in A and box 4B in Plate 1. 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.