LAND SUBDIVISION AND LAND USE CHANGE IN THE FRONTIER SETTLEMENT ZONE OF MOUNT MERU, TANZANIA

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ABSTRACT Taking an example from the frontier settlement zone of the mountainous areas in Arusha Region, Northeastern Tanzania, this study examines whether and how far land subdivision information can illuminate the way in which rural livelihood transformation has been reflected in land use at the local, land parcel scale for the period from 1962 to 2008, with a general scarcity of longitudinal information on the livelihood of rural households. It combines the reconstruction of the land subdivision process by way of Differential Global Positioning System land parcel measurements and interviews with smallholders on changing land ownership on the one hand, and the land cover/use analysis of aerial photo/satellite images on the other. Employing remote sensing and Geographical Information System techniques, the study identifies the land use patterns of particular households in particular years and examines the changes in relation to land subdivision, which is central to livelihoods. This study confirms that the initial expansion of home garden has stopped and that the land use pattern has begun to change in the reverse direction toward enlargement of cultivated open spaces, as previous studies have reported in an aggregated manner for the neighboring Kilimanjaro area. The present study also demonstrates that this process has developed along with land subdivision and is to be understood with the distinction between resident and non-resident use of the frontier zone.

Key Words: Land subdivision; Land use change; Local scale; Livelihood; Tanzania.

INTRODUCTION

The interaction between land cover/use change and livelihoods is an important theme for understanding the issue of rural poverty in the African context of both human-environment and local-global relationships. With a perspective of investigating the impact of world-system factors on land use in Northeastern Tanzania for the last 150 years, the study of region-wide "land cover and vegetation, as expressions of different political and economic structures in space and time, is gaining increasing attention in a variety of disciplines" to avoid simplistic explanations that rely on "short term data from localized studies" in understanding the causes of changes in land use/cover in terms of "population pressure or poverty" (Håkansson et al., 2008: 373). For example, in the recent context, such an important thesis as the coexistence of labor and land shortages in the North Pare mountains of the Kilimanjaro Region, where emigration of smallholders coupled with their traditional adherence to inherited land results in 'social fallow' and rural socio-economic decline (Maghimbi, 1992), is to be substantiated in a time-space setting. This requires both an examination of the physical changes in land cover/use and a socio-economic investigation on land inheritance and subdivision, and then putting this information together in a longitudinal context.

Currently in Northeastern Tanzania, livelihood diversification of smallholder households is a factor that may influence land use patterns. On the southeastern slopes of Mount Kilimanjaro, no substantial relationship was found between farm production levels and socio-economic variables, suggesting that various forms of livelihood diversification blur any single combination of assets and coping strategies of rural households that would lead to successful livelihood outcomes (Soini, 2005a). Soini (2005b) investigated the interaction between diversifying rural livelihoods and land use change in a concrete setting over four decades. In 1961, the highland area (1,200–1,800 m.a.s.l.) had small open fields of food crops and patches of grazing lands alongside home gardens planted with coffee and banana, which were integrated with multipurpose trees in a traditional agroforestry system. In 1982, the area was discovered to be more uniformly covered by home gardens. Grazing areas had disappeared as stall-feeding of dairy cattle became generalized and grain production moved down to the lowland (below 900 m.a.s.l.). As of 2000, the home garden area has once again become patchy, as new homesteads have been built on subdivided farms and food production has increased on the higher slopes, thus expanding cultivated open spaces. However, the significance of these revived open spaces in the highland zone is not clear, given that food crop production has largely shifted to lower areas (Soini, 2005b: 313). This general trend is apparently contradictory to the thesis that the recent establishment of new homesteads led to the expansion of agricultural open spaces in the highland areas, demanding further investigation as to its mechanism and implication for rural livelihood. The lack of additional space for new lowland plots close enough to the highland area may be one reason for this situation (ibid.: 313). When understood particularly in the context of agricultural and/or occupational diversification, differential access to non-farm income sources, for instance, may also play a determining role in the necessity to revive seasonal crop land at the expense of home gardens in the highland area.

The study of land use change tends to be undertaken at a more or less aggregated scale, without specifying a particular household that induced livelihood and land use change. Soini (2005b) provides an excellent case, where home garden areas were identified as patches with an average size of 7.6 ha in 1962, 27.4 ha in 1982, and 18.8 ha in 2000 (Soini, 2005b: 315). This is understandable when taking into account that the study objective was to examine a large part of the entire inhabited mountain slope and that a longitudinal approach to household investigation may not have been feasible owing to incomplete records and memories of smallholder respondents regarding their changing livelihood status connected to changes in local land use. The present study shares the same limitations, but aims to alleviate these by adding a specific aspect of livelihood change that is spatial and more readily and precisely known, i.e., the land subdivision process, and attempts to illuminate its relationship with land use change as identified by aerial-photo and satellite images, in a longitudinal manner.

This study examines whether and to what degree land subdivision information can explain the way in which rural livelihood transformation has been reflected in land use at the local, land parcel scale. The study area, the southern flank of Mount Meru in the Arusha Region, is another case from Northeastern Tanzania, which has equally experienced livelihood diversification mediated by different geographical conditions (Ueda, 2007). It is also likely that in the Meru case, the traditional home garden system has changed and livelihood sustainability is a serious concern, as for Kilimanjaro (Soini, 2005a: 164). This study expands upon an example from the frontier settlement zone located at a higher altitude and bordering the forest reserve and plantation, which still has space for human settlement and where the local Meru people began to use the land for cultivation and grazing before the 1960s. It is therefore expected that the frontier zone has undergone more substantial land use change. The study period was from 1962 to 2008. Information on socio-economic factors other than land subdivision that might have influenced changes in land use during the study period is difficult to collect, not available, or patchy at best for the entire research area and period. Therefore, this study provides a description of the relationship between land subdivision and use, rather than a full explanation. After confirming the tendency toward expansion of agricultural open space in the research area, this study focused distinctly on the land subdivision process at the local, land parcel scale, in contrast to previous aggregated studies on land cover/use change.

As a scale of analysis between the local community and the world system, "a *regional* historical approach to land cover changes provides an analytical field that can bridge the gap between local case studies and generalized macro-scale overviews" (Håkansson et al., 2008: 369). Nevertheless, a precise, longitudinal examination at the local scale is, as this study attempts to show, an indispensable part of the entire project. The broader changes in the political economy and their implication for local land use and livelihood in the research area are beyond the scope of this study, although these are partly discussed in a separate study in relation to economic liberalization (Ueda, 2007).

RESEARCH SETTING

This study focused on the changing land use pattern in a frontier settlement zone located in an area with declining production of mild Arabica coffee in Arumeru District in the Arusha Region of northeastern Tanzania (Ueda, 2007). Most of the regional population is concentrated in the vicinity of Mount Meru (4,565 m), especially on its more humid, southern flanks. This area is a relatively developed zone of the cash economy of Tanzania, where cash crops including coffee were introduced during the colonial era. The subsequent introduction of various crops shaped the history of indigenous agricultural intensification (Spear, 1997). The largely Meru-dominated villages extend to the upper, middle, and lower elevations of the mountain (900–1,800 m.a.s.l.).

The Meru people originated in the middle-tier villages and have a history of climbing up and down the mountain slope to find additional land for grazing, cultivation, and settlement, which is comparable to the Kilimanjaro case. The upwardly mobile settlement pattern, however, has been blocked by the forest

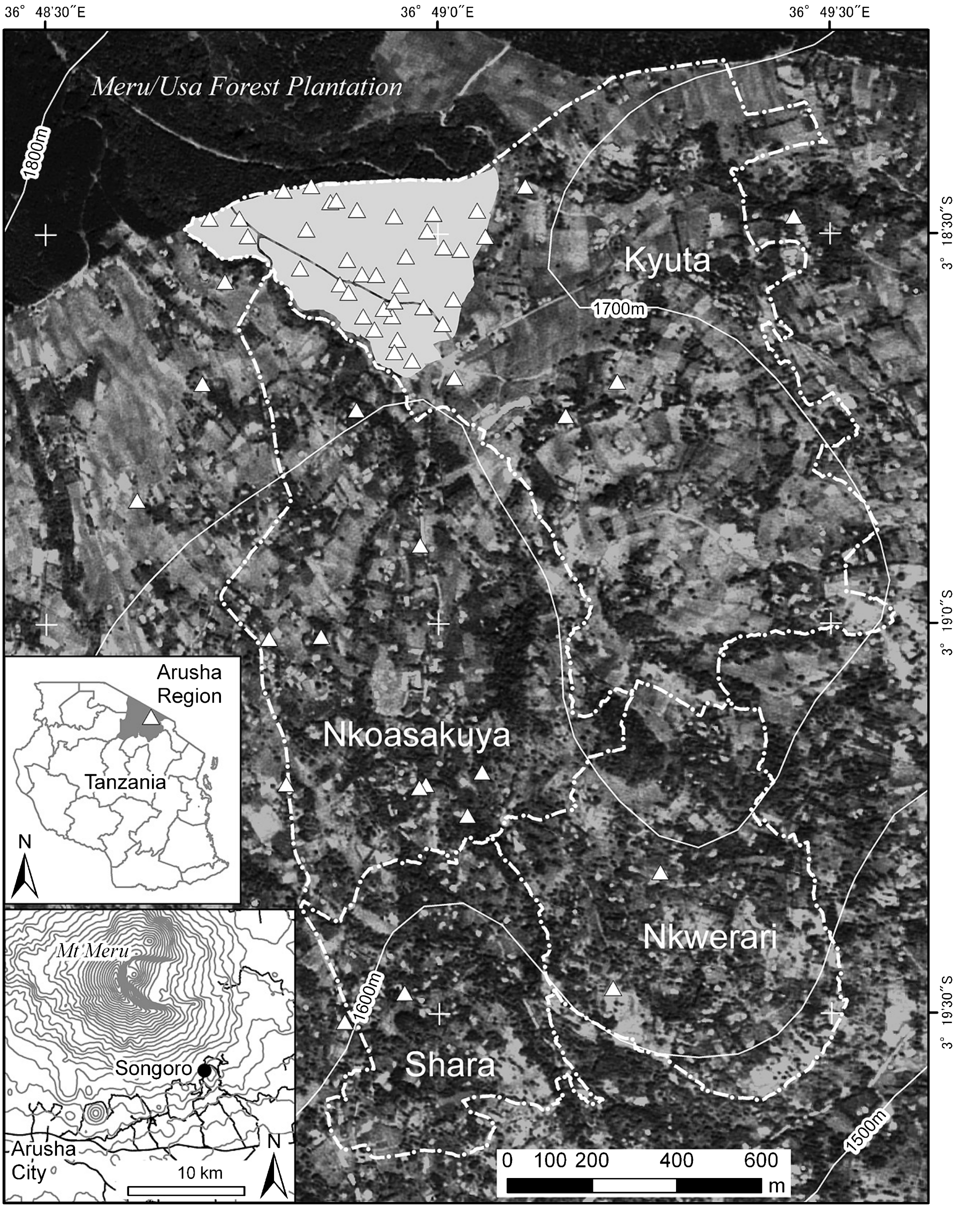

Fig. 1. Four Sub-Villages and the Research Area in Songoro Village, Arumeru District.
Note: The triangle symbols signify the locations of households with land inside the research area. Background image: SPOT panchromatic image of January 5, 2008.

reserve and plantations since colonial times. Located in the upper tier (1,600 m.a.s.l. or higher, with annual rainfall of approximately 1,500 mm), Songoro village is an uppermost spontaneous settlement, administratively registered in 1975. Kyuta sub-village, particularly its northern part, accommodates the frontier settlement zone bordering the forest plantation (Fig. 1). This study uses the triangular area

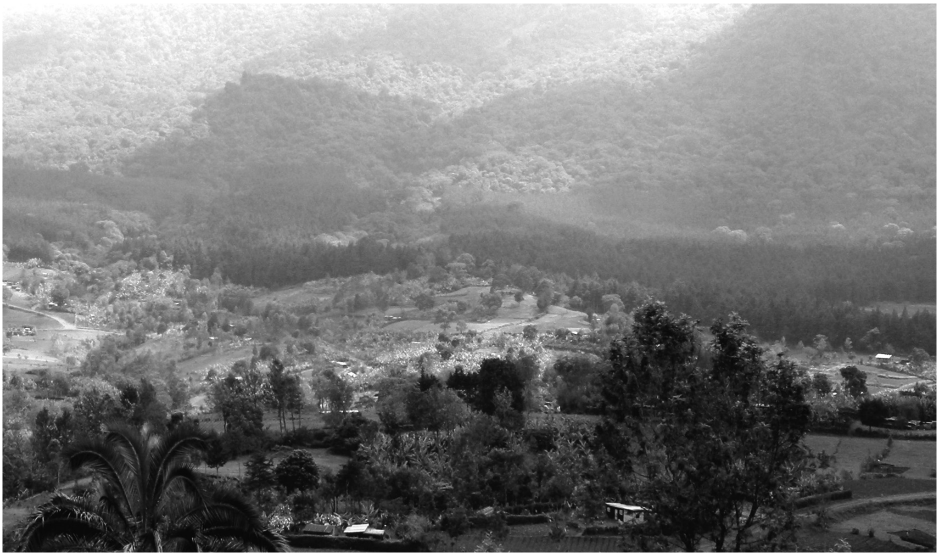

Photo 1. The Frontier Settlement Zone, Songoro Village.
Note: The research area spreads from left to right, bordering the Meru Forest Plantation and the Forest Reserve. Photographed by the author from a hill in the village on August 8, 2008.

delimited by a ravine, which is part of the village/sub-village boundaries, a main path, and the border with the plantation. The search upward for land is seen even at the village scale; many Songoro households and some in other villages downward live outside of, and retain land in, the research area (Fig. 1). Before the introduction of improved dairy cattle in the 1950s, local inhabitants began to clear this zone and use it for grazing of indigenous livestock and seasonal cultivation of food crops. This study examined the changing land use pattern in a part of this frontier zone. The population in Songoro was reported as 875 in 1978 (Tanzania, 1981), 1,514 in 1988 (Tanzania, 1991), and 1,485 in 2002 (Tanzania, 2005). Thus, the population has been approximately stable for the last two decades, implying substantial out-migration; this may be a situation comparable to that in which Maghimbi (1992) indentified the coexistence of labor and land shortages.

The research area in this study has also faced the same challenges that Soini (2005a; 2005b) pointed out for the Kilimanjaro case, including decreasing farm size attributable to population pressure and low coffee prices. However, the retreat from coffee production has been relatively less compared with that of the main production area expanding at the lower altitudes (around 1,500 m.a.s.l.), where smallholders have responded to new opportunities to produce more vegetables and milk as cash income sources. Therefore, the geographical incidence of the retreat from coffee production and the possible and/or adopted livelihood strategies are not uniform, and the extent of deagrarianization has been, on the whole, insignificant and economically stratified (Ueda, 2007). Coffee trees coupled with banana plants are still an important component of the home garden in Songoro. Furthermore, relatively land-rich households of younger generations have planted trees for timbers, while using pruned branches as firewood (Ueda, 2009). Along-

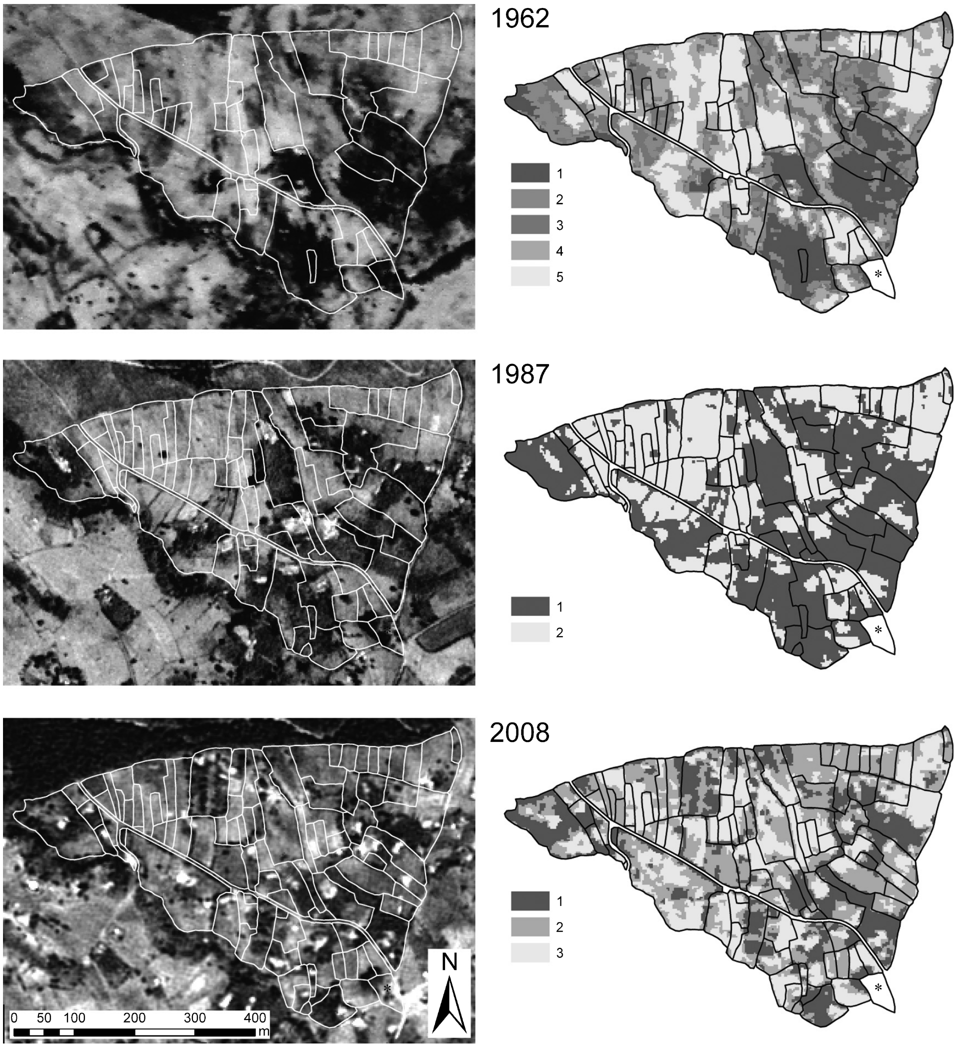

Fig. 2. Land Subdivision and Land Use in the Research Area, 1962–2008.

Note: The left column shows the three original aerial-photo/satellite images, and the right column contains the result of land use clustering, both of which have the land parcel boundaries in each of the three years. Boundaries of each of the 5,393 image objects are not shown for the convenience of visual interpretation, but they are partly distinguishable where they adjoin objects belonging to different clusters. Land parcels were already fragmented and complex by 1962, with a few enclaves. The latter cases in particular may be due to possible confusion by the respondents when recalling the sequence of owner households; this is likely because they attempted to specify a particular owner household at a particular year among those that were related to one another. A land parcel (∗) was excluded from the analysis because it was part of the village land. See Table 1 for the interpretation of land cover/use for each cluster.

side the land subdivision process, these potentially "greening" factors of the village environment may play a role in the frontier zone that used to be seasonal open spaces for grazing and cultivation (Photo 1).

METHOD

I. Data Preparation

To examine the relationship between the land subdivision process and land use change, the boundaries of individual land plots were located and traced using a Differential Global Positioning System (DGPS). This technique employs two GPS machines, one acting as a "base station" at a known location and the other collecting data in the field (rover data). These data were then processed using a Geographical Information System (GIS). This study employed two portable 12-channel GPS receivers (MobileMapper Pro and MobileMapper 6; Magellan Navigation, Inc., Santa Clara, California, USA), which provided sub-meter accuracy using post-processing differential correction(1). The receiver was set to attempt a GPS fix every five seconds while moving along the boundaries of land parcels. The information collected for each land plot included the personal and clan names of the owner, the year and modes of land acquisition, the relationship between the current and previous owners, and their current residential place. Family genealogies were also disclosed in additional interviews, in order to reconstruct the land subdivision process. Using this information as of August 2010, the land boundaries in 2008, 1987, and 1962 were retrospectively delineated, merging subdivided land parcels back into the original state for each year (Fig. 2). Using GIS, the boundary traces were overlaid on the geo-referenced aerial photographs and on a satellite image taken in each of the above three years, so as to measure the changes in land use composition over time and investigate the effect of land subdivision, by inheritance and/or transaction, on land use change(2).

A pair of aerial photographs, taken on 31 January 1962 and on an unknown date in January 1987, was acquired for land use examination(3). A SPOT panchromatic image taken on 5 January 2008 (spatial resolution: 2.5 m) was used as the most recent image(4). It was therefore possible to monitor land cover/use changes in the research area over a period of 46 years. For the three images, a set of 17 to 22 ground control points were identified within the research area, and the images were geometrically corrected and re-sampled at 2.5-m spatial resolution by applying a thin plate spline technique (nearest neighbor interpolation) to match the DGPS data(5). These three images were co-registered and subjected to analysis with the land boundaries. There was no cloud cover in any of the images.

II. Object-based Image Processing and Clustering

As part of object-based image processing, this study relied on an image segmentation technique, whereby an image is partitioned into groups of pixels that are spectrally similar and spatially adjacent by minimizing the within-object variability compared with the between-object variability. The object boundaries are derived as land cover/use polygons directly from the processed images and can be used in combination with other GIS information on boundaries of land parcels in this study. Another merit of this technique is that it is less sensitive to registration errors than traditional pixel-based analysis methods (Mäkelä & Pekkarinen, 2001). In this study, multi-date segmentation (Descleé et al., 2006) was applied to the three black-and-white aerial-photo and satellite images. The image objects were defined in a single operation from all three of the sequential images combined. This approach relies on spatial, spectral, and temporal information to delineate suitable land cover/use objects, so that pixels that are spectro-temporally similar in three-dimensional space are grouped together. Image segmentation also helped reduce the computation time for the land cover/use clustering procedure explained below.

Object delineation was achieved here using a general segmentation algorithm based on homogeneity definitions, as implemented in the Definiens commercial software (Definiens AG, 2006). This algorithm included three user-defined parameters. The spectral parameter, trading spectral homogeneity vs. object shape, was included to obtain spectrally homogenous objects while avoiding irregular or branched objects. The compactness parameter, trading compactness vs. smoothness, adjusts the object shape between compact objects and smooth boundaries. Finally, the scale parameter controlling the object size was selected corresponding to the threshold of heterogeneity (Descleé et al., 2006).

The scale parameter for image segmentation was set to 4, in order to obtain image segmentation with a minimum object size of 0.01 ha, or 16 pixels of the co-registered multi-date image. This enabled the identification of even a small grove and the generation of an image object that coincided with it; a larger scale parameter value might have merged a grove with its surroundings to create a spectrally heterogeneous object, which was undesirable for the purposes of this study. The spectral parameter was set to 0.9 in order to obtain very spectrally homogeneous objects, and the compactness parameter was set to 0.5 to equally balance smoothness and compactness. Although each band of the 3 years can potentially have a specific weight in the segmentation process, the same weight was considered for all bands in this study. The image segmentation procedure with these specifications subdivided the co-registered image of the research area into 5,393 land cover/use objects.

The mean values of these multi-date objects were calculated from their constituent pixel digital numbers for each of the three sequential image bands. This exploratory study did not take into account other properties of an image object, such as standard deviation of the pixel digital numbers, texture, and shape. Only the mean statistics were used to partition image objects into a land cover/use cluster of a particular year; as a result of this cluster analysis, three different cluster membership values were assigned to an image object after three separate clustering procedures. An unsupervised clustering method was applied because there was no additional information to enable a reliable and systematic way of training area setting and accuracy assessment for a supervised classification.

The determination of the optimal or appropriate number of clusters has been a difficult and controversial issue in unsupervised cluster analysis, and one of the most popular methods, K-means clustering, relies on guessing a pre-specified number of clusters and has known issues, including the "local minimum" problem (Pelleg & Moore, 2000; Pham et al., 2004; Wang et al., 2006; Chang et al., 2010). Given that the number of clusters, or how to partition the entire image to draw a land use map, greatly affects the conclusion on land use change, it is essential to avoid subjectivity as far as possible in the clustering process. This study used a non-parametric clustering method based on local shrinking (Wang et al., 2006; Chang et al., 2010); this allowed automatic estimation of the number of clusters and obtained the final cluster partition without any input other than the stopping rule for computing convergence(6).

After attaining the final clustering result separately for each of the 3 years, which may not necessarily have an identical number of land cover/use clusters, the clusters were numbered in increasing order of the mean digital number (reflectance) for the constituent objects, ranging from the lowest and darkest to the highest and brightest clusters (Fig. 2). The resultant land cover maps were then visually compared with their original photo/satellite images, and each land cover/use cluster was interpreted in terms of the following categories: grove, perennial farmland, seasonal farm/grazing land (open space), house and its immediate environs, and combinations of these categories. Transition matrices of land cover/use were computed from this information (Table 1). The fact that the number of clusters separately derived for each year may be different from one year to another is a disadvantage of the approach employed in this study, since a cluster of a particular year may include an unknown proportion of the land cover category that is excluded from a cluster of a different year with the same interpreted name. With no systematic way of conducting retrospective ground truth and upgrading the clustering result to the appropriate land use classification, however, this study avoids arbitrarily creating "pure" clusters for all years, thus allowing "mixed" clusters such as "Seasonal & Perennial".

III. Cross Aggregation of Land Parcel and Use

The image objects derived from the co-registered and multi-date segmented aerial photographs and satellite images were then aggregated by land use cluster for a particular year to calculate the area of each land use cluster within a particular DGPS land parcel of the same year. The result was used to compute the land use composition for each set of land parcels under a particular household for different years (Fig. 3 and Table 2), thus enabling an examination of the changing land use composition and an investigation of the effect of land subdivision for nearly five decades. It is noted that the accuracy of the answer given by a respondent as the year of land subdivision may be questionable because this totally relies on his or her memory. Moreover, there may be a time lag or discord between the land subdivision and use change. Therefore, the influence of the former as a factor for the latter may be imperfectly detected by this study. However, these difficulties are likely to be more or less avoided by the wide time intervals of more than 20 years among the three aerial-photo and satellite images.

Table 1. Land Use Transition Matrix: 1962–1987 and 1987–2008

(a1) (ha)

	Cluster no.	Visual interpretation	1987: 1 Grove & Perennial	1987: 2 Seasonal & House	Total	(%)
1962	1	Grove & Perennial	4.7723	0.5597	5.3320	(18.6)
	2	Perennial	2.8085	0.8070	3.6155	(12.6)
	3	Seasonal	2.2416	2.4040	4.6456	(16.2)
	4	Seasonal	2.7203	4.0070	6.7273	(23.4)
	5	Seasonal & House	2.1505	6.2363	8.3867	(29.2)
	Total		14.6931	14.0140	28.7071	(100)

(a2) (%)

	Cluster no.	Visual interpretation	1987: 1 Grove & Perennial	1987: 2 Seasonal & House	Total
1962	1	Grove & Perennial	89.5	10.5	100
	2	Perennial	77.7	22.3	100
	3	Seasonal	48.3	51.7	100
	4	Seasonal	40.4	59.6	100
	5	Seasonal & House	25.6	74.4	100
	Total		51.2	48.8	100

(b1) (ha)

	Cluster no.	Visual interpretation	2008: 1 Grove & Perennial	2008: 2 Seasonal & Perennial	2008: 3 Seasonal & House	Total
1987	1	Grove & Perennial	5.7639	5.8269	3.1024	14.6931
	2	Seasonal & House	2.1991	5.6794	6.1355	14.0140
	Total		7.9630	11.5063	9.2378	28.7071

(b2) (%)

	Cluster no.	Visual interpretation	2008: 1 Grove & Perennial	2008: 2 Seasonal & Perennial	2008: 3 Seasonal & House	Total
1987	1	Grove & Perennial	39.2	39.7	21.1	100
	2	Seasonal & House	15.7	40.5	43.8	100
	Total		27.7	40.1	32.2	100

LAND SUBDIVISION AND CHANGING LAND USE

I. The Trend in Aggregation

The number of households with land in the research area in August 2010 was 55, of which 34 were residents and 21 were non-residents. The households under consideration had 91 land parcels in total: 76 were inherited, 12 were purchased, and three were of unknown acquisition. A respondent recalled that in 1962, the year following the independence of Tanganyika (the present Tanzania mainland), only several households resided in this area. Land purchase goes back as early as the 1970s, when some households bought land from those living in villages at a lower altitude. The research area had a total area of 28.7 ha, comprising 5,393 land use objects derived from the three photo/satellite images and excluding the area of major earthen roads. There has been no sign of "social fallow" land in the frontier settlement zone under consideration in 2010.

Overall, the initial increase in the area of Grove & Perennial land use, or home garden land use, between 1962 and 1987, and its subsequent decrease between 1987 and 2008 (Table 1) are most important. Grove & Perennial land use covered an area of 8.9 ha, or 31.2% of the total area, in 1962, expanded to 51.2% in 1987, and then decreased to 27.7% in 2008, which was below the initial level. Between 1962 and 1987, the Seasonal Farmland use clusters dramatically decreased in absolute area, contributing to the expansion of Grove & Perennial clusters, and there was a lesser shift from Seasonal & House to Grove & Perennial land use. This trend reversed between 1987 and 2008, as only 39.2% of the 1987 Grove & Perennial area maintained its status in 2008; the other image objects belonged to Seasonal or Seasonal & House land use clusters. It is noted that the shrinkage in Grove & Perennial land use between 1987 and 2008 may be exaggerated, because only two land use clusters were found in 1987, possibly making them internally more heterogeneous than the clusters of the other two years, and because visual interpretation of the SPOT image determined that the 2008 Cluster 1 (Grove & Perennial) left out a small, but unknown, proportion of image objects under perennial crops that was statistically attached to Cluster 2. Meanwhile, the changing balance between the Seasonal and Seasonal & House clusters from year to year may largely reflect different stages of the same seasonal land use mainly for cropping, rather than implying drastic expansion or shrinkage of house building sites themselves. The following examination focuses on the changing proportion of Grove & Perennial objects.

The initial increase in home garden land use can be characterized as "greening of the land at the expense of seasonal crop production" following human settlement and population increases. However, home gardens constituted only half of the entire research area at most, and the remainder was still seasonal open spaces, which became larger by 2008. The second phase of shrinking home gardens coincided with the subsequent population stabilization along with emigration and shows at the local, disaggregated scale the same tendency that Soini (2005b) reported for the Kilimanjaro case. To look deeper into this process, the next section focuses on land subdivision and differentiation in land use change between resident and non-resident households in the research area.

II. Individual Shift at the Land Parcel Level

The effect that land subdivision and the establishment of homesteads had on land use is appropriately understood only when examined at the local, land parcel level. The image objects derived from the earlier analysis were aggregated by land use cluster for a particular year, to compute the area of each land use within a particular land parcel of the same year. The results were used to investigate the changing land use composition for each set of land parcels under a particular household as land subdivision proceeded.

As a land parcel was subdivided into smaller parts through inheritance and transaction, ownership of the parcel might have partially or entirely changed. Regardless of possible changes in ownership, the land use composition or pattern

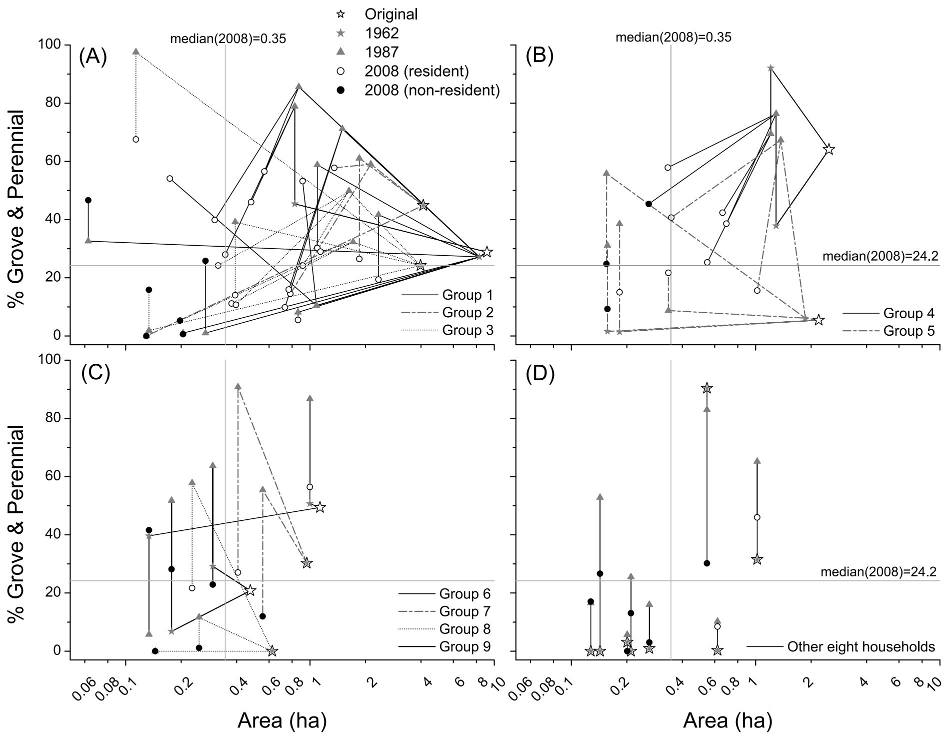

Fig. 3. Size and Home Garden Component of Land Parcels by Household, 1962–2008.

Note: The symbol for "original" indicates the 1962 state of all land parcels combined that had been owned by a single household before 1962. The symbol for "1962" shows the 1962 state of the parcels controlled by households in 1962. For original parcels that had already been subdivided by 1962, this symbol appears for each subdivided parcels, each of which is connected to the "original" symbol to show the derivation relationship, using plural lines from a symbol. The same applies to the symbols for "1987" and "2008." Unfilled 2008 symbols indicate that the owner resided on the land in 2008, and filled 2008 symbols indicate a non-resident case. The nine groups of households (Groups 1 to 9 in A, B, and C) are numbered in decreasing order of total area of land parcels controlled by each.

of a particular land parcel in the past can be compared with that of the smaller parcels derived from the original, and the examination of the process can illustrate the subdivision effect on land use. Fig. 3 indicates the total area of land parcels controlled by different households and their changing proportion of Grove & Perennial home garden use as land subdivision continued. Groups 1 to 9 (Fig. 3A, B, & C) were discovered to have begun using the land in the frontier zone before 1962 and experienced subsequent land subdivision due to inheritance and/or transaction; the current holders are not necessarily relatives of the original land owners, although those who bought land were a minority as mentioned earlier. For these cases, the relationship between land subdivision, diminishing area of household land, and the changing proportion of home garden land use can be examined. An additional eight households (Fig. 3D) were identified as those that did not divide their land during the entire research period, and thus factors other than land subdivision explained their land use change.

Groups 1, 2, and 3 (Fig. 3A) are the top three groups of households that have controlled relatively large tracts of land, 9.1, 4.1, and 4.0 ha, respectively, in the research area. These tracts have undergone land subdivision equally since 1962, and most households that inherited or bought land parcels from the original three maintained their land that was less than 1.0 ha in 2008. For these three groups, the first phase between 1962 and 1987 saw both land subdivision and overall increase in the proportion of Grove & Perennial land use; this is interpreted as the process of converting seasonal open spaces for cultivation to the homestead and home garden for human settlement, as household members increased and some became independent with inherited land parcels. Further subdivision from 1987 to 2008, however, did not realize the same “greening” effect; the home garden component diminished in most cases. It is also clear that those households residing outside their land holdings in the research area had land below the median area in 2008, implying that their land was too small to establish a homestead and home garden and that it was mainly kept as a seasonal field for non-resident cultivation.

Group 4 (Fig. 3B) controlled 2.5 ha of land in the research area. Its experience since 1962 is comparable to that of Groups 1, 2, and 3, and can be summarized as land subdivision and an initial increase in the proportion of home gardens, followed by a general decrease in home gardens as subdivision proceeded. Meanwhile, Group 5 (Fig. 3B), managing 2.2 ha, started with a distinctly low home garden proportion; the proportion expanded slightly before being minimized through subdivision by 2008. The reason why this group did not maintain a greater proportion of home gardens is not immediately clear. The land owned by Groups 6 to 9 (Fig. 3C) ranged from 1.1 to 0.5 ha; these groups experienced fewer instances of land subdivision, possibly because of their land areas were so small. In these groups, the home garden component became generally smaller by 2008, in the same manner as for Groups 1 to 4. Finally, the distribution of the other eight households that did not subdivide their land during the research period (Fig. 3D) were skewed to smaller, relatively less “green,” and non-resident land parcels in 2008. Although some of them experienced increase in the proportion of the home gardens above the original minimal level, they had only small areas of land in

Table 2. Summary of the Relationship between Size, Home Garden Component, and Residence, 2008

(Unit: household)

Area (m^2)	% grove & perennial	Resident				Non-resident				Total
		Subdivision frequency (time)				Subdivision frequency (time)				
		0	1	2	3	0	1	2	3	
median ≦	median ≦	1	3	8	3	1				16
	<median	1	1	6	3		1			12
<median	median ≦		1	1	2	1	2	4		11
	<median		2	2		4	6	2		16
Total		2	7	17	8	6	9	6	0	55

Note: The median values for the land parcel area owned by households in 2008 and for the area percentage designated as Grove & Perennial home garden land use are provided in Fig. 3. The subdivision frequency shows the times of land subdivision between 1962 and 2008, resulting in the land owned by each household in 2008.

the research area especially if they lived outside their land holdings in 2008.

The "greening" of the land proceeded as people continued to settle on the subdivided land, developing home gardens around their houses at the expense of seasonal cultivation of some food crops, which then had to be procured from other places. Table 2 summarizes part of this process in an aggregated way for 2008. Most households, 26 of the 28, with land areas equal to, or larger than, the median area resided there in 2008 (Table 2). Their land subdivision experience was more frequent, beginning with a larger landholding in the past, and 15 resident households exhibited a percentage of "greener" land that was at or above the median percentage. However, the existence of sizable minority households (11) that settled in larger land areas with below median "greenness" means that other socio-economic factors, possibly related to land availability outside the frontier zone and different patterns of agricultural and livelihood diversification, may play a decisive role in differentiating these households from the "greener" households with land of the same size range.

For cases in which the total area of land parcels controlled by a single household was smaller than the median value of the entire distribution, 19 (70%) of the total 27 households did not live there; in 12 cases, the percentage of Grove & Perennial land use was also below the median. This group of households had less frequent land subdivision in the past, indicating that their landholding in the research area had been very small from the beginning and was continuously meant for seasonal crop production, rather than for their own settlement and subsequent "greening" with home gardens. Although there are some cases of increasing home garden composition, the percentage is low, as pointed out earlier (Fig. 3D). Meanwhile, four of the eight households that resided on smaller land areas after more frequent subdivision rendered their land "greener" than the majority of households residing outside their land holdings, in the frontier zone (Table 2). Considering these cases of smaller and "greener" land areas of resident households together with the resident households controlling larger land areas examined above, it is hypothesized that the size of the area mediated by a residence is a determinant factor of a relatively larger home garden. Nevertheless, it is clear that this is true only to a certain point in the scale of land parcel size and/or according to past time periods, beyond which home gardens began to shrink, suggesting a major shift in livelihood strategies more or less away from perennial crops. It may also be that seasonal farmland, which non-resident smallholders managed in the research area, contributes to the maintenance of home gardens elsewhere. The mechanism of diminishing home gardens in a locality should be understood in a broader context of land availability in other localities.

CONCLUSION

Although by no means straightforward, what has occurred in the research area as a whole is the initial expansion of home garden land use at the expense of seasonal open spaces, followed by a second phase of home garden shrinkage. This apparently coincides with what Soini (2005b) found in the Kilimanjaro case. What is different, however, is the relative smallness of the total home garden area. This may be partly because of the difference in the spatial scale of consideration and partly due to the nature of the research area of this study, where the land still has room for additional settlement and home gardens. The case examined here also suggests in a more detailed manner that not all land in the frontier settlement zone was turned into home gardens in the first phase, and that the limit to home garden expansion was set by the maintenance of smaller, non-resident seasonal farmland, as well as by the changing necessity for residents to keep seasonal farmland as land subdivision and size reduction continued. On the other hand, the shrinkage in home gardens in the second phase is partly an aspect of the subdivision-induced land use change in resident land parcels. Putting aside the relationships among land subdivision, diminishing land size, and land use change, this study is inconclusive as to the roles of other socio-economic factors that might have contributed to changing land use for the entire research period. Further study should be given to the reality of land subdivision and ownership, in particular, the implication of the more recent shrinking process for different households of the mountainous areas in northeastern Tanzania; this may reflect the diminishing importance of coffee production that once pushed out subsistence food crop production down to lower areas. Nonetheless, this study showed the importance of land subdivision in the longitudinal analysis of land use change at a local scale, particularly when socio-economic histories of households are not readily available or are difficult to obtain.

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NOTES

(1) The average positional dilution of precision (PDOP) was 2.2, which indicates a wider GPS satellite spacing and high location accuracy on the ground during the field survey (D'Eon & Delparte, 2005). The average horizontal root mean square (RMS) error was 0.8 m.
(2) All remote sensing and GIS processing in this study were conducted with PCI Geomatica Version 9.1 and ESRI ArcMap Version 9.2, except object-based image processing, which was done with Definiens Professional 5. The non-parametric clustering method based on local shrinking was conducted using the "clues" package (Chang et al., 2010) of R (R Development Core Team, 2010).
(3) All of these and other aerial photographs mentioned in this note were available at the Map Office, Surveys and Mapping Division, Ministry of Lands, Housing and Human Settlements Development, Dar es Salaam, in August 2009. The information for the selected two photos is as follows. 1962 photo: 60TN6; 31 January 1962; 25,000'; 6"; No. 024 (the original negative film was not kept in the office, and a print was digitally scanned at 1,200 dpi). 1987 photo: J800 Mt. Meru Forest; 201TN3; January 1987; 1:30,000; SIDA, Run 4 exp 6214 (this was also printed and digitally scanned at 600 dpi). Two additional photos were also available, one from 1962 and one from 1982, but the print quality was not sufficient for use in the study. Their particulars were as follows. 1962 photo: VI 543RAF1615; 5 February 1962; 0625Z 6"; 23,000/34,000 Restricted; No. 0076 (the original negative film was missing). 1982 photo: D.O.S. Contract 201; TN3; 7040 m (23,000 ft) AMSL; 85–529 mm; 20 December 1982; No. 091 (the print was digitally scanned at 600 dpi). Another film (No. GS.I-49/March 1971; Scale 1:25,000/RC.10/87.88 mm/CFL) only covered part of the area of interest and so was not used (this was also available only in printed format).
(4) The Scene ID of the SPOT panchromatic image is 5 140–357 08/01/05 07:41:45 2 T.
(5) First, orthorectification was attempted on each photo based on the camera calibration information, the SRTM-3 DEM (spatial resolution: 90 m) and the 2008 SPOT panchromatic scene (Level 2A) as a geo-referenced image. However, the processed images did not coincide well with the land boundary polygons created from the GPS fixes, arguably due to the combination of the very rough terrain in the research area, low spatial resolution of the DEM used, and limited quality of the Level 2A orthorectified SPOT scene, especially at the local scale. Orthophoto generation from the stereo pair of aerial photographs was another option, but the priority was to overlay, with good precision, the GPS fixes on the research area. The thin plate spline method satisfactorily accomplished this. The Level 1A SPOT scene was also geometrically corrected and used to overview the research area and its surroundings at the village scale (Fig. 1).
(6) The strength measure (compactness of the clusters), which the algorithm maximized while analyzing the data and upon which the final partition depended, was set to the "silhouette index," and the Euclidean distance was used as the dissimilarity measure, among other default settings of the "clues" package of the R statistical language (Chang et al., 2010). The use of the Calinski and Harabasz (CH) index as the strength measure tends to generate many clusters (Wang et al., 2007: 295, 297), and this was also the case in this study, resulting in unnecessary and inappropriate partitioning; thus, the results were not used.

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