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Multi-Level Land Cover Change Analysis in the Forest-Savannah Transition Zone of the Kintampo Municipality, Ghana

Raymond Aabeyir [ab]*, Wilson Agyei Agyare [c], Michael J. C. Weir [d] and Stephen Adu-Bredu [e]

[a] WASCAL Graduate Research Programme, on Climate Change and Land Use, KNUST
[b] Department of Environment and Resource Studies, UDS-Wa Campus, Ghana
[c] Department of Agricultural Engineering, KNUST, Kumasi, Ghana
[d] Department of Natural Resources, Faculty of Geoinformation Science and Earth Observation (ITC), University of Twente, the Netherlands
[e] Biodiversity Conservation and Ecosystem Services Division, Forestry Research Institute of Ghana, Kumasi, Ghana

* Corresponding author: raabeyir@uds.edu.gh raypacka2012@gmail.com

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Abstract

This study presents a multi-level analysis of land cover change in the Kintampo Municipality of Ghana using Landsat TM, ETM + and Landsat 8 images from 1986, 2001 and 2014, respectively. The expected and observed annual rates of land cover change for the periods 1986 to 2001 and 2001 to 2014 were analyzed at temporal and intra and inter-land cover levels using post-classification change detection. The results reveal that the expected annual rate of land cover change for the time intervals is 2.55 %. The observed annual rate of change from 2001 to 2014 is 2.63 %, which is greater than the expected value. This shows that land cover changed faster than expected in this period. The observed intra-land cover gains and losses for woodland is 2.49 % which is less than expected for the change periods. This suggests that the observed gain and loss in woodlands are attributable to random changes. The inter-land cover level changes for both periods reveal that when woodland gained or lost, it did not target shrub/grassland. This shows that the process of gain or loss in woodland in both periods was random. This is an indication that woodland cover is sustained by a slow, natural regeneration process and not by anthropogenic activities. The findings highlight the relevance of multilevel land cover analysis in land cover assessment. The temporal level highlights the need to relate changes in land cover to anthropogenic activities for a better understanding of the changes. The study also revealed that multi-level land cover analysis can facilitate management decisions on whether to reduce loss in woodland or increase gain in woodland cover from shrub land.

1. Introduction

Land cover change arises from both natural and anthropogenic causes. In general, the former is progressive and gradual while the latter is often rapid and sudden due to increasing population pressure **[1]**, **[2]**. Anthropogenic land cover change poses a threat to the global natural environment because of the rapid nature of how it occurs, thus making it the most prominent form of global environmental change occurring at both a spatial and a temporal scale **[3]**. Anthropogenic land cover change is often a reflection of the most significant impact of human activities on the environment, especially in fragile ecosystems **[4]**, **[5]** **[6]**.

The current pace, magnitude and spatial extent of land cover change are unprecedented and significantly affect key aspects of Earth System functioning, notably climate change and ecosystem services **[7]**, **[8]** **[9]**. It has been observed that about one third of the earth surface is affected by human modifications **[10]**, **[11]** and the modifications are still on-going as population and the resulting demand for land continue to increase **[12]**. On-going anthropogenic land cover change occurs at a rate of 13 million ha year-1, with serious consequences for climate change **[11]**. Consequently, the analysis of land cover changes at global, regional, national and local levels is viewed as a critical step to policy decisions on climate change, adaptation and mitigation activities. Despite the critical role land cover analysis plays, many land cover change analyses (**[6]**, **[13]**–**[18]**) have focused on the identification of patterns of change and simple quantities of change, which often leads to a simplistic understanding of land cover dynamics **[19]**, **[20]**. Such land cover change analyses normally fail to highlight temporal, intra and inter-land cover changes, which are relevant for policy makers as they indicate the nature and direction of the change among land cover types, and whether the land cover change is driven by a systematic or a random process **[19]**–**[22]**, **[21]**. The direction of land cover change must be identified before any causal relationship can be postulated **[23]**.

The objective of this study is to assess the temporal, intra and inter-land cover transitions in the Kintampo Municipality of Ghana for the period between 1986 and 2014. The Municipality is known for commercial charcoal production and farming in Ghana **[24]**. Woodland degradation in the Municipality is largely attributed to commercial charcoal production and farming **[24]**. Therefore, increasing charcoal production and farming activities is currently exerting undue pressure on the already stressed woodlands **[25]**. As observed in a similar charcoal producing and farming community, charcoal production and farming have dictated and continue to dictate the state of land cover due to economic desperation and a need to meet immediate income needs **[26]**. This raises questions about changes in land cover over time in the municipality.

Thus, assessment of temporal, intra and inter-land cover change is relevant for identifying the interval within which these changes are fast, the land cover types that are gaining or losing more than what is expected under a random process of change, the sources and destinations of the gains and losses in each land cover type and whether the losses are random or systematic. This information is critical to decision makers to ensure that policies are formulated to target systematic processes of land cover change and not random processes. Furthermore, understanding each level of transition is important for climate change mitigation programs, such as Reducing Emissions from Deforestation and forest Degradation coupled with enhancing existing carbon stock (REDD+) **[27]**, **[28]**. For instance, the UNFCCC is yet to specify exactly what land-use reforms and activities will be promoted and rewarded under a future REDD+ mechanism. Taking such decisions depends on the availability of information from land cover assessments **[29]**.

2. Material and Methods

2.1 Description of the study area

The study was conducted in the Kintampo Municipality of the Brong-Ahafo Region, Ghana. The municipality lies between latitudes 7° 45′ N and 8° 50′ N and longitudes 1° 0′ W and 2° 15′ W (**Figure 1**) with a total surface area of about 5,108 km^2. It shares boundaries with the Central Gonja District to the North; the Bole District to the West; the East Gonja District to the North-East; the Kintampo South District to the South; and the Pru District to the South-East. The mean annual rainfall is between 1000 mm and 1200 mm and occurs in two seasons; May to August as the major rainy season and September to October as the minor rainy season **[30]**. The mean monthly temperature ranges from 30° C in March to 24° C in August, with a relative humidity varying from 90 % to 95 % in the rainy seasons and 75 % to 80 % in the dry season. The Municipality is part of the Forest-Savannah transition zone of Ghana, located between the Forest ecological zone in the south and the Savannah ecological zone in the north of the country **[31]**, **[32]**, **[4]**. However, the vegetation has more savannah-like characteristics compared to forest characteristics because it has lost most of its original forest cover due to anthropogenic activities **[31]**, **[4]**. Kintampo Municipality has a total population of 95,480 with a growth rate of 2.6 % **[32]**. The Municipality is a net receiver of immigrants, mainly settler farmers and charcoal producers **[33]**. Farming and charcoal production are major economic activities in the rural communities of the municipality **[25]**. About 71.1 % of the total working population is employed in agriculture and charcoal production and 28.9 % in commerce, industry and services **[33]**. The study site within the municipality was selected on the basis that Kintampo, the municipal capital, is expanding at a fast rate to accommodate the increasing number of immigrants. Furthermore, Asantekwa, Kunsu, Babatokuma, Attakura and Dawadawa are major farming and charcoal producing communities. Expansion of the municipality, and the increasing expansion of farmlands and charcoal production influence the dynamics of the vegetation cover of the area at different levels (temporal, intra and inter-land cover), hence the need to conduct a multi-level land cover assessment of the area.

2.2 Description of Images and Software

Landsat TM, ETM + and Landsat 8 images from 1986, 2001 and

2014, respectively, were used for the study based on a combination of the following considerations: cost of acquiring alternative high resolution images, availability of images covering the study area, appropriateness of the spatial resolution and temporal interval for change detection analysis **[34]**. Long time periods such as 10 – 11 years are often best for describing long-term changes such as woodland degradation due to logging and woodland recovery **[34]**. Charcoal production and farming being major drivers of land cover change in the Kintampo Municipality, an interval of 10 years was considered appropriate for this study. However, due to unavailability of cloud-free satellite images of the study area, it was not possible to use a ten-year time interval. The same limitation also resulted in the unequal time interval for the two periods. The difference in the time interval was accounted for by normalizing the extent of the changes in land cover. They were downloaded with path 194 and row 054 from the Global Land Cover Facility (GLCF) website. The 1986, 2001 and 2014 scenes were captured in the dry season on 11th November 1986, 12th January 2001 and 26th December 2014, respectively. The Landsat TM and ETM+ images are cloud free while the Landsat 8 image has 0.14 % cloud cover, which extends to a portion of the study area (**Figure 1**). Color Infrared band combinations of Red, Green and Blue (RGB) were used. Band combinations of 432 for Landsat TM and 543 for ETM+ and Landsat 8 were used for the image composite. These band combinations discriminate vegetation well **[4]**. Google Earth images, WorldView-2 images acquired on 12th January 2014, 14th February 2011, 2nd April 2015 and 6th April 2012 and Quickbird images acquired on 13th March 2012 from DigitalGlobe Foundation were used to validate the resulting classified images from 1986 and 2001. Remote Sensing software was used to process and classify the images and perform the change detection, and Geographic Information System (GIS) software was used to process and add map properties to the classified and changed images.

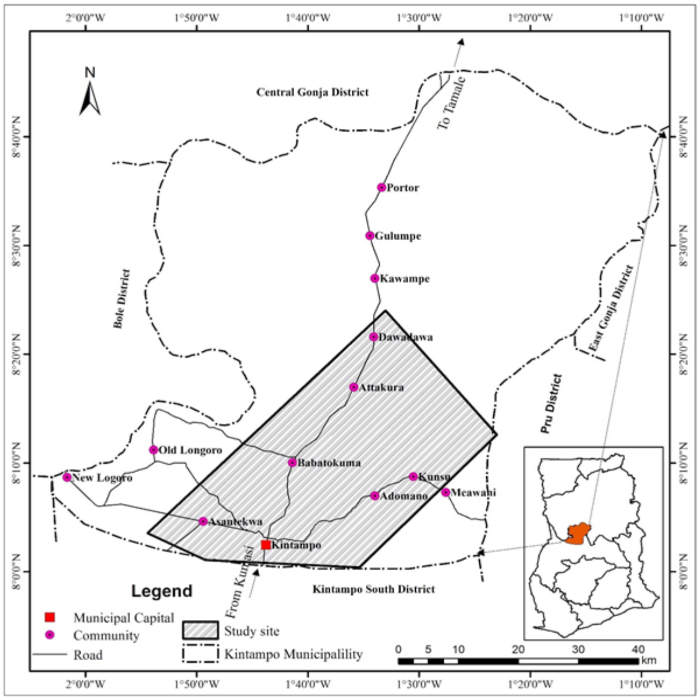

Figure 1: Kintampo Municipality. Adapted from **[30]**

2.3 Image Processing

Radiometric correction was performed to remove any inconsistency between spectral values captured by sensors and the spectral radiation brightness of the objects **[35]**. Misregistration can affect the accuracy of change detection results substantially. A misregistration of less than 0.2 pixel size is required to achieve a change detection error of less than 10 % **[36]**. The images were already geo-referenced to Universal Transverse Mercator (UTM) Zone 30 N. However, this geo-referencing was validated to check the geometric accuracies of the images. For this purpose, coordinates of well distributed 30 Ground Control Points (GCP), which were identifiable on the 2014 image, recorded with Garmin hand-held Global Positioning System (GPS) receiver (GPSmap 62s, Garmin, USA) were used. Of the 30 GCPs, 21 and 24 were identifiable on the 2001 and 1986 images, respectively. The extracted GCPs were road intersections, sharp curves and bridges across major rivers **[22]**. The Root Mean Square Error (RMSE) was computed using (Equation 1) **[37]**:

$$RMSE = \pm \sqrt{\left[\left(\sum_{i=1}^{n}(x-X)^2 + \sum_{i=1}^{n}(y-Y)^2\right)\Big/ n\right]} \qquad (1)$$

where (*X*, *Y*) and (*x*, *y*) are ground and image coordinates respectively and *n* is the number of reference points.

Generally, it is recommended that the RMSE of a good registration should be less than half a pixel **[22]**, **[38]**. However, Dai & Khorram **[36]** observed that for purposes of change detection, a registration accuracy of less than 0.2 pixel is generally required to detect 90 % of true change. The computed RMSE values were ± 5.1 m, 5.3 and ± 5.7 m for 2014, 1986 and 2001 images, respectively, which are less than 0.2 pixel size of the images used (30 m × 30 m Landsat image).

2.4 Description of land cover types

Three land cover classes, namely woodland, shrub/grassland, bare land/settlement were identified for the purpose of this study. Each of these classes is described in **Table 1**. Although it would have been desirable to separate grass land from shrub/fallow land, and bare land from settlement, farmlands and home gardens, this was not possible due the difficulty in separating them in the preliminary classification processes. This is because the images were captured in the dry season during which farmlands, home gardens and bare land appear similar, while fallow lands, shrub and grass also look similar. However, the three classes served the purpose of the study since the primary objective of the land cover assessment was to understand the transition of woodland to non-woodland.

Table 1: Description of land cover classes

Land cover type	Description
Woodland	Wooded land spanning more than 0.5 ha; with trees higher than 5m and a canopy cover of 5 – 10 %, or trees able to reach these thresholds in situ [39]. Dominant tree species are *Acacia sp., Anogeissus leiocrcarpus, Albizia coriaria, Daniellia oliveri, Pterocarpus erinaceus, Taminalia sp*.
Shrub/grass land	Refers to vegetation types where the dominant woody elements are shrubs i.e. woody perennial plants, generally more than 0.5 m and less than 5 m in height at maturity [39], [40]
Bare land/settlement	This cover type comprises built-up areas, bare or burnt farmland and open spaces [41].

2.5 Image Classification

Supervised classification was performed using Gaussian Maximum Likelihood Classifier (MLC) for the 2014 (Landsat 8) image. The MLC was trained with 100 land cover samples. One hundred and twenty (120) homogeneous pixels per land cover sample were selected on the image and assigned the appropriate class name. The MLC classifies an unknown pixel by computing and evaluating its probability of belonging to each land cover class defined during the training process and then assigns the pixel to the class for which it has the highest probability **[42]**. The MLC was chosen based on its advantages **[43]**, **[44]**. It quantitatively evaluates both the variance and correlation of a category of spectral response patterns when classifying an unknown pixel **[45]**, **[43]**. Atmospheric correction has little effect on the accuracy of a single date image classification using MLC provided both the image and training data are on the same relative scale (either corrected or uncorrected) **[44]**. Despite the advantages of MLC, its application requires that pixel values of the image and training samples are normally distributed. MLC provides good classification results of multispectral data, since it takes into account the shape, size and orientation of a cluster **[43]** in assigning an unknown pixel to a cluster.

A statistical unsupervised clustering algorithm, the Iterative Self-Organizing Data Analysis Technique (ISODATA) **[46]**, **[4]**, **[47]**, was used to classify the 1986 and 2001 Landsat images. The ISODATA algorithm requires three input parameters: number of clusters, the maximum number of iterations and the convergence threshold (the maximum percentage of pixels, whose class values were not allowed to change between iterations) **[46]**. The number of classes was set to 25, the number of iterations to 35 and the convergence threshold to 0.95. These values were set based on preliminary analyses of classification parameters, the results of the preliminary analyses and the literature **[46]**, **[47]**. The set values were considered optimum because they produced desired results and at the same time resulted in convergence during the preliminary analyses. The 25 intermediate classes were visually interpreted and reclassified into three land cover classes, namely woodland, bare land/settlement and shrub/grassland based on their spectral appearance on the image, knowledge of unchanged areas between 1986 and the time of data collection (2014) and interpretation of Google Earth images.

2.6 Accuracy Assessment of classified images

The accuracies of the 2001 and 1986 classified images were assessed with 50 ground truth points while the accuracy of the 2014 classified image was assessed with 165 ground truth points. The ground truth points used to assess the accuracies of the 1986 and 2001 images were picked in areas that remained unchanged between 1986 and 2014 at the time of the field work. Unchanged woodlands were found at cemeteries where cutting of trees is prohibited. Unchanged bare land/settlement areas were identified as the market center, old portions of the settlement, the primary school playing field and major road junctions. These unchanged areas were identified based on field observations and local knowledge from elderly community members. The GPS coordinates were pinned to Google Earth image of the area to validate the state of the current unchanged areas. The validated points were overlaid on the classified image for 1986 and 2001 to check the agreement between the land cover classes observed and the classified images **[48]**. Out of 50 ground points, 43 and 39 points were in agreement with the 2001 and 1986 classified images, respectively. Seven and eleven points were in disagreement with the classified images for 2001 and 1986, respectively.

2.7 Land Cover Change Detection

The 1986, 2001 and 2014 classified images were used as inputs for Remote Sensing software for the purposes of change detection for the time intervals of 1986 to 2001, 2001 to 2014 and from 1986 to 2014. Post-classification change detection was used in this study in preference to other methods such as direct classification, image differencing and change vector analysis. This is because it is most suitable for detecting land cover change **[49]**. It also minimizes errors due to atmospheric and sensor differences between two bi-temporal images if the images are classified independently **[50]**, **[45]**, **[44]**. It also generates a change matrix, which is appropriate for the purpose of this study. The change matrix is the basis for analysis of rates and processes of change in land cover types. Post-classification change detection, however, requires accurate geo-referencing, consistency in the extent of the study area and the selection of training signatures for the classification of the two images of interest, since errors in change detection results are greater when these conditions are violated **[49]**, **[51]**. Inconsistency in extent was minimized by using the same Area of Interest (AOI) to subset both images, while the geometric accuracy of the images was tested to be satisfactory under Section 2.3.

2.8 Land Cover Change Analysis

The transition matrix is the basis for the analysis of the extent of the gain, loss and swapping of each land cover type. The transition matrix in **Table 2** shows rows and columns of the reference and current years for a particular time interval **[52]**, **[22]**, **[53]**. For this study, two time intervals were assessed, namely 1986 to 2001 and 2001 to 2014. The reference years for 1986 – 2001 and 2001 – 2014 are 1986 and 2001, and 2001 and 2014, respectively. Entries along the leading diagonal of the transition matrix are the extent for each temporal interval, which did not change. The off-diagonal values are the extent of the transition from one class to another. Gain in any land cover class is the excess in the extent of a land cover class in the current year compared to its extent in the reference year. The loss is the deficit in the extent of a class in the current year compared to its extent in the reference year (**Figure 2**). Swapping is the simultaneous gain and loss in a given land cover class at different locations **[54]**, **[55]**.

Based on the generic land cover change matrix, the gain, loss and swapping for each land cover type were computed using Equations 2, 3 and 4 as in Huang *et al.* **[22]** and Pontius *et al.* **[19]**.

$$g_j = C_{+j} - C_{jj} \qquad (2)$$

$$l_i = C_{i+} - C_{ii} \qquad (3)$$

$$s = 2\,x\,MIN(C_{+j} - C_{jj},\, C_{i+} - C_{ii}) \qquad (4)$$

where g_j and l_i are the observed total gain and loss for land cover class j and i, respectively; s is swapping; C_{i+} and C_{+j} are the extent of land cover class i and j for the reference and current years respectively; and C_{ii} and C_{jj} are persistence class i and j respectively.

Table 2: Generic land cover change matrix

		Current year							
Land cover types		**1**	**2**	**3**	**4**	**5**	**...**	**j**	**Total**
Reference year	**1**	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	...	C_{1j}	C_{1+}
	2	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	...	C_{2j}	C_{2+}
	3	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	...	C_{3j}	C_{3+}
	4	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	...	C_{4j}	C_{4+}
	5	C_{51}	C_{52}	C_{53}	C_{54}	C_{55}	...	C_{5j}	C_{5+}
	⋮	⋮	⋮	⋮	⋮	⋮	...	⋮	⋮
	i	C_{i1}	C_{i2}	C_{i3}	C_{i4}	C_{i5}	...	C_{ij}	C_{i+}
	Total	C_{+1}	C_{+2}	C_{+3}	C_{+4}	C_{+5}	...	C_{+j}	

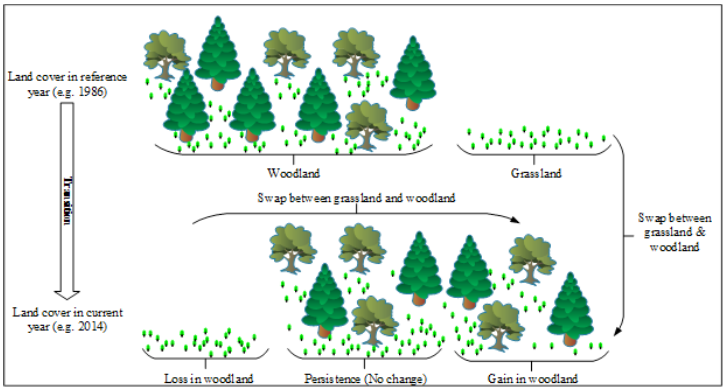

Figure 2: Land cover change concepts (Adapted from Angonese & Grau, 2014)

2.9 Analysis of the Annual Rate of Land Cover Change

A multi-level approach proposed by Aldwaik and Pontius **[52]** and Potius *et al.* **[19]** was used to analyze the land cover changes. The multi-level land cover change analysis is a mathematical framework for comparing uniform land cover change with observed land cover changes (**Figure 3**) **[52]**, **[56]**. Three assumptions were made in analyzing the annual rate of change **[52]**, **[19]**, **[57]**. These are: (i) The total gain in any land cover class and its proportion in the current year are fixed; (ii) The total loss in any land cover class and its proportion in the reference year are also fixed; and (iii) The annual rate of change in the extent of each land cover type for a time interval is linear. To enforce these assumptions, the two images were geo-referenced to the same coordinate system and the study area extracted from each image based on the same extent. The rates of change were expressed as a constant area per year and then as a proportion (%) of the total area **[52]**.

The levels of the analysis comprise the time interval, and the intra- and inter-categories. The time level changes were analyzed using Equations 5 and 6. Equation 5 was used to compute the expected annual rate of change for each interval, while Equation 6 was used for the observed rate of change for each time interval.

$$U=\left\{\sum_{t=1}^{T-1}\left\{\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J}C_{ij}\right)-C_{jj}\right]\right\}\middle/(Y_{t+1}-Y_t)\left[\sum_{j=1}^{J}\left(\sum_{j=1}^{J}C_{ij}\right)\right]\right\}\times 100\% \quad (5)$$

$$S_t=\left\{\left\{\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J}C_{ij}\right)-C_{jj}\right]\right\}\middle/(Y_{t+1}-Y_t)\left[\sum_{j=1}^{J}\left(\sum_{j=1}^{J}C_{ij}\right)\right]\right\}\times 100\% \quad (6)$$

where U is the expected transition for the interval level transition; T is the number of time lines; t is index for the initial (reference) time line for each time interval, J is the number of land cover types; j is the index for a land cover type in the second-time line of each time interval; i is the index for a land cover type for the reference time line of each time interval; Y_t is the year of the first time line of each time interval; Y_{t+1} is the second year of each time interval; C_{ij} is the extent of the transition from the cover type i to j; S_t is the annual intensity of change for the time interval $[Y_t, Y_{t+1}]$; Gj is the annual intensity of gross gain of land cover type j for $[Y_t, Y_{t+1}]$; L_i is the annual intensity of gross loss of land cover class j for [Yt, Yt+1]; Cij is the extent of transition from land cover class i to j; C_{ii} is the persistence in land cover class i; C_{jj} is the persistence in land cover class j.

Equations 7 and 8 were used to assess the intra-land cover level transitions for the two time intervals. Equation 6 serves as the uniform rate of change. Equation 6 provides the uniform rate of change for each interval with the assumption that if the annual mean rates of gain or loss for each land cover type in each time interval were equal, then that would have also been equal to the annual rate of change for the corresponding interval **[52]**. Equation 7 was used to calculate the annual rate of gain for each land cover type. Equation 8 was used to compute the corresponding annual rate of loss in each land cover type for both time intervals. Intra-land cover change analysis was used to assess the amounts gained and lost in each land cover type relative to the changes that would have occurred under a random process. This formed the basis for the identification of classes that gained or lost more than expected for each period.

$$G_j=\left\{\left[\left(\sum_{i=1}^{J}C_{ij}\right)-C_{jj}\right]\middle/(Y_{t+1}-Y_t)\sum_{i=1}^{J}C_{ij}\right\}\times 100\% \quad (7)$$

$$L_j=\left\{\left[\left(\sum_{j=1}^{J}C_{ij}\right)-C_{ii}\right]\middle/(Y_{t+1}-Y_t)\sum_{j=1}^{J}C_{ij}\right\}\times 100\% \quad (8)$$

Equations 9 – 12 were used to assess the intra-land cover transitions. Equations 9 and 11 were used to assess the inter-land cover gain for both time intervals, whereas equations 10 and 12 were used to calculate the inter-land cover loss. Equations 9 and 11 compute the expected gains and losses. Equations 10 and 12 compute the observed gain in one land cover type from other land cover types and losses to others.

$$W_j=\left[\left(\sum_{i=1}^{J}C_{in}\right)-C_{nn}\right]x100\%\middle/(Y_{t+1}-Y_t)\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J}C_{ij}\right)-C_{nj}\right] \quad (9)$$

$$R_{in}=\left[(C_{in})x100\%\right]\middle/(Y_{t+1}-Y_t)\left(\sum_{j=1}^{J}C_{ij}\right) \quad (10)$$

$$V_{mj}=\left\{\left[\left(\sum_{i=1}^{J}C_{imj}\right)-C_{mm}\right]x100\%\right\}\middle/(Y_{t+1}-Y_t)\sum_{i=1}^{J}\left[\left(\sum_{j=1}^{J}C_{ij}\right)-C_{im}\right] \quad (11)$$

$$Q_i=\left[(C_{mj})x100\%\right]\middle/(Y_{t+1}-Y_t)\left(\sum_{i=1}^{J}C_{ij}\right) \quad (12)$$

where *m* is an index for the lost land cover type in the transition of interest; *n* is an index for the gained land cover type in the transition of interest; R_{jn} is the annual intensity of gain in land cover type n from land cover class *i* during interval $[Y_t, Y_{t+1}]$ where $i \neq n$; W_n is the annual intensity of random gain in land cover n from all non-n land cover types during interval $[Y_t, Y_{t+1}]$; Q_{mj} is the annual transition intensity of loss from land cover class *m* to class *j* during interval $[Y_t, Y_{t+1}]$ where $j \neq m$; and V_i is the expected annual transition intensity of loss from m to all non-*m* land cover types $[Y_t, Y_{t+1}]$.

3. Results and Discussion

3.1 Spatial Extent of Land Cover and Patterns of Land Cover Change

The distribution of the spatial extent of the three land cover types for the three timelines is shown in **Figure 3**. Woodland was the main land cover type in the study area and constitutes 70.4 % of the landscape in 1986, 80.4 % in 2001 and 66.0 % in 2014. The results indicate that woodland increased from 1986 to 2001 and decreased from 2001 to 2014, while shrub/grass land increased consistently from 1986 to 2001 and from 2001 to 2014. The extent of bare/settlement decreased from 1986 to 2001 and increased between 2001 and 2014. What is remarkable and significant about the distribution of the extent of the land cover types is the existence of large areas of woodland (66.0 %) despite the decrease in woodland from 2001 to 2014. This suggests that the woodland in the area is recovering although the recovery is unable to surmount the anthropogenic pressure placed upon it. This is consistent with the view of **[21]** that degradation can be mitigated by natural regeneration.

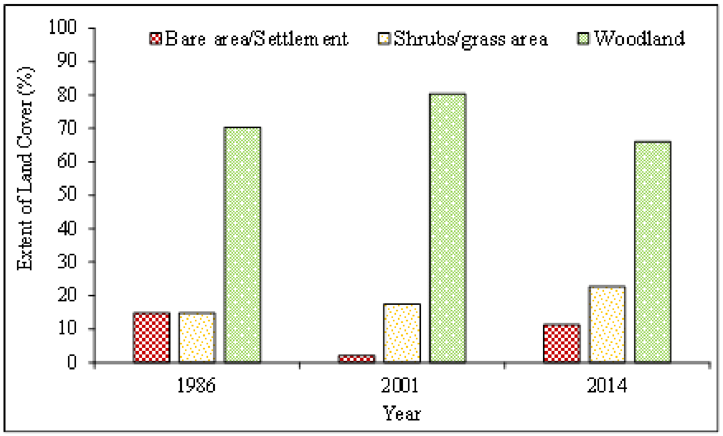

Figure 3: Distribution of each land cover type for 1986, 2001 and 2014

The spatial pattern of the land cover distribution showed that the area is dominated by woodland in 1986, 2001 and 2014 with patches of shrub/grass land and bare land /settlement (**Figure 4**). In 1986, the woodland is more fragmented, mostly by patches of bare land/ settlement relative to the other timelines (Fig. 4A and 4D). This is attributed to the 1982/1983 drought and devastating bushfires that occurred in Ghana. The bushfires and drought destroyed large tracks of vegetation in Agbosu **[58]**, Ampadu-Agyei **[59]** and Amanor **[60]**. It is therefore likely that the fragmentation of the woodlands by bare land in 1986 is due to the effects of the 1982/1983 drought and bushfires.

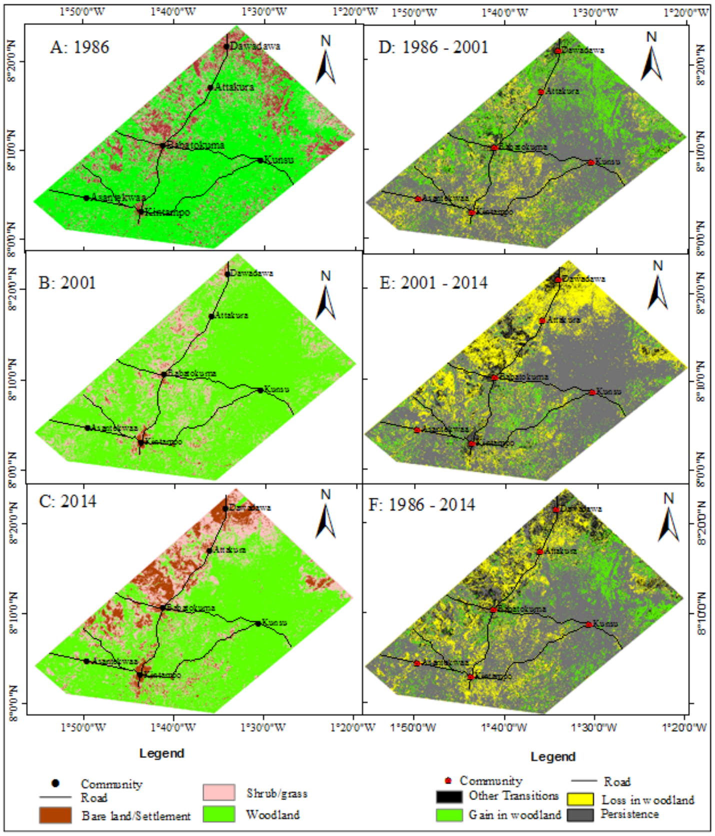

Figure 4: Patterns and changes in land cover for 2001 and 2014. (Source of raw images: Global Land Cover Facility website)

In 2001, shrub/grass land expanded from the levels in 1986 (**Figure 3**, 4B and 4E). The expansion in shrub/grass land can be attributed to the regeneration of vegetation especially in the areas burnt in 1982/1983. However, in 2014 shrub/grass land and bare land/ settlement increased along the Kintampo-Tamale highway which passes through major settlements, such as Kintampo, Babato-Kuma, Attakura and Dawadawa (Fig. 5C and 5F). Increasing numbers of immigrants in the municipality engaging in either farming or commercial charcoal production could have contributed to the expansion of bare land/settlement. This is because the Municipality is reported as a net receiver of migrants from the northern part of the country **[33]**. Farming and charcoal production are major livelihood activities in these communities as noted in Aabeyir *et al* **[25]**, and these activities have the likelihood of increasing the extent of bare land and shrub/grass land through the degradation of woodlands, as observed by Ravi *et al.* **[61]**. Although woodland was the largest land cover type in 1986, 2001 and 2014, it experienced an overall decrease from 1986 to 2014. This is an indication of the effects of increasing anthropic pressures on the woodlands such as charcoal production and farming. The declining trend in woodlands has negative consequences for woodland sustainability in the Kintampo Municipality, especially since charcoal production and sale is a brisk business in the Municipality, as noted in Aabeyir *et al.* **[24]**.

3.2 Extent of Land Cover Changes between 1986 and 2014

The changes in land cover from 1986 to 2001 (Fig. 5A and 5D) revealed that the extent of woodland that persisted was 58.6 % of the entire study area. However, it lost 11.8 % and gained 21.6 %. Analyses on the changes in woodland between 1986 and 2001 revealed that the changes are more swapping (23.6 %) than net gain, which is 10.0 %. Similarly, a 14.2 % gain and 11.4 % loss was observed in shrub/grass land for the same period, while 3.3 % of shrubs/grass remained unchanged. The changes in shrub/grass constituted more of swapping (22.9 %) rather than net gain (2.8 %). This suggests that while shrub/grass and bare land strives to gain the status of woodland, the existing woodland is being degraded. The overall positive net gain in both woodland and shrub/grass land for the period 1986 to 2001 has positive implications for sustainable woodland management. The findings that woodland in the Kintampo Municipality experienced a net gain for the period 2001 contradicts Pabi **[4]**, who observed a loss in woodlands in the same area for the period 1990 to 2001. This is due to the different temporal baselines and intervals, the extent of study sites, and differences in the anthropogenic pressures on the woodland as dictated by population dynamics and socio-economic development. Unlike the situation with woodlands described above, a net positive gain in shrub/grass could have both positive and negative implications for sustainable woodland management depending on the source of the gain. If the source of the gain in shrub/grass is bare land, that is good for woodland sustainability in the long term. However, if the source is woodland itself, that can have negative effects on woodland sustainability. The finding that bare/settlement had the highest net change is consistent with that of Braimoh **[20]** whose investigation of the surrounding Savannah area showed that cropland (a component of bare/settlement land cover in this study) had the highest net change for the period 1984 to 1999. Braimoh **[20]** observed a net gain contrary to the net loss in our case.

For the period between 2001 and 2014 (Fig. 5B and 5E), woodland maintained its dominance with a 58.4 % persistence although it gained less (7.6 %) and lost more than the other land cover types (Fig. 5 B). The changes in woodland consisted mostly of swapping (15.1 %) compared to a 14.4 % net loss. Changes in shrub/grass were 22.8 % swapping and 5.2 % net gain. The bare/settlement areas experienced 9.2 % swapping and 1.7 % net gain. What is significant about the changes in land cover for the period 2001 to 2014 is the net lost in woodland cover. This could be due to increasing dependence on woodland for livelihoods in the study area. This is consistent with the findings of Pabi **[4]**, and can be attributed to the increase in population due to the influx of immigrants. Kintampo Municipality is a net receiver of migrants as indicated in the Kintampo Municipal Assembly profile. Gradual increases in both woodland and shrub/grass land as indicated by the swapping figure has significance for woodland and shrub/grass sustainability, although the gradual increase for the period 2001 to 2014 is not enough for a net gain.

The results of the bi-temporal land cover changes for the entire period 1986 to 2014 (Fig. 5 C and 5 F) revealed that swapping was the largest change for the three land cover types, which was not the case for the 1986 – 2001 and 2001 – 2014 sub-intervals. The analysis for the entire period did not reveal the net gain in woodland that was observed for the first sub-interval and the net gain in bare/settlement that was also observed for the second sub-interval. These differences can be attributed to the nature and intensity of the main drivers of the changes, namely farming, charcoal production, and lumbering. These differences in land cover changes highlighted in the multi-temporal analyses are relevant in understanding land cover dynamics over a long period.

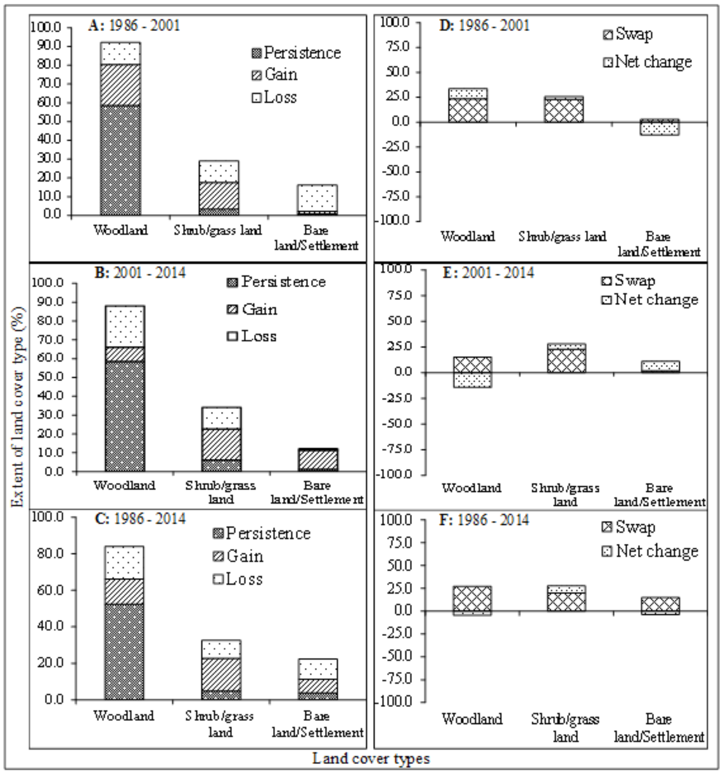

Figure 5: Extent of changes in land cover for the period from 1986 to 2014

3.3 Temporal Level Changes

The expected annual rate of land cover change for the period between 1986 and 2014 is 2.55 %, see dashed line in **Figure 6**. This shows that if the land cover change for the period 1986 to 2014 is random, each sub-temporal interval will experience annual change in land cover at 2.55 %. However, the observed annual rate of land cover change for the period from 1986 to 2001 is 2.49 % and for the period 2001 to 2014 is 2.63 %. This means that the land cover change during the period 1986 to 2001 is slow as compared to the period 2001-2014. The main land cover change observed for the period 1986 to 2001 is a gain in woodland and shrub/grass land, which is progressive and is part of a slow regeneration process, as noted in Butenuth *et al.* **[1]**. Hence, the gain from bare land to shrub land and to woodland accounts for the slow pace of land cover change for the period 1986 to 2001.

The period 2001 to 2014 experienced significant loss in woodland and gains in shrub/grass land. This can be attributed to expansion of farmlands and charcoal production. This is supported by the findings of Butenuth *et al.* **[1]**, as the impact of intensive anthropogenic activities on land cover is both rapid and sudden. The significance of this temporal analysis is that it provides direction for further investigations on the socioeconomic and demographic dynamics for predicting land cover dynamics.

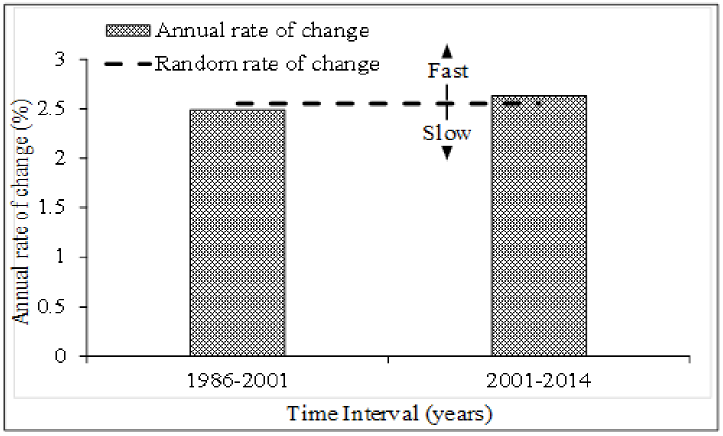

Figure 6: Land cover transition at the temporal level

3.4 Intra-Land Cover Changes

The intra-land cover type changes revealed that under a random process of change each land cover type is expected to gain or lose 2.49 % (dashed lines in Fig. 7A) for the period 1986 – 2001 and gain or lose 2.63 % (dashed lines in Fig. 7B) for the period 2001 - 2014. The observed gain and loss for shrub/grass land and bare land/settlement exceeded the expected values for both periods, implying that shrub/grass land and bare land/settlement gained and lost more than expected in a random process. This means the processes of change in shrub/grass and bare/settlement for both periods are due to systematic processes. Woodlands gained and lost less than expected for both periods and this is an indication that the processes of gain and loss in woodland are random. This is contrary to views expressed by Kintampo Municipal Assembly **[33]** that the woodland is being lost extensively due to the effects of activities such as charcoal production in the woodlands. The finding that the processes of gain and loss are random is in line with the views of Pontius *et al.* **[19]**, as they noted that large land cover types can experience random changes even with large gains and losses. This explanation is also consistent with the assumption on intra-land cover analysis as stipulated by Aldwaik and Pontius **[52]**. Thus, the dominance of woodland on the landscape (**Figure 4**) explains the random nature of the changes since it accounts for more than 60 % of the landscape in all three timelines.

3.5 Inter-Land Cover Type Level Changes

The expected gain in bare land/settlement from shrub/grass land and woodland under a random process is 0.1 % of the total land area (Dashed line in Fig. 8A) for the period 1986 – 2001. The observed gains are 1.5 % and 4.8 % from bare land/settlement and woodland, respectively (Fig. 8A). The gains from each of the two land cover types are more than expected and this is an indication that bare land/settlement consistently gains from both land cover types in its process of change. The expected loss from bare land/settlement to shrub/grass land and woodland for the same period is 1.0 % (Dashed line in Fig. 8B) while the observed loss is 1.3 % and 0.9 % for shrub/grass land and woodland, respectively. This shows that when bare land/settlement is lost, it consistently loses to shrub/grass land more than to woodland **[52]**.

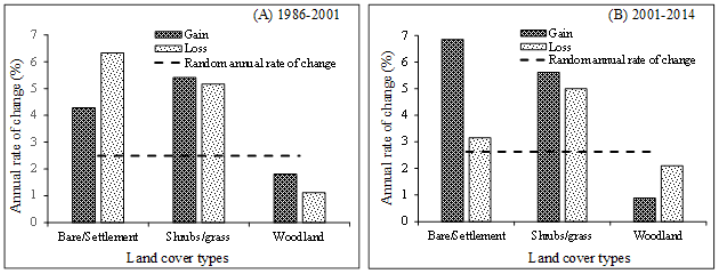

Figure 7: Intra-land cover level Transition for the periods 1986-2001 and 2001 2014

Similarly, the observed gain in shrubs/grass land from woodland is more than expected (Fig. 8 C) while that from bare land/settlement is less than expected under a random process of gain (Fig. 8 D). This implies that shrub/grass gained more from woodland than it gained from bare land/settlement. However, shrub/grass land did not lose substantially to both woodland and bare land/settlement (Fig. 8D). Both the observed gain and loss in woodland from both shrub/grass land and bare land/settlement were less than expected (Fig. 8E and 8F). This means that the amount of woodland lost and gained is less compared to shrub/grass land and bare land.

The findings from the inter-land cover change analysis revealed the direction of land cover changes relevant in understanding and anticipating future trends of the various land cover types in the area. The findings that the loss in shrub/grass land did not substantially translate into woodland and gain in shrub land from woodland are significant contributions to land managers in the area. This tells stakeholders in woodland areas, namely chiefs, charcoal producers, Ghana Forestry Commission and the Kintampo Municipal Assembly that if this trend continues it will affect woodland sustainability and livelihoods associated with woodlands. This explanation emphasizes the observation by Pabi **[4]** that the threat to woodland sustainability becomes serious when the potential of woodland to recover is not ensured. The findings also offer direction for investigating the drivers of the change. The findings and explanations are in line with the research by Trisurat *et al.* **[23]**, who found that the detection of the direction of change is a critical prerequisite for understanding the causal relationship, either among the land cover types or between land cover types and their drivers of change.

The comparison of observed and expected gains in bare land/settlement for the period 2001 – 2014 showed similar trends to the inter-land cover changes observed for the period 2001 to 2014 (**Figure 9**). The observed gains in bare land/settlement from both woodland and shrub/grass land are greater than expected (Fig. 9A). This implies that bare land/settlement gained more from both shrub/grass land

and woodland than expected under a random process. The observed loss from bare land/settlement to woodland is less than what is expected under a random process of loss, thus the loss process can be ascribed to random changes while the loss from bare/settlement to shrub/grass land is due to random changes (Fig. 9 B).

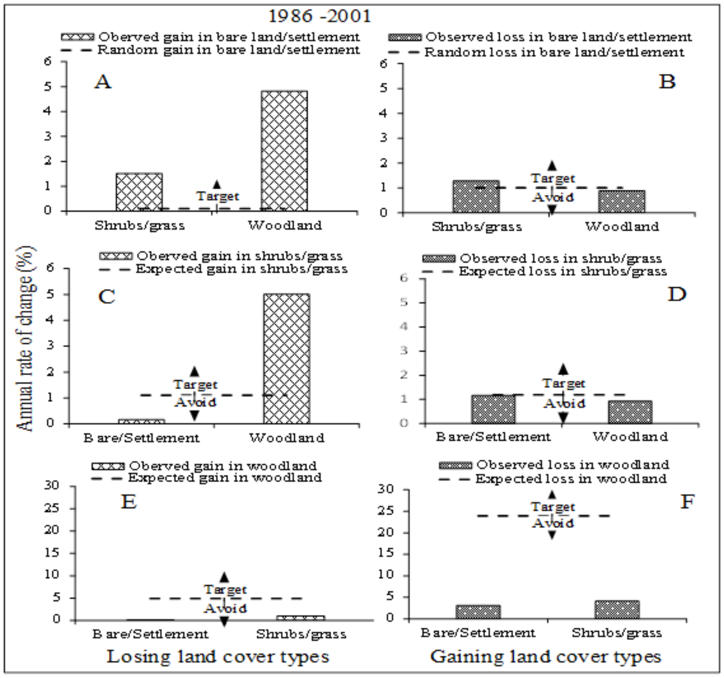

Figure 8: Inter-Land cover transition between 1986 and 2001

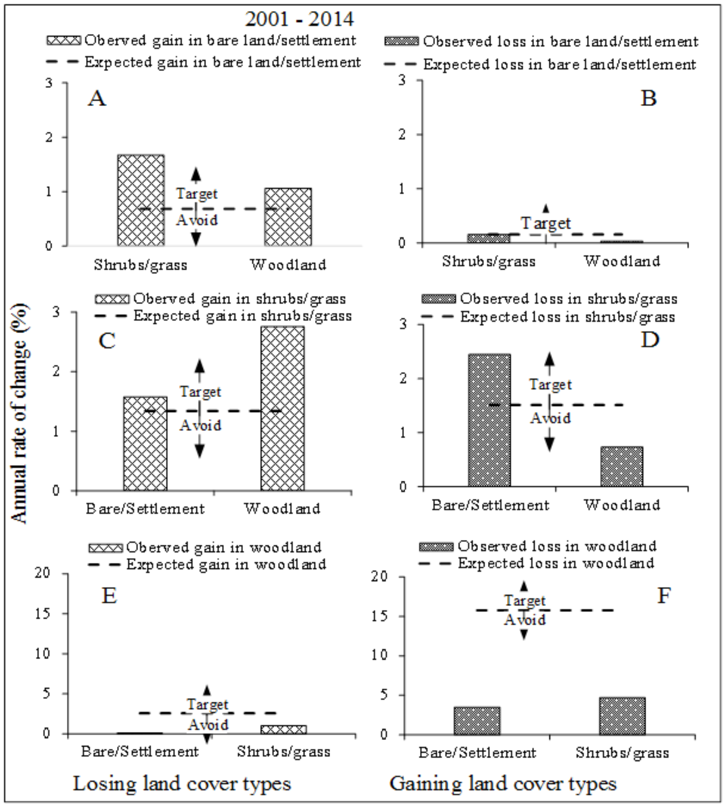

Figure 9: Inter-Land cover transition between 2001 and 2014

4. Conclusions and Recommendations

This study demonstrates that multi-level assessment of land cover changes provides a clear direction in understanding the nature of land cover dynamics in the Kintampo Municipality of Ghana, where a complex synergy of factors is responsible for the land cover dynamics. The study identified that the period 2001 to 2014 experienced faster land cover change than expected. The intra-land cover transition identifies that shrub/grass land and bare land/settlement gained more than it lost, while woodland lost more than it gained. These findings inform woodland management plans of the municipality in order to focus on whether to reduce the loss in woodland or loss in shrub land to bare land/settlement. The most active period of land cover changes can be related to anthropogenic activities that occurred within that time interval. The inter-land cover analysis points out that shrub/grass land loses to bare land/settlement instead of woodland. This emphasizes the need to reverse the trend in order to sustain woodland cover. The findings can help improve upon woodland management in the municipality to ensure long-term use of woodland for livelihoods such as charcoal production. Despite the significance of the methods applied, caution must be taken especially in areas where the landscape is dominated by one land cover type because it can suppress important changes in the dominant land cover type.

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