Land cover analysis of the Kambui Hills North Forest Reserve and its surrounds
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1. Introduction

Kambui Hills North Forest Reserve (KHNFR) was established in Kenema in 1919, but since the 1960s it has received relatively little management attention. In recognition of the reserve’s importance, the USAID and ACDI/VOCA funded Promoting Agriculture, Governance and the Environment (PAGE) initiative is in the process of establishing a community-driven forest management programme, called co-management, in the KHNFR. The idea behind this approach is to revitalise the management of the reserve by empowering forest edge communities so that they can participate in decision making processes. The research project described in this report is designed to help inform this initiative, providing an empirically-based analysis of the reserve’s dynamics upon which to base future interventions.

This report presents an analysis of the land cover change in the Kambui Hills and surrounding area (see Figures 1-3) based on Landsat images for 2010 and 2001. These analyses have been published in conjunction with the main project report: The governance and trade of wood-based products in and around the Kambui Hills North Forest Reserve, which examines the dynamics of the KHNFR’s management and nuances of the wood-based trade in and around the reserve. This report is therefore complementary to the analysis presented in the main report. The main report details the results of interview-based fieldwork and is more socio-economic and socio-political in nature, focusing particularly on the dynamics and governance of commercial trade in wood-based forest products in the study area. Conversely, the present report is predominantly biophysical in its emphasis, providing insights into environmental (forest) changes and issues that occurring around the forest reserve, based on analysis of remotely sensed images captured by Landsat satellites.

Figure 1 presents a general map of the research area, which includes the locations of major towns, roads and the forest reserve boundary. The map operates as base reference map, as the subsequent maps in the analysis do not have these key geographical features labelled to prevent cluttering. With respect to the forest reserve boundary, it is important to note that the boundaries are only rough estimates developed by ACDI/VOCA staff and by no means should be taken as fully accurate representation of the reserve’s actual legal boundaries. Indeed, the reserve’s boundaries are highly ambiguous as: boundary areas have not been marked or brushed in many years; descriptions of the boundaries published in Sierra Leone Gazette are difficult to reinterpret in the contemporary landscape (See Appendix A of The governance and trade of wood-based products in and around the Kambui Hills North Forest Reserve report), and; even official forestry maps of the reserve boundaries differ (See Figures 2 and 3). Thus the forest reserve boundaries on this map are presented for illustrative purposes only.

The overall results of the land cover change analysis are intriguing. In contrast to deforestation narratives in Sierra Leone, which generally frame the country’s forests as being in a state of constant and often rapid decline, these data strongly suggest a nearly constant and even increased area of “forest” in the study area over the past ten years. As well, they indicate that the vegetative land cover outside of the forest reserve is extremely dynamic, with a fine-grained mixture of forest and bush loss and gain patches. As detailed further below, these dynamics have likely been driven by recent mass population movements during and after the civil war (1991-2001), as well as the nature of the rotational fallow agricultural system employed by most communities in the area. Interestingly, these dynamics also exhibit a strong spatial pattern, and it appears that the area to the east of the KHNFR has predominantly experienced vegetation loss, while the area to the east is experiencing forest and bush gain. Finally, while the KHNFR itself appears to have lost some forest around its fringes, there is little evident vegetative change in its core forest area.

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Figure 1 - Map of Research Area, showing Major Towns (white), Roads (light blue), rivers (dark blue) and the approximate forest reserve boundaries (TO BE INSERTED WHEN AVAILABLE).

Figure 2 - Map of KHNFR from the Forestry Office in Freetown (left) and map of KHNFR from the District Forestry Office in Kenema. Note the slight difference in boundaries, particularly in the area of Komende just to the west of Kenema.
This report is divided into five main sections. After this introduction, section two discusses the methodology employed for the land cover analysis. This is important as the limitations of remote sensing analyses must be understood in order to be properly used for land management programs. Following this, section three presents results and discussion of the various land cover change analyses conducted. Next, section four links the observation from the land cover maps with interview-based data collected on the ground during fieldwork. Thus the analyses presented here move beyond simple description of landscape change patterns to an analysis of causal relations, providing some insights into why certain forest cover change dynamics may be occurring. Finally, section five offers some overall conclusions of the study.

1.1 What is a Landcover analysis: limitations and possibilities.

Remote sensing-based analysis of land cover is conceptually simple, but technically complex. In simple terms, it involves comparison of images that are captured by satellites orbiting high in the upper atmosphere. These images are essentially photographs, recording light reflected from the earth’s surface across a range of light wavelengths (e.g. red, green, blue, etc.). They differ from conventional photographs, however, in that the different wavelengths are captured separately, as discrete images, or image “layers”, allowing the analyst to assess landscape features or land cover types based on their unique reflectance “signatures” (or characteristics) across a range of different wavelengths of radiation. As well, remote sensing satellites (especially Landsat) capture layers for not only visible light wavelengths, but also non-visible infra-red wavelengths, which are particularly important for detecting vegetation (see section 2.3.1 for further discussion of this). In the process of analysis, the image layers for the different wavelengths (known as “bands”, e.g. red light is assigned to band 3 in landsat images) can be combined in various ways to create composite images for qualitative (visual) inspection and analysis of landscape features. An example of this is presented in Figure 1, where the Red, Near Infra-Red (NIR) and one of the Mid-Infra-Red (MIR) bands are combined using blue, green and red display colour ranges to produce a band 3,4,5 false-colour composite that offers much more scope for visual interpretation than the original black and white images for these individual bands.

Analysis is not solely, or even chiefly, based on such qualitative analysis, however, and most techniques for classification are actually quantitative in nature. Essentially, the image layer for each band is simply a mosaic of square pixels, each expressing a single quantitative value for the intensity of light recorded as being reflected from the place on the ground represented by the pixel. As such, the layer is simply a grid of numeric values, which means that it can be quantitatively analysed. One of the key ways in which quantitative analysis is conducted, is to develop “signatures” for different land cover types of interest. These signatures are simply descriptions of the range of values observed for a given cover type across each of the different bands (wavelengths of radiation) – (again, see section 2.3.1 for some further discussion). Once the signatures are established from “pure” sample sites, they can then be used to classify the entire image into a set of classes of interest for the analysis. Finally, once the various classifications have been conducted, change analyses can be conducted by comparing images from different dates, either quantitatively (e.g. subtracting a later image from an earlier one as with NDVI images – see below), or qualitatively (e.g. comparing the categories into which individual pixels with the same geographic locations have been classified in each of the two different date images.

The analyses presented here have been conducted using Landsat images captured in early February 2001 and 2010. With their 30m x 30m pixel size, Landsat images have a coarser resolution than other current sensor systems such as SPOT (15m) but they have effectively become the international standard for remote sensing analyses due to several advantages:
1) Whereas finer-resolution systems capture scenes on demand only, Landsat satellites provide continuous global coverage at 16 day intervals, increasing the likelihood of finding images from different years on near-anniversary dates (which is important to minimise the confounding effects of seasonal vegetation change);

2) The Landsat program has been in operation since the mid-1970s, providing a large continuous data set of images from highly similar sensor systems with near identical flight paths (reducing the difficulties involved with comparing images from different sensor systems, and allowing greater flexibility in choice of time-period for study);

3) The 185km x 185km coverage of Landsat images is several times larger than that of finer resolution sensor systems (normally reducing the number of images that need to be procured, corrected and calibrated to each other);

4) Perhaps most importantly, whereas SPOT, IKONOS and other fine-grained images can cost thousands of dollars per image, the entire Landsat image collection is now available free of charge.

Land cover change analysis is a potent tool for land use planning and management, and the analysis presented here is intended not only as a form of triangulation of interview based data collected in the field during this study, but also to support future decision making for the Kambui Hills area. Nonetheless, it is important to note certain limitations that users of these analyses and data must bear in mind:

1) As noted, the 30x30m pixel size is slightly coarse, limiting the scope for direct visual interpretation (one cannot see individual trees, for example) and introducing a certain margin of error, particularly in categorical classification of land cover types;

2) Despite the massive size of the Landsat image database, the collection for Sierra Leone is quite limited, because, as anywhere in the tropics, there is a great deal of cloud and/or atmospheric haze throughout the year, even in the driest months of December-February. This is particularly the case in hilly areas such as Kambui, where orographic effects induce “extra” cloud formation (indeed in the 2010 image used – the clearest of the recent images – not all cloud and haze could be eliminated);

3) In any case where change analysis (rather than simple classification for one date) is required, the issue of radiometric correction introduces further difficulties, and at least some margin of error. Differences in the atmospheric conditions (i.e. atmospheric dust, vapour etc.) between the dates of the various images being used affects the radiation reflected by the Earth’s surface as it travels 705 km through the atmosphere to the altitude of the satellite’s sensors. As described below in the methodology section, such effects can be accounted for through radiometric correction and image calibration, but never perfectly;

4) Topography also effects the surface reflectance recorded by the satellite’s sensors as the solar elevation is not at nadir (directly overhead) at the time of image capture, creating bright and shadowed areas on hillslopes facing toward and away from the sun, respectively. While this has been addressed through painstaking analysis of derived land cover classes and the use of alternative analyses such as the Normalised Difference Vegetation Index (NDVI) – explained further below – there are likely still a few small areas where topographic effects have resulted in misclassification;

5) Another issue, though minor, relates to vegetative phenology. As a few species (notably Yemani (Gmelina arborea) in this case) have much lighter leaves than others (mainly native tree species), mature stands of these may in some cases not be discernible from other light vegetation classes such as early or mid-stage forest regrowth;
6) Differences in weather from year to year are another factor which can affect overall vegetative greenness and vigour, generating some degree of difficulty in establishing the boundaries between certain vegetation classes and in isolating “true” change from “normal” variability;
7) Perhaps the greatest concern with respect to interpretation of the categorical classification of land cover types and changes in these, however, is the difficulty in distinguishing “heavy bush” (late forest regrowth) from more mature forest. As noted in much of the remote sensing literature, when forest regrowth reaches around 10 years of age, the colour of the leaves and the density of the foliage reach levels very similar to those of mature forest, and from this point on it is mainly woody biomass which increases, not foliage.

With these caveats in mind, therefore, the following approach to interpreting the significance of the results reported here recommended:

1) It should be noted that the categorical classifications were conducted using intentionally broad parameters in order to faithfully represent broader conditions and changes and minimise error (i.e. a sacrifice of precision to maintain overall accuracy);
2) In general, the maps presented here, and particularly the categorical maps, should be taken as broadly accurate, but not locally precise. In other words, they capture the changes in land cover and land use across the area of analysis quite well, but should not be taken as a definitive basis for fine-grained local planning without field-based verification – not least because conditions will have changed in many areas in the two years since the most recent image was captured in 2010 (and more recent cloud-free images are not available).
3) With respect to the forest class, the 2010 land cover map should be taken with some caution outside the core Kambui Hills reserve area. Greatest confidence should be placed in the forest class of the classification change map, which indicates core forest areas that have remained unchanged over the past 10 years (i.e. they emerged as mature forest classes in both of the two independent classifications for 2001 and 2010, respectively). In other areas, there may be some confusion between less dense forest and dense mature bush.
4) With respect to land cover change, the categorical change map is considered to be acceptably accurate. Nonetheless, greatest confidence should be placed in the 95% and 99% confidence level threshold maps of the NDVI changes. These indicate areas in which positive or negative changes in vegetation density has been greater than 2 or 3 standard deviations from 0, and which can therefore be considered significant with great confidence.

2. Methodology
2.1 - Image selection
Images for analysis were acquired from the United States Geological Survey (USGS) website with full Level 1 georegistration, terrain correction and radiometric correction (calibration to current sensor characteristics). The images for 2001 are from Landsat 7 (L7), but the images for 2010 are from Landsat 5 (L5) as L7 suffered a scan line corrector failure in 2003 resulting in strips of missing data in all subsequent images. Landsat 7 data is still being collected, but the missing data must be interpolated from adjacent pixels. As this would introduce a further source of error, such images were not considered. After careful analysis of the imagery available for different months, it was decided to focus on images for the period of late January to early February as this is the height of the dry season at which time: a) there are the most cloud-free images available for similar dates), and; b) grass dessication allows very easy separation of light vegetation areas. Fortunately, it was possible to
obtain images for all sections (see Figure 3) of both years that were captured on near anniversary dates (almost the same day of the year), minimising the effects of seasonality on vegetation characteristics – although this period is around the time when Yemane loses its leaves, another reason why Yemane plantation areas may not be classified as forest in the final maps (see Table 1). Finally, having eliminated unsuitable images in this way, images from 2001 and 2010 were selected as the earliest and the most recent ones for which a full spatial set of adequate quality could be obtained. The selection of this timer period is considered to be further justified by the fact that this is the period during which the most deforestation is generally considered to have occurred in recent decades. 

Table 1: Images selected for analysis

<table>
<thead>
<tr>
<th>Path</th>
<th>Year</th>
<th>Satellite</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 (EAST)</td>
<td>2001</td>
<td>L7</td>
<td>Feb 7</td>
</tr>
<tr>
<td>200 (EAST)</td>
<td>2001</td>
<td>L7</td>
<td>Feb 7</td>
</tr>
<tr>
<td>201 (WEST)</td>
<td>2001</td>
<td>L7</td>
<td>Jan 29</td>
</tr>
<tr>
<td>201 (WEST)</td>
<td>2001</td>
<td>L7</td>
<td>Jan 29</td>
</tr>
<tr>
<td>200 (EAST)</td>
<td>2010</td>
<td>L5</td>
<td>Feb 8</td>
</tr>
<tr>
<td>200 (EAST)</td>
<td>2010</td>
<td>L5</td>
<td>Feb 8</td>
</tr>
<tr>
<td>201 (WEST)</td>
<td>2010</td>
<td>L5</td>
<td>Jan 30</td>
</tr>
<tr>
<td>201 (WEST)</td>
<td>2010</td>
<td>L5</td>
<td>Jan 30</td>
</tr>
</tbody>
</table>

2.2 - Image pre-processing
As noted above, remotely sensed images must be geographically and radiometrically corrected and calibrated in certain respects before analysis of change can be conducted. In this case, thorough visual inspection revealed that all images had been georeferenced and terrain corrected to an extremely high level of precision by the USGS prior to delivery, hence no further correction was applied. Radiometric correction was somewhat more involved in this case, however, as the Kambui Hills area falls on the boundary between two Landsat Paths, and also on the boundary of two rows (i.e. at the corner of 3 different scenes. As a result, in order to display a reasonable amount of the area, 3 images had to be employed (see Figure 3).

Figure 3 - Example of Kambui Hills/surrounding location area relative to Landsat Paths/Rows

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2 For a published reference see, for example, the discussion and various quotes cited in G. Hiemstra-van der Horst, "We are Scared to Say No": Facing Foreign Timber Companies in Sierra Leone's Community Woodlands', Journal of Development Studies 47:4 (2011): 574-594; This includes the 2008 Forestry Regulations which opens with the statement that “since the war, the people have been destroying the forest".
While the USGS also applies radiometric correction, this is only to account for sensor calibration, not for atmospheric effects. Unfortunately, full atmospheric correction models require a great deal of detailed data on local atmospheric conditions at the exact time of image capture in order to be applied correctly. Since full local meteorological data for the dates are not available, no such model was applied. This is a normal situation in the tropics, however, and quite robust alternative methods have been developed for such cases. In this case, the following combination of commonly used procedures was employed:

1) In order to eliminate the small differences due to the two different sensors used (i.e. L5 and L7), Images were converted from the original unitless Digital Numbers (DN) recorded by the satellites into Top Of Atmosphere (TOA) units of Milliwatts/Steradian/Square Metre (i.e. from the sensor reading value of 1-255 to the actual intensity of the cone of light [steradian] reflected from the surface of the earth into space after passing through the atmosphere).

2) In order to compensate for Rayleigh and Mie scattering due to atmospheric gases/vapour and aerosols (e.g. dust), respectively, a Dark Object Subtraction (DOS) was applied using Chavez’s improved model. Essentially, atmospheric scattering distorts the “below atmosphere” surface reflectance values of various wavelengths of light, resulting in raised values. The blue wavelengths are the most affected, followed by the green, with decreasing effects in the red and Near Infra-Red (NIR), while the Short-Wave Infra-Red (SWIR) wavelengths are not affected significantly. In order to compensate, a Dark Object was located in the blue image layer that ought to have values of zero reflectance (e.g. deep water, dark hill shadows etc.). This darkest value was then subtracted from the blue image layer to “zero” it. Using Chavez’s model which preserves the relationship between the various bands sensed by landsat satellites, the blue DOS value was then adjusted for correction of the Green, Red, and NIR layers. The DOS procedure was applied to the 2001 images (East and West), as these were the clearest of the two dates, generating an Apparent Surface Reflectance image for 2001.

3) In order to calibrate the slightly more cloud/haze affected 2010 images (east and west, respectively) to the 2001 images (east and west, respectively), their layers were then each independently regressed against the corresponding layers of the 2001 images using Pseudo Invariant Features (PIF) common to the two images. In other words, bright (e.g. urban core areas, roads etc.) and dark (e.g. centers of lakes, very dark hill shadows etc.) features that should not have changed noticeably were selected from the images and a linear regression was conducted for each of the 2001 and 2010 layer pairs (e.g. blue, green, etc.). Once the PIF selections were purified to establish a very high and significant level of correlation (i.e. getting rid of parts that may actually have changed) the resulting set of linear equations was then applied to the corresponding layers of the 2010 image to bring its values into a range corresponding with the 2001 image. This technique is essential to isolate “true” change from variation due to atmospheric conditions.

4) In order to inter-calibrate the east and west paths prior to joining, a similar regression technique was applied, this time using dark and bright PIFs in the image overlap area (which extends from the western boundary of the reserve to the middle of Kenema town). Through an iterative process of careful calibration and re-calibration, a very close match was obtained between the east and west path

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4 As the effects of Rayleigh and Mie scattering diminish from the blue to the infra-red range of the radiation spectrum, Chavez’s model generates values from one of the visible wavelength that are appropriate for each wavelength, thus preventing over-correction, which would result in data loss.

5 Landsat 5 and 7 are designed to have nearly identical sensors which separately record independent images in specific blue, green, red, NIR and SWIR ranges, these are used as image layers in analysis.
images, which were then clipped to focus on the study area of interest. In the case of 2001 this was simpler due to the lack of cloud, but in the case of the 2010 set, some careful work was required to maximise the use of cloud-free areas in the overlapping areas of the two paths. Despite this effort, however, as Figure 4 illustrates, some residual cloud areas and their corresponding shadows remain, which unfortunately had to be masked out as “cloud” in subsequent analysis images.

![Figure 4 - Example of final correction – 2010 false colour composite of Red, NIR and SWIR bands](image)

2.3 - Image analysis

It is important to note that in the procedures described below, heavy haze, cloud and cloud shadow were masked out to minimise error and these areas appear brown, grey or black in the final imagery.

2.3.1 - NDVI and change NDVI mapping

As the PAGE project is principally concerned with forested areas and with environmental aspects of land use patterns more generally, the analysis particularly focused on vegetation patterns. Therefore, a first step taken was to generate a Normalised Difference Vegetation Index (NDVI) image. The NDVI is extremely useful for vegetation change analysis as it makes use of the reflective characteristics of green vegetation to generate a map of leafy vegetation density. In simple terms, vegetation has unique radiometric characteristics in the sense that red light is absorbed strongly by leaf chlorophyll while NIR is reflected strongly by leaves’ fleshy...
mesophyll tissues. As a result, the deeper and denser the vegetation, the lower the values of red light reflected and the higher the values of NIR radiation reflected. The NDVI index exploits this fact by expressing the normalised ratio (see equation 1) of the Red to NIR values, a function of leafy biomass (as well as vegetation maturity, as mature trees usually have somewhat denser chlorophyll in their leaves than younger ones). The result is an image in which urban/cleared areas and water bodies etc. score generally below 0.2-0.4, while increasing vegetation is represented by rising values from around 0.4 to 1 (See Figure 5).

Equation 1: \[ \text{NDVI} = \frac{(\text{RED} - \text{NIR})}{(\text{RED} + \text{NIR})} \]

Once the NDVI images were generated for each date, an NDVI change image was generated by subtraction of the 2001 image values for each pixel from those of the same pixels in the 2010 image. This image contains a great deal of minor variation, which makes the image complex, difficult to interpret visually and which is largely due to: a) residual atmospheric “noise” (random slight increases or decreases in individual pixel values); b) small residual image calibration error (leftover small differences between the images), the residual slight error in georegistration of the two images (in this case only a few metres, but this is enough to generate some apparent “variation”), d) slight differences in weather between the two years, and; e) other minor “normal” variability that is not of interest to the study (e.g. normal slight changes in bush density that affect its quantitative NDVI value slightly, but do not represent a change in class). In order to remove such noise and produce simpler images highlighting only areas of significant change, therefore, a series of images was generated in which progressively more of the lower-level (less dramatic/significant change is removed. This
was achieved by statistically thresholding the images about the mean to exclude non-significant values at progressively higher confidence levels. The result is a set of 3 images (Figures 16-18 below) displaying only data more than 1, 2, and 3 Standard Deviations from zero (the mean), respectively. Statistically speaking, the first of these images displays data that we can be 60% confident is significant change and not random/“normal” variability, while the second and third images display 95% and 99% confidence level data, respectively.

2.3.2 - Categorical classification and change mapping
Whereas the NDVI analyses provide relative\(^6\) quantification of biomass (i.e. values are quantified on a unitless scale of -1 to +1), a land cover classification was also conducted in order to assess changes in particular classes of interest. This was conducted in an iterative fashion, using multiple rounds of unsupervised and supervised classification algorithms. Unsupervised classifications involve the use of algorithms that statistically separate land cover classes based on common peaks and valleys in the overall distributions of pixel values for the various inputs bands – this is useful as a first step in defining existing classes, as it provides a map of “differences that make a difference” over multiple bands simultaneously. This aids significantly in developing training class sites for a supervised classification. In contrast, supervised classification is a process whereby the “lumping and splitting” of land cover classes is initially done manually by the analyst – i.e. training site areas are selected from the image that represent ideal representatives of each class of interest (e.g. forest, heavy bush, bush, grass, urban etc.). From these, a radiometric “signature” set (defining the radiance characteristics for the class in each band) is developed, which is then used to classify the rest of the image pixels according to which class they best fit into. For this analysis, Bands 1 (blue) and 2 (green) were excluded from the analysis as they are more susceptible to the residual haze in the 2010 image and hence would increase the margin of error. Bands 3, 4 and 5 (red, NIR and one SWIR) were use as these are the most sensitive to vegetation characteristics and the most insensitive to haze. The NDVI images were also included as layers as they express the relationship between bands 3 and 4 and therefore both add highly relevant information and help to counterbalance effects of variable such as topography\(^7\).

Specifically, the following methodology was employed:

1) While good samples of the “urban” and “dense forest” classes were readily available from core reserve and urban areas of the images, an unsupervised clustering algorithm was employed to establish clear and separable classes for other vegetation classes. From this iterative process, the following additional classes (and their initial locations) were identified from certain clusters: Grass/Light Vegetation; Bush, and; Heavy Bush. (as noted above, these classes were kept intentionally broad to minimise the classification error inevitable in attempting a fine-grained classification with moderate resolution data);

2) Histogram and scatter plot based tests were conducted to verify the separability and consistency of the classes. As well, systematic visual analysis of the locations of pixels assigned to these classes were conducted to assess the probability of their correctness as well as their spatial consistency;

3) Training sites were manually defined from the most representative areas of the various classes, including the forest and urban classes;

\(^6\) NDVI can be quantified to yield a map of absolute biomass values but systematic stratified random field sampling of actual biomass values is needed, which is quite labour intensive and beyond the scope and purpose of the study.

\(^7\) NDVI is relatively insensitive to topography because it expresses the ratio between the bands so if both bands are low (due to shadow) or high (due to strong sun), the ratio will be the same (e.g. 10/15 = 100/150).
4) These training sites were then “purified” using a purification algorithm to remove minority classes
(outliers that would spread the distribution of the training classes, increasing overlap and hence
confusion between the classes;
5) Signatures were extracted from the training sites for the band 3, band 4, band 5 and NDVI layers;
6) These signatures and the above layers were used to classify the entire images using a supervised
Maximum Likelihood algorithm, resulting in fully classified 2001 and 2010 images and;
7) A cross-tabulation of the classified 2001 and 2010 images was conducted to express the changes in
class between the two. This result includes an image displaying all changes between all categories. As
it is somewhat complex and therefore difficult to interpret, however, it has been broken down into
several component images displaying different changes classes of key relevance to the project.

The outputs of these analyses are presented and discussed in the following sections.

3. Land Cover Classification

It is in this section that a word of caution must be re-iterated, with emphasis on concerns related to the
classification images. While all imagery is susceptible to some degree of error, the categorical classifications
are particularly tricky. As discussed above, maintaining consistent classification of complex data across a
highly variable spatial environment is no simple statistical task, and is more difficult still when the classes are
continuous rather than highly distinct. Bare soil, urban development and light grass, for example, are very
easy to distinguish spectrally from heavy bush and forest because their reflective characteristics are
qualitatively quite different. With heavier vegetation classes, however, the issue is instead one of modest
quantitative shifts along a continuum of vegetative regrowth from bush to mature forest. For example, it is
not exceedingly difficult to establish what areas are certainly forested (using, for example the highest NDVI
scores). It is, however, rather more difficult to establish the most appropriate lower threshold for the forest
class – i.e. the division between what is classified as less mature forest and that which is classified as very
mature bush. Similarly, the divisions between heavy bush and medium bush should be taken with some
caution, for the same reasons.

It is important to also note that this is not merely a technical question, but also an ontological one: what
counts as “bush” or “strong bush” or “forest” is a qualitative assessment that may very noticeably from one
person to another or from location to location as these apparently self-evident conceptual categories mark
somewhat arbitrary (though useful) divisions along an essentially continuous variation in stages and
combinations of vegetation in the actual “landscape”.

In addition, the study area itself presents a challenging environment for analysis. Like much of Sierra Leone,
the area surrounding Kambui Hills is a diverse mosaic of often small and frequently subtly different
vegetation patches which, in addition, are in large part under continuous (and significant) change.

With this in mind, it is recommended that users of this data take some care in its interpretation, bearing in
mind the blurring and overlap between the classes, and therefore the ambiguity of some of the boundaries.
These concerns are most critical in the analysis of change between categories as, for example, areas identified
as having changed from heavy bush to bush may in some areas not have changed appreciably. It is therefore
necessary remember that categorically adjacent vegetative classes (e.g. Forest and Heavy Bush, or Bush and
Heavy Bush) are related and sometimes “confused”. It is for this reason that the categorical classification
analyses (which cannot be thresholded) are presented first, followed by the thresholded NDVI image set,
which presents less nuanced information, but in which we can have much fuller confidence, even at the local level.

3.1 - 2001 and 2010 classified images
Figures 6 and 7 display the final classified images for the two years, 2001 and 2010. As noted above, since direct interpretation of changes between them is hampered by the overall complexity of the images, discussion of changes will be mainly based on separated change images (different classes of change separated into individual images for easier interpretation).

Nonetheless, a few initial observations can already be made which will emerge as recurring themes in subsequent imagery:

1) The core forest areas remain relatively stable, including those of the Kambui Hills Reserves, except for some conversion to bush along the boundaries;
2) There has been a general increase in vegetation density to the west of the Kambui Hills, with a particular increase in the “forest” class (though some of this area may be “heavy bush”);
3) There have been distinct decreases in vegetation (though little “forest” loss)
   a. Along the Waanje River (far west of the image) and;
   b. To the east and northeast of Kenema Town.

![Figure 6 - 2001 Categorical classification image](image-url)
3.2 - Overall dynamism

While these images give a sense of the level of ecological “patchiness” of the study area, they do not adequately convey the level of dynamism present. As a full appreciation of the complexity of vegetative change in this socio-ecological system is critical to the kind of land management programs envisaged by the PAGE project, it seems important to briefly emphasize this by presenting the cross-tabulation image before moving on to the simpler images displaying key changes of interest. This image is displayed in Figure 8 without a legend because, first, there are too many categories for display and, second, category by category interpretation is presented separately below. Rather, the key purpose here is to present two key general observations:

1) Unchanged areas (displayed in the light brown/salmon colour) occupy a few larger patches of the image, including the core areas of Kenema Town and the core reserve area, but are also dispersed in small patches throughout the image, and;
2) Areas that have experienced change (other colours, except black) are generally very fine grained (very small patches) and are distributed throughout the image as well, thoroughly intermixed with the unchanged patches.
Despite the fine grained complexity of the land cover and land cover dynamics of this area, however, by separating out certain classes of change into groups, it is possible to detect some more specific trends regarding changes in key classes of interest. Nonetheless, it is important to remember that the maps and statistics presented represent fair estimates, not absolute quantifications.

3.3 - Stable areas

First, as we are interested in both overall landscape dynamism/stability generally as well as forest management and conservation specifically it is clearly important to establish which areas appear not to have changed noticeably. Figure 9 displays a map of these areas by class. What is evident in this image is that there are large contiguous areas of little change only for the “forest” and “urban” classes, the largest of which, again, cover the bulk of the Kambui Hills area, and Kenema Town. As these areas are largely not associated with significant farming or resource extraction activities, it is unsurprising that they have been relatively stable. Conversely, the stable areas for other vegetative classes cover a significant amount of area, but in a very fine grained mosaic of patches. This, again, is unsurprising, given the wide distribution of population, and hence, productive land management activities in the area – i.e. as in much of Sierra Leone, outside the core forest areas and urban centers, much of the landscape is managed according to some sort of fallow rotation farming system (swidden agriculture). In quantitative terms, according to the final classification

Figure 8 - Raw crosstabulation image of changes between classes, unchanged areas grouped together
results displayed in Table 2, roughly 60 percent of the image area has undergone some degree of change (however small), while 40 percent of the area of the image area has remained under the same classes between the two image dates. Additionally, the “bush” and “forest” are the largest stable classes (by a slight margin), at 12 and 10 percent of the image area, respectively.

<table>
<thead>
<tr>
<th>Category</th>
<th>Area (km²)</th>
<th>Proportion of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Changed</td>
<td>907</td>
<td>58%</td>
</tr>
<tr>
<td>Total Stable area</td>
<td>644</td>
<td>42%</td>
</tr>
<tr>
<td>Stable Bush</td>
<td>181</td>
<td>12%</td>
</tr>
<tr>
<td>Stable Forest</td>
<td>151</td>
<td>10%</td>
</tr>
<tr>
<td>Stable Grass/Crops/Scrub</td>
<td>134</td>
<td>9%</td>
</tr>
<tr>
<td>Stable Mature Bush</td>
<td>120</td>
<td>8%</td>
</tr>
<tr>
<td>Stable Urban</td>
<td>44</td>
<td>3%</td>
</tr>
<tr>
<td>Rivers</td>
<td>14</td>
<td>1%</td>
</tr>
</tbody>
</table>
3.4 - Forest Loss
Since forest management is a key concern of the PAGE project, a second key issue of interest is to establish in which areas “forest” loss (conversion to “urban”/cleared areas or other, less dense vegetation classes) has occurred. As Figure 10 illustrates, the losses to the “forest” class are not extremely widespread according to these classifications, and are predominantly along the fringes of core forest areas. Moreover, as Table 3 indicates, the greatest class to which “forest” appears to have been converted is “bush”, or young forest regrowth. Nonetheless, while forest conversion areas form a very small fraction of the overall image, they represent a loss of roughly 25% of the total 2001 “forest” area.

Table 3: Apparent area of forest conversion by class

<table>
<thead>
<tr>
<th>Category</th>
<th>Km2</th>
<th>Proportion of total area</th>
<th>Proportion of 2001 &quot;Forest&quot; area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest to Bush</td>
<td>35</td>
<td>2%</td>
<td>17%</td>
</tr>
<tr>
<td>Forest to Grassland</td>
<td>13</td>
<td>1%</td>
<td>6%</td>
</tr>
<tr>
<td>Forest to Urban</td>
<td>3</td>
<td>0%</td>
<td>1%</td>
</tr>
</tbody>
</table>

When total conversions of “Forest” and “Heavy Bush” areas to classes of lower vegetation density are considered there is an apparent loss of 56% of the original “Heavy Bush” class area (in the 2001 image). However, it should be noted that this 56% is made up of two components (see Table 5) – 18% converted to “Grass and light vegetation” (a significant loss of vegetation density) and 37% converted to “Bush” (not necessarily a significant loss of vegetation density). Overall, it would appear that most change in this class should be considered not so much a linear trend of progressive de-vegetation, but more likely an expression of the normal cyclical fallow system of clearance and re-growth.
Table 4: Apparent area of “Forest” and “Heavy Bush” conversion to various other classes

<table>
<thead>
<tr>
<th>Category</th>
<th>Km2</th>
<th>Percent of total area</th>
<th>Percent of 2001 same class area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest converted</td>
<td>51</td>
<td>3%</td>
<td>25%</td>
</tr>
<tr>
<td>Heavy Bush converted</td>
<td>301</td>
<td>19%</td>
<td>56%</td>
</tr>
</tbody>
</table>

Table 5: Apparent area of “Heavy Bush” conversion by class

<table>
<thead>
<tr>
<th>Category</th>
<th>Km2</th>
<th>Percent of total area</th>
<th>Percent of 2001 same class area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Bush to Bush</td>
<td>199</td>
<td>13%</td>
<td>37%</td>
</tr>
<tr>
<td>Heavy Bush to Grass</td>
<td>96</td>
<td>6%</td>
<td>18%</td>
</tr>
</tbody>
</table>

3.5 - Forest Gain

As all the analyses indicate, however, forest and bush loss is far from the only change dynamic that was present in the study area over this time period. As Figures 12 and 13 indicate, there have also been significant...
gains in areas classified as “Forest” and “Heavy Bush”. With respect to the “Forest” class, these gains have been largely confined to the west of the Forest Reserve area, while in the case of the “Heavy Bush” class the gains are well distributed throughout most of the image. Moreover, as Tables 6 and 7 indicate, while “Heavy Bush” gain appears slightly more significant in area, “Forest” gain appears much more significant relative to the previous extent of the class – i.e. an almost 90% addition to apparent “Forest” area compared to around 40% for “Heavy Bush”. Finally, as Table 7 indicates, despite the losses to the “Forest” class over the period, there remains a net gain of 60% relative to the 2001 “Forest” area. For “Heavy Bush” however, the situation is notably different, with a net loss of around 50% relative to its 2001 area. Ultimately, despite the “blurry” class boundaries (e.g. it is possible that some “Forest” areas may perhaps be better placed in the “Heavy Bush” class), there is a clearly evident net gain in dense vegetation (even considering the sum of the net changes there is an overall net gain of “Forest” in 2% of the image area, or 27 km$^2$), predominantly west of the Kambui Reserves.
Table 6: Apparent area of “Forest” and “Heavy Bush” gain

<table>
<thead>
<tr>
<th>Category</th>
<th>Km²</th>
<th>Percent of total area</th>
<th>Percent of 2001 same class area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Forest Gain</td>
<td>178</td>
<td>11%</td>
<td>88%</td>
</tr>
<tr>
<td>Total Heavy Bush Gain</td>
<td>201</td>
<td>13%</td>
<td>37%</td>
</tr>
</tbody>
</table>

Table 7: Net apparent area of “Forest” and “Heavy Bush” gain

<table>
<thead>
<tr>
<th>Category</th>
<th>Km²</th>
<th>Percent of total area</th>
<th>Percent of 2001 same class area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net forest gain</td>
<td>127</td>
<td>8%</td>
<td>63%</td>
</tr>
<tr>
<td>Net Heavy Bush gain</td>
<td>-100</td>
<td>-6%</td>
<td>-50%</td>
</tr>
</tbody>
</table>

### 3.6 - Urban dynamics

Vegetation classes are, however, not the only ones to have experienced significant change – the urban/cleared area class has also been dynamic over the period, exhibiting trends which both reinforce and begin to provide an explanation for the broad spatial trends in vegetation biomass described above.

As Figure 14 indicates, there has not only been a significant amount of growth in “Urban” areas in the image, there is also a spatial trend to this growth, as the majority of expansion has occurred to the north and east of the image, where vegetation classes appear to have experienced the most loss. At the same time, there has been a significant amount of decline in urban area to the north and east of the reserve areas, the same part of the image in which vegetation classes appear to have expanded most significantly. It is important to note that
these trends in the urban class can be taken to increase our confidence in the overall accuracy of the categorical classification and change analyses. As noted above, the precise definition of vegetation class boundaries is difficult and prone to some degree of error (relative to our predefined conceptual or “ideal” classes). Urban or cleared areas, however, have distinctly different spectral reflectance characteristics from other landscape features, and are therefore easy to classify with a high degree of accuracy and confidence. Therefore, since the urban class change analysis exhibits spatial trends that correspond with those of the vegetation class change analyses, we can be more confident that the overall vegetation trends depicted are accurate (though still subject to some confusion between similar classes as noted above).

Overall, it is evident from Table 8 that there has been some degree of net urban growth – an overall increase of around 20% for this class. Nonetheless, it is also evident that the most dominant changes have been in the form of spatial shifting of urban areas – i.e. almost 40% of the 2001 urban areas have become vegetated, while at the same time the class has also grown by 60% through clearing of previously vegetated areas.

![Figure 14 - Apparent Urban expansion and decline](image)

Table 8: Apparent total area of “Urban” expansion and decline

<table>
<thead>
<tr>
<th>Category</th>
<th>Km2</th>
<th>Percent of total area</th>
<th>Percent of 2001 same class area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Unchanged</td>
<td>44</td>
<td>3%</td>
<td>62%</td>
</tr>
<tr>
<td>Urban Loss</td>
<td>27</td>
<td>2%</td>
<td>38%</td>
</tr>
<tr>
<td>Urban Gain</td>
<td>42</td>
<td>3%</td>
<td>59%</td>
</tr>
</tbody>
</table>
3.7 - NDVI

3.7.1 - Raw change NDVI
As described above in section 2.3.1, the change NDVI (Figure 15) presents analysis of the difference in vegetation density in each pixel between the images for 2001 and 2010. This image is produced by generating individual NDVI images for each of the two dates, and then subtracting the 2001 NDVI image values from the later 2010 image to generate a difference image. In the result, areas which have lower biomass values in 2010 have negative values, whereas areas where biomass has increased over the time period have positive values.

This positive-negative value split enables effective use of a bi-polar palette, which makes the image visually much simpler, and hence easier to interpret. In Figure 15 it is evident that, despite the overall complexity (or “patchiness”) of vegetative change in the study area, the same broad trends can be detected: general biomass increase to the west of the reserve except along the Waanje river and some other discrete patches, and broad areas of biomass reduction to the east of the reserve.

Nonetheless, this raw image must be interpreted with some degree of caution: a fair amount of the change depicted is not dramatic in quantitative terms and hence will only serve to complicate the development of land management plans. As well, at least a modest fraction may be due to residual “noise” left over after radiometric correction. It is for this reason that the following sections present images depicting only biomass change that we can be confident (at various levels) is definitely significant.
3.7.2 - 60% confidence threshold

The first of the thresholded images displays only data either higher or lower than 1 standard deviation from the mean of zero. In statistical terms, these data are for areas that we can be 60% confident have undergone change that is not due to “normal” variability, and should therefore be considered significant. As evident from Figure 16, there is still a large amount of area identified as having undergone either positive or negative change. This illustrates, once again, the complexity and dynamism of the landscape, but while ti does illustrate some useful broad trends, is still somewhat too complicated for the development of targeted management plans. For this reason, the next subsections present maps of data at the 95 and 99% confidence levels, respectively.

![Figure 16 - Change NDVI – thresholded at 60% confidence level](image)

3.7.3 - 95% confidence threshold

At the 95% confidence level threshold (Figure 17), which excludes data less than two standard deviations from the mean (i.e. twice as far as in the 60% confidence threshold image), it is evident that there are still a
large number of patches which have experienced significant positive and negative change. Moreover, in agreement with the categorical classifications detailed above, these patches are well distributed throughout the image, but major increases in biomass are mainly clustered in the southwest of the study area, and the west and northwest of the Kambui Hills Reserves area (the mainly grey region in the centre of the image). In contrast, major declines in biomass between the two image dates occur largely in the east, and particularly to the north east of the KHNFR itself, and around Kenema town, with many patches clustered between these areas along the Kenema-Mano Junction axis. This result agrees well with the urban growth analysis detailed above.

![Figure 17 - Change NDVI – thresholded at 95% confidence level](image)

### 3.7.4 - 99% confidence threshold
Finally, the 99% confidence threshold image displays only those areas in which the change data are more than 3 standard deviations from the mean – i.e. the areas of very dramatic change in vegetation. It is included here
as, though it excludes a fair amount of relevant data, it aids in visualisation of the areas in which significant vegetation gain and loss have occurred, which may be particularly useful in terms of developing land use management plans.

From Figure 18 it appears that, aside from a few patches to the west of the reserve, the most significant vegetation decline has been in areas of strong urban growth along the Kenema-Mano Junction Axis. With respect to vegetation gain, it also appears that aside from a large patch to the far southwest along the highway (which is conversion from an urban area), there is only one main cluster of patches to the west and northwest of the reserve, an area in which there appears (from both interview and imagery data) to have been abandonment of a number of settlements during the time period under study. As well, the core forest reserve area in the centre of the image does not contain any noteworthy areas of significant change at this confidence level, but there are a number of notable patches, especially significant loss on its fringes, particularly along the eastern side, perhaps unsurprising due to the proximity of a major road and associated settlements.

Figure 18 - Change NDVI – thresholded at 99% confidence level
4. Causal relationships - Linking to interview data

4.1 Forest Gain and a Changing Urban Landscape

One of the most striking observations this land cover analysis is the increase in heavy vegetation to the west of KHNFR. This appears to be linked with urban dynamics, as than one third of the urban/cleared areas of 2001 have been increasingly vegetated, despite an overall increase in urban area. Moreover, field data strongly suggest that this development is linked to population displacement and migration during and after the recent civil war (1991-2001). Almost all of the villages interviewed during field research indicated that their settlements had been devastated during the war: buildings were burned down, people were killed and many youths were abducted. The impact of this violence on small settlements around KHNFR was devastating. Many of the villages that were visited to the west of KHNFR stated that they had only recently returned to their villages after fleeing to Kenema and Freetown for safety during and just after the civil war. Most of them also reported that when they had returned to their villages, they had found them to have been almost completely overgrown with thick vegetation. It is also very likely that many other villages in the area were completely abandoned and have now been consumed by some stage of forest regrowth. Thus while some villagers have returned to or near their original sites, many others have opted to remain in Kenema or one of the larger urban centres in the area such as Ngombu, Hangha, Mano Junction, Largo and Panguma, as many research participants noted that in the initial post-war era these larger settlements were perceived to be 'safer' than smaller isolated settlements. Also, in the longer term, these larger towns have proven to be economic centres, and have offered potential livelihood opportunities for those that had their agrarian livelihoods devastated during the civil conflict. In short, larger urban centres seem to have acted as magnets for migration flows, especially during the civil war, as points of safety and, in the post-war era, as centres for developing livelihood activities. The overall impact of these trends has been a relative depopulation and substantial forest regeneration in the area to the west and north-west of KHNFR, and an increasingly urbanized area along the Kenema-Kono axis to the east of the reserve, which appears to have experienced notable decline in vegetation density, particularly in terms of reduction of mature bush, as well as some forest conversion along the edge of the Kambui hills.

4.2 Forest Commodities and Forest Cover Change

The following set of maps display production villages for different wood-based commodities (boards, charcoal and firewood) layered on top of vegetation change maps with 95% confidence thresholds, to support assessment of the relationship between the production of certain wood-based commodities and forest loss. The maps are divided into three commodities - boards, charcoal and firewood. No map was created for pole production as only one village was involved in harvesting poles for sale in the area, and only on a very limited scale. In order to display the scale of the settlements’ involvement in each trade, each village was ranked on a four point scale to reflect the extent of its production. The data for these rankings was necessarily qualitative in nature, due to the near impossibility of obtaining reliable quantitative data at the village level in Sierra Leone. Nevertheless the data was sufficient to clearly illustrate the geography of different production sites. A ranking of one reflects a small village with very limited production of the commodity, while a ranking of four, at the other end of the spectrum, reflects a large village with widespread participation in the production of the commodity. The time that the village had been involved in the production (particularly in the case of charcoal) also had a bearing on its scale (the longer time in production the higher the ranking). Legends are not included in order to maximise display size and in order to maintain the sense of the data as relative rather than quantitative, the rankings are reflected by the size of the circles on the maps below.
4.2.1 Board producing villages

Figure 19 shows that many of the board producing sites are located along the Kenema-Kono highway. This is an area of the highest concentration of forest loss, though there is no clear evidence that this is linked to board producing activities specifically, as this is also the area with the highest concentration of population and therefore of many activities that could potentially impact forest cover (farming, urban encroachment and other wood-based product trade). There is no heavier concentration of forest loss specifically around any of these villages, suggesting there may be no major direct impact. However, it is important to note of all the commodities that board producers tend to travel furthest in search of trees. Thus, along the Kenema-Kono highway, the extent of the trade’s impact on forest cover remains unclear. As well, on the south-west edge of the KHNFR there is group of four board producing villages located in two clustered areas of forest loss (though some data is missing due to cloud), implying a possible linkage. However, the villages are not necessarily directly responsible for this. This area was also the site of Gava Forest Corporation Industry’s logging concession in KHNFR. The company ceased operations at the end of 2009, just before the second (2010) landsat image was captured, thus some forest loss in this area can likely be attributed to the company’s activities. The area was also identified by many research participants as a hot bed of illegal logging, mainly by chainsaw operators from Kenema. Hence, it is quite possible that the impacts of the village-based trade is outweighed by those of the international logging company and illegal urban based loggers. Finally, there are a smattering of small to medium scale board producing villages to the west and south-west of the KHNFR that are located in or near forest gain areas, suggesting their operations may have a modest impact on forest cover.

Figure 19 - Major board producing villages layered on a map of forest gain (green) and forest loss (red) at a 95% confidence threshold. Urban settlements are marked in grey

26
4.2.2 Charcoal producing villages

Figure 20 shows that all of the charcoal producing villages are located along the Bo-Kenema and the Kenema-Kono highways. This is to be expected as the highways act as strategic locations from which to sell and transport charcoal to buyers from Kono, Kenema, Bo and other urban centres around the country. The cost and effort involved in transporting charcoal from more remote sites would likely be prohibitive. Furthermore, unlike with boards where chainsaw operators will venture deeper into the forest or to remote villages to seek out specific valuable tree species, charcoal makers tend to be more flexible in terms of what tree species they use and therefore mainly operate close to villages and major highways.

In terms of the forest cover impacts of charcoal production the Kenema-Kono highway, the map is inconclusive. As mentioned before, this is an area of high activity (urbanisation, agriculture, other wood-based production) and it is difficult to pinpoint which, if any, one activity has the greatest impact on forest loss. Once again, as with board producing sites, there is no evidence of higher concentrations of forest loss around charcoal producing villages along the Kenena-Kono highway. Interestingly, however, the medium-scale charcoal producing villages along the Bo-Kenema highway, which are located near areas indicated to be experiencing forest gain, suggesting that charcoal production in these villages, at least at the current scale, have had no major negative impact on their surrounding forest cover.

Figure 20 - Major charcoal producing villages layered on a map of forest gain (in green) and forest loss (in red) at a 95% confidence threshold. Urban settlements are marked in grey.
4.2.3 Firewood producing villages
The geography of firewood producing sites around the KHHNR (Figure 21) is very similar to that of charcoal. Of all the commodities it has the least value, so it is unsurprising that production sites are close to highways and urban centres, which act as sale points for the bulk of the trade. There are numerous production villages along the busy Kenema-Kono highway corridor, and once again, there is no conclusive evidence to suggest any immediate links between firewood harvesting specifically and forest lost. Overall, however, it appears that firewood is the commodity that is likely to have the least impact on forest cover as interview data indicates that almost all of the area’s firewood is a product of the farming cycle not forest harvesting.

![Figure 21 - Major firewood producing villages layered on a map of forest gain (in green) and forest loss (in red) at a 95% confidence threshold. Urban settlements are marked in grey.](image-url)

5. Conclusions
The landscape of the area surrounding KHNFR has been highly dynamic over the past decade, with myriad patches of gain and loss in the various vegetation categories. The forest reserve itself appears to have remained reasonably intact with only a thin line of forest reduction along its (mainly eastern) fringes, while the entire area surrounding the reserve as a whole appears to have experienced a modest overall increase in forest, or at least dense vegetative, cover. This contrasts strongly with usual environmental narratives in Sierra
Leone, which present the country’s forest cover as being in a state of constant and/or rapid decline. The analysis has shown that there is a specific geography of forest and other vegetation change in the area, which has largely been a product of urban expansion on the edges of Kenema and in towns along the Kenema-Kono Highway. Overall the bulk of forest lost has occurred to the east and south of the KHNFR. Overall, it appears that the main factors affecting forest cover in the KHNFR area have been the related processes of population displacement/migration and urbanisation, while “bush” gain and loss patterns (as well as the overall ecological patchiness of the landscape) seem to be largely associated with the dynamics of the fallow agricultural system.

The ambiguity of the relationships between forest cover change and specific wood-based commodities is perhaps predictable, given the results of data collected during field interviews. Of the villages visited, some reported forest loss, some report no forest change and some report forest gain around their villages. The change in forest cover appeared to be less connected with the types of forest exploitation activities they were engaged in, and more with the details of local forest management practices. In other words, it seems that commercial exploitation of the forest is not itself the issue, but rather how the exploitation is managed. A key current influence on this is the Town Chief and village elders, and their decisions (i.e. community byelaws) to regulate exploitation of certain areas and certain trees. Where Town Chiefs were active in promoting local management practices (and not just collecting “Kola” from forest exploiters), then generally the village reported little or no forest loss, and even forest gain in a number of cases. This perhaps also helps to explain the numerous patches of significant vegetation gain within the widespread area of vegetation loss along the Kenema-Kono highway.

Ultimately, any forest management plan for the study area will need to take into account the geography and trajectories of forest cover change discussed above. In particular, any efforts to improve forest management, and therefore increase forest cover, should have a strong focus along the Kenema-Kono Highway, as well as Tinnihun-Komende access area (the former Gava Forest Industries Corporation concession). It is in these areas that one can state with the highest confidence that forest loss is occurring, particularly along the fringes of the KHNFR. Nevertheless it is important to note that even this forest loss is occurring in a fragmented fashion, and also includes some small areas of forest gain. This suggests that there should be good local examples of forest management to be learned from and further adopted in these areas. PAGE’s co-management approach could certainly take advantage of this given its focus on strong engagement at the village level. Overall, the KHNFR forest cover scenario presents some significant positive aspects, not least the increased forest cover to the west of the forest reserve. Given the right local forest management approaches the area could achieve a sustained increase in forest cover – an impressive feat considering the presence of Kenema Town, the country’s third largest urban centre.