Lewa Wildlife Conservancy
Habitat Changes
1962-2016

Wim Giesen, Paul Giesen & Kris Giesen

Study June 2016
Revised report, April 2017
This study is based on voluntary field work carried out at Lewa Wildlife Conservancy from 30 May to 18 June 2016, upon invitation from LWC. It also builds upon earlier work at Lewa by all three authors in 2006 and by the first author in 1979-80.
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List of Abbreviations

- **CLG**: Community Livestock Grazing
- **dpi**: Dots per inch (printing or scanning resolution)
- **ftp**: File transfer protocol
- **GIS**: Geographic Information System
- **GPS**: Global Positioning System
- **ha**: Hectare
- **HD**: High definition
- **ID**: Identification
- **LSC**: Lewa Safari Camp
- **LWC**: Lewa Wildlife Conservancy
- **NDVI**: Normalized difference vegetation index
- **NIR**: Near infra-red
- **PC**: Principal component
- **PCA**: Principal Component Analysis
- **Q1**: First quarter (of the year, = January, February, March)
- **RAF**: Royal Air Force
- **SOP**: standard operating procedure
- **UTM**: Universal Transverse Mercator
- **VIS**: Visible spectrum
Foreword

It has again been a great pleasure carrying out this study for Lewa Wildlife Conservancy (LWC), and we find ourselves privileged at having been able to spend this time at LWC with our partners and (grand-)daughter. We would particularly like to thank Mike Watson (CEO of LWC), Geoffrey Chege (Head of Conservation & Wildlife LWC) and Zeke Davidson (conservation biologist for Marwell Wildlife and advisor to LWC) for their support, without which this study would have been impossible. Special thanks also to other LWC staff, including Mary Mwololo (wildlife studies) and Edwin Kisio (grassland studies) both of the research department and who actively partook in field activities and discussions, and Francis Kobia Chokera (LWC head ranger), who accompanied us on a daily basis, helping out with field activities and keeping us out of harm’s way.

Thanks also goes to our driver, Benjamin Kiburi for taking good care of us in the field, and Caroline Kanana Nkonge and her assistant Mercy Wanjiru, who provided us with excellent meals throughout and kept the guesthouse spic and span. We would like to thank Sophie and Calum Macfarlane (of Lewa House) for their hospitality and generosity, and sharing of information and photos (esp. of plants). Lastly, we would particularly like to thank Sue Brown for her great help in the field surveys, as she has an excellent knowledge of the local flora and is a very keen field biologist. We also thank Sue and her husband David for their kind hospitality and hosting us in their lovely fairy tale house.

Wim, Paul and Kris Giesen,

12th November 2016
the Netherlands
1. Introduction

1.1 General introduction to changes at Lewa

Lewa has changed significantly over the past 50-odd years, from a livestock ranch (Lewa Downs) to a privately managed wildlife conservation area (Lewa Wildlife Conservancy or LWC; see www.lewa.org), and this has gone hand-in-hand with changes in management. When it was still a livestock ranch, fencing was done away with and livestock were herded by herdsmen and corralled in a traditional “boma”\(^1\) at night. Livestock were mainly cattle (about 4000 head in 1980), but sheep were also kept in smaller numbers (about 2000 in 1980). As fencing was eliminated wildlife populations increased, attracted by available grazing and browse, relative safety, and the presence of three permanent springs. In the 1970s ecotourism was established in the area, including the still existing “Wilderness Trails” and other, less regular tented safari camps. Lewa Swamp was partially converted for market gardening purposes (esp. maize and onions) and for the establishment of tilapia fish ponds. Water from Lolmotoni spring was used for producing melons, tobacco, lucerne and vegetables.

In 1983-84 2,000 ha of Lewa was fenced off as the Ngare Sergoi Rhino Sanctuary, and in 1995 the entire Lewa Downs area was fenced off and transformed into the Lewa Wildlife Conservancy. Livestock was phased out starting in the 1980s, while wildlife numbers significantly increased, especially of zebra, elephant, impala and giraffe. At the same time, both black and white rhino were re-introduced to the area since 1983-84 where they have since thrived, making it one of Kenya’s most important conservation areas for these species. Management changes further include: i) the addition of perimeter fencing; ii) the introduction of exclusion zone fencing starting in the 1990s to exclude elephant and giraffe from key habitats (esp. riverine vegetation dominated by fever trees); iii) temporary use of controlled burning to prevent build-up of fuel in savannah habitat; iv) translocation of wildlife, both from and to Lewa especially giraffe, but also rhino\(^2\); and v) restoration of Lewa swamp where former market garden areas and fishponds were restored to swamp habitat surrounded by fever trees \textit{Acacia xanthophloea}. Recent management interventions include grassland mowing and localized, intensive cattle grazing, in an attempt to reduce build-up of moribund grass. Livestock grazing is part of the programme “Linking Livestock Markets to Wildlife Conservation” established by the Northern Rangeland Trust in 2006 (see www.nrt-kenya.org/livestock/), whereby LWC purchased cattle from local pastoralists (via Ol Peteja), paying prices up to 30% above market rates. The cattle are transported to LWC where it is held, de-ticked and fattened for sale and eventually the high-quality meat is sold on premium markets such as Nairobi (Bell & Prammer 2012).

Lewa has expanded considerably over the past decades from 20,000 ha in the 1970s to more than 40,000 ha by 2016, by the addition of the Ngare Ndare forest reserve, adding several centrally located grassed plains, and more recently (since September 2014) linking with the adjacent Borana Conservancy in a move that included removal of fencing between the two areas (Figure 1). Cattle ranching still a prominent part of Borana Conservancy and this is unlikely to be phased out as it is considered by Borana management to be beneficial in facilitating and maintaining a healthy grassland ecosystem, with little moribund grass and a good mix and cover of palatable grass and forb species\(^3\).

\(^1\) A “boma” is a circular enclosure with a diameter of usually 10-15m, casually constructed out of layers of thorny \textit{Acacia} branches.

\(^2\) As numbers of reticulated giraffe increased to well over 200, a programme of transferring giraffe to Samburu National Park was undertaken, with mixed results. In the 1980s and 1990s, both black and white rhino were transferred to Lewa, but as conservation efforts there were successful and numbers increased by breeding, some were transferred to nearby conservation areas such as Ol Peteja Conservancy.

\(^3\) The two areas differ: Borana has long been run as a cattle ranch, has higher rainfall, different soils and fewer wildlife, while Lewa has primarily been managed for wildlife over the past 30 years and is generally drier.
1.2 Previous studies on ecology & habitats at Lewa

The first author of this report, Wim Giesen, has been involved in three studies at Lewa:

- MSc study on ecology and carrying capacity from 1979-1980 (Linsen & Giesen 1983)
- Study on habitat changes 1962-2006 (Giesen, Giesen & Giesen, 2007a)
- Present study on habitat changes 1962-2016

The first two are summarised below.

1979-1980 study by Linsen & Giesen

In 1979-1980 a seven month MSc field study was carried out at Lewa titled “An ecological study of Lewa Downs, a seasonally-dry, central Kenyan grassland” by Lex Linsen and Wim Giesen (Linsen & Giesen 1983). This study covered climate, soils, geology, geomorphology, vegetation, wildlife and rangeland utilization, and a range of maps were also produced including vegetation and soils/geomorphology. The aim of the study was to identify the cause of the ‘steady decline in yield of the ranch since it had been acquired by the Craig family in 1952’, hence a significant part of the study was devoted to determining carrying capacity and identifying signs of overgrazing. The two volumes of the report were provided to Lewa Downs in 1983, along with a photo album depicting various common plant species and brief descriptions of these.
The first author of the present study was, among others, responsible for the vegetation part of this 1979-1980 study. Herbarium specimens were collected of 208 species and distributed to various herbaria including Nairobi, Wageningen (The Netherlands) and Missouri (USA). For the study, most identifications were carried out by Kenya Herbarium in Nairobi and a list of plant IDs were provided in March 1981, after which data analysis could begin in earnest. Additional IDs were later provided by Wageningen Herbarium. A total of 138 relevés were carried out in 1980 as a central part of the vegetation study, and in these 145 plant species were recorded. Vegetation data was analysed using TABORD (van der Maarel et al. 1978), which was one of the first computerized classification and ordination programmes used for analysis of such data. Vegetation maps were produced using black and white aerial photographs dating from 1962 and results from the TABORD relevée data computer analysis. The original map was hand drawn on a radox red transparency, printed and hand coloured. This has since (in 2006) been digitised and has been provided to LWC.

Apart from water, settlements and disturbed areas, a total of 12 different vegetation types were recognised by Linsen and Giesen (1983): 1) *Acacia seyal-Pennisetum stramineum*, 2) *Acacia drepanolobium-Pennisetum stramineum*, 3) *Acacia mellifera-Pennisetum stramineum*, 4) *Acacia mellifera-Acacia tortilis-Pennisetum stramineum*, 5) *Acacia nilotica-Pennisetum stramineum*, 6) *Grewia holstii-Harpachne schimperi*, 7) *Acacia xanthophloea-Chenopodium opulifolium*, 8) *Acacia xanthophloea-Pavonia patens*, 9) *Acacia xanthophloea-Euphorbia candelabrum*, 10) *Euphorbia candelabrum-Aspilia pluriseta*, 11) *Solanum incanum-Privia curtisiae*, and 12) *Euphorbia nyikae-Maytenus putterlickioides*. The first four vegetation types are by far the most extensive and together account for 86.2% of the area of what was then the Lewa Downs farm. Hill vegetation (types 5,6,10 & 12) extend over 8.6% of the area, while riparian vegetation dominated by fever tree extends over 5.2% of the area.

2006 study by Giesen, Giesen & Giesen

During a 4-day visit to Lewa in 1999, the first author of the present study observed that many habitats had changed since 1980 and suggested to Lewa management that a study be carried out to compare the present situation with that during the 1979-1980 study. After a long gestation period and after receiving digital black and white aerial photographs taken in 2000, a new study was undertaken in 2006 by Wim Giesen and his two sons Paul and Kris. This new study worked on the assumption that the basic vegetation types and their distribution had not changed, but that changes in management of the area had

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4 Relevee = each of a number of small plots of vegetation, analysed as a sample of a wider area.
mainly resulted in changes to woody vegetation cover. This was a reasonable assumption, as a significant increase in large herbivores such as elephants and giraffe had resulted in widespread and conspicuous tree damage. On the other hand, installation of exclosure fences had reduced pressures on certain habitats such as riparian vegetation dominated by fever trees. Lastly, protection of the Ngare Ndare forest and restoration of Lewa Swamp had also had an effect on woody vegetation.

The 2006 study involved identifying areas of significant change in vegetation, by comparing aerial photographs dating from 2000, with 1962 aerial photographs and a vegetation map produced in 1979-80. These 26 areas of significant change were then surveyed in the field, and resulting relevee data analysed using statistical programmes. Results of these field surveys confirmed that changes had occurred in density of woody vegetation, and not in species composition. A number of possible causes of habitat changes, such as fires, wildlife numbers, elephant/giraffe exclusion zone establishment and rainfall patterns were evaluated as to their possible contribution to overall habitat change. Interestingly, fires over the previous 14 years (1992-2006) did not appear to have led to floristic changes in the vegetation, although densities of plant cover have been affected, especially that of woody vegetation.

In the Ngare Ndare Juniperus procera-Olea africana forest, tree density had more than doubled during 1962-2000, from 35% to about 80%, although much of this may be due to increases in cover by fast growing species such as Dodonea and Rhus. This increase is probably due to effective protection against logging and fires. Similarly, the riverine vegetation dominated by fever tree Acacia xanthophloea had also witnessed a significant increase in tree cover, from 13.4% average in 1980 to 31.8% in 2000. These changes were due to a combination of restoration of Lewa swamp, and protection against browsing damage by creating exclusion zones. Tree and shrubs of plain vegetation – dominated by whistling thorn Acacia drepanolobium and to a lesser extent Acacia seyal – had experienced a significant decline, with large areas of woodland having been converted to grassland with a few scattered trees. Average tree/shrub cover has dropped from a 12.7% average in 1962 to 7.1% in 2000 – meaning that this had virtually halved over these decades. This decline in woody species of this habitat appeared to have been caused by a combination of fires and heavy browsing. Lastly, hill vegetation characterised by a range of tree species has had fluctuating tree densities over the past decades, but remained fairly constant overall from 1962-2000. However, in 2006 it was observed that due to heavy browsing pressures and elephant damage, tree and shrub cover is declining although still at a reasonable level.

Photo 2. Paul Giesen (l), Wim Giesen (m) & Kris Giesen (r) in the field at Lewa Wildlife Conservancy in 2006
1.3 Reason for present study

There are various reasons for the present study. Some of the more obvious changes in habitat such as that of woody vegetation brought about (mainly) by elephant damage are evident throughout Lewa and there is a need to monitor this. However, some changes are less conspicuous. According to LWC, numbers of certain wildlife species such as waterbuck, warthog, gerenuk, plains zebra and Grevy’s zebra have declined over the past decade. The cause of this reduction is unclear, and although predation (mainly by lion) plays a role, it is thought (by Lewa management) that habitat change may also be a contributing factor, especially a decline in grazing value of grasslands.

This idea of habitat change affecting numbers of certain is supported by the comparison with adjacent Borana Conservancy, where many decades of grassland management (by cattle grazing) has resulted in a mixed grassland with good cover and a more varied mix of grass species than common at Lewa, where much is dominated by (often moribund) wire grass *Pennisetum stramineum* and (to a lesser extent) bamboo grass *Pennisetum mezianum*. The recent mowing and experiments with localized intensive livestock grazing of grassland forms part of an attempt by LWC management to increase wildlife numbers by making grasslands more appealing to grazers such as zebras. In summary, there are two main reasons: i) assess the degree of (further) changes in woody vegetation since 2006, and ii) assess possible changes in the herbaceous layer (grasses and forbs) since 1979-80.

In 2015 it was decided that a renewed survey of habitats would be of interest to management of LWC and plans evolved to carry out the present survey in May-June 2016.
2. Methodology & approach of present study

2.1 Aim of present study

The aim of the present study was mainly to:

1. assess the degree of (further) changes in woody vegetation since 2006, and
2. assess possible changes in the herbaceous layer (grasses and forbs) since 1979-80.

In addition, it was agreed that an update and expansion of the booklet ‘Flora & Vegetation of Lewa Wildlife Conservancy’ would be produced as an extra output, and that exploratory surveys would be carried out in the adjacent Borana Conservancy. Also, LWC scientific staff would be actively involved in the surveys so that they would be able to carry out similar vegetation surveys in the future and in adjacent areas.

2.2 Itinerary of study

Fieldwork was carried out at Lewa from 30 May to 18 June 2016 (see itinerary in Table 1).

Table 1: Itinerary of study

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<th>Date</th>
<th>Location</th>
<th>Activities</th>
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<tr>
<td>March-April 2016</td>
<td>The Netherlands</td>
<td>Preparations for study, including analysis of satellite imagery to assess changes in woody vegetation, purchase of equipment (e.g. drone), redrafting of relevée sheet, scanning of hard copies of 1980 relevée sheets, and setting up of ftp-server for data exchange</td>
</tr>
<tr>
<td>28 May 2016</td>
<td>Amsterdam – Nairobi</td>
<td>Flight from Amsterdam to Nairobi (KL565) leaving at 12:45, arrival 21:40), overnight at Fairview Hotel, Nairobi</td>
</tr>
<tr>
<td>29 May 2016</td>
<td>Nairobi</td>
<td>Meeting with Zeke Davidson (Marwell/LWC), visit Nairobi NP</td>
</tr>
<tr>
<td>30 May 2016</td>
<td>Nairobi-Lewa</td>
<td>SafariLink Flight to Lewa, leave Wilson Airport at 10:20, arrive at Lewa at 11:20, set up 'camp', lunch, introductory 'tour'</td>
</tr>
<tr>
<td>31 May 2016</td>
<td>Lewa Wildlife Conservancy</td>
<td>Morning: trial relevées by Giesen team; Lunch &amp; discussion; afternoon: continue trial relevées</td>
</tr>
<tr>
<td>1-4 June 2016</td>
<td>Lewa Wildlife Conservancy</td>
<td>Relevées Giesen team</td>
</tr>
<tr>
<td>5 June 2016</td>
<td>Lewa-Il Ngwesi</td>
<td>Day off: cultural boma tour</td>
</tr>
<tr>
<td>6-11 June 2016</td>
<td>Lewa Wildlife Conservancy</td>
<td>Relevées Giesen team with rangers, including on-the-job training in approach</td>
</tr>
<tr>
<td>13-16 June 2016</td>
<td>Lewa Wildlife Conservancy</td>
<td>Relevées Giesen team with rangers, including on-the-job training in approach</td>
</tr>
<tr>
<td>17 June</td>
<td>Lewa Wildlife Conservancy</td>
<td>Morning: presentation of preliminary findings; afternoon: wrap up, plus last rounds</td>
</tr>
<tr>
<td>18 June 2016</td>
<td>Lewa-Nairobi-Amsterdam</td>
<td>Flight from Lewa to Wilson Airport, Nairobi, leave 11:25; flight from Nairobi Int’l to Amsterdam at 23:59</td>
</tr>
<tr>
<td>19 June 2016</td>
<td>Amsterdam</td>
<td>Arrival in Amsterdam at 07:15, return to home base</td>
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</table>
2.3 Methodology

2.3.1 Remote sensing of habitat changes

In the previous studies in 1979-1980 and 2006, use was made of black and white aerial photographs to determine density of woody vegetation, and any changes that had occurred. In the present study, however, the authors did not have access to new aerial photographs and hence had to resort to satellite imagery. To reduce costs, use was made of Landsat-4, -5 and -7 images available free-of-charge. To avoid complications brought about by seasonal changes in vegetation, images were used from only the dry season (months June to September), and in all, 160 images were obtained for the period 1987-2016 and used in the assessment.

On Landsat imagery one cannot observe individual trees and hence one has to resort to a proxy, namely ‘normalized difference vegetation index’ (NDVI) as measured during the dry season. NDVI is a relatively simple graphical indicator based on ‘greenness’ of a landscape remotely as observed by satellite. While other methods also exist, NDVI is one of the most successful of many attempts to simply and quickly identify vegetated areas and their condition, and remains the most well-known and used index to detect live green plant canopies in multispectral remote sensing data (October 2016: https://en.wikipedia.org/wiki/Normalized_Difference_Vegetation_Index). There are potential pitfalls in using NDVI analysis, as this is affected by atmospheric effects (water vapour, aerosols), clouds, soils effects (mainly related to soil moisture), anisotropic effects (due to angle of reflection) and spectral effects (if different types of spectral imagery are used). However, these potential pitfalls were avoided by our using: i) composite images of many years spanning the period 1987-2016, ii) dry season imagery only, and iii) Landsat imagery only.

The NDVI is calculated from individual spectral measurements as follows:

\[
NDVI = \frac{(NIR - VIS)}{(NIR + VIS)}
\]

where VIS and NIR stand for the spectral reflectance measurements acquired in the visible (red) and near-infrared regions, respectively.

These spectral reflectances are themselves ratios of the reflected over the incoming radiation in each spectral band individually, hence they take on values between 0.0 and 1.0. By design, NDVI therefore varies from -1.0 to +1.0. It should be noted that NDVI is functionally, but not linearly, equivalent to the simple infrared/red ratio (NIR/VIS). Differences in NDVI therefore reflect changes in greenness and hence changes in vegetation. Given that the images were taken from the dry season, the NDVI changes are mainly linked to changes in woody vegetation and not the herbaceous vegetation layer.

2.3.2 Vegetation surveying using relevees

Starting with the 1979-1980 study a relevee\(^5\) approach was used to sample vegetation. The approach was developed by Josias Braun-Blanquet as a standard method of sampling for vegetation classification according to the Zurich-Montpellier School of phytosociology (Mueller-Dombois & Ellenberg 1974). In the 1979-1980 and 2006 studies a stratified random approach was used to determine locations for vegetation surveys (i.e. relevee sites or sampling points). In this approach the surveyor allocates sampling points across the different vegetation types guided by the principle of relative area; if allocated purely on the basis of relative area less common vegetation types would be under-represented in the surveys, and hence these are allocated more sampling points relative to size. Within each vegetation types, however, point allocation is randomly distributed and clustering avoided.

\(^5\) French term meaning a collection of data, and is often used in terms of surveys.
The relevees carried out consisted of a combination of quadrants (or plots) for herbaceous vegetation and line transects (or line intercepts) for woody vegetation.

- In the 1979-80 study 5x5m plots were used in the plains and 10-10 m plots in the hills, but in 2006 and 2016 10x10m plots were used only. In the plots, each herbaceous species was recorded, along with its percentage cover (if appropriate) or relative abundance using a modified Braun-Blanquet scale\(^6\) (Mueller-Dombois & Ellenberg 1974).

- In the 1979-1980 study 3x100m long line transects were used, but in both 2006 and 2016 3x30m line transects were used as these proved to provide sufficient information (i.e. extra length of transect did not provide extra information). All individual tree and shrubs of each species were recorded along the lines and each species given a score on the modified Braun-Blanquet scale (see footnote 5).

A standard operating procedure (SOP) for conducting relevees is included in Appendix 1.

Pre-printed relevee data sheets were used in all three studies (1979-1980, 2006 & 2016) as this guided data collection and helped avoid overlooking certain aspects of the survey. The relevee data sheet used in 2016 is attached in Appendix 2. Apart from relevee ID data (relevee number, date, location, names of surveyors) the data sheet prompts for information on slope, landform, lithology, general habitat type, presence of exclosures/fencing, and vegetation data. Note that the data sheet also prompts for certain common species, such as various *Acacias* in the trees/shrubs category, *Pennisetum stramineum* in the grass and sedge category and *Achyranthes aspera* in the herb category.

### 2.3.3 Relevee site selection

Relevee sites in 2016 were selected as follows:

- A relatively large (30-40) sub-set of the (138) 1979-1980 relevees were to be repeated. Sites were selected to achieve a good geographic coverage throughout Lewa, and also so that all habitat types were adequately covered. It was possible to locate about 65% of the 1979-1980 relevee sites as the first author still had in his possession most of the original aerial photograph enlargements used in the field, upon which relevee sites were pin-pointed and numbered.

- A sub-set of the (78) 2006 relevees were to be repeated. These 2006 relevees were carried out in 26 clusters of three (3) relevees, and only one per cluster would suffice as a repetition.

---

\(^6\) The modified Braun-Blanquet scale: 1= rare (occurring once only in plot), 2 = present but no appreciable cover, 3 = 1-2% cover, 4 = 3-5% cover, 5 = 6-10% cover, 6 = 11-20% cover, 6 = 21-30% cover, 7 = 21-30% cover, 8 = 31-60% cover, 9 = >60% cover.
• Extra survey sites were added to provide a better geographic coverage across Lewa, including areas that had been added later such as Ngare Ndare forest.

• 10 change sites based on the NDVI analysis, i.e. sites with significant change during 2007-2016 (see 3.3.1).

2.3.4 Plant identification

In the 1979-1980 study a herbarium collection was established and plant IDs were carried out by (East African Herbarium, now) Kenya Herbarium and Wageningen Herbarium in the Netherlands. In the 2006 and 2016 studies, however, this was not possible as special permits would be required for vegetation sampling and plant collecting is discouraged as Lewa is now a protected area. For that reason, plant identification had to be carried out on the spot (with live specimens) or from digital photographs using a variety of general Kenyan/East African plant identification guide books such as Agnew & Agnes (1994), Beentje et al. (1994), Blundell (1987), Dale and Greenway (1961) and Dharani (2002). In addition, use was made of the plant ID booklet previously produced by Giesen et al. (2007b) whereby use was also made of many volumes of the Flora of Tropical East Africa, and Haines and Lye (1983) for identification of sedges.

2.3.5 Additional data recorded

In keeping with new technology, it was decided that photographs and video 360° panoramas would be taken of all relevée sites with a drone (DJI Phantom 3 standard drone with four propellers, HD 1080P video with 3-axis gimbal/stabilizers, f/2.8 lens with an image angle of 94°, and direct viewing on screen of what drone camera is aimed at) from a height of about 20-25 metres. From this height the vegetation can be well observed and recorded given the resolution of the camera (12 megapixels). Care was taken to avoid disturbing wildlife and it was therefore not used in the immediate vicinity of wildlife (i.e. always from a distance of more than 2-300m). The drone in action is depicted in photo 5, while photo 6 shows an example of one of the photographs taken from a height of 20-25m.

All drone photographs and films were provided to LWC management and the LWC Conservation Department while still at the conservancy. These files were also stored on the ftp-server established for this study (see 2.3.6).

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7 The DJI Phantom 3 drone has four propellers (see Photo 5) and the whirring noise sounds like a swarm of bees. At a distance of 200-300m most wildlife ignores the drone, but there are some exceptions. Rhino, for example, became uneasy and would slowly move away from the source of the noise.
Photo 5. Using the DJI Phantom 3 drone. In windy conditions (prevailing late afternoons) landing and take-off in the tall grass was problematic, but otherwise no difficulties were encountered.

Photo 6. Example of a drone photo taken of one of the plots in the hills. The four corners of the plot are marked by persons, except the bottom right one marked by the white box.
2.3.6 Data analysis & exchange

In a first instance, relevee data was analysed using the standard Microsoft excel spreadsheet programme in which basic (and even relatively sophisticated) analyses can be carried out. In order to assess relationships between relevees and species, a Principal Component Analysis (PCA) was performed using the Excel add-in Multibase package (Numerical Dynamics, Japan). The aim of this add-in programme is to identify meaningful patterns between environment (e.g. habitat characteristics, fire, fencing) and vegetation (based on floristic composition only).

Principal Component Analysis (PCA) is a so-called ordination method of data analysis, which is a statistical analysis that calculates dissimilarity between either species or relevees (van der Maarel et al. 1978). The two most dissimilar relevees or species are then used as terminal ends for the first axis (axis-1 or Principal Component 1/PC1). The next step is identifying the two most dissimilar relevees or species located in the central part of axis-1 (i.e. almost equally dissimilar to the first two terminal points). These are then used as terminal ends for the next axis (axis-2 or PC2), and the process repeats itself. Ordination can be carried out on the basis of ‘attributes’ (in our case, floristics), which is designated as R-type analysis, or on the basis of ‘individual units’ (in our case, the relevees), which is designated as Q-type analysis.

An ftp-server has been established by the authors of this report specifically for information and data exchange for this study, and key LWC staff have been provided with access and assisted in setting this up on their laptops. Data that has been stored includes:

- Reports, including scans of the 1979-1980 study (Linsen & Giesen 1983), the vegetation ID booklet (Giesen, Giesen & Giesen 2007b) and the vegetation study (Giesen, Giesen & Giesen 2007a).
- Scans (1200 dpi) of the 1962 aerial photographs used by Linsen & Giesen (1983)
- Digital black and white aerial photographs of 2000 used by Giesen, Giesen & Giesen (2007a)
- Drone photographs & films taken at all relevee sites in 2016
- Excel files of all relevees (1980, 2006, 2016)
- Scans of all filled out original relevee data sheets of 1980, 2006 and 2016.
- Shape files of maps produced by the study
- Plant photographs

The authors will keep this ftp-server will be kept operational and accessible for the immediate future and at least until 2018.

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8 This Excel add-in Multibase package (Numerical Dynamics, Japan) is available online, only a free donation is requested.
3. Results & discussion

3.1 Overview of releves

Figure 2 provides a map depicting the location of the releves carried out in 2016. In all, 66 releves were carried out, of which:

- 32 are repetitions of 1980 releves,
- 20 are repetitions of 2006 releves,
- 10 are releves of change sites identified by NDVI analysis (see 3.3.1),
- 4 are releves of new sites on Lewa (as per pre-2013 boundary, i.e. without Borana).

Figure 2 Location of 2016 releves in Lewa landscape
3.2 Overview of plant species

A total of 200 plant species were recorded in these relevees, including 36 grasses and sedges, 93 forb species and 71 tree and shrub species. Table 2 provides an overview of the degree to which these plant species have been identified. Overall, 76% have been identified to species level and a further 11% to genus level and 5% to family level. Almost 9% (17 species) remain ‘unidentified’, often due to a lack of flowers or fruit.

Table 2: Summary of number of species and % identified

<table>
<thead>
<tr>
<th></th>
<th>totals</th>
<th>species level</th>
<th>genus level</th>
<th>family level</th>
<th>unidentified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasses &amp; sedges</td>
<td>36</td>
<td>28</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>77.8</td>
<td>22.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Forbs</td>
<td>93</td>
<td>66</td>
<td>11</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>71.0</td>
<td>11.8</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Trees &amp; shrubs</td>
<td>71</td>
<td>57</td>
<td>3</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>80.3</td>
<td>4.2</td>
<td>2.8</td>
<td>12.7</td>
</tr>
<tr>
<td>Totals</td>
<td>200</td>
<td>151</td>
<td>22</td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>75.5</td>
<td>11.0</td>
<td>5.0</td>
<td>8.5</td>
</tr>
</tbody>
</table>

The overall list of plant species recorded at Lewa along with photographs and descriptions of species will be recorded in an update to the plant species booklet produced in 2007 (Giesen, Giesen & Giesen 2007b). This is planned to be produced by late Q1 2017.

3.3 Changes in cover of trees & grasses

3.3.1 NDVI analysis

Figure 3 depicts the results of the NDVI analysis for 1987-2016, whereby the areas in red are where there is a substantial increase in ‘greenness’ (i.e. tree cover), while the areas in blue depict areas with a decrease in tree cover. Areas where tree cover has increased are mainly the Ngare Ndare forest, along with Lewa swamp and the *Acacia xanthophloea* (fever tree) riverine vegetation near LWC headquarters. Areas with a decrease in tree cover appear to be mainly in the central and northern valleys, mid/central- and mid-northern plains.

Figure 4 depicts an overlay between the NDVI differences (2016-2007) and the exclusion zones. From this it is apparent that exclusion zones appear to be functioning well in some areas (e.g. mid-southern area, Lewa headquarters), but are not doing so well in other areas (e.g. mid-northern and northern). Partly this is because some exclusion zones are of recent origin. However, it is also because some fenced off areas have been breached by elephants that have discovered ways to avoid (or deactivate) the electric fencing. Recent innovations in the design of the fencing (i.e. equipped with ‘feelers’) may improve the level of protection, but past experience shows that sooner or later wildlife will probably find a new point or method of entry and fencing may in the long run have only mixed results.

During the present study we were mainly concerned with changes since 2006, and ten locations were visually selected on the basis of the 2007-2016 changes (NDVI) map (Figure 5) and surveyed during the relevee rounds.

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9 2007 was chosen as many exclusion zones were established in the last 10 years.
Figure 3  Map with results of NDVI analysis 1987-2016

Figure 4  NDVI difference and exclusion zones

Lewa total, mean NDVI difference: -0.055
Lewa exclusion zone mean NDVI difference: +0.009
3.3.2 Changes in tree and grass cover from 1980-2016

In Figure 6, data is plotted on tree and grass cover from the 32 relevees that are 2016 repetitions of 1980 relevees. Overall (as per these 32 sites), tree/shrub cover has decreased from an average of 24% in 1980 to 9% in 2016\(^{10}\), while at the same time grass cover increased from an average of 50% in 1980 to 70% in 2016. This reciprocal (inverse) relationship between tree and grass cover is a natural one: higher tree cover results in a lower grass cover due to shading and competition for nutrients and water. Possible underlying causes are discussed below. However, as indicated is our previous study (Giesen et al 2007a), the relationship is not as simple as appears at first glance, and savanna trees can both increase or decrease the productivity of understorey grasses. Trees can reduce grass growth through competition for nutrients, water and light, but may also stimulate grass production through increased soil nutrient availability, shade, and hydraulic lift (Ludwig, 2001).

\(^{10}\) Note that while there is an overall decrease in cover of woody species, this is not true for all species as some (such as Boscia mossambicensis, Euclea, Grewia, Gymnosporia (Maytenus) putterluckioides, Searsia (Rhus) natalensis, Vangueria) have actually increased (see 3.6.1).
Three exclosure sites (circled in red) are included in these 32 relevees, and two of these are the only examples of where tree/shrub cover has (mildly) increased since 1980. The third exclosure site was only recently established and still shows a significant decrease in tree/shrub cover.

Three outliers (blue circle) that have a significant reduction in grass cover from 1980-2016 are located in the plains on black cotton soils. Half of the plain relevees on black cotton soils show a decrease in grasses cover from 1980-2016, while all plain relevees on non-black cotton soils show a significant increase in grass cover. Observations on black cotton soil vegetation at Sambara Plain (northern part of LWC), for example, shows that tracks are 10-20 cm lower than the base of the surrounding grass tussocks, while plants may have exposed roots (Photo 7). These both indicate significant erosion, and apparently these soils are susceptible to erosion (e.g. due to trampling and/or grazing).

This susceptibility is confirmed by scientific literature. Black cotton soils belong to the Vertisol class of soils, characterized by high levels of clay (up to 60%, mainly montmorillonite), deep cracking in the dry season and dark colours. According to Eswaran and Cook (undated) “during the onset of the rains in dry regions, there is tremendous soil loss due to erosion, although subsequent rains are less destructive”. As concluded by Freebairn et al (1996), “soil erosion is a major limitation to long-term production on Vertisols. This is a consequence of their low infiltration rates when wet and relatively high erodibility.” Singh et al (1992) report an annual loss of 20 tons/ha.year and list black cotton soils as “highly erodible”. The draft Grassland Management Plan produced for LWC (Schultz et al 2014) “proposes that black cotton soils be grazed throughout the year (with heavy grazing immediately after the rains) while red soils will be grazed only during the dry season.” Based on apparent trends in grass cover on black cotton soils and the fact that these soils are highly erodible, particularly during rains, heavy (and certainly year-round) grazing of black cotton soils seems less advisable.
Underlying causes of the decline in woody vegetation (tree cover) were assessed by Giesen et al. (2007a). When the area was still primarily a cattle ranch (e.g. in the 1970s) there was an active programme to reduce tree cover as the prevailing view at the time was that the competition with grasses led to reduced grazing for livestock. This ‘bushclearing’ programme especially targeted *Acacia drepanolobium*, and consisted of cutting the tree and applying ‘Tordon’ (Picloram) brushkiller herbicide to the cut stump. This bushclearing, in combination with the occasional accidental fire, has undoubtedly played a role in reduction of woody vegetation over the years. Fire was also intentionally used as a tool by LWC (e.g. in 2005-2006) to reduce the amount of moribund grass and improve nutritional value of grasslands, but was abandoned as it was perceived as ‘wasteful’ (by neighbouring pastoralists) and was seen to lead to a loss of woody vegetation. However, as assessed by Giesen et al (2007a) fires explain only half of the loss of woody vegetation, and factors such as heavy browsing pressures by giraffe and especially by elephant also play a significant role. Signs of elephant damage to woody vegetation are obvious throughout LWC, and appear more pronounced than in 2006.

Over the past two decades LWC has undertaken a programme of ‘exclusion zone fencing’ (using electrified fencing) to protect woody vegetation from large browsers (esp. elephant), and this has met with mixed results. In some locations fencing reduced browsing pressures, but subsequent fires led to loss of woody vegetation (Giesen et al 2007a). Elsewhere, elephant have discovered ways of by-passing the fencing11, and some exclusion zone areas have therefore not been very successful. LWC have therefore introduced a recent innovation of electrified fencing equipped with ‘feelers’, as this is less likely to be breached, and for now these new fences appear more resilient to being breached.

Changes in woody vegetation in the plains may also have been affected by rainfall. Lind and Morrison (1974) report that in Kenya black cotton soils have *Acacia mellifera* wooded grassland when rainfall is 380-635 mm, which with heavy grazing becomes *A. mellifera* bushland. With increasing rainfall *Acacia seyal* becomes more important with occasional specimens of *Acacia drepanolobium*; above 760 mm rainfall *A. drepanolobium* becomes common. On the Laikipia plateau, however, *A. drepanolobium* is common and dominant at rainfall levels of 500-600 mm (Shaw et al. 2002). *A. drepanolobium* appears restricted to black cotton soils in East Africa, and although it can germinate and grow on other soils the species probably

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11 Elephants have proven to be resourceful and inventive in by-passing electrified fencing, resorting to a variety of means such a: i) using branches and trees to pull down a section of fencing; ii) crawling under the fencing (e.g. where this crosses a gully or river channel); and iii) forcing juvenile elephants to crash through the fencing.
does not compete well with other Acacia species on these soils (Okello & Young 1999). Long-term average annual rainfall at Lewa is 506 mm (1975-2015), although there is a lot of variation within LWC: in 2015 this varied from +34% at Kisima and Subuiga, to -44% at Melima Mbogo. Rainfall patterns for the decades 1975-2015 are provided in Figure 7a. 1975-1994 were close to (within 1-2%) the long-term average of 503 mm, and while 1995-2004 was +13%, 2005-2015 was at -9% and considerably drier. These decades mask the fact that 1999-2001 were particularly dry (see Figure 7b), with annual rainfall at only 62-74% of the long-term average. Given that much of the damage to savanna trees such as Acacia drepanolobium and A. seyal by large browsers has occurred after about 2000, changes in rainfall patterns may also have contributed to the lack of recovery. Similar circumstances were found at the 9000 ha Sweetwaters Black Rhino Reserve in Laikipia, where Birkett (2003) found that a combination of low rainfall and heavy browsing by elephants, black rhinos and giraffes led to a very rapid tree loss of 25% in five years, from 1998-2002.

Figure 7 Rainfall at Lewa 1975-2015: a) seasonal patterns, & b) annual total rainfall
Figure 8 depicts changes in tree/shrub and grass cover in the two major habitat types: plains and hill vegetation, from 1980-2016. The pattern that emerges is very similar as grass cover increase and tree/shrub cover decreases between 1980 and 2016 in both of these habitats. However, the decline in tree/shrub cover is more pronounced in the plain habitats where the decline is 70%, compared to a 60% decline in hill vegetation. The increase in grass cover is 29% in the plain vegetation and 45% in hill vegetation from 1980-2016. If the relationship between woody vegetation and grass cover was a simple inverse one based on competition, then the increase in grass cover should have been more pronounced in the plains than in the hills. There are several possible explanations for this. On the one hand, there could be a greater facilitation of grass growth by woody vegetation in the plains than in the hills (e.g. a greater impact of ‘hydraulic lift’ in the plains than in the hills). However, it is also possible that the presence of large herbivores plays a role as larger concentrations in the plains (than in the hills) may lead to a lower degree of colonisation by grasses due to the effects of trampling.

3.3.3 Changes in tree/grass cover from 2006-2016

In 2006 26 sites were recognised where significant changes had occurred to the woody vegetation. These were either areas with a significant increase in woody vegetation, often due to habitat recovery after introduction of fencing (i.e. exclusion zones), or areas with a significant reduction in tree cover (due to fires/elephant damage).

20 of these sites were re-surveyed in the present study, and the comparison between the two is depicted in Figure 9. These changes are also summarised and described in Table 3. At most of the nine (9) sites where there was an increase in woody vegetation up to 2006, this trend continued up to 2016, with an average increase in tree cover of 48% from 2006-2016. Most of these ‘increaser’ sites were locations where exclusion zone fencing had been installed (see red circles in Figure 9). At the eleven (11) sites where woody vegetation was decreasing up to 2006, this trend was on average reversed (with an increase in tree cover of 37%) by 2016 due to the introduction of new exclusion zone fencing between 2006 and 2016. However, the latter is mainly due to a significant increase at one location alone (Safi Corner), where there had been a very serious fire in 2000 that greatly reduced tree cover, but where exclusion fencing introduction in 2008 had been very successful (see point 26 in Table 3). One may conclude that trends of increase or decrease of woody vegetation continued from 2006 to 2016, unless new exclusion zone fencing had been introduced in this period. In the latter case the decreasing trend was found to have reversed in half of the cases (n=2) where fencing was introduced >5 years ago, while in areas with recent introduction of fencing (n=2) showed no reversal of the decreasing trend.
Table 3 on the next page summarises tree density changes at a selected number of locations throughout the LWC, from 1962-2016. Generally, key tree species remain the same over time, in spite of major changes in density. Table 3 also indicates which of these sites has exclusion fencing, along with the date of installation. Two out of three exclusion fences that have been installed at least eight (8) years ago have been very effective in that tree cover has increased remarkably (sites 3, 5 & 26). Four sites that had fencing installed recently are not (yet) effective and have yet to have a positive impact on tree cover (sites 6, 7, 9 & 17).

Figure 10 summarises changes in tree cover for the major habitat types from 1980-2016. Note that the information for 2016 is based on relevées and not on areas mapped (as detailed vegetation mapping was not carried out in the present study), and hence the results are indicative only. However, the trends are probably correct, and these show that woody vegetation has decreased in density/cover in plains, hills and riverine areas since 1980, and while for plain vegetation this has levelled off (at a low level) from 2006-2016, this downward trend continues in the hills and riverine vegetation.
## Table 3: Vegetation change at selected points, 1962-2016

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>10-20</td>
<td>&gt;40</td>
<td>65%</td>
<td>2002</td>
<td>Grassland with scattered <em>Acacia xanthophloea</em></td>
<td><em>Acacia xanthophloea-A. drepanolobium</em> woodland</td>
<td><em>Acacia xanthophloea-A. drepanolobium</em> woodland</td>
</tr>
<tr>
<td>4</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>20-40</td>
<td>10-20</td>
<td>20%</td>
<td>None</td>
<td>Grassland &amp; scattered <em>Acacia mellifera</em> &amp; <em>A. tortilis</em></td>
<td><em>Acacia brevispica-A. senegal, A. tortilis</em> wooded grassland</td>
<td>*Acacia brevispica-A. senegal, Gymnosporia-Commiphora, woodland</td>
</tr>
<tr>
<td>5</td>
<td>2-10</td>
<td>&lt;2</td>
<td>20-40</td>
<td>20-40</td>
<td>18%</td>
<td>2009</td>
<td>Grassland with scattered <em>Acacia mellifera</em> &amp; <em>A. tortilis</em></td>
<td><em>Acacia mellifera-A. senegal</em> woodland</td>
<td>*Acacia mellifera-A. nilotica, Gymnosporia-Terminalia woodland</td>
</tr>
<tr>
<td>6</td>
<td>10-20</td>
<td>2-10</td>
<td>20-40</td>
<td>10-20</td>
<td>30%</td>
<td>Recent, ineffective</td>
<td><em>Acacia mellifera-A. tortilis</em> wooded grassland</td>
<td><em>Acacia mellifera, A. brevispica-A. tortilis</em> wooded grassland</td>
<td>*Acacia brevispica, A. mellifera-A. tortilis-Boscia woodland</td>
</tr>
<tr>
<td>7</td>
<td>2-10</td>
<td>2-10</td>
<td>20-40</td>
<td>20-40</td>
<td>18%</td>
<td>Recent, ineffective</td>
<td><em>Acacia mellifera-A. tortilis</em> wooded grassland</td>
<td><em>A. drepanolobium, mellifera, nilotica &amp; brevispica</em> wooded grassland</td>
<td>*Acacia mellifera-A. tortilis-Grewia woodland</td>
</tr>
<tr>
<td>9</td>
<td>&gt;40</td>
<td>20-40</td>
<td>10-20</td>
<td>2-10</td>
<td>3-5%</td>
<td>2009, ineffective</td>
<td><em>Acacia mellifera-A. nilotica</em> wooded grassland</td>
<td>Grassland with scattered <em>Acacia mellifera</em> &amp; <em>A. tortilis</em></td>
<td><em>Acacia mellifera-A. nilotica-A. tortilis</em> wooded grassland</td>
</tr>
<tr>
<td>11</td>
<td>10-20</td>
<td>&lt;2</td>
<td>10-20</td>
<td>10-20</td>
<td>15%</td>
<td>None</td>
<td>Grassland with scattered <em>Acacia mellifera</em> &amp; <em>A. tortilis</em></td>
<td><em>Acacia mellifera &amp; A. senegal</em> wooded grassland</td>
<td><em>Acacia tortilis-A. hockii-Gymnosporia-Grewia</em> woodland</td>
</tr>
<tr>
<td>12</td>
<td>2-10</td>
<td>&lt;2</td>
<td>10-20</td>
<td>10-20</td>
<td>4%</td>
<td>None</td>
<td>Grassland with scattered <em>Acacia mellifera</em> &amp; <em>A. tortilis</em></td>
<td><em>Acacia nilotica, A. tortilis, A. mellifera &amp; A. senegal</em> wooded grassland</td>
<td><em>Acacia nilotica, A. tortilis, A. mellifera</em> wooded grassland</td>
</tr>
<tr>
<td>13</td>
<td>10-20</td>
<td>10-20</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>0.5%</td>
<td>None</td>
<td><em>Acacia drepanolobium</em> wooded grassland</td>
<td>Grassland with scattered <em>Acacia drepanolobium</em></td>
<td>Grassland with scattered <em>Acacia drepanolobium &amp; Grewia</em></td>
</tr>
<tr>
<td>15</td>
<td>&gt;40</td>
<td>&gt;40</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>0.3%</td>
<td>None</td>
<td><em>Acacia drepanolobium</em> woodland</td>
<td>Grassland</td>
<td>Grassland with occasional <em>Acacia</em></td>
</tr>
<tr>
<td>16</td>
<td>&lt;2</td>
<td>10-20</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>0.5%</td>
<td>None</td>
<td><em>Acacia drepanolobium</em> wooded grassland</td>
<td>Grassland with scattered <em>Acacia drepanolobium</em></td>
<td>Grassland with scattered <em>Acacia drepanolobium &amp; A. mellifera</em></td>
</tr>
<tr>
<td>17</td>
<td>10-20</td>
<td>10-20</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>1%</td>
<td>2015</td>
<td><em>Acacia drepanolobium - Acacia seyal</em> wooded grassland</td>
<td>Grassland with scattered <em>Acacia drepanolobium</em></td>
<td>Grassland with scattered <em>Acacia drepanolobium &amp; Boscia coriaceum</em></td>
</tr>
<tr>
<td>20</td>
<td>20-40</td>
<td>10-20</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>0.5%</td>
<td>None</td>
<td><em>Acacia drepanolobium</em> wooded grassland</td>
<td>Grassland with scattered <em>Acacia drepanolobium</em></td>
<td>Grassland with few scattered <em>Acacia drepanolobium</em></td>
</tr>
<tr>
<td>21</td>
<td>&gt;40</td>
<td>&gt;40</td>
<td>10-20</td>
<td>&lt;2</td>
<td>0.5%</td>
<td>None</td>
<td>Mixed woodland along river course</td>
<td>Grassland with scattered trees</td>
<td>Grassland with scattered <em>Acacia drepanolobium, Grewia, Sear sia</em></td>
</tr>
<tr>
<td>22</td>
<td>&gt;40</td>
<td>&gt;40</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>1%</td>
<td>None</td>
<td><em>Acacia drepanolobium</em> woodland</td>
<td>Grassland with scattered <em>Acacia drepanolobium</em></td>
<td>Grassland with scattered <em>Acacia drepanolobium &amp; Boscia</em></td>
</tr>
<tr>
<td>24</td>
<td>&lt;2</td>
<td>&gt;40</td>
<td>2-10</td>
<td>2-10</td>
<td>2%</td>
<td>None</td>
<td><em>Acacia drepanolobium</em> woodland</td>
<td><em>Acacia drepanolobium</em> wooded grassland</td>
<td>Grassland with scattered <em>Acacia drepanolobium &amp; Boscia</em></td>
</tr>
<tr>
<td>26</td>
<td>&gt;40</td>
<td>&gt;40</td>
<td>2-10</td>
<td>10-20</td>
<td>45%</td>
<td>2008</td>
<td><em>Acacia drepanolobium - Acacia seyal</em> woodland</td>
<td><em>Acacia drepanolobium - Acacia seyal</em> wooded grassland</td>
<td><em>Acacia drepanolobium, with some- Acacia seyal &amp; Boscia woodland</em></td>
</tr>
</tbody>
</table>

Notes: Numbers in first column correspond with the 26 ‘habitat change points’ used as a basis for surveys in the 2006 study (Giesen et al 2007a; see map figure 6). These are habitat change numbers, not relevee numbers as three (3) relevees were carried out per change site. Change site 3 corresponds with 2006 relevees no. 4, 5 & 6. The column on fencing refers to the installation of exclusion zone fencing; date gives the date of construction.
3.4 Changes in species composition

3.4.1 Changes in numbers of grass, forbs & tree species

Figure 11 shows the results of the analysis of the numbers of grass, forb and tree/shrub species occurring in the 32 2016 relevees that are repetitions of 1980 relevees. The aim of this comparison is to assess if there are any changes in species numbers for these three physiognomic classes since the time of the 1980 study. The average number of species found in any one relevee site increased from 15.6 in 1980 to 21.8 in 2016, while the average number of grasses and sedges increased from 3.9 to 4.7, forbs from 6.9 to 10.5 and trees/shrubs from 4.7 to 6.5 species over the same period (Table 4). More than half (58%) of the increase in number of species is because of an increase in forbs, i.e. herbaceous species other than grasses and sedges, and this includes a large number of weeds that are easily spread by wildlife and livestock. Note that the large number of weedy species may also be linked to changes in soil condition.

Linsen and Giesen (1983) concluded that in 1980 Lewa Downs was overgrazed by livestock, i.e. stocking rates exceeded the long-term carrying capacity. Indications of this were the low coverage of perennial grasses and large numbers of (unpalatable) weed species in the grassland. With the transition of the area from livestock grazing to wildlife, overgrazing is no longer a concern and cover of perennial grasses has risen throughout all habitats. The reduction in grazing pressures has not only led to a rebounding of perennial grass cover, but also in numbers of species of grasses and forbs. Heavy grazing pressure from livestock also prevents colonisation by tree/shrub species, as their seedlings are also readily and easily consumed by cattle. What is unusual is that the number of woody species increases between 1980-2016, while at the same time the cover/density of woody species decreases. This cannot be explained because of exclosures, as only three of the 32 relevees are located in fenced off exclosure areas (see Figure 4).

Figure 11 Changes in species composition 1980-2016 – all habitats combined

<table>
<thead>
<tr>
<th></th>
<th>Grasses</th>
<th>Forbs</th>
<th>Trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>3.9</td>
<td>6.9</td>
<td>4.7</td>
</tr>
<tr>
<td>2016</td>
<td>4.7</td>
<td>10.5</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Table 4: Summary of number of species per plant habitus type

<table>
<thead>
<tr>
<th>Species groups</th>
<th>1980</th>
<th>Range (1980)</th>
<th>2016</th>
<th>Range (2016)</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasses &amp; sedges</td>
<td>3.9</td>
<td>1-12</td>
<td>4.7</td>
<td>1-12</td>
<td>+20%</td>
</tr>
<tr>
<td>Forbs</td>
<td>6.9</td>
<td>2-16</td>
<td>10.5</td>
<td>2-20</td>
<td>+52%</td>
</tr>
<tr>
<td>Trees &amp; shrubs</td>
<td>4.7</td>
<td>0-13</td>
<td>6.5</td>
<td>1-16</td>
<td>+40%</td>
</tr>
<tr>
<td>Totals</td>
<td>15.5</td>
<td>21.8</td>
<td></td>
<td></td>
<td>+40%</td>
</tr>
</tbody>
</table>

3.4.2 Changes in numbers of grass, forbs & tree species per habitat type

Figure 12 shows the changes in numbers of grass, forb and tree/shrub species between 1980 and 2016 for the different broad vegetation types, i.e. for hills, plains, riverine and forest vegetation. The broad vegetation types show similar changes from 1980 to 2016, and in most cases this represents an increase in the number of species. Table 5 summarises the changes. While most vegetation types have significant increases in grasses, forbs and trees/shrubs there are some exceptions. Plain vegetation only has an increase in forbs (which have almost doubled in number of species), and riverine vegetation only has a significant increase in the number of trees/shrub species.

Figure 12  Changes in species composition 1980-2016, per habitat type
Table 5: Summary of changes in # plant species per major habitat (% change)

<table>
<thead>
<tr>
<th></th>
<th>Grass species</th>
<th>Forb species</th>
<th>Tree &amp; shrub species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plains</td>
<td>+4</td>
<td>+97</td>
<td>-8</td>
</tr>
<tr>
<td>Hills</td>
<td>+30</td>
<td>+40</td>
<td>+65</td>
</tr>
<tr>
<td>Riverine</td>
<td>+2</td>
<td>+2</td>
<td>+56</td>
</tr>
<tr>
<td>Forest</td>
<td>+167</td>
<td>+117</td>
<td>+75</td>
</tr>
</tbody>
</table>

3.5 PCA analyses of relevees

The results of the Principal Component Analyses generally showed a better correlation in the Q-type analyses (i.e. between relevees) than in the R-type analyses (i.e. between species), and hence only the results of the Q-type analyses are discussed below.

3.5.1 Comparison of 1980, 2006 and 2016 relevees

Figure 13 illustrates the results of PCAs of all relevees of 1980 (138 relevees), 2006 (78 relevees) and 2016 (66 relevees), and the colouring indicates the clustering of plain (yellow), hill (brown) and riverine (blue) vegetation types. Apparent is the similarity between the three, with a large variation occurring within the hill vegetation type and a much lower variation in the plain and riverine vegetation types (as indicated by closer clustering). Especially 1980 and 2016 are very similar in appearance, while the dissimilarity with 2006 can be explained by the fact that the 2006 sites were less representative of their type, as the relevee sites were chosen on the basis of significant change from 1980-2000.

3.5.2 Comparison of 1980 and 2016 relevees per habitat type

The 32 relevees carried out in 2016 that represent repetitions of 1980 relevees were compared with the 1980 relevees in a PCA. Lumping all 64 relevees proved difficult to interpret, hence these were regrouped according to their broad vegetation types (i.e. plains, hills and riverine). These results of these are provided below in Figure 14.
From the PCA it is clear that in 1980, both the plain and riverine vegetation types were much less homogenous than in 2016, as the points are spread far more widely in 1980 and are closely clustered in 2016. As apparent from 3.4.2, the average number of grass, forb and tree/shrub species increases slightly for plain and riverine habitats from 1980-2016; for the plains this increase is mainly in the number of forb species, and for riverine vegetation this increase is in tree/shrub species. In summary, there is an increase in number of species in riverine and plain habitats from 1980-2016, but the differences within each habitat type has decreased from 1980-2016.

For the hill vegetation type (middle graph in Figure 14) the degree of variation between relevees appears to be the similar for both 1980 and 2016, with limited overlap between the two. This implies that there may have been a shift in species composition in the hill vegetation over this period, but variation between locations has remained similar and pronounced.

**Figure 14  PCAs of 1980 versus 2016 relevees**

Plains: 1980 (yellow), 2016 (orange).  
Hills: 1980 (pale), 2016 (dark).  
Riverine: 1980 (pale blue), 2016 (dark blue).

### 3.5.3 Comparison of 2006 and 2016 relevees

Figure 15 illustrates the results of the PCA for relevees of 2006 that were repeated in 2016, segregated for plains (left graph) and hills (right graph). There were too few (2 only) riverine relevees repeated from 2006 to 2016 to perform a useful PCA. What is obvious from these two graphs is that in 2006 there is less variation between relevees in both the plain and hill vegetation types than in 2016. I.e. in 2006 the sites were less species diverse and/or were more similar in terms of species composition than in 2016. However, one needs to bear in mind that the 2006 relevee locations were chosen on the basis of ‘significant change’ in vegetation from 1980-2000 and are thus rather specific locations. For example, some of these were sites of fires, others were areas where exclosure fencing had been installed.

**Figure 15  PCAs of 2006 versus 2016 relevees**

Plains: 2006 (yellow), 2016 (orange)  
Hills: 2006 (pale), 2016 (dark) dots
3.6  Additional observations on habitats/species

3.6.1 Decreasing/increasing species

One of the key questions in managing vegetation of LWC is which species are increasing and which are decreasing, and what are the long-term trends. While it is apparent that woody species have been affected by fires and by high browsing pressures, how has this affected occurrence and coverage, and what about other common species? Table 6 lists the occurrence and cover of key species for both plain and hill vegetation, in 1980 and 2016.

Table 6: Changes in presence of key species 1980-2016

<table>
<thead>
<tr>
<th>Species</th>
<th>Occurrence in % releves</th>
<th>Average cover 1980</th>
<th>Occurrence in % releves</th>
<th>Average cover 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acacia drepanolobium</td>
<td>100.0</td>
<td>5.2</td>
<td>60.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Acacia mellifera</td>
<td>13.6</td>
<td>2.3</td>
<td>42.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Acacia seyal</td>
<td>54.5</td>
<td>3.3</td>
<td>46.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Asparagus racemosus</td>
<td>50.0</td>
<td>2.0</td>
<td>46.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Balanites aegyptiaca</td>
<td>29.5</td>
<td>2.0</td>
<td>10.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Barleria spinisepala</td>
<td>40.9</td>
<td>1.8</td>
<td>17.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Boscia coriaceum</td>
<td>50.0</td>
<td>2.2</td>
<td>42.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Hibiscus flavifolius</td>
<td>72.7</td>
<td>2.0</td>
<td>60.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Pennisetum mezianum</td>
<td>75.0</td>
<td>3.4</td>
<td>82.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Pennisetum stramineum</td>
<td>100.0</td>
<td>7.5</td>
<td>96.4</td>
<td>7.8</td>
</tr>
<tr>
<td>Searsia (Rhus) natalensis</td>
<td>15.9</td>
<td>2.1</td>
<td>10.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Hill vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acacia mellifera</td>
<td>47.9</td>
<td>3.3</td>
<td>55.6</td>
<td>3.6</td>
</tr>
<tr>
<td>Acacia nilotica</td>
<td>64.4</td>
<td>3.3</td>
<td>51.9</td>
<td>2.3</td>
</tr>
<tr>
<td>Acacia tortilis</td>
<td>43.8</td>
<td>3.2</td>
<td>44.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Asparagus racemosus</td>
<td>43.8</td>
<td>1.8</td>
<td>59.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Barleria spinisepala</td>
<td>35.6</td>
<td>1.8</td>
<td>44.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Boscia angustifolia</td>
<td>37.0</td>
<td>1.6</td>
<td>37.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Grewia species</td>
<td>56.2</td>
<td>2.4</td>
<td>81.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Gymnosporia (Maytenus) putterlickioides</td>
<td>47.9</td>
<td>3.3</td>
<td>70.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Heteropogon contortus</td>
<td>16.4</td>
<td>3.8</td>
<td>44.4</td>
<td>3.8</td>
</tr>
<tr>
<td>Hibiscus flavifolius</td>
<td>46.6</td>
<td>1.7</td>
<td>63.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Pennisetum mezianum</td>
<td>61.4</td>
<td>3.4</td>
<td>63.0</td>
<td>2.6</td>
</tr>
<tr>
<td>Pennisetum stramineum</td>
<td>84.9</td>
<td>6.2</td>
<td>81.5</td>
<td>6.6</td>
</tr>
<tr>
<td>Searsia (Rhus) natalensis</td>
<td>38.4</td>
<td>2.2</td>
<td>77.8</td>
<td>2.2</td>
</tr>
</tbody>
</table>

* % occurrence has been calculated for plain and hill vegetation separately. For example, in 1980 Acacia mellifera is found in 47.9% of the 73 hill relevees, and in 13.6% of the 44 plain relevees.

** Note: average cover is expressed on the modified Braun-Blanquet scale: 1= rare (occurring once only in plot), 2 = present but no appreciable cover, 3 = 1-2% cover, 4 = 3-5% cover, 5 = 6-10% cover, 6 = 11-20% cover, 7 = 21-30% cover, 8 = 31-60% cover, 9 = >60% cover.
Plain habitats. Whistling thorn *Acacia drepanolobium* used to occur in 100% of plain habitats throughout Lewa in 1980, with an average density of 8-10% cover and often in the range of 20-60% cover. In 2016 it still occurs in 61% of all plain habitats, but at much lower densities, averaging at 1-2% only\(^\text{12}\). Also, many whistling thorn found at present are resprouting specimens or seedlings rather than mature trees. This change appears to be mainly because of heavy browsing pressures rather than fires, although locally fires may play a major role (e.g. Safi Corner in 2000). *Acacia seyal* was common in 55% of the plain habitats throughout Lewa in 1980 at an average density of 2-4%, but occasionally up to 30%. Nowadays (2016) it is recorded in a similar number plain habitats (46%), but at lower densities of only 1-2% (rarely, in one instance, 3%) cover. *Balanites aegyptiaca* stands used to be more common and in 1980 this species was found in 30% of plain habitats; by 2016 this had dropped to only 11% of plain habitats and healthy mature trees have become rare. The woody and spiny herb, *Barleria spinisepala*, is also less common in plain habitats in 2016 compared to 1980, with % occurrence dropping from 41% (1980) to 18% (2016). *Acacia mellifera* is the only common species with a reverse trend, being more common now (2016) in plain habitats than in 1980, with % occurrence increasing from 14% (1980) to 43% (2016). The increase in *Acacia mellifera* and the decrease in *Acacia drepanolobium* in the plains may also be linked to changes in rainfall patterns. As mentioned in 3.3.2 (p.17), *A. mellifera* is common on black cotton soils at annual rainfall levels of up to 635 mm, while *A. drepanolobium* is more common at rainfall levels above 760 mm.

Hill habitats. *Acacia mellifera*, *A. nilotica* and *A. tortilis* occur in about an equal percentage of hill habitats in 1980 and 2016 – the difference is mainly in the percentage cover, which for both *A. nilotica* and *A. tortilis* has dropped from 1-2% cover (in 1980) to ‘present but with no measurable cover’ in 2016. A number of tree/shrub species have increase in occurrence from 1980 to 2016, namely *Grewia* species (from 56% to 82%), *Gymnosporia* (*Maytenus*) *putterickioides* (from 48% to 70%) and *Searsia* (*Rhus*) *natalensis* (from 38% to 78%), although densities remain about the same. Both *Asparagus racemosus* and *Barleria spinisepala* have decreased in average cover (from “present” to “rare”), although they still occur in similar numbers of hill habitats.

There are significant differences between species in what they can tolerate in terms of browsing pressures. *Acacia brevispica* is almost always browsed very heavily and few specimens have intact branches; nevertheless, it usually survives and resprouts. *Acacia nilotica* is at the other end of the extreme, and trees that have been browsed and have had only a few branches snapped off often do not survive, and one can observe many dead but still standing specimens throughout Lewa. Possibly *Acacia nilotica* is easily infected (by fungi) or infested (by insects) after damage. *Balanites aegyptiaca* seems to be affected in a similar way to *Acacia nilotica*, with fewer large, live specimens remaining in 2016. Reportedly, *Lannea rivae* and *Commiphora* species (*Commiphora africana* & *C. madagascariensis*) are also declining in numbers (pers. comm. Mrs. Sue Brown), although relevée data is too incomplete to confirm this.

\(^{12}\) This is the overall trend, and the dynamics may differ from site to site. Some locations such as the Sambara Plain show a sharp decrease in whistling thorn from 1980 to 2006 (at Sambara due to 1998 fires), but an increase since then.
A number of tree species seem to be increasing in spite of browsing pressures. As mentioned earlier, *Acacia mellifera* is now more common throughout Lewa, both in the hills and (especially) in the plains. This may also be linked to changes in rainfall, as long-term trends show a decrease since 2004 (see 3.3.2). However, while more widespread it also has a significantly lower cover in 2016 than in 1980, and with fewer large tree specimens occurring. Increased browsing pressures may be spreading seeds more in recent years compared to 1980, as much of what was recorded in 2016 was either resprouting or (more commonly) consisted of seedlings. *Grewia* species are also more common (in hill habitats) in 2016 than in 1980, although it has basically gone from widespread (56% of hill habitats) to very widespread (82% of hill habitats). As with *Acacia mellifera*, most specimens found are seedlings or resprouting, although there has been an increase in average cover from 1980 (<1%) to 2016 (2-3%). Other tree species that do not seem to be (much) utilised by elephant also appear to be increasing, and these include *Croton dichrogamus* (toxic and generally avoided), *Euclea divonorum*, *Rhamnus staddo* and *Vangueria* sp. (?madagascariensis) (pers. comm. Mrs. Sue Brown).
If these trends continue, the vegetation composition at Lewa is likely to change over time. Less palatable species (e.g. *Croton dichogamus*) and species that more readily tolerate browsing (e.g. *Acacia brevispica*, *A. mellifera*, *Grewia* species) will tend to dominate more over time, while sensitive species (e.g. *Acacia drepanolobium*, *A. nilotica*, *A. tortilis*, *Balanites aegyptiaca*) will become uncommon or disappear over time.

### 3.6.2 Exclusion zones

Since 1995, LWC has addressed the issue of browsing damage to wooded areas by means of establishing ‘exclusion zones’, i.e. areas that are fenced off for large browsers by means of an electric fence. To date 21 exclusion zones have been fenced off, totalling about 2770 ha or about 11% of LWC’s total area excluding Borana (see map of exclusion zones, Figure 4, and 16 below). The level of success achieved has been mixed: some areas have been successful in eliminating large browsers (elephant and giraffe) while others have not. Where exclusion fencing has been breached repeatedly LWC has started with the introduction of electric fencing equipped with ‘feelers’ that are more difficult to breach (see 3.3.2). In theory, the introduction of exclusion fencing could lead to undesirable hard boundaries in the landscape, with grassland devoid of trees on one side, and dense woodland on the other side of the fence. However, because of the mixed success of the exclosure fencing, this is less likely to arise.

A form of rotational browsing could also be considered in some areas, as this would provide much needed browse and lead to less hard boundaries in the landscape. Rotational browsing could especially be considered in the plains, which from a distance often appear devoid of trees and shrubs but upon closer inspection (and quite remarkably, given browsing pressures) still have a considerable number of seedlings and/or resprouting stems. While seedlings occur in most locations, the best options for exclusion zones in the plains are those with considerable numbers. Table 7 lists seedling abundance in relevées per broad habitat type. In 6 out of 28 relevées in the plains, seedlings are abundant, and these are mapped in Figure 16 below. Seedlings are abundant in a much larger number of relevées in the hills, but that is also due to the fact that six (35%, no’s 41,42,49,53,54 & 57) of these are located in exclusion zones.

<table>
<thead>
<tr>
<th>Seedling abundance</th>
<th>Present</th>
<th>Common</th>
<th>Abundant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plains</td>
<td>20</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Hills</td>
<td>5</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>Riverine</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Forest</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: numbers indicate number of locations/relevées
3.6.3 Forage value of plains & hills

Table 8 summarises cover and number of species in plain and hill vegetation for 1980 and 2016.

Plains: From 1980 to 2016 there is an increase in grass cover on the plains from 56.5% to 72.7%, while at the same time the number of forb species almost doubles (from 5.0 to 9.8). While some forbs are unpalatable or poisonous (e.g. Tagetes minuta) and do not contribute to nutrition for grazers, the wider range of forbs available probably represents a better nutrition. Key grass species remain the same, so one may tentatively conclude that the grazing value has probably increased during this period, as more forb species probably increases nutritive value. At the same time, tree/shrub cover has dropped significantly (by about 70%), and with it the amount of browse available. The number of tree/shrub species found has increased from 6.2 to 10.2, but this probably does not compensate the loss of tree/shrub cover in terms of overall available forage.

Hills: In the hills, species numbers have increased from 1980-2016 for all species groups, be it grasses, forbs and trees/shrubs. At the same time, the grass cover has increased from 48.5% to 70.4%, while the tree/shrub cover dropped from 26.6% to 10.7%. As in the plains, the forage value for grazers has improved, while the situation for browsers has declined over the same period.

Table 8: Summary of cover and species 1980-2016

<table>
<thead>
<tr>
<th></th>
<th># grass species</th>
<th># forb species</th>
<th># tree/shrub species</th>
<th>% cover grasses</th>
<th>% cover trees/shrubs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plains</td>
<td>3.6</td>
<td>5.0</td>
<td>3.8</td>
<td>56.5</td>
<td>13.9</td>
</tr>
<tr>
<td>Plains</td>
<td>3.8</td>
<td>9.8</td>
<td>3.5</td>
<td>72.7</td>
<td>4.1</td>
</tr>
<tr>
<td>Hills</td>
<td>4.6</td>
<td>8.2</td>
<td>6.2</td>
<td>48.5</td>
<td>26.6</td>
</tr>
<tr>
<td>Hills</td>
<td>6.0</td>
<td>11.5</td>
<td>10.2</td>
<td>70.4</td>
<td>10.7</td>
</tr>
</tbody>
</table>
3.6.4 Expansion of Lewa Swamp

Annex 7 of Giesen et al (2007a) provided a general description of Lewa swamp, including the dominant species found. The main species found at Lewa swamp is the sedge *Cyperus dives* Del., which accounts for about 90% of the bulk of the vegetation. Other species found include other sedges such as *Cyperus assimilis*, *C. esculentus*, *C. involucrata*, *C. sphacelata* and *Scirpus brachyceras*. In addition, a range of herbs and grasses are also found, including *Eragrostis paniciformis*, *Eriochloa meyerana*, *Leersia hexandra*, *Sporobolus pyramidalis* (grasses), *Alisma plantago-aquatica*, the uncommon *Berula erecta*, *Lythrum rotundifolium*, *Mentha aquatica*, *Ranunculus multifidis*, *Sphaeranthus gomphrenoides* and *Veronica anagallis-aquatica* (herbs). The bullrush *Typha domingensis* occurs in at least two small patches in the swamp, but does not extend over more than 1-2% of the total cover.

Prior to the establishment of the Wildlife Conservancy in 1993, the area around Lewa swamp had been converted to fishponds and for irrigated market gardening. Following establishment of LWC the fishponds were removed and agricultural areas were abandoned and allowed to recover. As a result, the swamp area increased from about 27ha in 1980 to about 61ha in 2000 (Figure 17), which is an increase of 125%. In recent years Lewa swamp has increased again, especially along the northern and north-eastern sides and has expanded from 61ha in 2010 to 74ha in 2016, an increase in area of 21% since 2000. At the same time areas around the swamp have changed from *Pennisetum*-dominated grassland and are now dominated by more palatable species such as *Eriochloa*, *Leersia* and *Panicum*.

![Figure 17 Changes at Lewa swamp](image)

The expansion of Lewa swamp has made it necessary to relocate the road leading along the north of the swamp as this was first waterlogged and is now largely submerged. This expansion of the swamp had led to die-off of fever tree *Acacia xanthophloea* vegetation on the northern and western shores of the swamp, probably because these trees cannot withstand the permanent water logging that now occurs.

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13 The circumference of Lewa swamp was plotted on 17 June 2016 using a hand-held GPS.
The expansion of Lewa swamp appears to be caused by a combination of an increase in volumes of incoming water and by sedimentation in the swamp, which has made it shallower. The following processes (pers. comm. Mrs Sue Brown) may all play a role, but warrant further investigation:

- Larger volumes of water emerging from the springs at Lewa. The 1997 El Niño when there seemed to be an underground shift and some new springs emerged.
- Suboiga ranch to the south of Lewa and the Meru communal grazing grounds to the east were converted to smallholdings from the 1960s onwards, and this (initially) led to significant erosion. Large amounts of topsoil were transported by the western Marania River which drains into Lewa swamp, and significant amounts of this soil could have ended up in Lewa swamp, making it shallower.
- Deforestation on Mount Kenya which has depleted the overall water retention (‘sponge’) effect and hence precipitation now drains more quickly, including into Lewa swamp.
- Global warming has resulted in the disappearance of glaciers on Mt. Kenya; however, this appears to have started many years before the recent increase in area of Lewa Swamp.

The larger volumes of water from the springs at Lewa do not appear to be linked to higher precipitation in the upper catchment (i.e. Mt. Kenya highlands). Recent studies of rainfall data from 50 stations around Mt. Kenya from 1979-2011 indicate a decrease in precipitation during the long rains (March to May) and an increase during the short rains (October to December), but overall no statistically significant increase or decrease, just variation between years (Schmocker et al. 2016).

14 This would need to be measured and monitored, and one can only speculate as to the reason (e.g. climate change, changes in land use in the upper catchment, etc…).
15 Inserting benchmarks in the swamp could make it possible to determine if incoming sediment still plays a role.
16 The main spring at Ngare Niting that is the water supply for Lewa HQ and its many residents, the CEO’s house and Lewa House apparently dried up in 2016 and flow has already diminished now in January 2017 (pers. comm. Mrs Sue Brown). It is hoped that the growth of Lewa swamp now does not begin to recede.
Photo 9. Fever trees along the margins of the swamp have died because of prolonged waterlogging and expansion of the swamp.
4. Conclusions

1. The **aim of the present study** was mainly to assess the degree of (further) changes in woody vegetation since 2006, and assess possible changes in the herbaceous layer (grasses and forbs) since 1979-80. The basis of the assessment is formed by 66 relevees (surveys), of which 32 are repetitions of 1980 relevees, 20 are repetitions of 2006 relevees, 10 are relevees of change sites identified by NDVI analysis (see 2) and four are relevees of new sites on Lewa (as per pre-2013 boundary, i.e. without Borana).

2. According to the **NDVI analysis**, areas where tree cover has increased during 2007-2016 are mainly the Ngare Ndare forest, along with Lewa swamp and the *Acacia xanthophloea* riverine vegetation near LWC headquarters. Areas with a decrease in tree cover over this period appear to be mainly in the central and northern valleys, mid/central- and mid-northern plains. [10 locations of major change were assessed during the present study.]

3. **Cover comparison between 1980 and 2016 relevees** (n=32):
   a. Tree/shrub cover has decreased from an average of 24% in 1980 to 9% in 2016, while at the same time grass cover increased from an average of 50% in 1980 to 70% in 2016. While fires played a role (especially in the past), the main cause seems to be feeding by large browsers, although changes in rainfall may explain a lack of recovery since 2006.
   b. Two exceptions where tree cover has increased are locations with exclosure fencing, while three exceptions where grass cover has decreased are all three located on black cotton soil, which are known to be highly erodible.
   c. Plain and hill locations show similar changes; however, although the decline in tree/shrub cover is more marked in the plains than in the hills (70% versus 60%), the increase in grass cover is lower (29% for plains, 45% in hills). The role of trees/shrubs in facilitating grass growth may be more pronounced in the plains than in the hills, although trampling may also play a role.

4. **Cover comparison between 2006 and 2016 relevees** (n=20) (note: the 2006 sites were chosen on the basis of significant increase or decrease of woody vegetation):
   a. At most of the nine (9) sites where there was an increase in woody vegetation up to 2006, this trend continued up to 2016, with an average increase in tree cover of 48% from 2006-2016; most of these ‘increaser’ sites had exclusion fencing.
   b. At the eleven (11) sites where woody vegetation was decreasing up to 2006, this trend was on average reversed (with an increase in tree cover of 37%) by 2016 due to the introduction of new exclusion zone fencing between 2006 and 2016.

5. **Species composition comparison between 1980 and 2016 relevees** (n=32):
   a. The average number of species found in any one relevee site increased from 15.6 in 1980 to 21.8 in 2016 (=40% increase), while the average number of grasses and sedges increased from 3.9 to 4.7, forbs from 6.9 to 10.5 and trees/shrubs from 4.7 to 6.5 species.
   b. Phasing out cattle grazing during the 1980s and 1990s has reduced grazing pressures; it is suggested that this led to a rebounding of perennial grass cover and an increase in numbers of species of grasses, forbs and trees/shrubs. What is unusual is that the number of woody species increases between 1980-2016, while over the same period the cover/density of woody species decreases.
   c. Analysis of broad vegetation types show similar changes from 1980 to 2016, with increases in grasses, forbs and trees/shrubs. Plain vegetation, however, only has an increase in number of forb species, while riverine vegetation only has a significant increase in the number of trees/shrub species.
6. Results of the PCA assessments shows that:
   a. In broad lines vegetation data from 1980 and 2016 is very similar: there is a large variation within the hill vegetation type and a much lower variation in the plain and riverine vegetation types (as indicated by closer clustering).
   b. In 1980 both the plain and riverine vegetation types were much less homogenous than in 2016; there is an increase in number of species in riverine and plain habitats from 1980-2016, but the differences within each habitat type has decreased from 1980-2016. For the hill vegetation type the degree of variation between relevées appears to be the similar for both 1980 and 2016.

7. Changes in species composition 1980-2016:
   a. Plains. *Acacia drepanolobium* used to occur in 100% of plain habitats in 1980, with an average density of 8-10% cover and often in the range of 20-60% cover. In 2016 it still occurs in 61% of all plain habitats, but at much lower densities, averaging at 1-2% only. *Acacia seyal* has performed in a similar way, but the changes are less pronounced than with *A. drepanolobium*. In 1980 *Balanites aegyptiaca* was found in 30% of plain habitats, but by 2016 this had dropped to only 11% of plain habitats and healthy mature trees have become rare. Similarly, *Barleria spinisepala* occurrence from 41% (1980) to 18% (2016). *Acacia mellifera* is the only common species with a reverse trend, with occurrence increasing from 14% (1980) to 43% (2016), although large, mature specimens are less common. The increase in *A. mellifera* and decrease in *A. drepanolobium* both indicate that lowered rainfall may play a role in changes in vegetation.
   b. Hills. *Acacia mellifera*, *A. nilotica* and *A. tortilis* occur in about an equal percentage of hill habitats in 1980 and 2016, and the main change has been in the percentage cover which in 2016 is much lower. A number of tree/shrub species have increase in occurrence from 1980 to 2016, namely *Grewia* species (from 56% to 82%), *Gymnosporia (Maytenus) putterickioides* (from 48% to 70%) and *Searsia (Rhus) natalensis* (from 38% to 78%), although densities remain about the same.
   c. If these trends continue, the vegetation composition at Lewa is likely to change over time. Less palatable species (e.g. *Melia volkensii* and *Croton dichogamus*) and species that more readily tolerate browsing (e.g. *Acacia brevispica*, *A. mellifera*, *Grewia* species) will tend to dominate more over time, while sensitive species (e.g. *Acacia drepanolobium*, *A. nilotica*, *A. tortilis*, *Balanites aegyptiaca*) will become uncommon or disappear over time.
   d. Changes in rainfall (i.e. lowered rainfall since 2004) may also contribute to changes in vegetation, adding to the decline of *Acacia drepanolobium* and *A. seyal*, and leading to an increase in *A. mellifera* on the plains.

8. Seedlings are abundant in 6 out of 20 (30%) locations in the plains and in 17 out of 27 (63%) of locations in the hills. The latter is at least partly explained by the presence of more exclusion zones in the hill habitats than in the plains.

9. Lewa Swamp has increased in size from 27ha in 1980 to 61ha in 2000 and 74 ha in 2016. At the same time areas around the swamp have changed from *Pennisetum*-dominated grassland and are now dominated by more palatable species such as *Eriochloa*, *Leersia* and *Panicum*. The increase was initially due to restoration of the wetlands (explaining the change from 1980-2000), but recent expansion appears to be due to increased flow from Lewa springs.
5. Recommendations

1. Mapping of vegetation

The present study provides information based on point data (i.e. taken at various relevee points over time), but in the absence of a recent and detailed vegetation map it is difficult to extrapolate conclusions to the entire area. LWC should aim to obtain sufficiently detailed remote sensing imagery (at a resolution of « 1m) and produce a new vegetation map of Lewa based on tree density classes.

2. Plain vegetation

Plain vegetation dominated by the grasses *Pennisetum stramineum* and *Pennisetum mezianum*, along with *Acacia drepanolobium*, *Acacia seyal* and (increasingly) *A. mellifera*.

- In 2006 it was recommended that some of this habitat be protected with exclusion fencing to prevent further loss of woody species. This has happened to some extent, but this has not been sufficient to halt the overall decline of *Acacia drepanolobium* wooded grassland. It is recommended that further areas are fenced off for large browsers, especially areas where seedlings of these two *Acacias* are common but overall tree cover is low (<1%).
- Rotational fencing could also be considered for these areas (where seedlings of these two *Acacias* are common but overall tree cover is low (<1%)), for example, with a cycle of 5-10 years depending on the degree of recovery of woody species, which should be monitored. This could provide additional browse, while leading to fewer hard boundaries in the vegetation and landscape.
- On a trial basis, fence off small areas (1-10 ha) of *Pennisetum* grassland that was known to be wooded 10, 20, or 40 years ago but now no longer has trees/shrubs. This should then be monitored to assess if regeneration is possible after x-number of years due to the persistence of a seed bank.

3. Hill vegetation: browsing & *Acacia nilotica*

Why does *Acacia nilotica* often succumb to what seems to be limited damage by elephants (e.g. with a few large branches destroyed but the rest of the tree intact)? Is this because of insect attack (e.g. borers, termites) or because of fungal attack? Or does the tree simply ‘bleed’ to death, losing vital fluids? This could be tested by: i) cutting off branches that have recently been damaged by elephant and treating this with an agent used in tree pruning (e.g. wound paint or pruning sealer); ii) assessing what happens to these trees post-elephant damage in terms of infestation with insects and/or fungi.

These slopes are highly diverse and have a fragile soil, so it would be very useful to closely monitor effects of grazing (e.g. as has been done with cattle), especially of grass cover and (forb and grass) species diversity.

4. Riverine vegetation dominated by *Acacia xanthophloea*

According to Von Holdt (1999), heavy browsing by small browsers such as impala may prevent recruitment of *Acacia xanthophloea*. *Acacia xanthophloea* stands should be studied to assess size-class distribution of this species, and assess if natural recruitment is healthy enough to maintain the population.

5. Water resources

LWC has a number of permanent springs that are highly important features for the landscape, wildlife and human utilisers of water. Volumes have varied over time, with Lolnotoni spring appearing to have been reduced over the past 4-5 decades, while Lewa spring (feeding Lewa Swamp) have increased over the
past five years. Such changes do not appear to be linked to changes in rainfall in the upper catchment, but are more likely linked to changes in land use/land cover. It is suggested that:

- Lewa establishes a programme of monitoring volumes being emitted (litres/sec or m³/s) so that seasonal and long-term changes can be identified (rather than guessed), and appropriate management interventions could be undertaken.
- Lewa continues to monitor changes in Lewa swamp, e.g. by remapping the perimeter every two years or so (at least, while it does not appear stable). This could be linked to a study, as vegetation around the expanding swamp changes from a dry *Pennisetum*-dominated grassland to one with mixed (and more palatable) grasses and sedges.

6. Black cotton soils

Black cotton soils are susceptible to erosion and degradation, and at Lewa this phenomenon is evident from how grasslands on these soils perform, with a dwindling grass cover in spite of a reduction in tree/shrub cover (see 2016 relevee locations 8, 33, 43 & 50). It is recommended that grazing of these areas with herds of cattle be avoided, and that on a trial basis some areas be fenced off (and monitored for grass and woody vegetation cover, and signs of erosion) to assess the impact of grazing wildlife. The draft grassland management plan’s (2014) advice for year-round grazing of black cotton soils in an attempt to reduce the dominance of *Pennisetum* grasses and promote other grass species should be reconsidered.

7. Studies by MSc students

Some of these recommendations could well form the basis for studies by MSc students, such as:

- **Seed bank study.** On a trial basis, fence off small areas (1-10 ha) of *Pennisetum* grassland that was known to be wooded 10, 20, or 40 years ago but now no longer has trees/shrubs. This should then be monitored to assess if regeneration is possible after x-number of years due to the persistence of a seed bank. It would be excellent to be able to assess how long a seed bank lasts, and of which species.

- **Study on vulnerability of Acacia nilotica.** Why does *Acacia nilotica* often succumb to what seems to be limited damage by elephants (e.g. with a few large branches destroyed but the rest of the tree intact)? Is this because of insect attack (e.g. borer, termites) or because of fungal attack? Or does the tree simply ‘bleed’ to death, losing vital fluids? This could be tested by: i) cutting off branches that have recently been damaged by elephant and treating this with an agent used in tree pruning (e.g. wound paint or pruning sealer); ii) assessing what happens to these trees post-elephant damage in terms of infestation with insects and/or fungi.

- **Impacts of cattle grazing on condition of hill/slope vegetation.** The hills and slopes are highly diverse and have a fragile soil, so it would be very useful to (have an MSc student) closely monitor effects of grazing (e.g. as has been done with cattle), especially of grass cover and (forb and grass) species diversity.

- **Natural recruitment of fever trees Acacia xanthophloea.** According to Von Holdt (1999), heavy browsing by small browsers such as impala may prevent recruitment of *Acacia xanthophloea*. These fever tree stands should be studied (by an MSc student) to assess size-class distribution of this species, and assess if natural recruitment is healthy enough to maintain the population.

- **Expansion of Lewa swamp.** Lewa swamp has increased significantly over the past 30-40 years, and a study of the changes of the vegetation around the expanding swamp is recommended, as this is changing from a dry *Pennisetum*-dominated grassland to one with mixed (and more palatable) grasses and sedges.

- **Use of exclusion zones by black rhino.** A study into the use of exclusion zones by black rhino might be useful, as it has been suggested that in a lot of the exclusion zones the browse had become too high for rhino to utilize. [this might be linked to trials with rotational browning in exclusion zones]
6. References


Appendix 1  SOP for conducting relevees

1. Selection of relevee locations.

General vegetation surveys. A stratified random approach is to be used to determine locations for relevees for general vegetation surveys (i.e. relevee sites or sampling points). In this approach the person doing the survey allocates sampling points across the different vegetation types, guided by the principle of relative area. However, if locations are allocated purely on the basis of relative area less common vegetation types would be under-represented in the surveys, and hence more sampling points are allocated to relative to size for the less common vegetation types. Within each vegetation types, however, point allocation is randomly distributed and clustering of sampling points is to be avoided avoided. Over the entire area, sites are to be selected so that there is a good geographic spread – i.e. ensure that not all relevee sites are located in one part of the conservancy, for example. Points are to be identified as coordinates, which are to be the centres of the relevee points.

Habitat change surveys. These are relevees focused on particular locations where changes are known to be happening. This can, for example, be from anecdotal information, changes observed by comparison of aerial photos form different dates, or from NDVI analysis of satellite imagery that identifies changes in (tree) cover (see 2.3.1). These sites are to be as accurately sampled as possible, hence coordinates of the centres of areas of change are to be used.

2. What to record?

A pre-printed relevee data sheet is attached in Appendix 2. Such a sheet (or something similar) should be used, as it prompts the recording of information, otherwise one can easily forget to record something. In addition to physical factors and flora/vegetation, recording aspects related to land use (e.g. fencing) and use by wildlife is useful. Its is essential to record an ID (i.e. relevee number) with coordinates, as without this the record loses its value. It is also good to take a photo, but ensure that it is linked to the relevee ID.

3. Recording species

The pre-printed relevee sheet includes lists of the most common trees/shrubs, forbs/herbs, and grasses, and it is good to record them in such groupings. It is best to start with overall cover of these groups, i.e. what is the overall tree/shrub cover? overall grass cover? and cover of forbs/herbs? After that one determines the density of individual species. For example, if the grass cover is estimated to be 60% and one has four grass species of which one, e.g. Pennisetum stramineum, dominates (i.e. 90% of the grass occurring), two (Pennisetum mezianum & Aristida keniensis) are only minor in terms of cover (a few %) and one (Eragrostis superba) has a few specimens but no cover. One could note this as: P stramineum 55%, P. mezianum 1-2%, A. keniensis 1-2% and E. superba «1%. Alternatively, one can use the commonly used modified Braun-Blanquet scale, which is as follows: 1= rare (occurring once only in plot), 2 = present but no appreciable cover, 3 = 1-2% cover, 4 = 3-5% cover, 5 = 6-10% cover, 6 = 11-20% cover, 6 = 21-30% cover, 7 = 21-30% cover, 8 = 31-60% cover, 9 = >60% cover. The examples used previously would look as follows:

<table>
<thead>
<tr>
<th>Species</th>
<th>Percentage cover (%)</th>
<th>Modified Braun-Blanquet scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pennisetum stramineum</td>
<td>55</td>
<td>8</td>
</tr>
<tr>
<td>Pennisetum mezianum</td>
<td>1-2</td>
<td>3</td>
</tr>
<tr>
<td>Aristida keniensis</td>
<td>1-2</td>
<td>3</td>
</tr>
<tr>
<td>Eragrostis superba</td>
<td>«1</td>
<td>2</td>
</tr>
</tbody>
</table>
One does not need to do both, but a percentage cover can be converted to the modified Braun-Blanquet scale, but not vice versa, so noting percentage cover is probably best/most versatile.

4. Sampling method

Relevees are to consist of a combination of 10m by 10m quadrants (squares or plots) for herbaceous vegetation (i.e. grasses and forbs/herbs) and three (3) line transects (or line intercepts) each 30m long for woody vegetation (i.e. trees and shrubs).

Plots. Ideally, the centre of the plot would be the point of which the coordinates were identified on the map when identifying locations for relevees. However, this may sometimes be impractical. One needs to avoid bias and edge effects, so if the plot contains an unusual feature not present elsewhere in the vegetation being sampled, one would move the point slightly, but note the unusual feature on the relevee sheet (and take a photo). Sampling sites need to be as homogenous and representative as possible. The easiest way to sample a plot is to bring (or improvise) four markers to mark the corners of the 10m by 10m plot and assess the area within these four corners.

Line transects. Three (3) 30m transects are to be measured from the centre of the plot. A 30m line is to be laid out using a measuring tape, and all trees and shrubs within 5m on either side of this line are to be recorded. This is then repeated twice more, aiming to space the lines evenly (i.e. about 120° between them) and avoiding bias (e.g. over- or under-sampling of certain species or strata). It is also useful to distinguish between mature trees/shrubs and seedlings, as this provides useful information about recruitment of species. Only live trees are used in data analysis, but dead trees should be noted as this may also provide useful information about changes/trends.

Figure 18 Example of plot & line transects
### Relevee data sheet

**Giesen, Giesen & Giesen (2016)**

<table>
<thead>
<tr>
<th>Vegetation study, Lewa Wildlife Conservancy, Kenya</th>
<th>Relevee No.:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison Relevee 1980</td>
<td>Survey team:</td>
</tr>
<tr>
<td>Comparison Relevee 2006</td>
<td>XY Coordinates</td>
</tr>
<tr>
<td>Weather: rain / cloudy / sun / ...........</td>
<td>Altitude:</td>
</tr>
</tbody>
</table>

#### Geology, Geomorphology & Soils:
- rock lithology: 
- soil texture: 
- geological formation: 
  - volcanic 
  - basement complex 
  - mixed 
- landform: 
- slope (%): 
- slope length: 
- remarks: 

#### Vegetation data

**Physiognomy:**
- Tree cover: 
  - height: 
  - Shrub cover: 
  - Herb layer cover: 
  - grasses: 
  - other herbs: 
- Climbers: 
- remarks: 

**main plant species:**
- Herbs: 
  - Achyranthes aspera 
  - Barleria sp. 
  - Solanum incanum 
- Grasses: 
  - Pennisetum mezianum 
  - Pennisetum stramineum 
  - Themeda triandra 
- Trees: 
  - Acacia brevispica 
  - Acacia drepanolobium 
  - Acacia melilera 
  - Acacia nilotica 
  - Acacia seyal 
  - Acacia tortils 
  - Acacia xanthophloea 

#### Land-use / influences / impacts

**Wildlife grazing/browsing/tree damage:**
- Cattle: 
- Burning: 
- Fencing: 
- Remarks: 

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**Revised draft report 3.0, April 2017**