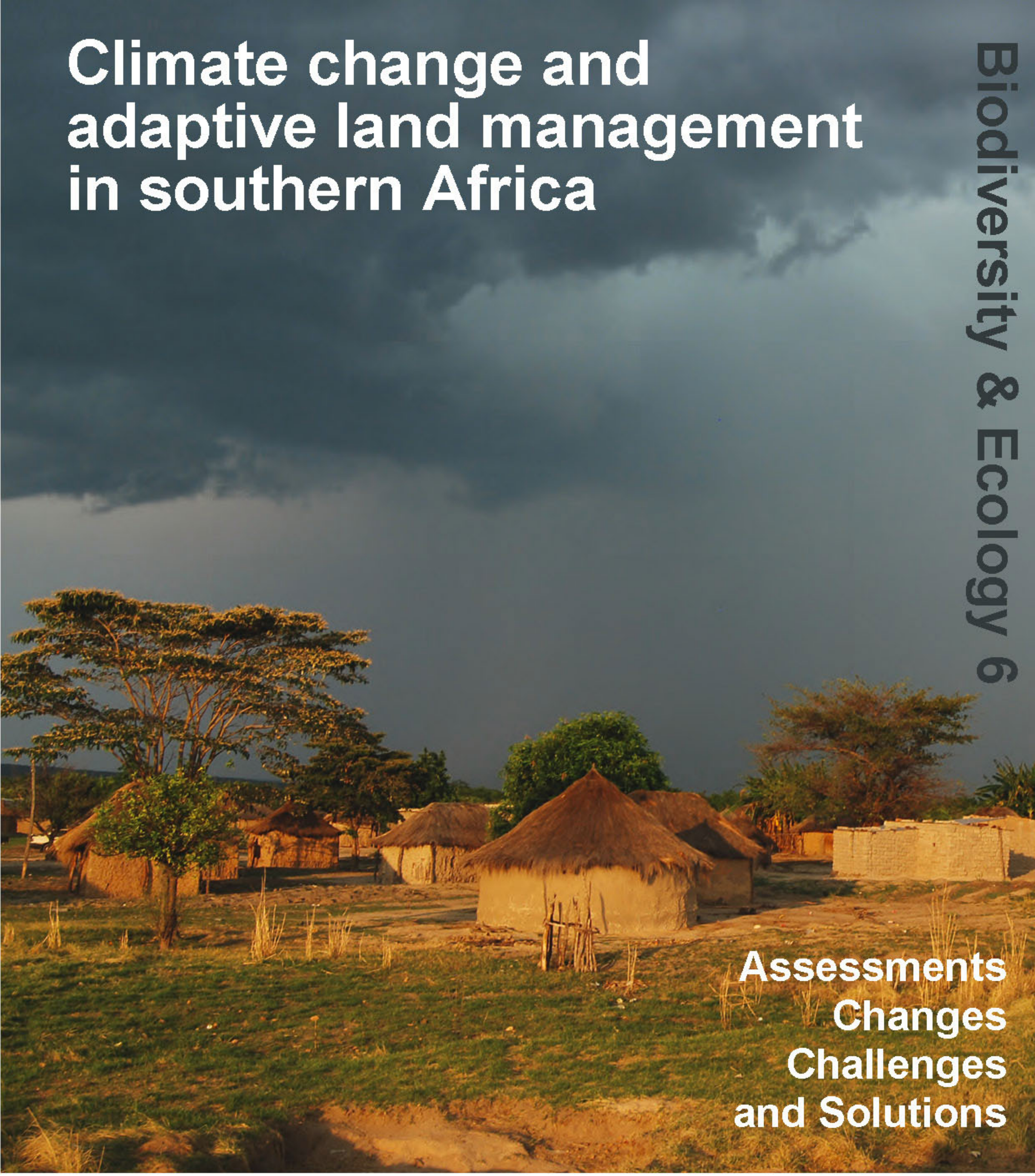
# Climate change and adaptive land management in southern Africa

Biodiversity & Ecology 6



Assessments
Changes
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Product of the first research portfolio of

**SASSCAL 2012–2018**

Southern African
Science Service Centre for
Climate Change and
Adaptive Land Management

SPONSORED BY THE

Federal Ministry
of Education
and Research

Klaus Hess Publishers
Göttingen & Windhoek
www.k-hess-verlag.de

ISBN: 978-3-933117-95-3 (Germany), 978-99916-57-43-1 (Namibia)

Language editing: Will Simonson (Cambridge), and Proofreading Pal
Translation of abstracts to Portuguese: Ana Filipa Guerra Silva Gomes da Piedade
Page desing & layout: Marit Arnold, Klaus A. Hess, Ria Henning-Lohmann
Cover photographs:
front: Thunderstorm approaching a village on the Angolan Central Plateau (Rasmus Revermann)
back: Fire in the miombo woodlands, Zambia (David Parduhn)
Cover Design: Ria Henning-Lohmann

ISSN 1613-9801

Printed in Germany

Suggestion for citations:
Volume:
Revermann, R., Krewenka, K.M., Schmiedel, U., Olwoch, J.M., Helmschrot, J. & Jürgens, N. (eds.) (2018) Climate change and adaptive land management in southern Africa – assessments, changes, challenges, and solutions. *Biodiversity & Ecology*, **6**, Klaus Hess Publishers, Göttingen & Windhoek.

Articles (example):
Archer, E., Engelbrecht, F., Hänsler, A., Landman, W., Tadross, M. & Helmschrot, J. (2018) Seasonal prediction and regional climate projections for southern Africa. In: *Climate change and adaptive land management in southern Africa – assessments, changes, challenges, and solutions* (ed. by Revermann, R., Krewenka, K.M., Schmiedel, U., Olwoch, J.M., Helmschrot, J. & Jürgens, N.), pp. 14–21, *Biodiversity & Ecology*, **6**, Klaus Hess Publishers, Göttingen & Windhoek.

Corrections brought to our attention will be published at the following location:
http://www.biodiversity-plants.de/biodivers_ecol/biodivers_ecol.php

# Biodiversity & Ecology

Journal of the Division Biodiversity, Evolution and Ecology of Plants,
Institute for Plant Science and Microbiology, University of Hamburg

Volume 6:


# Climate change and adaptive land management in southern Africa

## Assessments, changes, challenges, and solutions


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Hamburg 2018

Land cover dynamics

# Long-term land use change analysis in south-central Angola. Assessing the trade-off between major ecosystem services with remote sensing data

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**Abstract:** Dry tropical forests are facing large-scale conversion and degradation processes and are the most endangered forest type worldwide. We analyse these processes in the dry tropical forest type of miombo woodlands in a rural area of south-central Angola. We show that large-scale conversion to agricultural areas takes place in this area, as does modification of woodland areas, i.e. by degradation due to the extraction of natural resources. By using remote sensing data, spatial drivers of this conversion and its effects may be assessed for the time period 1989–2013. We identify settlement dynamics and the location and quality of streets as major underlying determining factors for conversion processes. Since the 1980s, the rate of agricultural expansion has strongly depended on socioeconomic background factors and is currently on a level of ca. 9 000 ha/year in the study area. Fallows were found to only slowly regenerate, and there is a change in cultivation pattern to more permanent forms of cultivation. Large portions of the study area are undergoing degradation processes, leading to an additional loss of biomass. The results indicate that there is high pressure on the natural ecosystems of the study area, which will probably aggravate in the future with a high likelihood of emerging land use conflicts.

**Resumo:** As florestas tropicais secas enfrentam processos de conversão e degradação de larga escala, sendo o tipo de floresta mais ameaçado mundialmente. Analisámos estes processos em bosques de Miombo (tipo de floresta tropical seca) numa área rural do centro Sul de Angola. Mostramos que ocorrem processos de conversão de grande escala para áreas agrícolas, bem como modificação de áreas de bosque, i.e., degradação devido à extracção de recursos naturais. Com recurso ao uso de dados de detecção remota, os factores espaciais desta conversão e os seus impactos puderam ser avaliados para o período de 1989 a 2013. Identificámos que as dinâmicas das povoações e a localização e qualidade das ruas são factores fundamentais, determinantes e subjacentes para os processos de conversão. Desde a década de 1980 que a taxa de expansão agrícola depende fortemente do contexto socioeconómico, estando actualmente a um nível de cerca de 9000ha/ano na área de estudo. Foi observado que os terrenos em pousio apenas regeneram lentamente, e há uma mudança no padrão de cultivo para formas de agricultura mais permanentes. Grandes zonas da área de estudo passam por processos de degradação, levando a uma perda adicional de biomassa. Os resultados indicam que existe uma alta pressão nos ecossistemas naturais da área de estudo, a qual irá provavelmente agravar no futuro com uma grande probabilidade de conflictos emergentes relacionados com o uso das terras.

## Introduction

The conversion of forest to cultivation areas can be considered one of the main land use change processes of our time, and dry tropical forests, considered the most endangered forest type worldwide, are facing particularly massive conversion and degradation processes (Janzen, 1988; MEA, 2005). In Sub-Saharan Africa, the rapid rate of land conversion to agriculture can be attributed to a lack of modern farming techniques, e.g. fertilisation (MEA, 2005). This is also the predominant process witnessed in the miombo woodlands that stretch from the western coast of Angola to near the eastern coast of Mozambique and extend north-eastwards

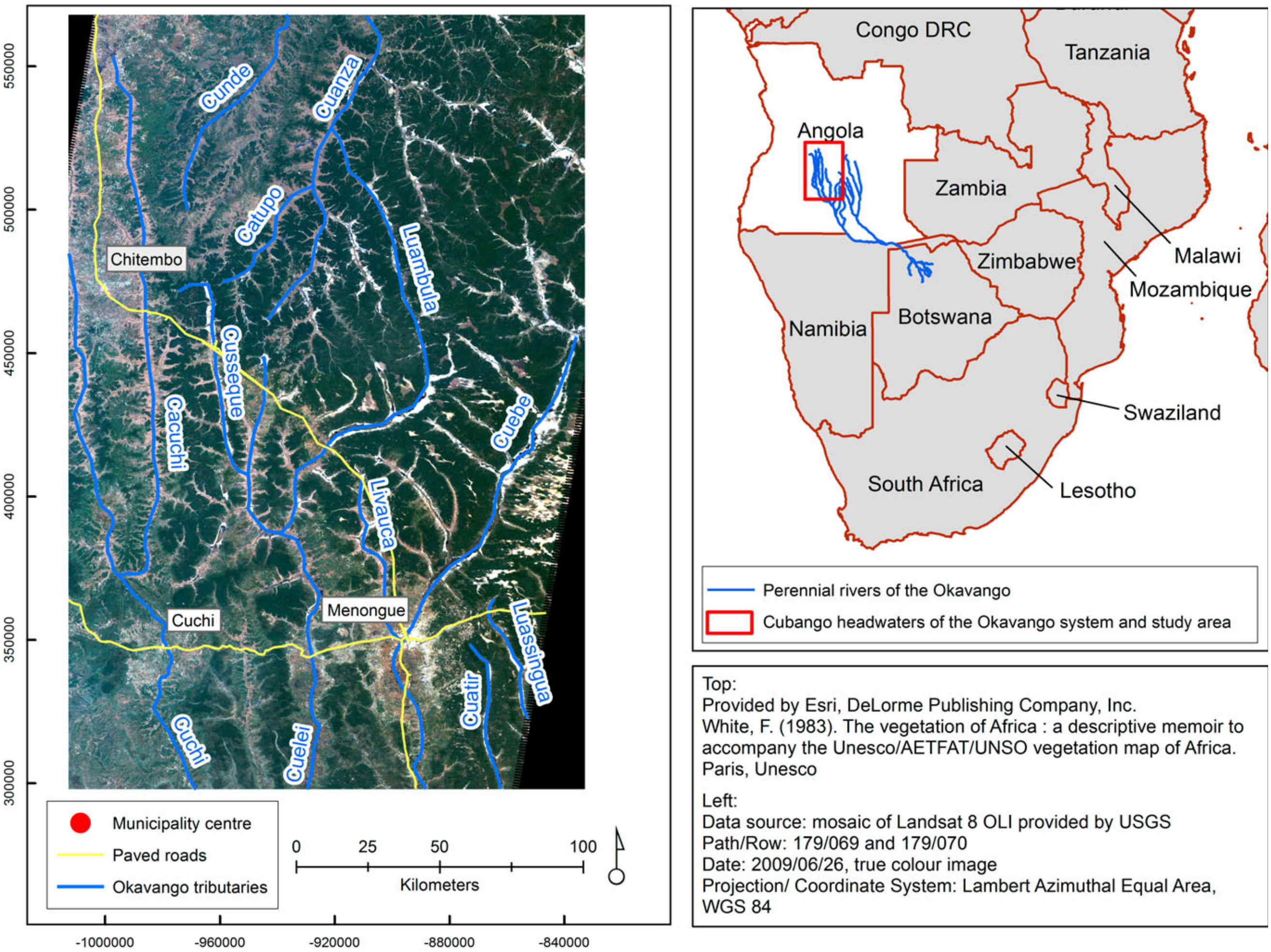


Figure 1: Overview of the study area, including the municipality administrations of Chitembo, Cuchi, and Menongue, as well as the main paved roads and areas of cultivation.

into Tanzania (Chidumayo & Gumbo, 2010). The largest proportion of miombo woodlands are located in Angola, and are of no interest to industrial logging. However, transformation and conversion processes due to smallholder agriculture, use of plants, charcoal and honey production, and the predicted investments of large-scale agricultural production put significant pressure on miombo ecosystems and have already reached the borders of sustainability (Dewees et al., 2010; Piedade, 2013; Finckh, 2015; Muzima & Mendy, 2015). This is partly due to the history of the country, as Angola still struggles with food shortages and insufficient medical and educational supply, as well as the ongoing reconstruction of infrastructure after 27 years of civil war.

The government of Angola was and is still confronted with infrastructure construction and demining issues, as well as with much-needed improvements to basic medical and educational services, especially in rural areas (BTI, 2014). Thus, the local population is still heavily dependent on the consumption of natural resources and subsistence agriculture. Currently, food is predominantly produced at the expense of woodland ecosystems by converting them to new fields; this process is presently indispensable to provide a basic food supply for human livelihood (Friis & Reenberg, 2010). On one hand, this leads to many areas of miombo woodlands being converted for cultivation purposes, but on the other hand to degradation processes due to the selective use of woodland resources (Piedade, 2013).

Providing a synthesis of a number of studies, we analyse processes of conversion and modification of miombo woodlands and assess the predominant trade-off between food production from agriculture and timber resource extraction. The two spheres, agricultural area and woodlands, are temporally and spatially analysed. Overall, the study objectives are as follows:

- to describe the temporal and spatial dynamics of agricultural expansion and the loss of miombo woodlands and quantify the trade-off between timber extraction and agricultural food production.
- to analyse changes in cultivation patterns and connect them to socioeconomic settings.
- to spatially and temporally describe woodland degradation processes.

## Study area

The study area is located in south-central Angola and incorporates parts of the provinces of Bié, Cuando Cubango, and Moxico, covering an area of 48 600 km². The mean altitude is about 1 500 m above sea level (a.s.l.), ranging from 1 350 m a.s.l. in the wetlands to approx. 1 650 m a.s.l. in the hills (Fig. 1).

The study area is characterised by a large network of rivers that stretch from north to south with lateral valleys crossing the woodlands, which are situated on higher slopes and hilltops. At the centre of the valleys, wetlands with thick peat layers occur due to the constant inflow from the slopes. The soils of the slopes are predominantly Arenosols or shallow soils on granitic bedrock. The hilltops are covered by woodlands and also consist of Arenosols with medium concentration of nutrients (Gröngröft et al., 2013). The woodlands are characterised as open to dense miombo woodlands and are dominated by species of the genera *Brachystegia, Cryptosepalum,* and *Julbernadia*. Most of the geoxylic grasslands on the slopes are dominated by dwarf shrubs, particularly *Cryptosepalum maraviense* and *C. exfoliatum* spp. *suffruticans* and tall growing grasses (Revermann et al., 2013).

## Methods

The presented work consists of several studies that were combined to answer the objectives formulated above. In each of these studies, multi-temporal and time series approaches were applied using satellite images provided by the Landsat sensor family. The Landsat-TM, -ETM+, and OLI sensors all have a medium resolution (30 x 30 m) and a regular monitoring frequency (up to 16 days), thus providing detailed and consistent information on land cover and land ecosystem changes for up to 35 years of history, which forms an ideal database for environmental monitoring at large (Wulder et al., 2008; Wulder et al., 2012). We make use of a pre-processing framework that provides radiometrically corrected Landsat images organised in a tiling structure that allows for efficient data access, which has been described in more detail by Röder et al. (this volume).

### Agricultural expansion and trade-offs

In a first step, the impact of infrastructure reconstruction and improvement was assessed by using a bi-temporal unsupervised classification approach (1997/1998–2008/2009) based on Landsat data in combination with higher-resolution RapidEye data (Schneibel et al., 2013). For this purpose, an unsupervised classification using the ISODATA clustering algorithm was calculated on Landsat images from 1997/1998 as well as 2008/2009. The results of this classification were iteratively grouped based on aerial imagery using RapidEye data as reference. This resulted in a land use classification including the fields that were established between the two time steps. Additionally, roads and dirt tracks were captured and the locations of fields were analysed according their proximity to the streets by using a buffer analysis around both types of roads: paved and dirt tracks.

In a second step, the exact location of deforestation due to agricultural expansion was established for a larger study area and in higher temporal detail (Schneibel et al., 2016). This multi-temporal approach, again based on an unsupervised ISODATA algorithm, was also used to quantify the trade-off between food (maize) and timber by applying indicator values based on literature values (Chidumayo, 2014) as well as on household surveys. We could thus quantify the amount of maize grains (103 ± 54.1 kg ha$^{-1}$) that could potentially be harvested from the new fields that were established during one time step. In contrast, we could also denominate timber biomass (79.9 ± 11.05 t ha$^{-1}$) that was lost due to slash-and-burn activity for each time step (for the whole study period 1989–2013). The time steps ranged between 4–6 years, depending on data availability (see Fig. 3 for time step definition). Regeneration of biomass on fallows was also assessed by using the enhanced vegetation index (EVI) and stratification of the study area with spectral angle mapping (Schneibel et al., 2016). The EVI is a spectral index that is considered to be robust against background cover; its values do not saturate in dense vegetation areas (Huete et al., 2002). We calculated the EVI based on a 2014 Landsat image for those areas that were detected as new field areas in any of the time steps. For comparison reasons, we also calculated the mean EVI for 300 random points in woodland areas that could be considered as stable throughout the whole study period.

### Cropping patterns

Although previous studies allowed the accurate delineation of agricultural fields and permitted analysis of the main drivers of agricultural expansion, we included a further study to focus on the temporal dynamics of field expansion and cultivation patterns (Schneibel et al., 2017a). We used an algorithm for temporal segmentation of annual Landsat time series (LandTrendr, Kennedy et al., 2010) from 1989 until 2013, which led to a temporally detailed analysis of cultivation dynamics. The LandTrendr algorithm automatically builds a time series based on a previously defined index. We chose the normalised burn ration (NBR) because it was most precise in detecting disturbances caused by the clearcutting of miombo woodland. LandTrendr provides pixel-based automatic selection of best observations according to the optimal phenological season via the day of the year and the absence of cloud cover. It uses the concept of time series segmentation and can detect both short- and long-term changes and yet is robust against intra-annual variations. For a detailed description of the LandTrendr approach, please see Kennedy et al. (2010). Outcome of the LandTrendr segmentation was a fitted time series that showed long-term trends as well as abrupt changes. To interpret this fitted time series, we only analysed those zones that were detected as agricultural areas in the previous studies. We used several parameters to interpret the fitted time series, adapted to the specific study area characteristics. The parameters were based on results from household surveys and resemble the known cultivation characteristics (e.g., onset of disturbance, length of disturbance, magnitude of disturbance). As a result, we were able to quantify onset, duration, and regeneration on an annual basis

### Forest degradation

Whereas the previous studies primarily focused on the conversion process from woodland to agricultural areas, we complemented these in a last step by also analysing subtle modification processes occurring from 1989 until 2013 (Schneibel et al., 2017b). These processes, often

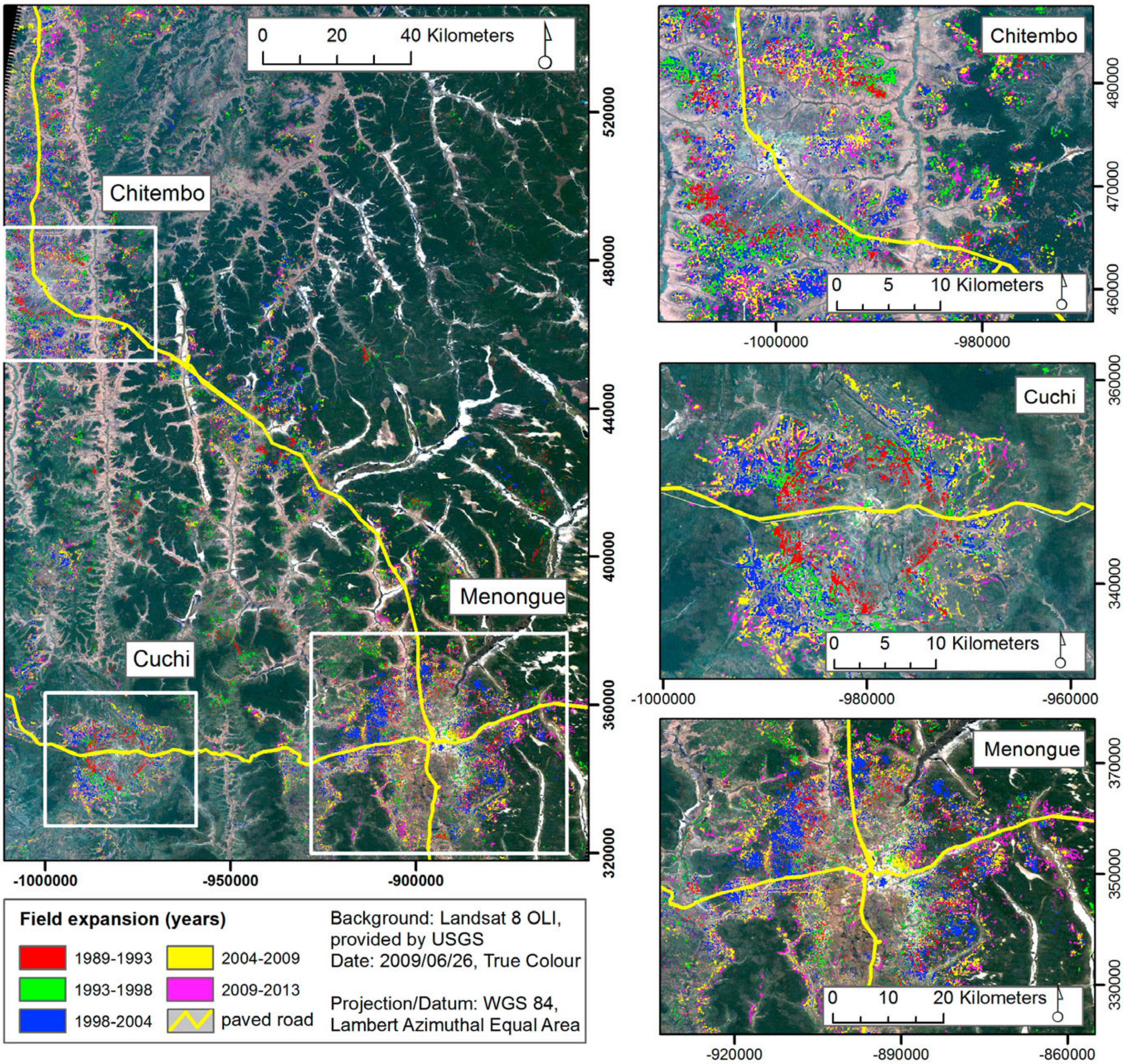


Figure 2: Agricultural expansion based on unsupervised classification (ISODATA) of Landsat data for five time steps. The different colours represent the different time steps. A close-up look for the cities Chitembo, Cuchi, and Menongue is also provided (right). The two paved roads are shown in yellow (Schneibel et al., 2016).

taking the form of degradation, were mainly due to selective logging for timber use, charcoal production, or honey production. For this purpose, the disturbance index (DI) was applied to a Landsat annual time series. The DI is a linear transformation of the Tasseled Cap indices (Kauth & Thomas, 1976) and is based on the assumption that disturbances will result in higher brightness and lower greenness and wetness values (Healey et al., 2005). The index minimises external influences like inter-annual variation of rainfall by rescaling the index via image statistics (mean and standard deviation of reference woodland population). The corresponding time series was analysed on a per-pixel basis by linear regression and parameters including intercept, significance of trend, mean absolute error, and maximum residuum were obtained. These parameters can be attributed to processes like previous use or disturbance, as well as different degradation or regeneration processes. Based on the parameters, the study area was classified into different degradation and regeneration areas, as well as stable woodland areas. To identify the impact of fire, MODIS ignition points were used for the time from 2000–2012 to assess spatial correspondence between fires and woodland degradation areas (Frantz et al., 2016).

## Results

### Agricultural expansion and trade-offs

The spatial delineation of fields shows agricultural expansion for five time steps and is illustrated in Figure 2. We found that expansion is spatially concentrated around roads and settlements and depends on the quality of streets (Fig. 2). Proportionally, the improvement (pavement) of a street led to a strong increase in agricultural areas being established in close proximity.

Regarding the temporal dynamics, a constant increase in the rate of agricultural

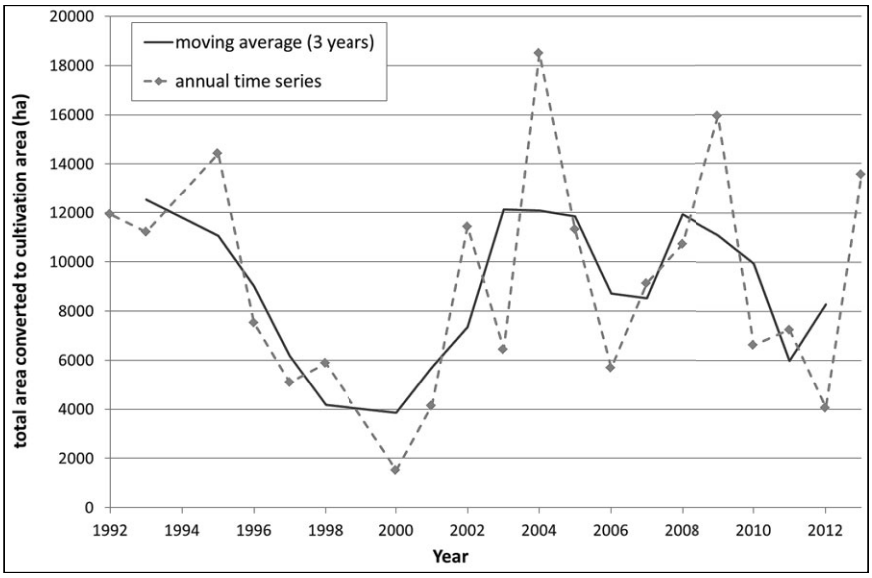


Figure 3: Annual area (ha) that is changed to agriculture (dotted line), including moving average for three years (straight line) (Schneibel et al., 2016).

expansion was detected over the five time steps for the whole study area (Schneibel et al., 2016). Nevertheless, the detailed analysis of annual time series shows specific temporal dynamics (Schneibel et al., 2017a) (Fig. 3). The rate of new fields after the nominal ceasefire period from 1994–1998 decreased from 12 000 ha per year to a minimum of 4 000 ha per year during the resumption of fighting from 1998–2002. Another maximum was reached shortly after the termination of the civil war; expansion in that period fluctuates heavily around 10 000 ha per year (Schneibel et al., 2017). Since 2004, expansion has decreased, which might be due to the changes in cultivation patterns from shifting to semi-permanent cultivation (Schneibel et al., 2016).

The rate of crop yield according to the conversion rate varied highly between farmers because of different soil types, farming techniques, or damage from insects or pests ($103 \pm 54.1$ kg $ha^{-1}$ of maize grains). Accordingly, this results in a highly variable overall available harvest. During the last several years, 1 200 tons of maize grains per year were available due to the large increase in agricultural area. For woodland biomass, the indicator value showed less variation, resulting in lower variabilities between a minimum of about 370 000 tons and a maximum of about 480 000 tons for the first time step. The loss of biomass also maximised for the last time step (2009–2013) with a mean of about 970 000 tons (Schneibel et al., 2016).

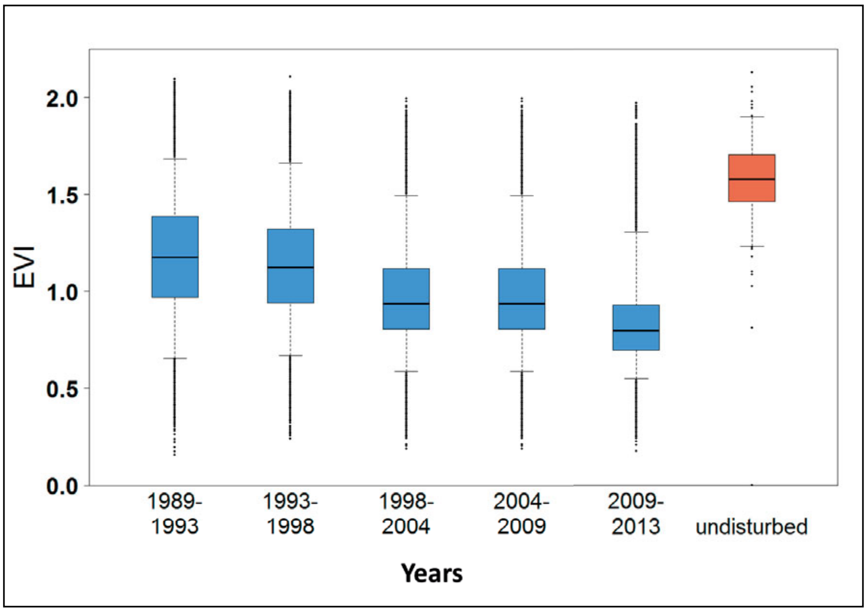


Figure 4: EVI values that relate to biomass regrowth for the five time steps. EVI values for undisturbed woodlands are displayed in red (Schneibel et al., 2017a).

## Cropping patterns

Although the main cultivation regime is shifting cultivation, the analysis of regrowth showed only slow regeneration. Regrowth was assessed for all areas that were detected as expanded agriculture. The EVI only provided an approximation to actual biomass cover. Regarding regrowth on former fields, it showed that from 1989 to 2013, the initial level of biomass was not reached again, which might be due to the relatively short recovery time period of 24 years. The highest EVI values were found in undisturbed woodlands, while the lowest EVI values occurred, as expected, on the most recently established fields (2009–2013) (Fig. 5) (Schneibel et al., 2016).

As biomass did not recover even in areas that are assumed to be mainly used for shifting cultivation, we also assessed if differences in cultivation patterns were visible within the study area. For the same observation time (1989–2013), the change from shifting to semi-permanent/permanent cultivation was evaluated. This change to more semi-permanent forms of cultivation was found when analysing regeneration of fields after the traditional cultivation time that was stated by the farmers in a household survey. Those fields that did not recover above a certain threshold after their assumed abandonment were regarded as being semi-permanent or permanent. This state was found for 22% of all fields in the study area; however, it holds especially true around the cities.

## Forest degradation

In addition to the conversion processes of woodland to field, we also analysed woodland degradation processes. The following map (Fig. 5) shows that degradation processes are widespread not only around cities and infrastructure, but also in the presumably undisturbed woodland

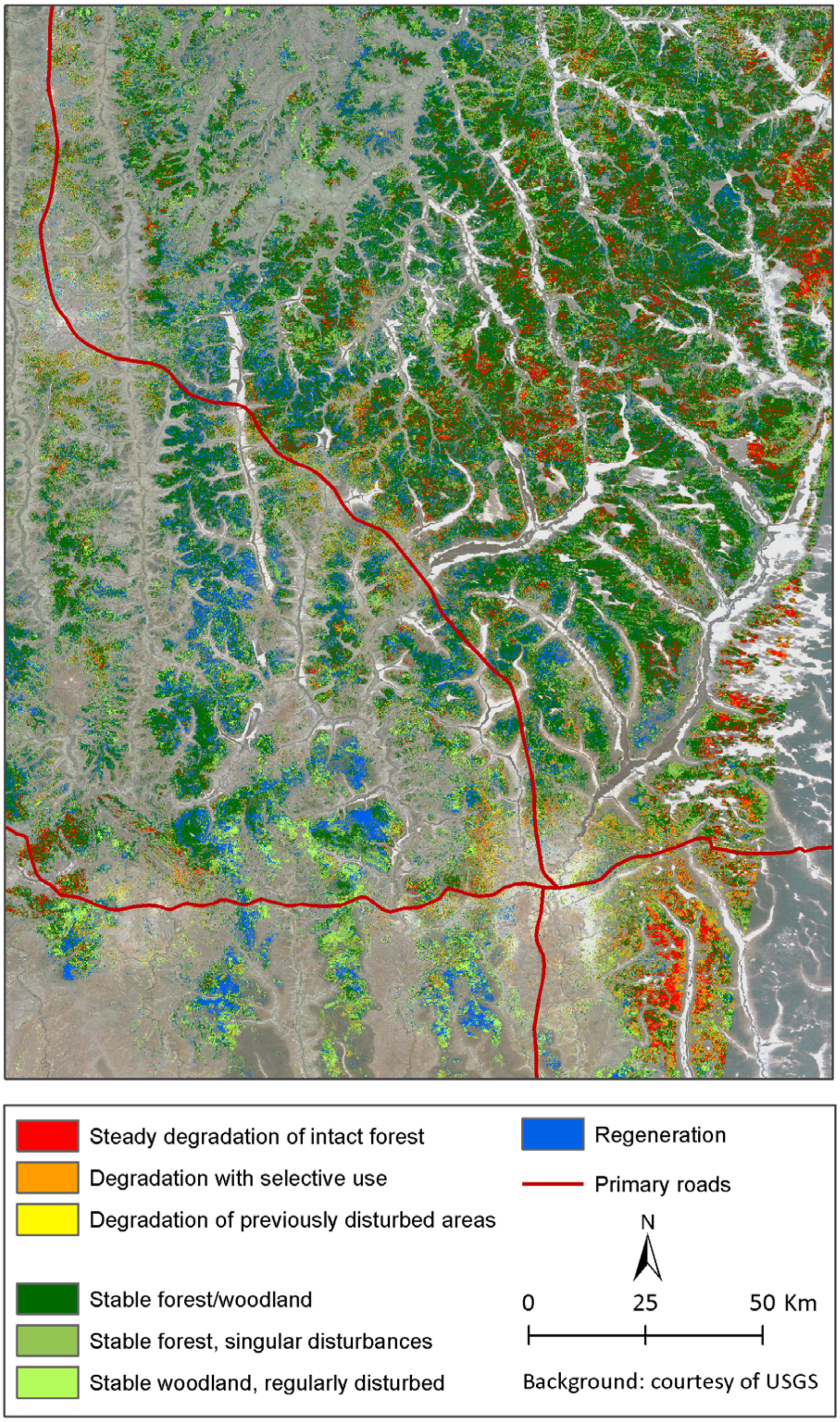


Figure 5: The map shows degradation processes within the miombo woodlands (red and pink colours) as well as regularly disturbed but stable woodlands (orange colours) and undisturbed woodland regions (green colours) for the time between 1989 and 2013 (Schneibel et al., 2017b).

areas in the eastern part of the study area. Nevertheless, almost 74% of the miombo woodlands did not show any significant conversion trend and could thus be considered undisturbed. Overall, 13.3% of woodlands showed degrading trends and almost the same proportion (12.8%) can be considered to be regenerating (Schneibel et al., 2016) (Fig. 5). Furthermore, we could identify regular disturbances (e.g., due to selective use) taking place in woodland areas. This information is based on the maximum residuum, leading to high short-term fluctuation in the time series.

The results were evaluated against MODIS ignition points. Although a quantitative assessment of spatial correlation was not possible due to different observation periods (2000–2013 for MODIS ignition points and 1989–2013 for the Landsat time series), there seems to be a relationship between regular fires and degradation areas.

## Discussion

The trend of increasing deforestation must be evaluated in the context of socioeconomic changes and, in particular, increasing population numbers. When observing large-scale resettlement dynamics and population growth, it is not surprising that there is still a lack of available food supply, and thus a high demand for food (BTI, 2014). These resettlements primarily occurred during the civil war, due to people fleeing into the cities, seeking safety and basic supplies, but also to the government moving people closer to cities and to refugees returning after the final ceasefire. These dynamics can be seen in the rapid deforestation of miombo woodlands around the cities, especially after the ceasefire in 2002, as well as in a high number of early fields (1989–1998) that were established in the woodlands but given up around the civil war's termination.

Deforestation and cultivation patterns are connected to infrastructure destruction and reconstruction. The two main roads of the study area were reconstructed from 2008–2010. This enabled access to new woodland areas and, at the same time, to local trading hubs. Furthermore, after the civil war, former refugees were resettled by governmental orders close to streets and existing settlements. These resettlement actions, in combination with the increased safety of using woodland areas, might have affected the first wave of agricultural expansion from 2000–2004. Later decreases in the rate of agricultural expansion might be attributed to the life cycle of fields.

Our results showed that the cultivation cycle has been changing slowly from shifting cultivation to semi-permanent or permanent forms of cultivation. Household surveys of farmers showed that a lack of seeds, field input, and knowledge prevents them from adopting new production practices (Domptail et al., 2013). Especially around urban areas in which there is improved market access and higher population pressure, however, shifting cultivation seems to be in the process of being replaced by more permanent types of cultivation. This development follows a typical transition of tropical smallholder farming systems: from shifting cultivation to semi-permanent cultivation or permanent rain-fed cultivation (Ruthenberg et al., 1971). In the long term, this can result in decreased yields and degraded soils and is therefore considered an undesired form of intensification.

But even if a field lies fallow for decades, our evidence suggests that biomass is not recovering. This is in line with Chidumayo (2014), who explains that miombo woodlands rarely recover to their previous tree biomass due to the loss of root biomass that is caused by cutting, and also by recurring fires. Other authors indicate a relatively quick recovery of biomass after abandonment and a resilience of tree species diversity to clearing by shifting agriculture (McNicol et al., 2015), but this work does not contain any time series data to relate findings to the pre-disturbance state. The factor of recurring fires also played a major role in the study of woodland degradation, where potentially stable woodlands are regularly disturbed by fire events, although to a far lesser extent than occurs during woodland clearing. According to our results, many woodland areas are affected by fires, but these events seem to mainly affect the understorey.

The impact of woodland disturbance could not be considered in the trade-off analysis. Nevertheless, the calculation of maize yield and biomass loss gives an impression about the dimension of disturbance. Those numbers, however, have to be interpreted in light of the knowledge that maize can be harvested annually, while deforestation and the loss of woody biomass is a single-time action.

This trade-off will likely worsen in the future, because the prevalent global driving forces of degradation (e.g. commercialisation) (Geist & Lambin, 2002) are not yet dominant in rural Angola. We found that deforestation and agricultural expansion are strongly connected to population movements and the need for basic supply. This leads to a high dependency on the international food market and still-insufficient governmental food imports (World Bank, 2013). Additional underlying drivers of dry tropical forest disturbance and degradation, such as agricultural expansion, wood extraction, and infrastructural development (Geist & Lambin, 2002), are clearly applicable within the study area. Furthermore, commodification products like charcoal and honey will gain more importance in the region, yet their production also relies on the availability of woodland areas.

The effects of woodland conversion, changes in cultivation systems, and degradation illustrate that people are still highly dependent on natural resources, and thus must rely on sustainable management actions. The overall dynamics of deforestation and woodland degradation in the study area express the urgent need for a broader base of field data, for further spatial analysis of subtle and direct woodland cover loss, and for the integration of these results into studies that account for ecosystem service provision, like carbon budgeting programs. Remote sensing can contribute to these programs by delivering spatially and temporally consistent information on land cover change that can be conceptually connected to socio-economic and environmental field data to delineate current and future endangered areas.

Our studies demonstrate the potential of using operational earth observation data to address a variety of aspects of forest conversion and modification, and show how remote sensing-based results may bridge information gaps in areas with only sparse ground-based information. The advent of new waves of sensors, such the Sentinel program launched by the European Space Agency or the numerous micro-satellites that have emerged only recently, will provide increased monitoring and observation capabilities, while the Landsat data utilised for this study will continue to form the backbone for many long-term studies due to their historic legacy.

## Acknowledgements

The research was carried out in the framework of SASSCAL and was sponsored by the German Federal Ministry of Education and Research (BMBF) under promotion number 01LG1201C.

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