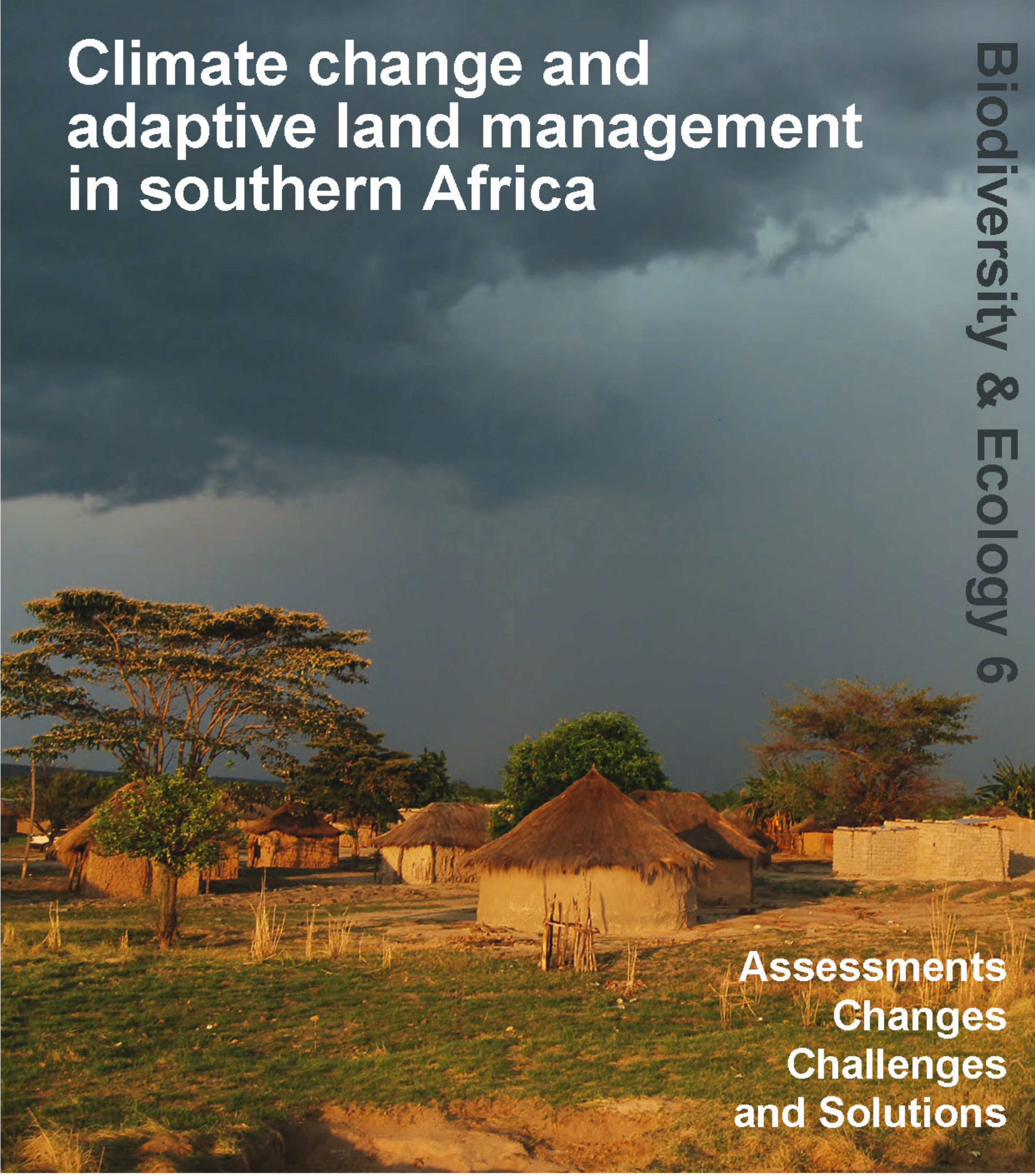
Climate change and adaptive land management in southern Africa

Biodiversity & Ecology 6



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Changes
Challenges
and Solutions

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Climate change and adaptive land management in southern Africa

Assessments, changes, challenges, and solutions

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Determining the degree of deforestation in the Omusati Region, northern Namibia, with the aid of drone imagery

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Abstract: Deforestation, caused both by clearing of fields and by excessive wood harvesting, has been reported to be widespread in the north-central communal areas in Namibia, yet little quantitative information is available on the severity of this form of land degradation. The two biodiversity observatories Ogongo and Omano go Ndjamba are located in the Omusati Region, taking advantage of the unique situation at the Ogongo Campus of the University of Namibia, where the vegetation is protected in a near-pristine condition. The Omano go Ndjamba observatory is situated about 5 km to the west of this, within the typical communal subsistence agriculture land use system found in the region. High-resolution aerial surveys have been undertaken during March 2017 at both observatories. From the resulting images, normalised excessive green index maps (exG2) have been calculated and individual woody plants were delineated. The woody cover and height of plants could be determined at both observatories using the exG2 index and a DSM generated from the aerial images. Direct deforestation (i.e., the clearing of natural vegetation) occurred on 2.5% of the total area in the Ogongo observatory, and on 13.1% at the Omano go Ndjamba observatory. Forest degradation through wood harvesting, however, is of a far greater concern: whereas the woody cover at Ogongo is on average 43.3%, this has been reduced to between 17.7% and 7.5% (depending on land use) at Omano go Ndjamba. This trend is also associated with a reduction in plant height, with tall shrubs and trees being replaced by short coppicing shrubs at Omano go Ndjamba. The impacts of this forest degradation are a loss of provisioning ecosystem services and the potential for total desertification of the area. The use of UAV (drone) aerial images proved to be very suitable for a quick assessment of degradation states, provided a suitable baseline is available.

Resumo: A desflorestação, tanto pela limpeza dos campos como pela extracção excessiva de madeira, tem uma distribuição ampla nas áreas comuns do Centro-Norte da Namíbia. No entanto, existe pouca informação quantitativa sobre a severidade desta forma de degradação da terra. Os dois observatórios de biodiversidade, Ogongo e Omano go Ndjamba, estão localizados na Região de Omusati, aproveitando-se da situação única no Campus Ogongo da Universidade da Namíbia, onde a vegetação está protegida em estado quase pristino. O observatório Omano go Ndjamba situa-se a cerca de 5Km a Oeste do campus, inserido no sistema de uso da terra comunitátio típico na região, baseado na agricultura de subsistência. Foram realizados levantamentos aéreos de alta resolução durante o mês de Março de 2017, em ambos os observatórios. A partir das imagens resultantes, foram calculados os mapas do Índice Verde Excessivo Normalizado (Normalised Excessive Green Index) (exG2) e delineadas as plantas lenhosas individuais. A cobertura e altura das plantas lenhosas pôde ser determinada em ambos os observatórios com recurso ao uso do índice exG2 e um Modelo Digital de Superfície (DSM) gerado a partir das imagens de satélite. A desflorestação directa (ou seja, a remoção da vegetação natural) ocorreu em 2,5% da área total no observatório de Ogongo, e em 13,1% no observatório de Omano go Ndjamba. No entanto, a degradação florestal devida à extracção de madeira é muito mais preocupante: enquanto que a cobertura lenhosa em Ogongo é, em média, 43,3%, esta foi reduzida para entre 17,7% e 7,5% (dependendo do uso da terra) em Omano go Ndjamba. Isto está também associado a uma redução da altura da planta, com arbustos altos e árvores a serem substituidos por pequenos arbustos de talhadia em Omano go Ndjamba. Os impactos desta degradação florestal são a perda dos serviços de ecossistemas, e o potencial para a total desertificação da área. O uso de imagens aéreas UAV (drone) provou ser bastante adequado para uma rápida avaliação dos estados de degradação, desde que uma referência adequada esteja disponível.

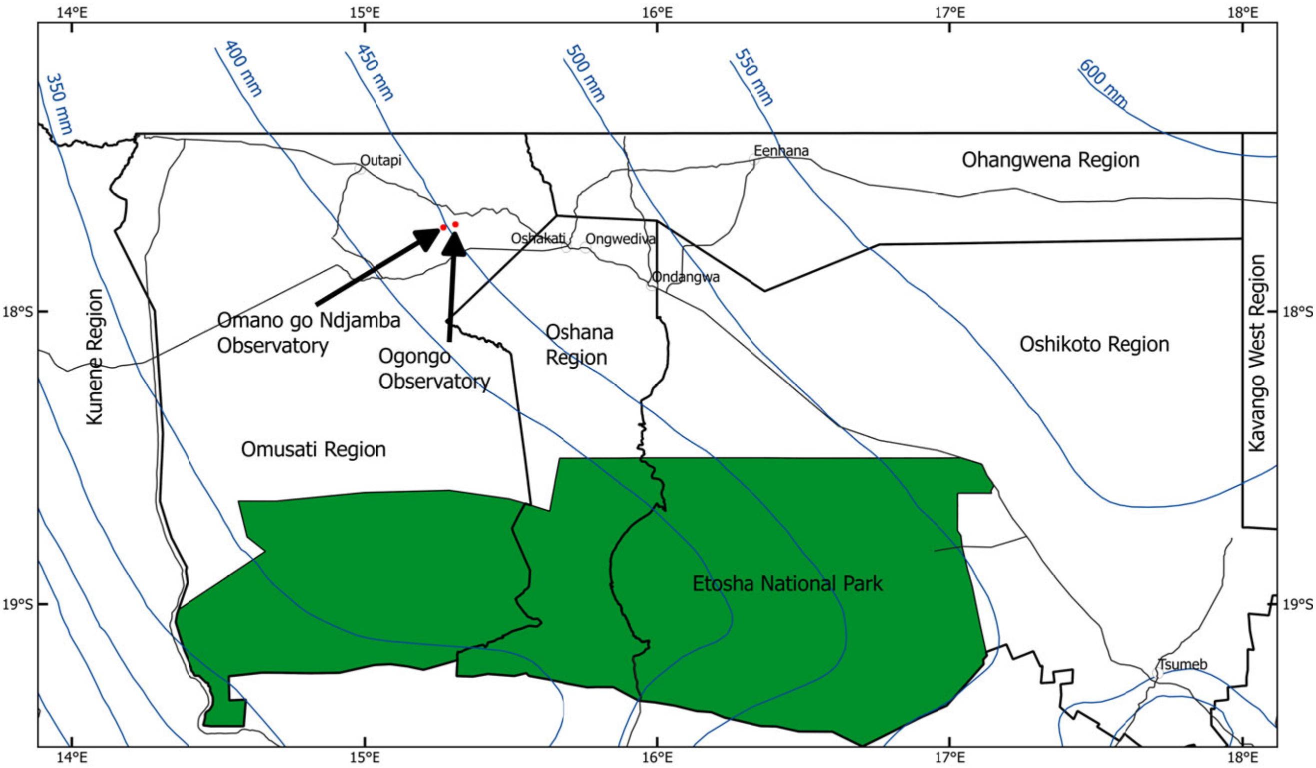

Figure 1: Location of the Ogongo and Omano go Ndjamba biodiversity observatories in northern Namibia. Regional boundaries are indicated in bold black lines, main roads in thin grey lines, and rainfall isohyets in blue lines, with their value along the top edge of the figure.

Introduction

Deforestation is said to be one of the main causes of land degradation and desertification, leading to disrupted ecosystem functioning and a loss of ecosystem services. Hosonuma et al. (2012) make a distinction between deforestation *sensu stricto* as caused by both commercial and subsistence cropping, and forest degradation as caused by timber extraction, logging, firewood collecting, and charcoal production. Both forms (deforestation *sensu stricto* as caused by land clearing as well as forest degradation) are common practices in central northern Namibia, and are commonly referred to as 'deforestation' (Erkkilä, 2001; Klintenberg et al., 2007; Strohbach, 2001). However, little quantitative information on these forms of land degradation is available for Namibia.

Deforestation for cropping is one of the main causes of land degradation in semi-arid regions of the world (Imeson, 2012; Mainguet, 1991; Reynolds et al., 2007). One of the major causes of deforestation in Africa is unsustainable cropping practices (Hosonuma et al., 2012; Mainguet, 1991). Mainguet (1991) specifically mentions a tendency to overcrop (i.e., to clear more land than necessary) to compensate for crop failures resulting from drought and/or poor soils. This holds also true for northern Namibia, where widespread deforestation has been reported (Erkkilä, 2001; Klintenberg et al., 2007; Mendelsohn & el Obeid, 2003; Mendelsohn et al., 2000; Pröpper et al., 2010, 2015).

To study the effects of long-term climate change, a series of permanent biodiversity observation plots were established in 2001 and expanded in 2006. As land use has been identified as a major driver in land degradation, many of these biodiversity observatories have been established in a paired fashion across a land use gradient (Jürgens et al., 2012). Two such biodiversity observatories have been established in the Omusati Region in northern Namibia (Jürgens et al., 2010). The Ogongo observatory is located on the southern part of the Ogongo campus of the University of Namibia. This area is used exclusively for extensive (but fairly light) livestock grazing. In the Cuvelai Delta, no other such (semi) pristine example of Mopane woodlands exists. Roughly 5 km west of this, in the village of Omano go Ndjamba, a second observatory has been established inside a typical communal land use setting. Land uses include cropping, wood and timber harvesting, and livestock grazing. This observatory pair is used as examples to compare the degree of deforestation in the Omusati Region, both as a result of clearing for cropping and from forest degradation caused by timber extraction and general wood harvesting. Using easy-to-obtain high-resolution UAV (drone) aerial photography, we attempt to quantify these land degradation trends in the Omusati Region and compare them to the unique semi-pristine Mopane woodlands at the Ogongo observatory.

Methods

Study area

A regular biodiversity observatory is 1 km^2, or 1,000 by 1,000 m, in size, and is subdivided into one hundred 1 ha units. Hectare numbering is in rows, starting from 0 in the NW corner and ending with 99 in the SE corner (Jürgens et al., 2010, 2012). The position of the observatory is quoted as the northwestern corner.

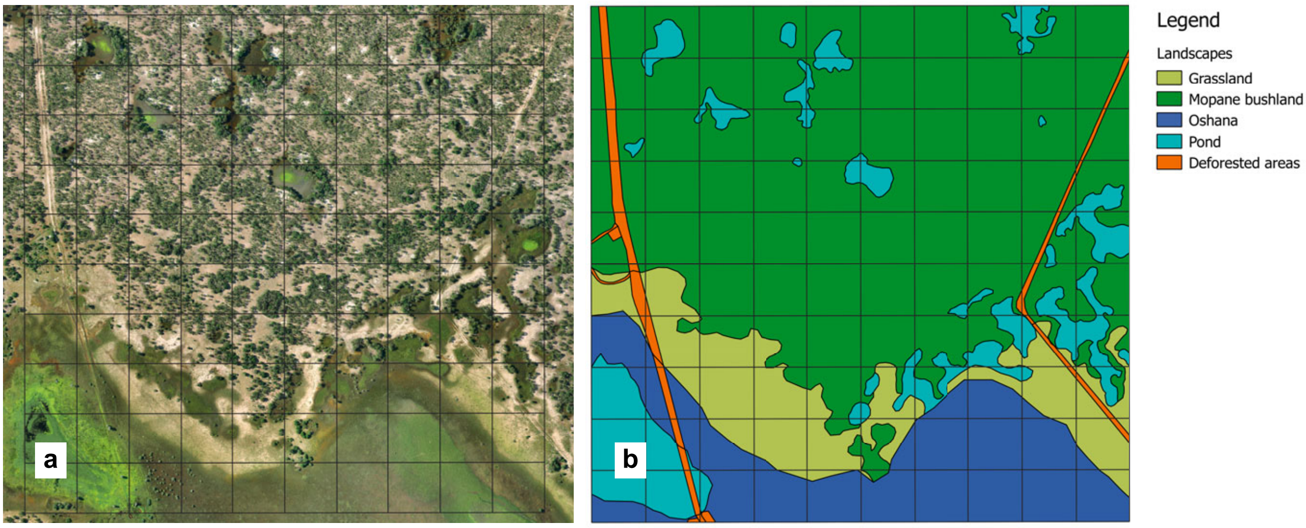

Figure 2: a) aerial image of the Ogongo observatory with observatory hectare grid overlaid; b) map of the landscapes at the observatory with ha grid; c) typical view of the Mopane bushland at the observatory.

The Ogongo observatory is situated at 17.697169˚ S, 15.305209˚ E; the Omano go Ndjamba observatory is at 17.708034˚ S, 15.264797˚ E (Fig. 1).

Both the Ogongo and Omano go Ndjamba observatories are situated in the Mopane savanna *sensu* Giess (1998). The vegetation is dominated by *Colophospermum mopane* shrubs and trees, making it a bushland *sensu* Edwards (1983). A common feature of Mopane-dominated vegetation is the poorly developed herbaceous layer (du Plessis, 2001; Siebert et al., 2003). The Mopane bushlands are interspersed with extensive *iishana* (plural *oshana* — i.e., shallow, broad watercourses of the Cuvelai Delta; Mendelsohn et al., 2013). A full description of the vegetation is presented by Jürgens et al. (2010, pp. 140–163) and Kangombe (2010). The soils are dominated by albic, even glossalbic Solonetz (Jürgens et al., 2010). The brightly bleached topsoil with inherent low herbaceous cover is in stark contrast to the woody vegetation, making discrimination between woody vegetation and the background soil matrix quite feasible.

The topography is almost flat, with a relative altitudinal range at Ogongo of between 1,116.8 and 1,117.7 m above sea level (asl), and at Omano go Ndjamba of between 1,116.8 and 1,119.2 m asl (as derived from the orthophotos, excluding trees, relativized by a possible processing error). The climate is a typical subtropical steppe climate, with roughly 450 to 470 mm mean annual precipitation falling in the summer months between November and April (Jürgens et al., 2010). Full climatic data from the Ogongo weather station are available from the SASSCAL WeatherNet (SASSCAL, 2017; Muche et al., 2018).

Drone survey

An aerial survey of the Ogongo and Omano go Ndjamba observatories was undertaken on 20 March 2017 starting at 16h49 and 17h49, respectively. For the purpose, an eBee (Sensefly) was used with a Canon G9X RGB camera aboard. The weather was clear and sunny, but the sun elevation was fairly low, being shortly before sunset (Ogongo: A_Z 282.4°, β 32.7°; Omano go Ndjamba: A_Z 276.7°, β 18.6°) (A_Z denotes the azimuth angle, β the elevation angle of the sun from the surface) (Cornwall et al., 2017). Pictures were taken from approximately 211 m altitude above ground level, with a planned ground resolution of 5 cm, an individual image footprint of 273.6 m x 182.4 m, and a lateral/longitudinal overlap ratio of 60% by 75%. For Ogongo, 210 individual pictures were taken, whilst for Omano go Ndjamba, 213 pictures were taken. No NIR images could be taken because of equipment failure.

Aerial image analysis and data extraction

The individual images were merged into two separate orthophotos using Pix4Dmapper Pro (Pix4Dmapper Pro, 2016). No ground control points were used. Together with the orthophoto processing, a digital surface model (DSM) and the vegetation indices excessive green

Table 1: Landscapes and land uses in the Ogongo and Omano go Ndjamba observatories, indicating the area covered and/or destroyed within the observatories.

Landscape	Land use	Area at Ogongo observatory (ha)	Area at Omano go Ndjama observatory (ha)
Grasslands	Total	12.6	3.2
	Grazing	12	2.8
	Paths & infrastructure	0.6	0.4
	Total area destroyed [1]	0.6 (4.9%)	0.4 (12.6%)
Mopane bushland	Total	61.9	73.2
	Grazing	60.5	Fenced grazing: 44.1 Open access grazing: 17.5
	Fields	0	9.1
	Houses	0	0.3
	Paths & infrastructure	1.4	2.2
	Total area deforested	1.4 (2.3%)	11.6 (15.8%)
Iishana	Total	15.6	17.8
	Grazing [2]	15.3	17.4
	Paths & infrastructure	0.3	0.4
	Total area destroyed	0.3 (1.9%)	0.4 (2.2%)
Ponds	Total	10.0	5.8
	Grazing	9.8	5.1
	Fields	0	0.7
	Paths & infrastructure	0.2	Negligible
	Total area deforested	0.2 (1.4%)	0.7 (11.3%)
Total area deforested/destroyed		2.5 (2.5%)	13.1 (13.1%)

[1] By definition, grasslands, including the *iishana*, do not have trees and thus cannot be 'deforested'. Instead, typically through trampling action, the ecosystem functioning is destroyed, generally leading to increased erosion by wind and water.

[2] It is common to see cattle and donkeys wade into the shallow *iishana* in the communal areas to graze (as open-access grazing). This is also apparent from the grass cover of the *iishana* when comparing the two observatories in the aerial photos (Fig. 2 and 3). It is, however, not clear whether ponds are used for this purpose — a slight difference in colouring is apparent, though.

(exG), normalised excessive green (exG2), excessive red (exR), and normalised green-red difference (NGRDI) were calculated again using the Pix4Dmapper Pro software (Gitelson et al., 2002; Meyer & Neto, 2008; Rasmussen et al., 2016; Woebbecke et al., 1995).

Based on descriptions of the BIOTA observatories (Jürgens et al., 2010, pp. 140–163), four landscape units were identified on each orthophoto and hand-digitised as a map of these landscapes. In addition, visible land use features were also digitised. These included homesteads, paths, cattle-handling infrastructure ('kraals', etc.), fields, and fenced or unfenced grazing areas. The area of each polygon was determined in QGIS (QGIS 2.14.5-Essen, 2016). Areas in which the natural vegetation has been removed (i.e., fields, homesteads, paths, and other infrastructure) were assumed to be directly deforested, whilst fenced and unfenced (communal) grazing areas were assumed to be either 'pristine' (at Ogongo) or subject to wood harvesting practices.

By way of visual inspection, following the method suggested by Meyer and Neto (2008), a threshold value of 0.1 for the exG2 index was determined to be suitable for discriminating the trees from the background grasses at both the Omano go Ndjamba and Ogongo observatories. The normalised excessive green index (exG2) was found to differentiate trees best from the background, given the low sun elevation at the time of image acquisition.

Using the contour extraction utility in QGIS (QGIS 2.14.5-Essen, 2016), lines were drawn around the trees based on this threshold and linked up to form polygons using the fTools plug-in. To facilitate easier processing, the data matrix was reduced as follows:

- All contours other than those of 0.1 threshold were selected and deleted prior to creating polygons.
- Likewise, all contours within landscapes other than the Mopane bushlands were selected and deleted. This selection was extended to include all contours within degraded/deforested areas (e.g., fields, paths, homesteads). The remaining contours were thus only outlines of trees and shrubs standing in grazing areas within the Mopane bushlands.
- After creating polygons, the area of each resulting polygon was calculated. All polygons smaller than 0.01 m^2 (i.e., 10 x 10 cm) were selected and deleted.

The remaining polygons represent trees and shrubs, even juvenile plants. Because of the dense clustering of woody plants at Ogongo, though, it proved difficult to use these 'tree' polygons to measure vegetation cover directly and accurately. Therefore, to determine the difference in woody vegetation cover and structure, systematic sampling points 5 m apart were created across the entire observatory using the Regular Points tool of the fTools plug-in. For each of these 40,401 sampling points, the following values were extracted using the Point Sampling Tool plug-in: the landscape and land use type, the observatory hectare designation, the exG2 value, and the DSM value. These values were exported as a CSV file and imported into Excel for further processing. As the observatories are relatively flat (< 0.5% slope), the DSM value was converted to a vegetation height by deducting the lowest DSM value of a moving window of 20 points across any particular point from the DSM value of that particular point (i.e., the difference in height of any particular point and the lowest altitude within 100 m from that particular point). Thereafter, the dataset was sorted according to landscape and land use, and the sampling points for the Mopane bushland, as used for grazing (light grazing in Ogongo, fenced grazing and open-access grazing at Omano go Ndjamba), extracted. Secondary sorting of the data points was done according to the relative height, and the trees and shrubs grouped into height classes of 0–1 m, 1–2 m, 2–5 m, and higher than 5 m (following Edwards, 1983). Although Edwards (1983) makes a distinction between *single-stemmed* trees and *multi-stemmed* shrubs in the 2–5 m height class, these could not be separated apart based on the aerial photographs and were thus lumped together.

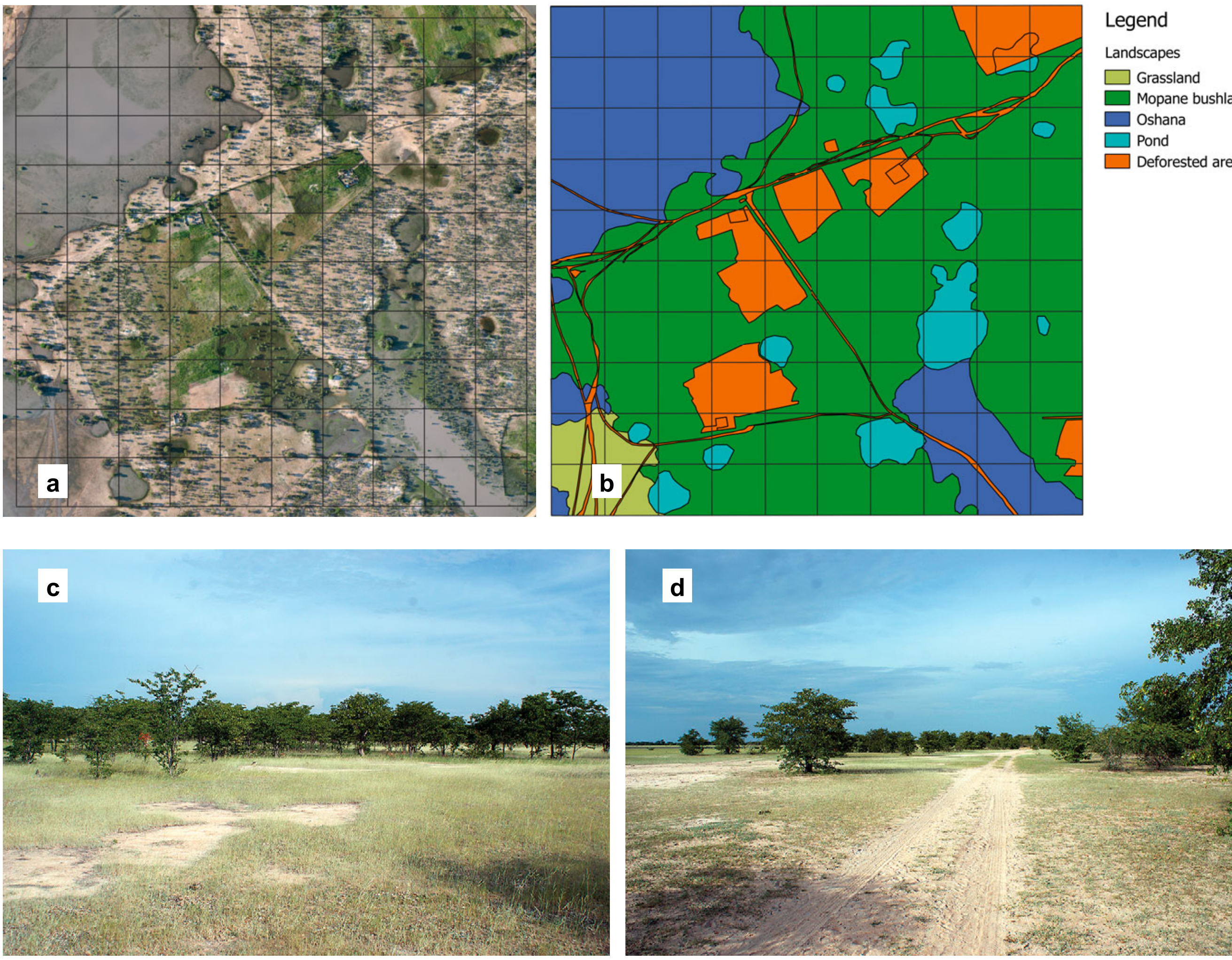

Figure 3: a) aerial image of the Omano go Ndjamba observatory; b) map of the landscapes at the observatory; typical view of the Mopane bushland at the observatory c) fenced and d) open access.

The total number of points in each height class was determined, as was the total number of points (trees, shrubs, and background grass/soil matrix) for the given hectare, landscape, and land use type within each observatory. This frequency distribution (expressed as a percentage of the total number of points) represents the percentage cover for each woody height stratum. For this study, only structural data for the Mopane bushlands were further processed for reporting.

No recent ground data were available for this study. Previously collected data from the observatories date back to 2009 (Jürgens et al., 2010) and can thus be used only as indicative information.

Results

The aerial survey at Ogongo resulted in a GeoTIFF covering 172.38 ha at an average ground sampling distance of 5.13 cm (Fig. 2). Geolocation accuracy (RSM error) is *x* 0.652 m, *y* 0.475 m, and *z* 1.427 m. The aerial survey at Omano go Ndjamba produced a GeoTIFF covering 162.15 ha at an average ground sampling distance of 4.94 cm (Fig. 3). Geolocation accuracy (RSM error) is *x* 0.331 m, *y* 0.324 m, and *z* 0.999 m.

Landscapes and deforestation

The area covered by each landscape and each land use for each observatory is provided in Table 1. A distinction could be made between *iishana*, the associated grasslands on the edge of the *iishana*, ponds, and a matrix of Mopane bushland. Land use features identified included roads and paths, cattle-handling infrastructure ('kraals'), fields, and homesteads (grouped as 'deforested areas'). The remaining area was classed as grazing areas. At Omano go Ndjamba, a differentiation could be made between fenced and open-access grazing areas (Tab. 1).

Woody cover and structure

The contour extraction of the woody plants based on the exG2 index at Ogongo is illustrated in Figure 4, and in Figure 5 for Omano go Ndjamba. The difference in tree and shrub cover between the two land use systems is clearly visible in these images.

Woody cover on Ogongo, as determined by point sampling, was 43.3% (*n* = 24,048, *sd* = 14.0%). At Omano go Ndjamba, the woody cover is reduced to 17.7% (*n* = 16,473, *sd* = 14.6%) within fenced grazing areas, and to as little as 7.5% (*n* = 6,630, *sd* = 5.5%) within the open-access areas. The differences in woody vegetation cover of the two observatories and three land use types are depicted in Figure 6.

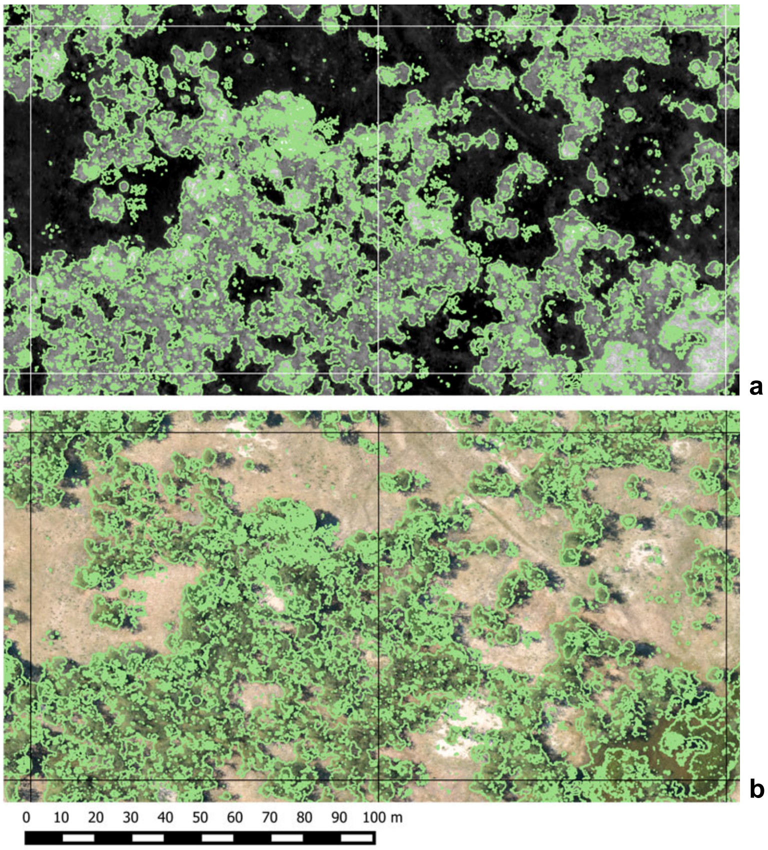

Figure 4: a) exG2 index image of Ogongo hectares 55 and 56; b) RGB image of the same hectares. On both, the contours extracted from the exG2 image to delineate trees and shrubs are superimposed.

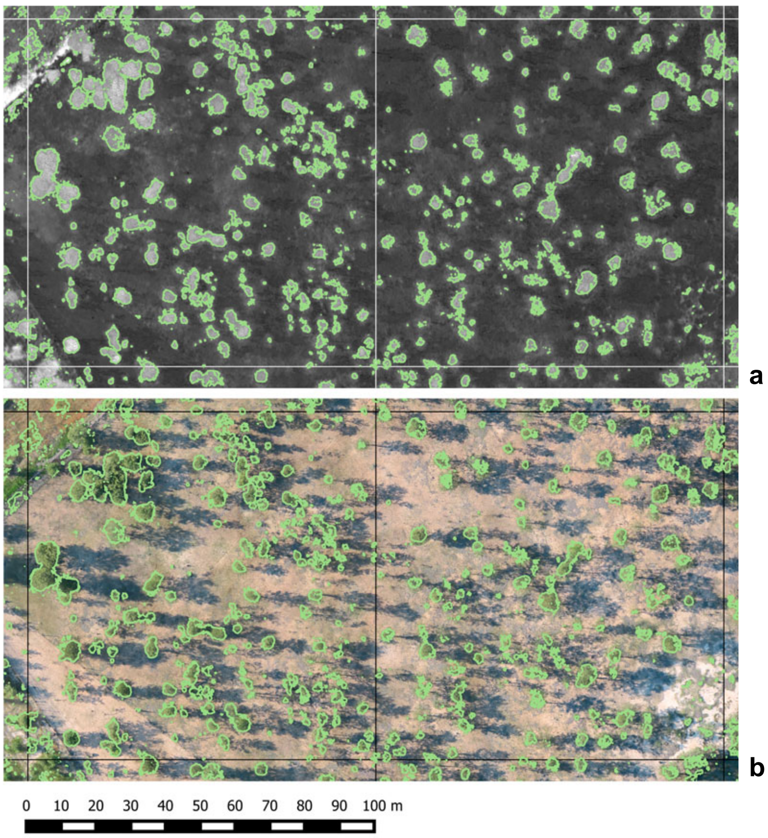

Figure 5: a) exG2 index image of Omano go Ndjamba hectares 55 and 56; b) RGB image of the same hectares. On both, the contours extracted from the exG2 image to delineate trees and shrubs are superimposed. Note the stark difference in tree cover compared to Ogongo in Figure 4.

Discussion

Direct deforestation is remarkably low at Omano go Ndjamba, with only 13.1% of the total area of the Omano go Ndjamba observatory cleared for various purposes. Yet at least half of the cleared fields seem uncultivated, overgrown with weeds. The reason for this fallowing is not known. Soils in the north-central regions are known to be of low fertility and subject to further degradation through erosion and leaching (Mendelsohn et al., 2000; Rigourd & Sappe, 1999). This could be the cause of fallowing, as is happening extensively in the Kavango Region to the east of the present study area (Pröpper et al., 2010, 2015). This trend strongly suggests overcultivation as defined by Mainguet (1991).

Little recognised as a cause of degradation is the excessive number of paths seen at both observatories. Where Ogongo has only two paths crossing the observatory, these are associated with a wide cut line, covering in total 2.6 ha (Fig. 2, Tab. 1). At the Omano go Ndjamba village, paths are generally limited to single-track vehicle tracks, but often with multiple tracks next to one another. These tracks cover 3 ha (Fig. 3, Tab. 1). It is often observed in these communal areas that as tracks deteriorate, new tracks are formed adjacent to the previous track. 'Shortcuts' to 'new destinations' also lead to excessive tracks in these areas (own observation). These tracks not only destroy the biota on the soil surface but also cause damage to the subsoil layers by compaction and reduced soil moisture availability, and are a potential cause of erosion (Webb & Wilshire, 1983).

Of far greater concern is the forest degradation resulting from wood harvesting, as depicted in Figure 6. Mopane wood is widely used for construction and firewood. For fencing, both posts are cut and young branches are used for cladding the fence (Mendelsohn et al., 2013; own observations). This high use of timber for construction and fencing is very evident in the difference in the 2–5 m height class between the two observatories. The strong coppicing ability of Mopane allows it to survive quite a while after being harvested (Mlambo & Mapaure,

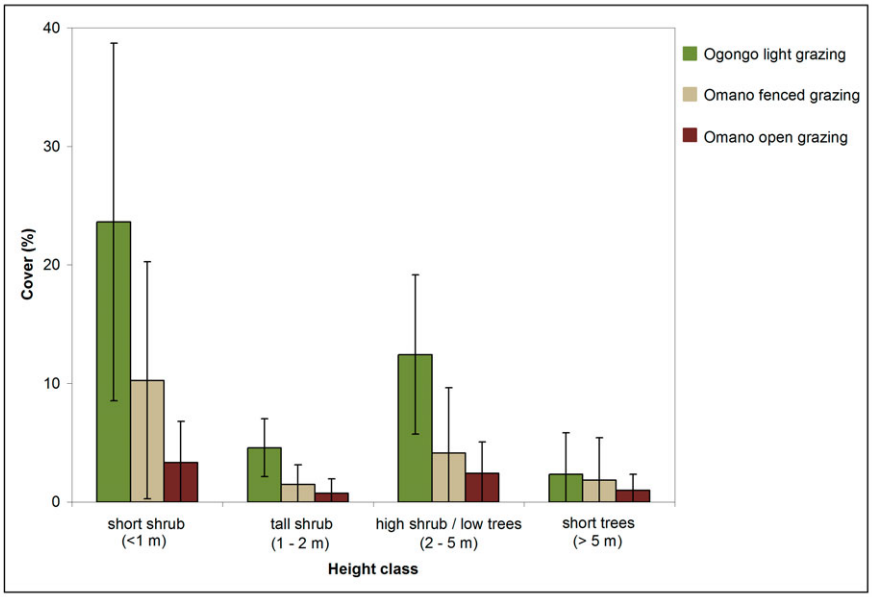

Figure 6: Woody plant density illustrating the vegetation structure of the Mopane bushlands at Ogongo (light grazing) and Omano go Ndjamba (fenced grazing and open-access grazing). Error bars indicate the standard deviation.

2006; Scholes, 1990; Strohbach, 2000). The high cover of short shrubs on Omano go Ndjamba is likely a result of coppicing Mopane shrubs. The reason for the high cover of this size class at Ogongo is not clear — it could be seedlings and/or juvenile plants as a first stage to very dense bush encroachment. Mopane, however, does not survive repeated harvesting and intense browsing for an extended period of time, resulting in the very low cover of this species in the open-access grazing areas at Omano go Ndjamba. This overutilisation eventually leads to desertification in the most severe form.

Conclusion

High-resolution aerial photography proved to be a valuable tool in assessing the current condition of the vegetation. Because of the high resolution of the imagery, identification of individual trees and shrubs is easy. Similar trends have been described by Jürgens et al. (2010). Unfortunately, the available data are outdated concerning the rapidly changing environment through intensive land use and seasonal climatic variations.

Ground truth data are therefore not crucial for determining the density of woody plants but will help with species identification (Oldeland et al., 2017) and thus with improved interpretation of the aerial imagery. This is more important if studying species dynamics as a result of various forms of land use and/or land degradation. The use of drones allows for regular repetition (ad lib) of such an aerial survey at a fraction of the cost of conventional aerial surveys. Added advantages are the high resolution of these images, allowing for the easy recognition of features and the possibility of developing a three-dimensional image through stereoscopic effects (see Knox et al., 2018). Drawbacks are the relatively small area that can be surveyed at once with this technology (compared to the large areas covered by regular aerial photography or even satellite-based remote sensing), and the difficulty in exact geolocation of the imagery without the use of accurate ground control points and/or differential GPS technology. Nevertheless, this manner of monitoring the degree of deforestation on selected sample sites is quite feasible in future.

Experimentation with the most suitable season for such a survey should be done to be able to best discriminate between woody plants and the background soil/grass matrix. An aerial survey during spring, after leaf flush by the woody species but before the onset of the rainy season, might be ideal here and for other observatories throughout Namibia.

Direct deforestation for cropping still seems to be within reasonable limits, judging by the example of the Omano go Ndjamba observatory. Of far bigger concern is the indirect deforestation caused by the extensive harvesting of timber and nontimber products. At this stage, roughly two-thirds of the woody vegetation has been lost. This indirect deforestation is a good indication of the cause of the commonly observed vegetation cover difference along the Namibian-Angolan border (Marsh & Seely, 1992; Mendelsohn et al., 2000, 2013). In turn, this is likely resulting in a severe reduction in ecosystem functioning and thus in ecosystem service delivery. One obvious result will be the reduction in wood availability (both wood for construction and firewood) to the subsistence farmers. Less well understood, but likely of equal importance, is the effect that deforestation has on soil protection and soil fertility, especially considering that *Colophospermum mopane*, as a leguminose woody plant, is known to enrich soils with plant-available nitrogen (Mlambo et al., 2007).

It needs to be considered that the Omano go Ndjamba observatory is only a single, small sample within the larger Mopane savanna in the north-central regions of Namibia. Conversely, Ogongo is a uniquely conserved location, and similar conserved areas are unlikely to be found in the Omusati Region.

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