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The historical ecology of Namibian rangelands: Vegetation change since 1876 in response to local and global drivers

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ABSTRACT

The influence of both local and global drivers on long-term changes in the vegetation of Namibia's extensive rangelands was investigated. Fifty-two historical photographs of the Palgrave Expedition of 1876 were re-photographed and used to document changes over more than 130 years, in grass, shrub and tree cover within three major biomes along a 1200 km climatic gradient in central and southern Namibia. We showed that patterns of change are correlated with mean annual precipitation (MAP) and that below a threshold of around 250 mm, vegetation has remained remarkably stable regardless of land-use or tenure regime. Above this threshold, an increase in tree cover is linked to the rainfall gradient, the legacies of historical events in the late 19th century, subsequent transformations in land-use and increased atmospheric CO_2. We discuss these findings in relation to pastoral and settler societies, paleo- and historical climatic trends and predictions of vegetation change under future global warming scenarios. We argue that changes in land-use associated with colonialism (decimation of megaherbivores and wildlife browsers; fire suppression, cattle ranching), as well as the effects of CO_2 fertilisation provide the most parsimonious explanations for vegetation change. We found no evidence that aridification, as projected under future climate change scenarios, has started in the region. This study provided empirical evidence and theoretical insights into the relative importance of local and global drivers of change in the savanna environments of central and southern Namibia and global savanna ecosystems more generally.

1. Introduction

This paper explores the historical ecology of central and southern Namibia using repeat landscape photography based on an extensive collection of archival images made in 1876. We present one of the most comprehensive accounts of what the region looked like and the causal factors that lay behind this, before the onset of colonization. Previous studies of long-term ecological responses to land-use and/or climate change in Namibia are either site specific (Ward et al., 2000; Heine, 2005), lack historical context (Eitel et al., 2002), or analyse environmental change at centennial, millennial or epochal temporal scales (Gil-Romera et al., 2007, 2010; Chase et al., 2009). Many sources of evidence suggest that landscapes of central and southern Namibia have changed radically since the 19th century but there are no detailed documentary sources that authenticate the state of the pre-colonial environment and how it has changed since then, across such a large spatial scale.

Understanding the extent and cause of change is important since degradation in Namibia is commonly blamed on inappropriate land-use practices (local drivers) leading to bush encroachment, soil erosion, aridification and a decline in agrarian productivity (Eitel et al., 2002; de Klerk, 2004; Getzin, 2005; Dirkx et al., 2008). Furthermore, future climate change scenarios predict that these ecological processes will be exacerbated by the regional impact of global drivers in the form of anthropogenic global warming (Midgley et al., 2005; Haensler et al., 2011). Future projections based on bioclimatic envelope models suggest that desert and arid shrublands will expand into present grassland savannas with a concomitant reduction in net primary productivity (Thuiller et al., 2006) and negative impacts on biodiversity, ecosystem services and livelihoods (Kruger, 1997; de Wit and Stankiewicz, 2006; Reid et al., 2007). Using the detailed evidence provided by repeat photography spanning more than 130 years we were able to test claims about the causes of change in the past and identify trends in vegetation dynamics that relate to future climate change projections. We describe and analyse vegetation change across several bioclimatic zones that co-occur with the steep west/east rainfall gradient from the Namib Desert to the interior highland savannas and from there south along a more gradual aridity gradient through the dwarf shrub savanna to the desert margin of the Orange River basin. We addressed the following key questions: (a) What are the major patterns of change in grass, shrub and tree cover since 1876 along an environmental gradient in Namibia? (b) How have political,

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socio-economic, cultural and climatic conditions influenced these changes? (c) Are the historical trajectories of change consistent in direction and magnitude with those projected for the future? (d) What are the relative influences of biotic/abiotic and local/global factors in relation to vegetation change in arid and semi-arid savannas?

2. Historical and biophysical background

2.1. The Palgrave photographs and historical ecology

The archival photographs used in this research were made during the 1st Commission of William Coates Palgrave to what was then called Great Namaqualand and Damaraland, in 1876. They represent one of the first and certainly the most detailed and comprehensive visual records of central and southern Namibia before the onset of German colonisation (Silvester et al., 1999). At the time, two pastoral societies (Herero and Nama/Oorlam) dominated the political economy of the region, along with a handful of European traders, hunters and missionaries.

Palgrave was sent to the territory by the Cape Colony in order to determine the possibility of its annexation by Britain. He arrived in Walvis Bay for the first of five Commissions to the region in April 1876 along with a secretary, a photographer and a servant. Kitted out with 'state-of-the-art' uranium dry-plate camera equipment and a waggon pulled by 18 oxen, he spent the next nine months travelling between, and camping in the main settlements of the territory, holding meetings with various Herero, Nama, Oorlam, Baster and European leaders and groups. The documentary record of his five commissions to the territory between 1876 and 1885, consisting of diaries, reports, photographs and maps, constitutes a rich historical source (NLSA, 1876; Palgrave, 1877; Davies, 1942; Stals, 1991). These were an essential aid in helping us to retrace a 1200 km transect following Palgrave's ox-waggon route from Walvis Bay to Okahandja and south to Windhoek, Keetmanshoop and Warmbad to the Orange River during the 1st Commission (see Fig. 1). Palgrave made this trip during a brief period of peace in the territory. Prior to, and following his five missions, raiding and intermittent conflict between and within groups of Nama, Oorlam, Herero, and Europeans was the order of the day (Gewald, 1999).

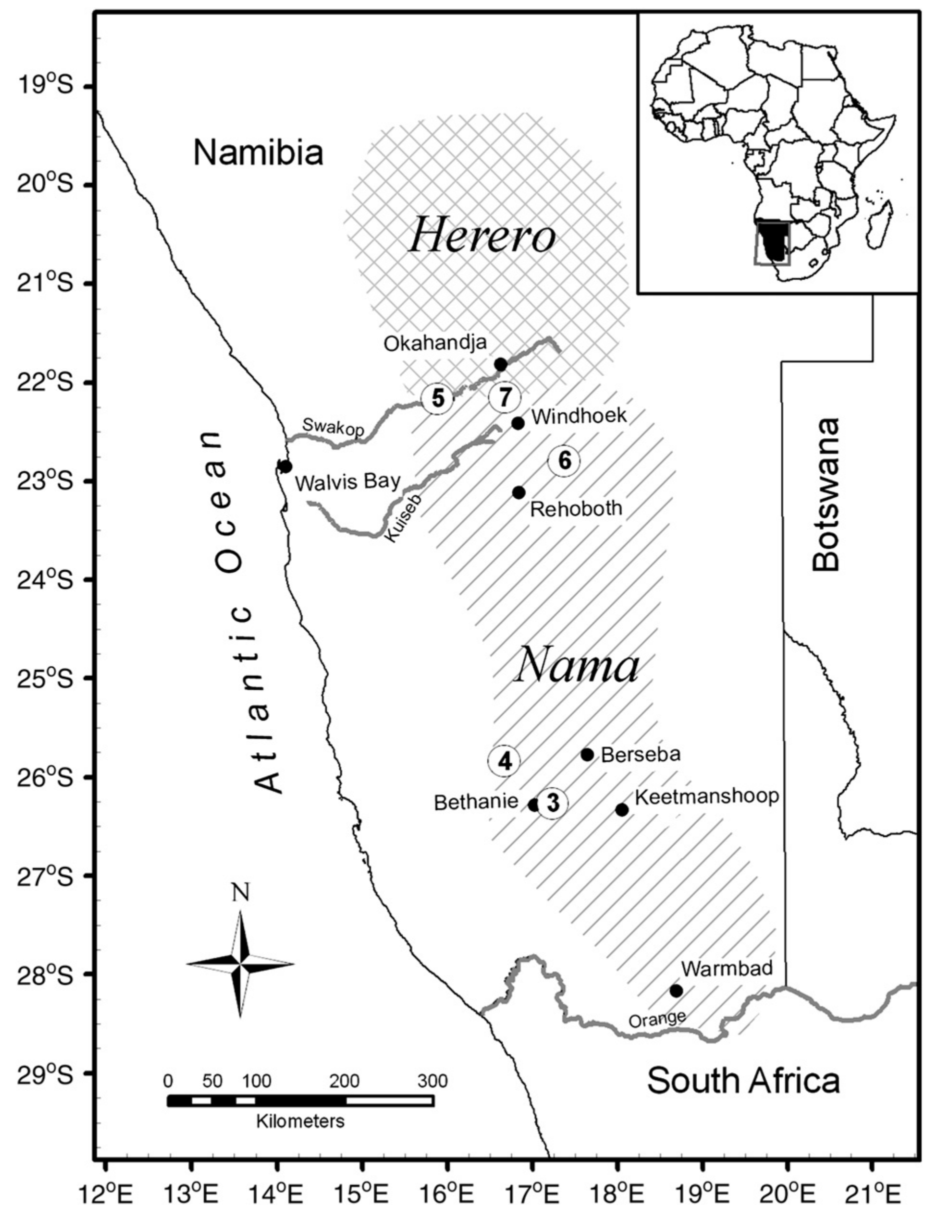


Fig. 1. Map of central and southern Namibia showing towns and rivers mentioned in the text as well as the main territories of Herero and Nama ethnic groups at the time of Palgrave's Commission in 1876. Numbers show locations of Figs. 3–7.

The chronicle of interaction between the various ethnic groups and subgroups that dominate the political history of the territory are too complex to explore in detail here. However, a brief overview of the most important changes in land-use and disturbance events that occurred both before and after Palgrave's trip are necessary in order to understand the extent and dynamic of environmental change that was underway at the time. We adapted a historical ecology approach that explores the interactive relationship between humans and nature and allowed us to interpret the imprint of culture, political processes and climatic events on the landscape (Swetnam et al., 1999; Balée and Erickson, 2006). Environments are in a continual process of change – dialectically shaped by social entities and in turn shaping society – and are therefore fundamentally historical (Ingold, 2000), shaped as much by conflict involving class, power and money as by climate and geology (Rohde and Hoffman, 2008; Davies, 2010).

2.2. Historical outline

Prior to 1800, the human impact on the environment was patterned by land-use practices associated with decentralised, relatively unstratified pastoral societies. Archaeological evidence for the presence of pastoralists along the western coastal areas of southwest Africa dates back to around 1900 BP (Barnard, 1992). This early Iron Age population probably consisted of small groups of Khoekhoen herders, the ancestors of present day Nama-speakers in southern Namibia, who until the early 19th Century were engaged in pre-capitalist cattle trading as well as being prone to internecine clan conflict and raiding (Kinahan, 2001). The migration of Ovaherero Bantu speakers from present day Angola and northern Namibia into the central highland region of Namibia only took place around 300 BP (Barnard, 1992). The social organisation of the Herero polity was fractured into many disparate chieftainships based on extended families and households. Raiding also formed an important part of the Herero economy and mitigated against the creation of fixed wealth disparities and differentiation. Pastoral land-use practices included seasonal transhumance and fire management that helped maintain grasslands. Prior to the introduction of firearms, large herds of wild herbivores also impacted the vegetation at a landscape scale. Subsequent to the annexation of the territory by Germany in 1884, radical changes in these land-use impacts across differing bio-climatic zones left an imprint and legacy of vegetation change of varying degrees in what might be considered a *colonial ecological revolution* that reverberates into the present (Merchant, 1997).

The first portent of the colonial ecological revolution was felt in southern Namibia when disaffected indigenous inhabitants of the Cape Colony (Oorlams) migrated north during the late 18th Century, bringing with them guns, horses and an economy based on commando groups and raiding (Lau, 1987). By the time missionaries arrived in the area in the early 19th Century, these Oorlam groups had transformed and become integrated with the indigenous Nama social economy. At the same time, missionaries and traders were importing more guns, creating permanent settlements and promoting a primitive form of market capitalism. At the time of Palgrave's 1st Commission in 1876, there were approximately 150 Europeans in central Namibia, consisting of missionaries, hunters and traders, who were often caught between warring factions of Nama/Oorlam groups to the south and Herero to the north along a line roughly defined by the Swakop River (see Fig. 1).

The images made by Palgrave's photographer depicted a cultural landscape shaped by pastoral migration, fire management and newly established missionary and trading settlements around natural water resources, which would gradually develop into the main urban centres of modern Namibia. The photographs also recorded a landscape which had become devoid of wildlife as a result of several decades of rapacious hunting (primarily for elephants and ostrich) and the virtual decimation of the region's mega-herbivore population (Gewald, 1996). Examples from other semi-arid savanna regions suggest that the effects of this sudden discontinuation of disturbance associated with browsing and seasonal migration of large numbers of ungulates on the region's vegetation structure would have been profound (Owen-Smith, 1987; de Beer et al., 2006). Concurrently, the process of land-use change associated with the commercialisation of livestock production was beginning to impact the environment along the drove routes south to the Cape (Andersson, 1989).

Following Palgrave's commissions, these changes were punctuated and overlaid by floods, droughts, epidemics, panzootics and violent political events that escalated towards the end of the 19th century and into the early 20th century. The German subjugation of Nama clans was brutally prosecuted in the early 1890s and during the later half of that decade the entire indigenous population would be visited by the equivalent of the four horsemen of the apocalypse. The Rinderpest cattle disease reached the borders of South-West Africa in April 1897 and spread through the country “like a tempest” (Bley, 1971, p.125). German authorities estimated that 50% of the country's cattle herd perished within the first six months of the panzootic and over the next year up to 90% mortality was reported among Herero herds in the central highlands (Schneider, 1994). In the spring and summer of 1898 malaria and typhoid epidemics affected Herero communities the hardest with up to 90% of the population contracting the diseases resulting in high mortality (Bley, 1971). In the same year a plague of locusts devastated the few crops that were planted by pastoralists in the hopes of sustaining them while their herds recovered. This was followed by exceptionally good rainfall years and catastrophic floods (1897–1900) and then prolonged drought (1901–1904) both of which further reduced the success of river-bed crop cultivation (Gewald, 1996). The response of the region's inhabitants to this series of disasters was desperate: raiding of other people's cattle and livestock increased, indigenous Namibians joined the contract labour gangs needed for the German colonial government's expanding infrastructure, tracts of ‘tribal’ lands were sold by desperate chiefs to pay their debts (Wellington, 1967) and large-scale migration took place, on both local and regional scales (Rohde, 1997a). All this set the stage for the final act of the apocalypse — the German/Herero War (1904–1907) which led to the subjugation of native populations through genocide, concentration camps and the permanent alienation of native land and property (Olusoga and Erichsen, 2010).

Herero and Nama populations were reduced by up to 80% as a result of the war while the European population expanded from less than 300 at the beginning of German occupation to almost fifteen thousand in 1913. As a consequence of these overlapping natural and man-made disasters, large areas of central Namibia were abandoned by both native and European populations, only to be recolonised by white settler farmers during the first decade of the 20th century (Gewald, 1996; Olusoga and Erichsen, 2010). This process of privatisation and commercialisation of the landscape continued throughout the 20th Century as the more arid areas of the southern and western Namibia were titled and fenced, leaving small, confined communal ‘reserves’ scattered across the study area (Rohde et al., 1999). Today, there are approximately 6000 commercial livestock farms of over 3000 hectares in size (averaging 5700 ha) which dominate the land tenure system of the study area (LAC, 2005).

2.3. Biophysical and climatic characteristics of the study region

Palgrave's route from Walvis Bay to the Orange River traversed a range of physiographic regions, climate zones and vegetation types which are well described by Mendelsohn et al. (2002). Three main biomes dominate the region. The Desert biome is situated in the arid western part of the country along the relatively low-lying coastal platform and generally receives less than 100 mm of rain per annum. Between 80 and 120 km from the coast the relief rises sharply to form an escarpment of more than 2000 m in places that runs in a north–south direction. The Nama-karoo biome dominates the

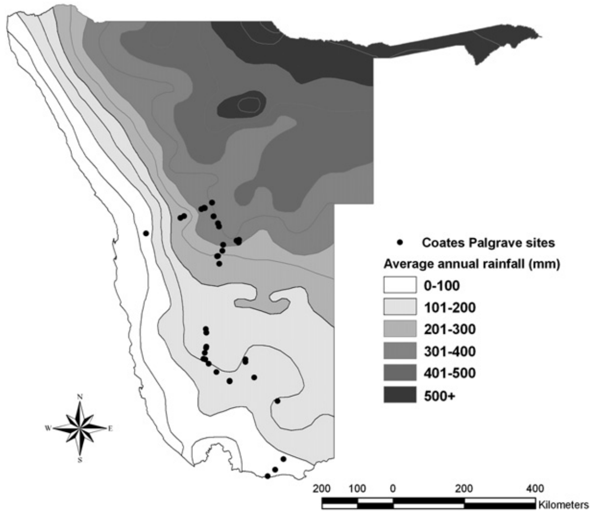


Fig. 2. Average annual rainfall (mm) and the location of repeat photo site localities (dots) in central and southern Namibia.

foothills of this escarpment as well as the first few hundred km of broad plateau to the east and the south where rainfall ranges from 100 to 250 mm per annum. From Rehoboth to the region north of Okahandja rainfall increases from 250 to more than 400 mm per annum and elements associated with the Tree and Shrub Savanna biome dominate the landscape. Azonal vegetation, associated with the major riverine and drainage line habitats in the region is a common feature of southern and central Namibia. Since substrate and hydrogeological condition exert a strong influence on the structure, composition and dynamics of the vegetation of azonal habitats (Mucina and Rutherford, 2006) we discuss them as a single unit, separate from the major biomes in the region.

Overlain on the physical environment is a relatively complex land use pattern which has changed significantly over the last 130 years. The repeat photo sites depict tenure regimes ranging from state-owned areas, large-scale commercial farms and communally-farmed settlement areas. Within each of these tenure systems, land use practices themselves have also changed in response to a range of influences and stresses including population growth, development interventions, market forces and technological change (Young, 2010).

3. Methodology

3.1. Photographic images

Repeat photography requires both the re-location and re-photographing of a historical image as well as the interpretation of changes visible in the landscape (Munro et al., 2008; Nyssen et al., 2010; Webb et al., 2010). The Palgrave Album contains 77 plates depicting landscapes which are made up of 121 photographs (NLSA, 1876). These images were taken along the ox-waggon routes of the territory and portray heavily utilized settlements and water holes as well as more remote and infrequently impacted grazing lands, many of which consist of two, three or four photos in panoramic sequences. We did not locate 29 plates due to either featureless landscapes or highly disturbed urban settings, but were able to re-photograph 48 plates following the approach described in Rohde (1997b) during three field trips between 2006 and 2009. For the purposes of vegetation analysis eight plates were eliminated due to excessive disturbance, often related to urban developments. Where clusters of repeat photos were located within 5 km of each other and did not comprise statistically independent samples, they were amalgamated into 25 site localities comprising 39 plates and 52 photographs (Fig. 2). This avoided some of the problems of pseudo-replication as outlined by Hurlbert (1984).

3.2. Field notes and surveys

A detailed description of our methodology is described in Rohde and Hoffman (2010) and what follows is a summary of our approach. Major changes in land-use and vegetation cover evident between the two periods were noted in the field. Local land users were consulted for their views on the changes that had occurred in the landscape, and for an explanation of the history of land-use at the location. Many of the repeat photo sites were located on farms that had been continuously owned by the same family for the last 100 years and therefore detailed records were often available of stocking rates and climatic conditions as well as socio-political events. Archival sources also provided detailed insights into past land-use practices. In addition, we categorised the landscape within eleven discrete landform units[1] and by consensus, applied this classification systematically at each location. We then surveyed each landform unit by walking through it and listing the percentage cover of the dominant species (Rohde and Hoffman, 2010). In addition, key species (e.g. *Acacia erioloba* E. Mey.) were surveyed in detail and age or size class details recorded. Taxonomic nomenclature follows Germishuizen and Meyer (2003).

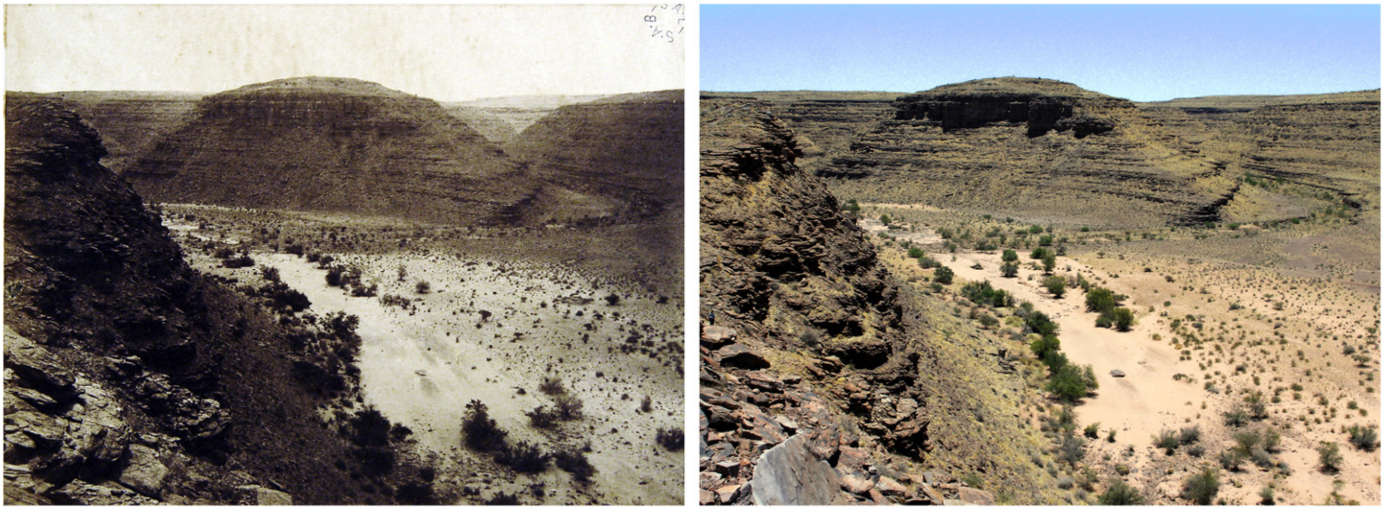
3.3. Data analysis

Overall changes in percentage vegetation cover were derived using digitized and exactly matched images which were compared by the authors for total percentage cover of vegetation in both the Palgrave images and repeat photographs, using the survey data as a base-line comparison to estimate change in the archival image. Vegetation cover was further divided into three growth forms viz. grasses, shrubs (<1.5 m in height) and trees (>1.5 m in height) and the percentage cover of each growth form estimated for each time period, again using survey data as a base-line.

The species composition data collected in the field for each landform unit were grouped using TWINSPAN in Community Analysis Package (version 2.13) (Henderson and Seaby, 2002). These groupings and associated dominant species were displayed in two-dimensional space derived from Reciprocal Averaging Ordination methods. Several landform units were excluded from the final data set either because the unit was 1) not sampled; 2) less than 1 ha; 3) a disturbed settlement; 4) disturbed road verge and/or 5) comprised a unique vegetation unit with little or no replication, leaving a final total of 71 landform units and 193 species which were included in the analysis. The landform units fell naturally into three main vegetation units corresponding with the Nama Karoo biome, the Tree and Shrub Savanna biome and Azonal riverine areas.[2] The percentage change in tree cover was assessed separately for each of these three main vegetation units and related to mean annual rainfall using a linear regression approach. Values for mean annual rainfall were derived for each landform unit using Worldclim (www.worldclim.org/bioclim), the most detailed and spatially accurate dataset of climatic variables available for the study area, providing monthly rainfall and temperature values with a resolution of 1 km^2 appropriate to biological niche modelling (Hijmans et al., 2005). We believe that this methodology represents an innovative advance on vegetation studies using repeat photography to analyse ecological processes (Webb et al., 2010).

[1] Landform units: sandy river course, rocky river course, sandy river bank/terrace, rocky river bank/terrace, sandy footslope, rocky footslope, sand dune, sandy plain, rocky plain, rocky ridge, saline pan.

[2] The only Desert Biome repeat photo site has been amalgamated with the Nama Karoo sites due to the fact that species composition was consistent with that of the Nama Karoo as derived from TWINASPAN and Reciprocal Averaging Ordination methods as described above.



A. November 16, 1876 B. December 6, 2006

Fig. 3. Guireb River, Karas Region. Stability in vegetation cover and composition characterise this site over the last 130 years. Apart from some turnover and a slight increase in tree cover in the main Azonal riverine area, there is no apparent change in either grass or shrub cover across the wider landscape [Biome: Nama-karoo; MAP: 131 mm]. Photo 3A: ALBX 5 (INIL 11690) courtesy of the National Library of South Africa, Cape Town; Photo 3B: Rohde and Hoffman.

3.4. Climate records

Monthly rainfall and temperature data for Windhoek and Keetmanshoop were obtained from the Namibian Weather Bureau. These two climate stations reflect broad weather conditions for the Tree and Shrub Savanna and Nama-karoo biomes respectively and comprise some of the longest climate time series available in Namibia. Total rainfall values for the months September to August were summed to provide an annual total for each station. Average monthly maximum and minimum temperature values for each climate station were calculated for the period Jan–Dec and an average value for all twelve months calculated for each year. We used a non-parametric Mann–Kendall test (Makesens Freeware, (Version 1.0) developed by the Finnish Meteorological Institute (2002)) to test for a monotonic increase or decrease in the annual rainfall and temperature time series for both climate stations.

4. Results

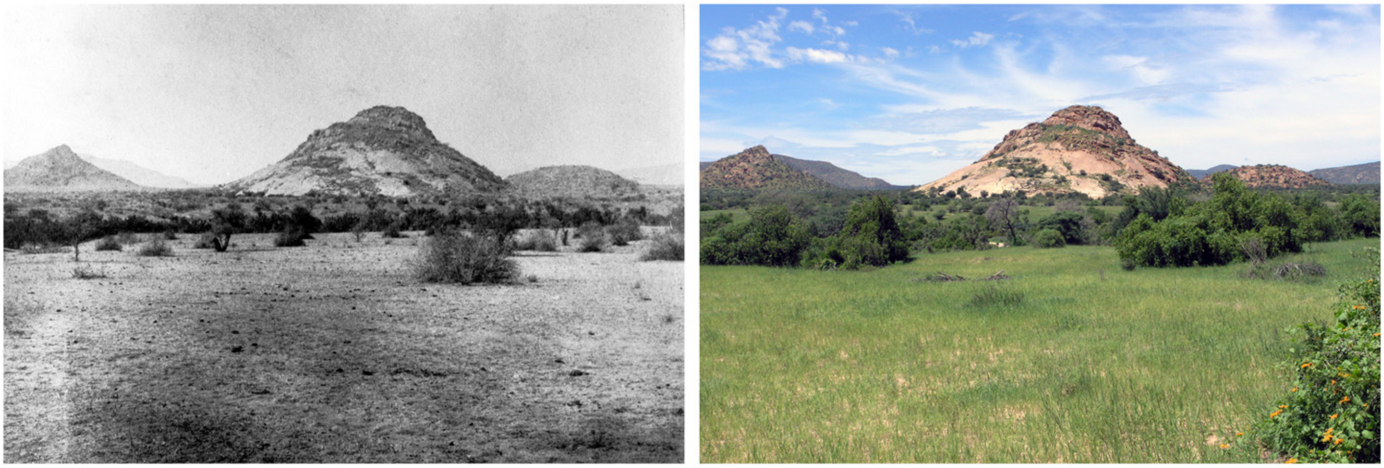
4.1. Analysis of repeat photographs

Of the 25 repeat photograph site localities, 14 depict landscapes with a mean annual precipitation (MAP) of <200 mm and the remaining 11 show landscapes with MAP of between 200 mm and 375 mm. Eleven repeat photo site localities illustrate conditions and changes within long-standing communal 'reserves' or 'Homelands'. All other repeat photo site localities were situated within privately owned commercial farms apart from one site in the hyper-arid Namib National Park. The photographs that illustrate this paper are representative of the region's arid (Figs. 3 and 4), riparian (Figs. 3, 5 and 6) and semi-arid (Figs. 6 and 7) landscapes.

The arid landscape of Fig. 3 is situated in what is now a communal livestock farming area on the old ox-waggon route between Berseba

A. November 14, 1876 B. December 5, 2006

Fig. 4. Sorrento Farm, Karas Region. Very little change was detected at this site apart from the obvious increase in grass and a small increase in tree cover, primarily along minor drainage lines that probably developed from disturbance caused by ox-waggons and latterly motor vehicles [Biome: Nama-karoo; MAP: 163 mm]. Photo 4A: ALBX 5 (INIL 11679) courtesy of the National Library of South Africa, Cape Town; Photo 4B: Rohde and Hoffman.



A. August 29, 1876 B. February 27, 2009

Fig. 5. Uitdraai, Erongo Region looking south across the Swakop River. The ephemeral flush of annual grass (*Schmidtia kalahariensi)* in 2009 is a response to recent heavy rains while the more modest increase in shrubs (+2%) and trees, especially in the more dynamic riverine area (+15%) is evident in this transition zone between the Nama Karoo and the Tree and Shrub Savanna [MAP: 203 mm]. Photo 5A: ALBX 5 (INIL 11631) courtesy of the National Library of South Africa, Cape Town; Photo 5B: Rohde and Hoffman.

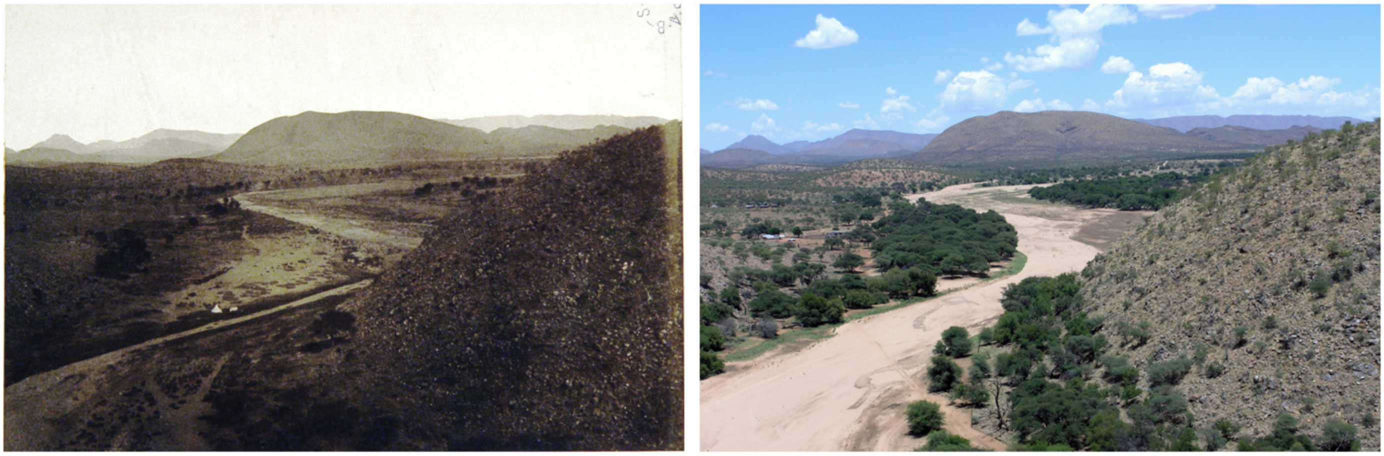
and Bethany in the south of the Namibia. This was open, unfenced rangeland in 1876, used by neighbouring Nama herders until the 1930s when it became a privately owned farm. Thirty years later, the South African government returned this farm to the expanded communal 'Homeland' of Namaland, although the neighbouring farm of Waterval remained in private ownership. This image is one of two photographs looking in opposite directions from the same photo station, encompassing the border between communal and privately owned farmland. There is no appreciable difference in either cover or species composition across the communal/private fence-line.

The landscape depicted in Fig. 4 was part of the main southern trek artery for cattle trading with the Cape Colony during the mid 19th century (Andersson, 1989). Situated in the Karas Region south of Helmeringhausen, it became a private commercial livestock farm around 1910. Palgrave's photo was taken on the ox-waggon route about half way between water holes — about 30 km in either direction. The 1876 image was taken at the end of the dry season after a year of below average rainfall, whereas the 2006 photo was taken during the summer of an exceptionally good rain year and this probably accounts for the increased cover of the grasses, *Stipagrostis uniplumis* (Licht.) de Winter (60% cover) and the more patchily-distributed clumps of *S. ciliata* (Desf.) de Winter (3%). However, judging by the plant morphology in combination with the sandy substrate, in 1876 the dominant grass species was probably *S. ciliata* with what appears to be patches of *Schmidtia kalahariensis* Stent all of which are palatable but which indicate a change from annual to more perennial grass cover. There has also been an increase in the encroacher shrub *Rhigozum trichotomum* Burch. (7%) mainly along drainage lines and a slight increase in the number of the long-lived *A. erioloba* E. Mey. (2%) in the region. The track of the old ox-waggon route is still discernable and slightly deeper whereas the new drainage channel to the left has been colonised by shrubs such as *R. trichotomum*, *Lycium* spp. and *Cadaba aphyla* (Thunb.) Wild as well as by *A. erioloba*. The old *A. erioloba* present in the 1876 image (middle-distance left) is present today. This site is within a 5000 ha farm, carrying 700–800 ewes, which has been continuously stocked for the best part of the last 100 years. Again, this arid environment shows remarkable stability although the disturbance caused by ox-waggons in the 19th and early 20th century has left distinct and persistent markers in the landscape.

Fig. 5 is the repeat of one frame from a three-framed panorama taken near the site of a wetland in the Swakop River (running left to right in mid-ground) which in 1876 was near a watering place for ox-waggon teams travelling between Otjimbingwe and Gross Barmen, part of the route from Walvis Bay to the interior. Today, the photo site is located on a private commercial cattle farm overlooking communal grazing land on the far side of the Swakop River. Again the increased grass cover (*Schmidtia kalahariensis*, 30%) in 2009 is undoubtedly a result of seasonal factors. Riverine shrubs and trees such as *Salvadora persica* L. (20%) *Tamarix usenoides* E. Mey. Ex Bunge (15%) and *Faidherbia albida* (Delile) A. Chev. (10%) have increased in cover by an estimated 15%. While this reflects a general trend observed in the riparian habitats of the study sites, the construction of the Swakopoort Dam 50 km upstream in the 1970s has undoubtedly affected the periodic flood events which would have scoured the river channel more frequently in the past. Woody vegetation (*Acacia erubescens* Welw. Ex Oliv. 15%; *Salvadora persica* 5%; and *A. erioloba* 2%) on the sandy plains within the commercial farm have increased very slightly (2%) although there is little change in cover on the communal plain surrounding the low granite hill in the distance. This agrees well with the findings of Ward et al. (2000: 351) who found that in the communal area of Otjimbingwe "plant species cover, richness and diversity as well as grass availability after a rainy season is similar to that on surrounding commercial ranches, which have approximately tenfold lower stocking densities".

Noticeable changes over the 130 year period become pronounced in the more mesic areas in the central highlands. Fig. 6 overlooks the Skaap River at Hatsemas and is one of five photographic plates of the immediate surrounding environment. It depicts communal livestock farming land of the Rehoboth Gebiet although the river forms a border with neighbouring private ranches. The general finding in all five photographs is that *A. erioloba*, *A. karroo* Hayne and *Ziziphus mucronata* Willd. have increased considerably along the river margins particularly on the deeper sands. *A. erioloba* individuals can live longer than 200 years. Subsequent to seedling establishment, the occurrence of release events, promoted in part by good rainfall, give the impression of cohorted or pulsed recruitment of this species (Seymour, 2008). Considering the large stem circumferences (>150 cm) typical of individuals older than 100 years (Steenkamp et al., 2008) and uniform population structure of this population, it is reasonable to assume that they originated either as a seedling cohort or as an apparent release cohort sometime between 1876 and 1910.

The rocky hill slopes show a marked increase in *Acacia mellifera* (Vahl) Benth. which co-occurs with a lower cover of *Dichrostachys*



A. October 16, 1876   B. December 2, 2006

Fig. 6. Hatsemas, Komas Region. *Acacia erioloba* individuals have colonised previously bare or sparsely vegetated river terraces, probably in a single recruitment event around 1900. The increase in small trees and shrubs on the rocky pediments and hill slopes is indicative of regional bush encroachment patterns. For scale, note the white tent and ox-waggon at the bottom left quadrant of the 1876 image [Biome: Tree and Shrub Savanna; MAP: 320 mm]. Photo 6A: ALBX 5 (INIL 11662) courtesy of the National Library of South Africa, Cape Town; Photo 6B: Rohde and Hoffman.

cinerea (L.) Wright & Arn. (both classic bush encroachment species) and a few *Acacia hebeclada* DC. individuals in places (c.f. Oldeland et al., 2010).

Repeat photos from the highland plateau region (Tree and Shrub Savanna) illustrate two distinct trends in these more mesic landscapes. The large increase in *A. erioloba* along the riverine margins as seen in Fig. 6 is indicative of a recruitment event that took place some time after Palgrave's visit. This stand of trees consists of a single cohort that could have recruited in response to the sudden release of grazing pressure between 1890 and 1910. This area was within the disputed border zone between Nama and Herero territory that the Germans effectively depopulated at this time. The conjunction of depopulation, the absence of wild ungulates and favourable climatic conditions (above average MAP between 1903 and 1910) would explain this relatively even stand of mature trees.

Palgrave's image of Otjisewa depicts a newly established mission station inhabited by several hundred Herero and Nama/Damara pastoralists situated around a wetland in a tributary of the Swakop River. Intermittant conflict, cattle theft and violent confrontation took place between Nama and Herero until the 1890 s when a police station was established here under German administration. Otjisewa farm was bought from the local Herero chief in the early 1900s and has remained a privately owned commerical cattle farm owned by a succession of German and Afrikaner farmilies. A store existed here for several decades in the early 1900s on what was then the main road to Walvis Bay. Fig. 7 is a double-framed panorama of this landscape illustrating the general open rangeland of the highland savanna region in 1876 and the radical bush thickening that typifies these more mesic highland areas today. *Catophractes alexandrii* D. Don (20%) *Acacia mellifera* (10%) and *Agrostis* sp. (20%) provide the dominant species cover in the foreground. *Acacia tortilis* (Forssk.) Hayne (40%) is the dominant tree across the sandy plains with scattered *A. mellifera* (5%). Riparian vegetation has probably been affected by the introduction of karakul sheep spreading seed during the 1950s and semi-purified water being pumped into the river upstream during the mid 1960s causing an increase in phreatic vegetation (Stromberg et al., 2007; Benito et al., 2010; Hoffman and Rohde, 2011).

4.2. General changes across the gradient: analysis of vegetation survey data

The 71 landform units, grouped according to species composition, using Reciprocal Averaging Ordination methods, comprise three main vegetation units: Nama Karoo, Tree and Shrub Savanna and Azonal/Riverine. We used this classification to group our results further and to derive a more general understanding of growth form changes within vegetation units along an aridity gradient in Namibia. The change in the cover of different growth forms and total vegetation cover within the different vegetation units is shown in Table 1.

- The Nama Karoo sites [Average MAP = 140 mm] generally experienced an increase in grass cover although there was considerable variation between sites. Shrub cover declined slightly and together with tree cover rarely comprised a large part of the overall vegetation cover. Three sites showed a decline in shrub cover of 10% due to disturbance associated with livestock farming. Although total vegetation cover declined in two of the Nama Karoo landform units, it increased by an average of 13.5% within this vegetation unit.
- Tree and Shrub Savannas [Average MAP = 318 mm] were characterised by a substantial yet variable increase in grass cover and an even larger but less variable increase in tree cover. Shrub cover changed very little between 1876 and 2009. Total cover increased by nearly a third in this vegetation unit with considerable variation between sites. Five communal sites (MAP = 310 mm) had an average of +18% tree cover; five commercial farm sites (MAP = 342 mm) averaged +35%.
- The change in the percentage cover of different growth forms within Azonal/Riverine vegetation units [Average MAP = 235 mm] showed that grass and tree cover increased at most sites while shrub cover declined on average by 3% although this figure was skewed by one site where a 29% decline in cover was observed due to the scouring of the river channel. There was a high degree of variation between sites although total cover generally increased within Riverine Habitats between the two time periods.

The large variability between sites in each of the vegetation units is affected in part by initial starting conditions as well as by historical differences in land use practices and climatic conditions at a site. Also, the area covered by each view is not uniform and issues of spatial scale also need to be considered when assessing the extent of change within each vegetation unit. Despite these differences, however, the average values shown for each vegetation unit provide a general account of the trend and extent of change for each growth form.

A regression analysis of the % change in tree cover between 1876 and 2009 in each vegetation unit in relation to mean annual rainfall (Fig. 8) shows that there was no significant relationship in Nama Karoo sites

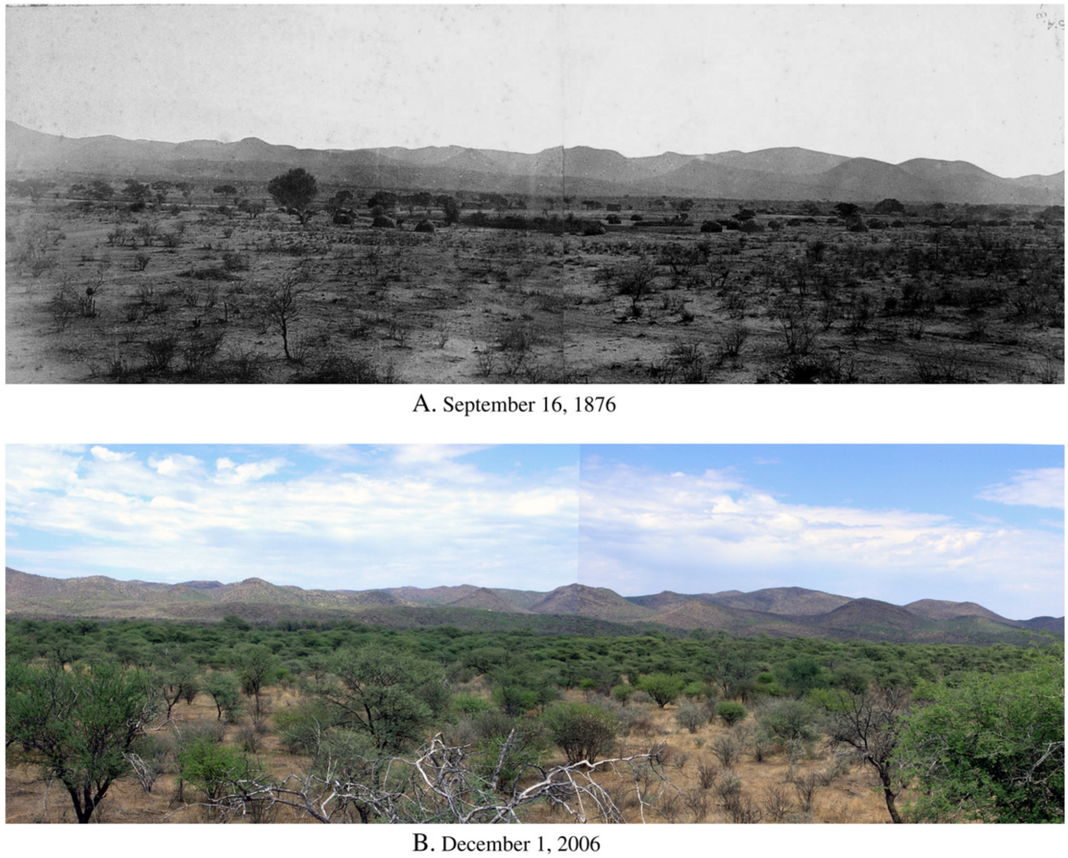


Fig. 7. Otjisewa, Otjozondjupa Region. The Lycium shrubs in the foreground have changed little over time although taller shrubs (*Salvadora persica*) and low trees across the sandy plain (*Acacia tortilis* and *A. erubescens*) have increased substantially (+48%). The population of *A. erioloba* (visible mid-frame, left in 1876) has remained relatively stable with mixed age classes present. Judging by the size, shape and morphology of the trees in the archival photograph, the composition of riparian vegetation in 1876 was probably similar to that of today, including *Faidherbia albida* (20%), *A. tortilis* (15%) and *A. erioloba* (2%) although *A. mellifera* (5%) was probably absent in 1876. Total riverine cover has increased from 15% to 42% [Biome: Tree and shrub savanna; MAP: 347 mm]. Photo 7A: ALBX 5 (INIL 11647) courtesy of the National Library of South Africa, Cape Town; Photo 7B: Rohde and Hoffman.

($n=8$, $y=0.0103x-0.6914$, $R^2=0.1046$, p=NS). However, for Tree and Shrub Savannas ($n=13$, $y=0.1932x-37.268$, $R^2=0.4566$, $p<0.05$) and Azonal/Riverine Habitats ($n=19$, $y=0.0803x+0.4225$, $R^2=0.3196$, $p<0.05$) tree cover increased more at sites with a higher mean annual rainfall than at drier sites. For all sites combined there was also a significant positive relationship between the % change in tree cover and mean annual rainfall ($n=40$, $y=0.0993x-7.0819$, $R^2=0.4391$, $p<0.01$).

Table 1
The difference in the percentage cover of grass, shrub, tree and total vegetation cover between 1876 and 2009 within three different vegetation units in Namibia as determined from repeat photograph pairs. "n" refers to the number of landform units in which it was possible to assess the change in cover of a particular growth form.

Vegetation unit	Growth form			Total cover
	Grass cover	Shrub (<1.5 m) cover	Tree (>1.5 m) cover	
	%	%	%	%
Nama Karoo				
n	9	20	11	21
Average change	31	−0.4	0.5	13
(±std.dev.)	27	5	1.0	22
Range	4–75	−10–5	0–3	−10–21
Tree and Shrub Savannas				
n	6	10	21	21
Average change	21	1.5	22	29
(±std.dev.)	28	5	14	19
Range	−10–65	−5–15	−5–48	−5–85
Azonal (Riparian)				
n	4	8	29	29
Average change	14	−3.0	19	20
(±std.dev.)	20	11	17	18
Range	−5–39	−29–7	0–65	−9–65

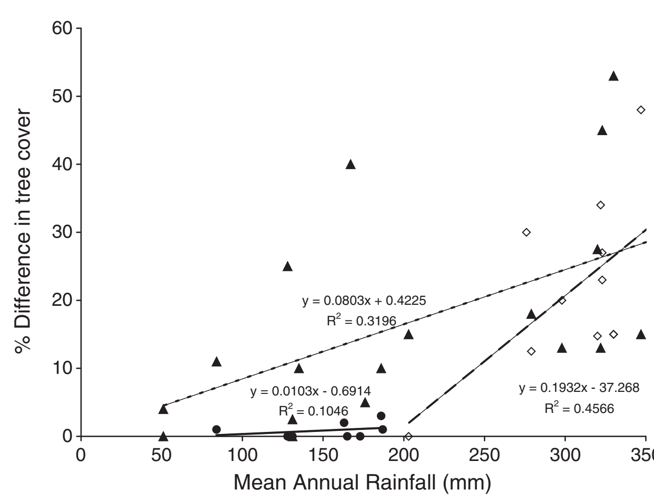


Fig. 8. The relationship between MAP and % difference in tree cover between 1876 and 2009 for sites within Nama Karoo (filled circles and solid line) Tree and Shrub Savanna (open diamonds and dashed line) and Azonal (filled triangles and dotted line) vegetation units. There are fewer data points than sites due to multiple sites with the same values.

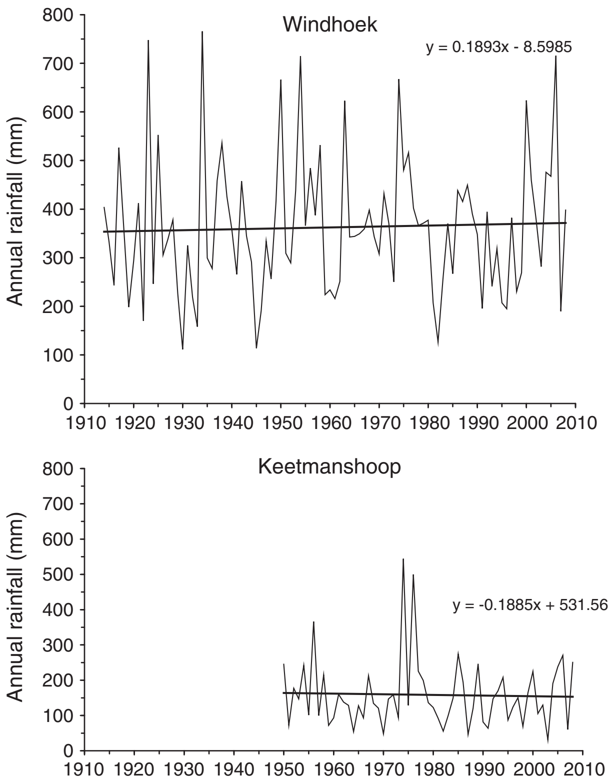


Fig. 9. Annual (Sep–Aug) rainfall totals (mm) for Windhoek (1914–2008) and Keetmanshoop (1950–2008).

4.3. Analysis of climate data

Climate data spanning 1876 to 2009 are not available. MAP for the period 1913–2008 for Windhoek is 362 mm while less than half

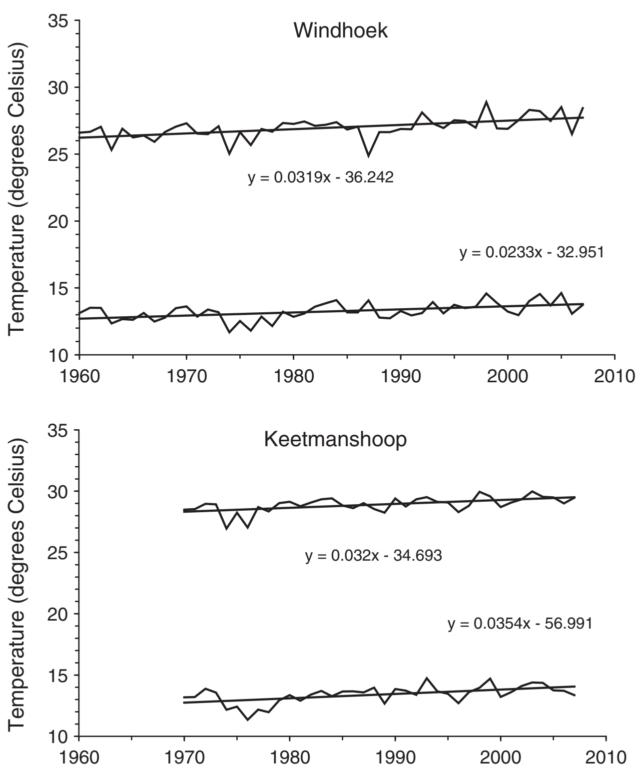


Fig. 10. Average annual maximum and minimum temperatures (°C) for Windhoek (1960–2007) and Keetmanshoop (1970–2007).

(158 mm) was recorded at Keetmanshoop over the period 1949–2008 (Fig. 9). Although there was considerable inter-annual variation in rainfall amount at both stations there was no significant trend either for Windhoek ($n=95$, $Z=0.79$, $p>0.05$) or Keetmanshoop ($n=59$, $Z=0.02$, $p>0.05$) (Fig. 10).

Average annual maximum temperature values for the period 1960–2007 were slightly lower at Windhoek (27.0 °C) than at Keetmanshoop (28.9 °C) for a similar period (1970–2007). Average annual minimum values at Windhoek (13.2 °C), however, were comparable to those obtained at Keetmanshoop (13.4 °C). Average annual maximum and minimum temperatures increased significantly at both Windhoek (Tmax: $n=48$, $Z=4.12$, $p<0.001$; Tmin: $n=48$, $Z=3.36$, $p<0.001$) and Keetmanshoop (Tmax: $n=38$, $Z=3.53$, $p<0.001$; Tmin: $n=38$, $Z=3.43$, $p<0.001$) over the course of the recording period. Maximum temperatures increased at both sites by about 0.032 $°C.yr^{-1}$ while minimum temperatures increased more rapidly at Keetmanshoop (0.035 $°C.yr^{-1}$) than at Windhoek (0.023 $°C.yr^{-1}$).

5. Discussion

5.1. Patterns of change

Our results showed a general increase in vegetation cover throughout central and southern Namibia since 1876, particularly of trees taller than 1.5 m in height. While grass cover has generally increased, this is a relatively ephemeral component in the arid and semi-arid landscapes of southern Africa and can be heavily influenced by seasonal and short-term climatic cycles (O'Connor and Roux, 1995). Palgrave made reference to the dry conditions in Namibia at the time of his journey (Stals, 1991) while our three field trips occurred after a relatively benign period in Namibia's climate history.[3] Despite the ephemeral nature of changes in grass cover we interpret this increase along with the relative stability in shrub cover as indicative of a landscape which has not become more degraded with time. The Nama Karoo biome in particular is susceptible to significant changes in shrub and grass cover in response to heavy overgrazing (O'Connor and Roux, 1995). Several studies in semi-arid southern Africa have reported on the widespread increase of unpalatable shubs (e.g. *Rhigozum trichotomum, Lycium cinereum* Thunb.) in response to grazing impacts (Milton and Hoffman, 1994; Todd, 2006; van Rooyen and van Rooyen, 1998). Nine out of 16 photo site locations in the Nama-karoo biome had one or more landform units with *R. trichotomum* cover >5%. These ranged between 10% and 20%, but often comprised landform units that represented only a small proportion of the total landscape, suggesting that *R. trichotomum* encroachment has not been a widespread occurrence across the region. Replacement of perennial palatable grasses (e.g. *Stipagrostis spp.*) by the less palatable annual *Schmidtia kalahariensis*, is also claimed to have occurred generally, especially in communal areas (Kuiper and Meadows, 2002). However, we recorded *S. kalahariensis* cover of >5% in only two sites, one communal and one privately owned commercial farm.

The increase in tree cover supports the general perception that bush thickening is widespread in the more mesic areas of Namibia (Seely and Montgomery, 2008). The encroachment and thickening of woody species in previously sparsely treed grasslands has been observed in many African savanna regions during the last 50 years (Scholes and Archer, 1997; Ward, 2005). Rangeland ecologists (e.g. Sankaran et al., 2005) claim that in the absence of other limiting factors, maximum tree cover increases linearly along a precipitation gradient up until 650 mm (Bond, 2008), and our findings confirm this trend over the arid and semi-arid landscapes of the study area. In sites with <250 mm MAP there has been very little increase in tree cover (average 0.5%) while tree cover in sites with MAP>250 mm

[3] Three field trips (Nov–Dec 2006; Aug–Sept 2008; Feb–Mar 2009) coincided with higher than average rainfall years.

have increased by an average of 22.2%. Tree cover in the riparian zone has increased across the entire gradient by an average of 19% primarily because of the accessibility of shallow groundwater in alluvial aquifers in ephemeral rivers, streams and drainage channels that support phreatic species such as *Faidherbia albida*, *Ziziphus mucronata*, *A. erioloba* and *A. karroo*.

The Nama Karoo (MAP = <200 mm) study site locations are subject to stochastic fluctuations in the biotic system that are directly related to quantitatively and spatially highly variable rainfall distribution (Sullivan, 1996). Stability and a high degree of resilience over large spatial and temporal scales is an inherent feature of these ecosystems (Gunderson, 2000; Sullivan and Rohde, 2002). In these sites we find very little change, apart from the incision and deepening of drainage lines in sandy substrates (e.g. Fig. 4) as a result of either cattle grazing (Eitel et al., 2002) or vehicle disturbance, as well as some tree and shrub thickening in minor drainage channels and ephemeral water courses generally. The ephemeral component of these landscapes has no doubt fluctuated in keeping with the dynamics of arid environments that have been described extensively elsewhere. These sites are representative of the resilience (Holling, 1973) inherent in arid pastoral landscapes. They illustrate the 'qualitative persistence' inherent in non-equilibrium environments where weak biotic coupling, independence of species and abiotic limitation govern livestock/vegetation interactions across a range of temporal and spatial scales (Sullivan and Rohde, 2002).

The remaining sites (MAP 203 mm–372 mm) fall within the semi-arid Tree and Shrub Savanna. Sites with MAP above a threshold of 250 mm are associated with processes of bush thickening. Historical accounts of bush thickening prior to colonialism in Namibia (Andersson, 1856) and empirical studies suggest that savannas exist as a mosaic of grass- and tree-dominated patches that vary in abundance over local to regional spatial scales. Some authors (e.g. Wiegand et al., 2005) have also suggested that these patches are dynamic, oscillating over time between states of grass and tree dominance. Bush thickening of smaller, short-lived trees (30–40 years) such as *A. mellifera* is a natural process within Namibia's highland savanna where a patch mosaic of thickets persists within a grassy matrix (Joubert et al., 2008). Pastoral fire management promotes and maintains a grassy savanna while fire exclusion in conjunction with high grazing densities results in thicket patches becoming a widespread self-perpetuating mixed-aged matrix as observed in many of our highland savanna sites. However, there is no evidence in our repeat photographs of a reversal, even at a patch scale, from a woody to a grassy state. This suggests that either the phase of bush thickening and reversal takes place over a time scale of centuries rather than decades or that other factors are responsible for the steady increase over the period in question.

In the Tree and Shrub Savannas sites, we found that rates of bush encroachment in communal landscapes were half of those observed on privately owned commercial farms. Although our sample size is small, this result can be explained at least partially by the fact that communal farmers typically practice a more opportunistic stocking strategy and carry more browsers than commercial farmers (Burke, 2004).

5.2. Causes of change

5.2.1. Past climates

Across both Nama Karoo and Tree and Grassy Savannas, MAP is recognised as having the most influence on vegetation cover (Tews and Jelsch, 2004). It is therefore necessary to examine the evidence for climate change, especially precipitation, both before and after 1876. Paleoclimatic evidence indicates that the region was more arid in the Late Holocene between 3500 and ca. 300 cal yr B.P. and has become more humid and warm since around 1700 AD (Chase et al., 2009). The coolest and driest periods during the last 1000 years correspond with the Little Ice Age (LIA) between 1450 and 1750 AD, after which rainfall and temperature regimes rapidly came to approximate those of today (Tyson and Lindesay, 1992; Tyson et al., 2000; Eitel et al., 2005). It is probably not coincidental that this amelioration in climate coincided with the southerly migration of Herero pastoralists into the Kaokoveld during the middle of the 16th century, finally settling in central Namibia during the 18th century, occupying the land north of the Kuiseb River and the 24th parallel (Werner, 1998). There is no evidence that MAP has changed significantly in central or southern Namibia since records began in the late 19th century (Haensler et al., 2010). Given the large spatial scale at which open grasslands occurred in Palgrave's landscape images, we can infer that the dominance of C4 grasses that dominated the savanna flora during the LIA (Eitel et al., 2002) was maintained by pastoral practice into the mid-nineteenth century (Little, 1996). We find no evidence to support the hypothesis that the radical change in tree cover in the Tree and Shrub Savanna, evident in the Palgrave repeat photographs, has occurred in response to a long-term increase in MAP.

5.2.2. Fire

Anthropogenic fires, used as a management tool by pastoralists, have occurred across African savannas for millennia as a means of maintaining open grasslands and inhibiting woody encroachment (Sheuyangea et al., 2005). Sankaran et al. (2008) analysed the relationships between resource availability and disturbance regimes on woody cover in 161 African savanna systems and found that predictor variables in order of importance were: MAP; fire return interval; soil properties; elephant biomass and finally browser and grazer biomass. Many authors have described the effects of fire exclusion on savanna ecosystems (Bond and Keeley, 2005; Wiegand et al., 2006; Wigley et al., 2010). Their findings correspond with those of Joubert et al. (2008) who conducted detailed studies of encroacher species (*Acacia mellifera, Dichrostachys cinerea*) in the Tree and Shrub Savanna of central Namibia, in proximity to the Palgrave transect. They found that fire is the most important management tool for suppressing seedling and sapling establishment in grassy savanna systems. At a landscape scale, such as on commercial ranches of several thousand hectares, the transition from a grass-tree savanna mosaic to a bush encroached landscape is likely to occur under conditions of high grazing intensity over an extended period of several years in conjunction with fire exclusion. The suppression of fire under German and later South African colonial land management systems (Lau and Reimer, 1993) must therefore have had a significant role in the bush thickening that we see in the repeat photographs from the Tree and Shrub Savanna sites.

5.2.3. Herbivory, land-use and demographic change

Wild ungulate populations in the Nama Karoo of southern Namibia were probably always relatively sparse and highly mobile due to the spatial and temporal variability of rainfall but wildlife numbers would have fallen substantially in these areas with the introduction of firearms in the late 18th century (Lau, 1987). The decimation of megaherbivores and large herds of wild ungulates in the more mesic Tree and Shrub Savannas took place during the middle decades of the 19th century (Andersson, 1856) and by the late 1870s elephant populations had been virtually eliminated from this region of Namibia (Gewald, 1996). Elephants and other megaherbivores are recognised as playing a key role in savanna ecosystems where they are an important factor in reducing woody plant survival and may have played a major role in biome modification (Owen-Smith, 1987; Jacobson, 1997; de Beer et al., 2006; Hoffman and Rohde, 2011). The mixed feeding and browsing habits of wild ungulates weakens the competitiveness of woody cover in relation to grasses, whereas grazers, such as cattle and sheep weaken the competitiveness of grasses in relation to trees and shrubs and hence promote woody vegetation encroachment when their biomass exceeds a certain threshold (van Langevelde et al., 2003; Ward, 2010; Sankaran et al., 2008). The findings of Eitel et al. (2002), based on the analysis and dating of sedimentation and erosional processes in an area similar to that of the more mesic sites along the Palgrave transect in the Tree and Shrub Savanna, found that stable grassland vertisols were buried by slope wash sediments during the early 19th century. It is unlikely that this was merely coincidental with an increase in Herero cattle herds during the same period. This was followed by aridification related to erosion and bush thickening during the last decades of the 19th and the first decades of the 20th century, precisely the period during which large demographic changes were occurring in both human and livestock populations associated with German colonialism. Other vestiges of this transformation can be found in the Highland and Camelthorn subregions (Mendelsohn et al., 2002) of the Tree and Shrub Savanna (see Fig. 6), where even-aged cohorts of mature *A. erioloba* are the physical legacy of a widespread recruitment event resulting from the hiatus in land-use at the end of the 19th and early 20th centuries (Peters et al., 2006).

The human population decreased significantly under colonial rule in the commercial farming districts: prior to 1904, over 80,000 Herero and 20,000 Nama/Oorlam occupied an area that was re-colonised by approximately 1300 German settler families in 1913. Today, more than 70% of central and southern Namibia is occupied by 4000 commercial farmers (Mendelsohn et al., 2002), although total livestock numbers have undoubtedly increased substantially as a result of the provision of watering points and fencing (Adams, 1990; Bayer et al., 1991). The loss of habitat and resource heterogeneity through the dissection of the landscape into discrete farming units is characteristic of the settler farming land tenure system (Hobbs et al., 2008). This fragmentation of productive landscapes culminated in woody vegetation thickening by encroacher species across this region (Fisher, 2005; Kreike, 2009).

5.2.4. Elevated atmospheric CO_2

Elevated levels of atmospheric CO_2 could mitigate the effects of projected climate aridification by increasing water use efficiency (WUE), especially in C_3 plants (Ward, 2010). Furthermore, this competitive advantage could allow saplings to escape fire disturbance bottlenecks due to faster growth as CO_2 continues to rise (Bond and Midgley, 2000). While these influences have been demonstrated elsewhere, we are unable in our study to attribute increased woody biomass to either direct effects of CO_2 on photosynthesis or indirect effects resulting from increased WUE and soil moisture profiles (Morgan et al., 2004). Nor are we able to distinguish the relative importance of CO_2 in relation to fire, herbivory and land-use at a landscape scale over the 130 year period of this study. Our analysis does, however, support the findings of Wigley et al. (2010), that global drivers such as elevated atmospheric CO_2 favour woody thickening in grassy savannas regardless of land-use.

5.2.5. Climate change

Temperatures have been rising at three times the global average in Namibia during the 20th century (Haensler et al., 2010) and our analysis for Windhoek and Keetmanshoop supports this trend. Temperatures are projected to rise by between 2° and 6 °C during the 21st century while rainfall, particularly in Central Namibia, is predicted to decline by 30 mm to 200 mm per year compared to current averages and to become more variable (Reid et al., 2007; Haensler et al., 2011). Another analysis, based on projected changes in total monthly rainfall derived from six statistically downscaled GCM rainfall estimates, predicts a slight increase in MAP with an extended late summer rainfall period and more extreme rainfall events (Dirkx et al., 2008). Our analysis of two of the longest climate records in the study area showed no significant trend in rainfall during the 20th century.

The environments discussed in this paper are classified as ecologically highly vulnerable to future climate change (Dirkx et al., 2008). Dynamic global vegetation models and bioclimatic niche models, used to simulate changes in vegetation structure for over 800 plant species in Namibia forecast widespread aridification with an expansion of Desert and 'Arid shrublands' (Nama Karoo) by up to 43% at the expense of 'Grassy and Mixed Savanna' (corresponding with Tree and Shrub Savanna) classes concurrent with a decrease in cover and reduction in net primary productivity (NPP) by 2050 (Midgley et al., 2005; Woodward and Lomas, 2004). However, when elevated atmospheric CO_2 is taken into account, these models predict a potential increase in bush encroachment and a decline in perennial C_4 grasses.

Our look backward through the Palgrave photographic repeats is almost three times as long as most future climate change projections which focus on likely conditions in 2050. While we acknowledge that past climate trends cannot foretell future scenarios, our evidence of vegetation change since 1876 (coinciding with the onset of anthropogenic greenhouse gas emissions), is inconsistent with predictions of aridification resulting from global warming. However, predictions of bush encroachment due to atmospheric CO_2 fertilisation are corroborated by our findings although we are unable to disentangle the relative influences of local (land-use) and global (atmospheric CO_2) drivers.

6. Conclusions

Repeat photography is a powerful means of investigating historical ecology. The Palgrave photographs and their repeats covering a 130 year interval provide a relatively comprehensive site and regional scale understanding of the condition of rangelands at the onset of the colonial ecological revolution that transformed Namibia in the late 19th century, as well as how they have changed since then and some evidence as to why.

Our analysis of matches made from Palgrave's pre-colonial photographs showed that although regional vegetation change is more nuanced and dynamic than previously assumed, general patterns are apparent. Patterns of change are correlated with MAP and below a threshold of around 250 mm, vegetation in these more arid parts of Namibia, regardless of land tenure system or land use practice, has been remarkably stable since 1876 with little evidence of a decline in cover, species composition and primary productivity. Above this threshold, woody thickening leading to a state of bush encroachment, is linked to the rainfall gradient in conjunction with land-use practices associated with colonialism and privatised commercial farming. The onset of bush encroachment coincided with political events linked to colonialism, in conjunction with drought, epidemics and epizootics of the late 19th and early 20th centuries. Legacies of demographic collapse, land-use change and landscape fragmentation are evident in these more mesic Savannas. We see no evidence that savanna patch dynamics promote the reversion from bush encroached to open grassland over the timescale of this study.

Our look backward through the Palgrave photographic repeats might be expected to reveal trends of change along a continuum that correspond with future predictions. We argue that local drivers (decimation of megaherbivores and wildlife browsers, fire suppression, cattle ranching) across a climatic gradient and the global driver of increased atmospheric CO_2, provide a parsimonious explanation for past and ongoing vegetation change (Archer et al., 1995). We see no evidence for the expansion of desert and arid shrublands into Tree and Shrub Savanna areas (Midgley et al., 2005; Woodward and Lomas, 2004), nor do we find any proxy evidence of a predicted decrease in groundwater or increased evaporation as a result of global warming (Dirkx et al., 2008; Haensler et al., 2011). The Palgrave repeat photographs, used within a multi-disciplinary approach to historical ecology, provide detailed insights into the importance of both local and global drivers of change in the savanna environments of central and southern Namibia and global savanna ecosystems more generally.

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