Southern Forests 2010, 72(1): 47–55
Printed in South Africa — All rights reserved

SOUTHERN FORESTS
ISSN 2070–2620 EISSN 2070–2639
doi: 10.2989/20702620.2010.481071

Spatial changes in forest cover on the KwaNibela Peninsula, St Lucia, South Africa, during the period 1937 to 2008

BM Corrigan[1]*, M Kneen[2], CJ Geldenhuys[3] and B-E van Wyk[1]

[1] *Department of Botany and Plant Biotechnology, University of Johannesburg, PO Box 524, Auckland Park 2006, South Africa*
[2] *Department of Geography, Environmental Management and Energy Studies, University of Johannesburg, PO Box 524, Auckland Park 2006, South Africa*
[3] *Department of Forest and Wood Science, University of Stellenbosch, c/o Forestwood CC, PO Box 228, La Montagne 0184, South Africa*
* *Corresponding author, e-mail: bcorrigan@mweb.co.za*

The KwaNibela Peninsula is situated in the northernmost region of Lake St Lucia in KwaZulu-Natal. It is covered by forest patches of either Sand Forest or Coastal Forest within the Maputaland Coastal Vegetation. The area and the forests are heavily used by inhabitants of the region. The current and historical distributions of the forest patches were mapped to determine the changes in their cover (area) and character since 1937. A series of seven aerial photos, dating from 1937, 1960, 1969, 1979, 1990, 2002, to 2008 were used to quantify changes in land-cover type. The land-cover types were classified into core forest, regrowth forest and open areas (open woodland and anthropogenically altered land) and the percentages of each cover type were compared across years to determine the overall vegetation change, as well as the direction of change. Characteristic species were recorded at different stages of forest succession throughout the study area and are presented as supplementary information. The ratios of these land-cover types are shown to shift in both directions, with core forest ultimately expanding and open areas contracting slightly between 1937 and 2001. The nature of the land-cover types has changed significantly, with increasing fragmentation of both the core forest and open areas. This information has important implications for understanding forest dynamics in a changing environment, with shifting disturbance-recovery processes.

Keywords: Aerial photography, disturbance, KwaNibela, Landscape Shape Index, Sand Forest

Introduction

There are conflicting viewpoints regarding forest disturbance and recovery. A common perception is that forests had a far greater historical occurrence in South Africa than at present and that they have been lost and degraded under human pressure. However, observations in parts of South Africa show the opposite trend, whereby grassland predated existing forest and has given way to woody vegetation over time. The challenge is to provide an objective assessment of the reality to better understand the ecological dynamics of forest/grassland boundaries.

Within South Africa, forests currently cover between 0.1% and 0.3% of the total land area (Fairbanks et al. 2000, von Maltitz et al. 2003, Geldenhuys 2004). Clearing for commercial plantations and farming, uncontrolled harvesting, grazing pressure, mismanagement and patch isolation often put forests at risk of degradation (Geldenhuys 1992, Lambin et al. 2001, Geist and Lambin 2002, Goodman 2003, Lawes et al. 2004). The effect of forest area on species richness is variable. Usually, extensive continuous forest areas result in greater species richness (Wilcox and Murphy 1985, Lawes et al. 2005, Kotze and Lawes 2007). However, the effects of altitude, presence of dispersal corridors, disturbance regimes and proximity to other forest areas also contribute to the species richness of forest flora (Everard et al. 1994). In some cases, very small areas of forest may have high species richness and retain landscape processes (Geldenhuys 1992, Lawes et al. 2005, 2007a).

The Maputaland and Eastern Cape regions have been subjected to various anthropogenic disturbances since the Iron Age settlers were thought to have influenced the ecology of the region through fires, grazing and agriculture (Bruton et al. 1980, Feely 1986, von Maltitz et al. 1991). The indigenous Tembe-Thonga and Khoisan people of Maputaland often revered forests as sacred sites and refugia but also used them as a source of food, medicine and diverse other materials, such as structural timber and fuel wood (Wilson 1959, Pooley 1980, Prins and Lewis 1992). The region was also affected, to a limited extent, by the early European settlers and explorers, through hunting, trading and wildlife eradication as a disease-control measure (Bruton et al. 1980, McCracken 1986). The more recent British colonisation of KwaZulu-Natal prompted an increase in forest exploitation with industrialisation and the subsequent clearing of certain forested areas for agriculture or timber harvesting, affecting forest condition and the availability of preferred timber species (Lawes et al. 2007b).

The effects of human settlement and utilisation on the extent of forest cover are not necessarily clearly defined and different viewpoints exist on the severity and extent of human-induced deforestation. Historical accounts provide evidence, albeit rather broad and vague, for relatively recent changes from forested areas to fragmented landscapes, built-up areas and other infrastructure. One such viewpoint is that forests existed more extensively within South Africa (Acocks 1953) and that human activities have resulted in a substantial loss of forest and the establishment of secondary grasslands in those areas (Bruton et al. 1980, Sisk et al. 1995, Lawes et al. 2007b). In contrast, what now appears to be established forests was actually grassland or woodland that has given way to forest in the absence of disturbance (Weisser 1978). The archaeological evidence for ancient grasslands in areas of KwaZulu-Natal now covered in forest or woodland, suggests that grasslands must have predated forests as the predominant vegetation type in these areas (von Maltitz 1991, von Maltitz et al. 1991, Whateley and Wills 1996, Eckhart et al. 1997, West et al. 2000, Bond et al. 2003). Photographs and written records of landscapes from several parts of South Africa dating from the late 1700s or early 1900s indicate that areas currently occupied by natural forest were then grassland with small forest patches (Thunberg 1779, Weisser 1978).

The determination of historical reference conditions is an important component of any study in landscape change (Egan and Howell 2001). In this paper we attempt to provide such information on the forest patches of the KwaNibela Peninsula. Understanding how the landscape has changed allows managers to set conservation goals as objectively as possible (Swetnam et al. 1999, Ripple et al. 2000, Egan and Howell 2001).

Within the South African context, climate change is purported to have a greater effect on various types of coastal forests (Eeley et al. 1999), with regard to a decrease in forest cover over geological timescales as well as the shifting of marine coastlines (Matthews 2005). These effects need to be distinguished from the more recent impacts due to precolonial iron-smelting, changes in veld management practices and burning regimes (Feely 1980, 1986). Human use of fire and the exclusion of fire through control/protection of plantations, agriculture, settlements and urbanisation, resulted in an increase in woody cover and forest expansion (Weisser 1978, West 1999, Geldenhuys, 2004). Both climate change and veld management practices need to be taken into account when evaluating vegetation changes on the KwaNibela Peninsula because natural and anthropogenic factors change landscapes in different ways and on different time scales (Bond et al. 2003).

There is a need to establish the temporal and spatial changes in forest cover, in areas that do not fall within conservancies, because these forests may eventually be lost or permanently altered due to over-harvesting and mismanagement (Ferrier 2002). Protected areas are also subject to mismanagement through over-protection, which can cause a loss of a certain component of the suite of development stages, each with its own species. A historically mosaic landscape can shift towards forest, as in the case of the Soutpansberg (Geldenhuys and Venter 2002). This can result in the loss of a functional ecosystem, but also the loss of certain natural resources, a reduction in gene flow and fewer ecotourism opportunities. In extreme cases it can result in the displacement of the inhabitants. By providing accurate quantitative data on changes in forest cover, we hope that authorities and decision-makers will be able to formulate an effective and site-specific management plan (Shi et al. 2005, Gaugris and van Rooyen 2007).

There has been considerable research conducted on different types of coastal forest in KwaZulu-Natal (Weisser 1978, Weisser et al. 1982, Weisser and Muller 1983, Eeley et al. 1999, Kirkwood and Midgley 1999, West 1999, Izidine et al. 2003, von Maltitz et al. 2003, Lawes et al. 2004, Matthews 2005, Mucina and Rutherford 2006, Gaugris et al. 2008) with the focus largely on forests that fall within the boundaries of a conservancy. It is of particular interest to examine the human–forest interface in areas of indigenous forest where people still reside in the forest and utilise the resources (Obiri et al. 2002, Obiri and Lawes 2002a, 2002b, 2004, Gaugris et al. 2004, Boudreau and Lawes 2005, Boudreau et al. 2005, Robertson and Lawes 2005, Gaugris and van Rooyen 2007). This appears to be the first ecological study of the KwaNibela Peninsula. The vegetation changes are of scientific interest to understand how, why and in which direction the vegetation has shifted (BMC et al. unpublished data). The analysis of aerial photographs with geographic information systems has proved to be an effective method of displaying and analysing similar spatial and temporal data at different scales (Mladenoff et al. 1993, Mast et al. 1997, Hudak and Wessman 1998, Bowman et al. 2001, Lawes et al. 2004) and is therefore a relevant and applicable tool to meet the needs of this study.

Against the backdrop of climate change and human reliance on forests as a natural resource, the purpose of this study is to answer the question: how have the areas of core forest on the KwaNibela Peninsula changed over the last 71 years and how much of this change can be attributed to human influence? This formed the basis for a more detailed ecological study of the floristic and structural changes that are associated with the spatial changes in forest cover. Objective criteria are required to distinguish between the effect of climate change and human impacts, particularly in terms of forest expansion.

Study area

KwaNibela is located to the north of Lake St Lucia in southern Maputaland, at 27°56'10.9" S and 32°26'35.9" E. It has a surface area of 3 690 ha and is 10 m to 60 m above sea level. There are no significant topographical features and the geology consists of shale and sandstone, overlain in some areas by aeolian sands with a very low clay content (Mucina and Rutherford 2006). According to the climate statistics for the St Lucia Lake Research Centre from 1960 to 1984 (South African Weather Service 2008), a subtropical climate characterises the area, with a mean daily minimum temperature of 16.5 °C and a mean daily maximum of 26.3 °C (recorded over a period of 24 years). Over the period 1960–1984, the average rainfall was 1 044 mm y^{-1}; the minimum annual rainfall (576 mm) occurred in 1979 and the maximum annual rainfall (1 987 mm) in 1984.

KwaNibela is classified as tribal land and is not currently under formal protection from the state or any private organisation. There is a larger human population in the northern part of the peninsula than in the south (StatsSA 2001), which may be linked to the presence of water points in the north-east, a state clinic, and easier access to the main road, west of the peninsula. The inhabitants use the forests for building materials, firewood, medicine and food. Livestock and poultry are kept for traditional practices and for sustenance; cattle and goats are allowed to graze within the forest and woodland areas. It is not known when people first settled in KwaNibela and under what circumstances; however, according to the census data for the area, the population has decreased by 30% between 1996 and 2001. In 2001, most of the population of KwaNibela lived in traditional dwellings, had little to no schooling and were not economically active (StatsSA 1996, 2001). Historical information on settlement patterns, resource use and local events in the KwaNibela Peninsula is limited and uncertain, unlike regions with more complete records (Bürgi et al. 2000). During World War II, the South African Defence Force manned a radar tower near Cape Vidal, approximately 5 km from KwaNibela and operated Sunderland and Catalina boats in the area. False Bay National Park and St Lucia Nature Reserve were established in 1939 and 1944, respectively (Bruton et al. 1980) and elephants were recorded on the Eastern Shores as recently as 1937 (Natal Parks Board 1979). It is not known what effect, if any, these military activities had on the vegetation. Both spatially and temporally, there have been varying degrees of disturbance and use, which contributed to the complex ecological system seen today.

Methods

Aerial photograph digitisation

Eight-bit greyscale aerial photographs of varying scales and resolutions were obtained from the Chief Surveyor General (Mowbray, South Africa) and the spatial and temporal changes in forest cover of the KwaNibela Peninsula were mapped from these images. Six series of aerial photographs, spaced nine to 23 years apart, were available. These were from 1937, 1960, 1969, 1979, 1990 and 2002. A 2008 Google Earth 4.3 image was included in the broader analyses, simply to illustrate the most current state of forest cover on the peninsula (Google Corporation, Mountain View, CA, USA). It was not used in landscape metrics due to resolution inconsistencies.

Each photograph was digitised in TNTMips 7.0 (MicroImages Corporation, Lincoln, USA), georeferenced and mosaiced (combined with other photographs) to form a combined image of the study area for each of the six years. Each combined image was image-processed manually in Corel PHOTO–PAINT 11 (Corel Corporation, Ottawa) to reduce the disparities in contrast at the edges of the photographs. The processed images were imported into ArcView 9.2 (Esri Corporation, Redlands, USA), where each image was adjusted with a majority filter to reduce the effect of light reflectivity variation. A low pass filter was then run on each image to further reduce heterogeneity within land-cover types and to classify the image into three classes of vegetation cover, namely open areas, regrowth forest and core forest.

The area of KwaNibela was delineated based on the extent of aerial photograph coverage. That area was clipped, extracted and reclassified to display the attribute table of the raster image, from which the pixel count was obtained for each class. Classification was done manually by identifying pixel values in areas deemed as open areas, regrowth forest and core forest. The upper limits of these pixel values were used as the class breaks and to separate the area of KwaNibela into the three land-cover types.

General characterisation of the land-cover types

A distinction was made between core forest, regrowth forest and open areas (open woodland and anthropogenically altered areas), based on the greyscale differences in the aerial photographs. The cover types were groundtruthed for 2008 through species composition and structural data collected in the field. The structure and composition of the forest patches will be presented elsewhere (BMC et al. unpublished data). The characteristic features and species were described by field observations and sampling of circular 400 m^2 plots in each land-cover type. The following characteristics of each cover type were used to map their boundaries:

Core forest: generally taller vegetation than the other cover types, dominated by trees with a closed canopy (>75% closed canopy). It appears dark grey to solid black on the aerial photographs.

Regrowth forest: generally shorter vegetation than core forest with a dense stand of small trees and a few scattered large remnant trees and many saplings in the herb layer. It appears medium to dark grey on the aerial photographs.

Open areas: the open woodland contingent consists of predominantly grassland and woodland species interspersed with a few individual bushveld species. The canopy is not continuous and saplings are infrequent. Anthropogenically altered areas consist of cultivated land, abandoned cropland and infrastructure such as roads, homesteads, kraals and buildings. Both types of open area appear white to light grey on the aerial photographs. The disturbed areas are often distinguished by geometric shapes and straight line boundaries.

Changes in the land-cover types from 1937 to 2008

The percentage area of each cover type was calculated for each of the seven maps (the 2008 Google Earth Image included) and compared, with the aim of broadly determining how the cover types have changed over time in relation to each other.

To determine the human influence on the peninsula, analyses of the fragmentation of the core forest areas as well as open areas were carried out using the Landscape Shape Index (LSI), as described by Limpitlaw and Woldai (2004). Only the six aerial photograph-maps were used (the Google Earth image was excluded). The LSI is the sum of all patch perimeters divided by the perimeter of the circle with a surface area corresponding to the surface area of the patches. An increase in the LSI values is directly proportional to an increase in fragmentation of the landscape and this can usually be attributed to human activities. The LSI was obtained, using the following formulae:

$$P_c = 2\pi\sqrt{\sum A/\pi}$$

where A = patch area and P_c = perimeter of the circle;

$$\text{LSI} = P_x/P_c$$

where P_x = sum of perimeters.

The mean patch size was then calculated for each of the six years by dividing the total area of the site by the number of patches. An additional weighting factor to account for the varying pixel sizes was added to the standard LSI formula. The LSI was multiplied by the area of one pixel. This factor weighted the results so that the effects of different pixel sizes on the perimeter lengths were eliminated.

To identify where most of the changes occurred, the peninsula was divided into four sections. The six maps from 1937 to 2002 were clipped into four quadrants, overlaid and the percentage changes in area of core forest were compared. This provided a measure and description of change for each quadrant.

Results

General characterisation of the land-cover types

The characteristic features of each land-cover type are provided in Table 1 to show that there are differences in the floristic and structural features of the cover types. These features were ground-truthed in a reconnaissance site visit and are only elementary representations of the cover types.

Changes in the land-cover types from 1937 to 2008

The overall changes in percentage and area of each cover type (Table 2; Figure 1 and 2) show that the core forest areas have increased only slightly and the open areas have decreased from 1937 to 2008. There was a marked increase in core forest cover from 1937 to 1969 and, subsequently, a relatively steep drop from 1969 to 1979. From 1979 to 2008, the core forest seemed to have re-established itself as the percentage of core forest cover increased steadily until the present.

A more telling analysis of the vegetation changes can be extrapolated from the Landscape Shape Index (LSI). The LSI results (Figure 3) show that the degree of fragmentation of the core forest patches and open areas both increased slightly from 1937 to 1960 and, in 1969, the peninsula showed the least degree of fragmentation. From 1969 to 2002, the LSI increased consistently and reached its highest level in 2002. Other landscape metrics used were mean patch size and maximum patch size. Both showed a similar trend of increasing fragmentation. The mean patch size and the maximum patch size were greatest in 1990 and smallest in 1937 and 1969.

The north western section of the peninsula showed the greatest degree of change and increased in core forest area by 13.5%, while the south western section showed the least degree of change (7%). Most overall change occurred in favour of core forest, apart from the north eastern quadrant, in which core forest decreased by 11.9%.

Discussion

There has been continuous change in forest cover over 71 years and the overall ratios of the three different cover types (core forest, regrowth forest and open areas) were found to oscillate, with a general increase in core forest area and a decrease in open areas. It is also apparent that the greatest proportion of change occurred in the north western section of the peninsula, where extensive open areas were colonised by forest patches. The south western section has changed the least in 71 years and this may be as a result of minimal human settlement, in comparison to the other quadrants. The effects of climate change over 71 years (a relatively short period) would most likely be one directional, and would affect all parts of the relatively small peninsula in the same way. Human impacts would vary, depending on the geographical concentrations of people. The climatic data and the population data both fluctuate and cannot be attributed to specific areas of the peninsula. Therefore, the causal effects of vegetation change are speculative.

The core forest areas in KwaNibela became increasingly fragmented from 1969 to 2002 and this pattern corresponds to the visual changes observed in Figure 2. Although the area under core forest increased overall, the core forest became more fragmented and this may have a negative effect on the ecological integrity and species diversity of the forest patches (Kotze and Lawes 2007).

That the population of KwaNibela decreased from 1996 to 2001 (StatsSA 1996; 2001) may be a result of urban pull/rural push, where the younger generation have migrated to the cities in search of employment. However, the landscape changes between 1990 and 2001 cannot be explained by population numbers alone and may be attributed to changes in veld management practices, military activities, increased reliance on natural resources and climatic conditions. The climatic extremes at the St Lucia Lake Research Centre from 1960 to 1984 show that the highest air temperatures were reached in the summer of 1976 (43.5 °C) and the lowest average annual rainfall occurred in 1979 (South African Weather Service 2008). The Lake St Lucia area was also affected by a severe drought in the late 1960s and early 1970s (Pitman 1980). Although this data is limited and subject to other variables not accounted for, the hot and dry conditions experienced between 1976 and 1979 may have reduced the 'lushness' of the forest foliage, visible in the aerial photographs and not the actual extent of the forest cover (Geldenhuys 1993). It is also clear that forest cover at present has not attained the levels observed in 1969 and this may be a result of local climatic fluctuations or time of the year the photographs were taken. From the 1950s to the 1980s, approximately 1 200 households were removed from the Greater St Lucia Wetland Park (now iSimangaliso) to make way for nature conservation, plantation forestry and the establishment of a South African Defence Force (SADF) missile base on the Ndlozi Peninsula in 1968 (Walker 2005). KwaNibela does not fall within this conservation area and although it was not

Table 1: Floristic, structural and anthropogenic characteristics of three land-cover types in the KwaNibela Peninsula, St Lucia

Core forest	Regrowth forest	Open area	
		Open woodland	Disturbed areas
Acacia robusta Burch. subsp. *clavigera* (E.Mey.) Brenan	*Acacia karroo* Hayne	*Chromolaena odorata* (L.) R.M.King & H.Rob.*+	Abandoned cropland
Achyranthes aspera L.*	*Achyranthes aspera* L.*	*Dovyalis caffra* (Hook.f. & Harv.) Hook.f.	Active cropland
Asparagus species*	*Balanites maughamii* Sprague	*Lantana camara* L.*+	Harvesting site
Balanites maughamii Sprague	*Bauhinia tomentosa* L.	Various saplings	Homesteads/structures
Chaetacme aristata Planch.	*Cordia caffra* Sond.	Various grass species*	Road/footpath
Cordia caffra Sond.	*Cussonia zuluensis* Strey	*Sclerocarya birrea* (A.Rich.) Hochst.	
Dialium schlechteri Harms	*Grewia caffra* Meisn.	*Combretum molle* R.Br. ex G.Don	
Englerophytum natalense (Sond.) T.D.Penn.	*Isoglossa* species*	*Dichrostachys cinerea* (L.) Wight & Arn.	
Isoglossa species*	*Sansevieria hyacinthoides* (L.) Druce*	Small *Strychnos spinosa* Lam.	
Large *Tabernaemontana elegans* Stapf	Small *Englerophytum natalense* (Sond.) T.D.Penn.		
Large *Teclea natalensis* (Sond.) Engl.	Small *Teclea natalensis* (Sond.) Engl.		
Ptaeroxylon obliquum (Thunb.) Radlk.	*Strychnos decussata* (Pappe) Gilg		
Sansevieria hyacinthoides (L.) Druce*	Various grass species*		
Sclerocarya birrea (A.Rich.) Hochst.	Various saplings		
Various saplings	*Ziziphus mucronata* Willd		

*Herbaceous species; +Alien species

Table 2: Percentages and areas (ha) of the three land-cover types in the KwaNibela Peninsula, St Lucia, from 1937 to 2008

Cover type	1937		1960		1969		1979		1990		2002		2008	
	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha
Core forest	47	2469	56	2903	67	3478	48	2482	52	2749	51	2644	55	2860
Regrowth forest	21	1073	14	711	21	1067	15	766	20	1040	22	1142	26	1363
Open area	32	1647	30	1576	12	637	37	1940	28	1475	27	1403	19	966

necessarily subjected to all of the abovementioned disturbances, Mckenzie (1998) lists the potential impacts that military activity may have had on the fauna and flora within St Lucia conservation area, such as low-flying aircraft, firing of missiles, bush fires and vehicle tracks. These activities would very likely have been a factor on the KwaNibela Peninsula as well.

The results give an indication of the timeframes involved for the development of historically open woodland through regrowth forest to the more mature core forest, in the absence of human exclusion. Within seven decades, the presence of relatively large expanses of open woodland, evident in the 1937 map, was dramatically reduced by 2002 and recovered, slightly, in 2008. Most open areas in 2008, however, are most likely disturbed areas and not natural woodland, considering their geometric shapes and small sizes. The vegetation of KwaNibela is not formally protected and the inhabitants regularly use the forest resources and clear areas of vegetation for dwellings and crop-planting. The level of disturbance taking place in KwaNibela (intensity

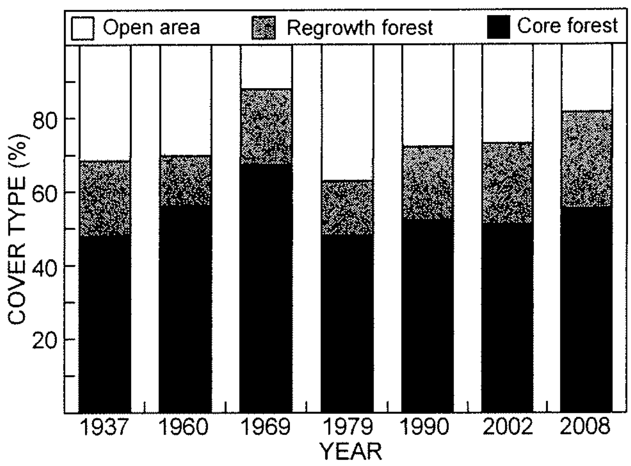

Figure 1: The changes in the ratio of the three land-cover types, i.e. core forest, regrowth forest and open area, on the KwaNibela Peninsula from 1937 to 2008

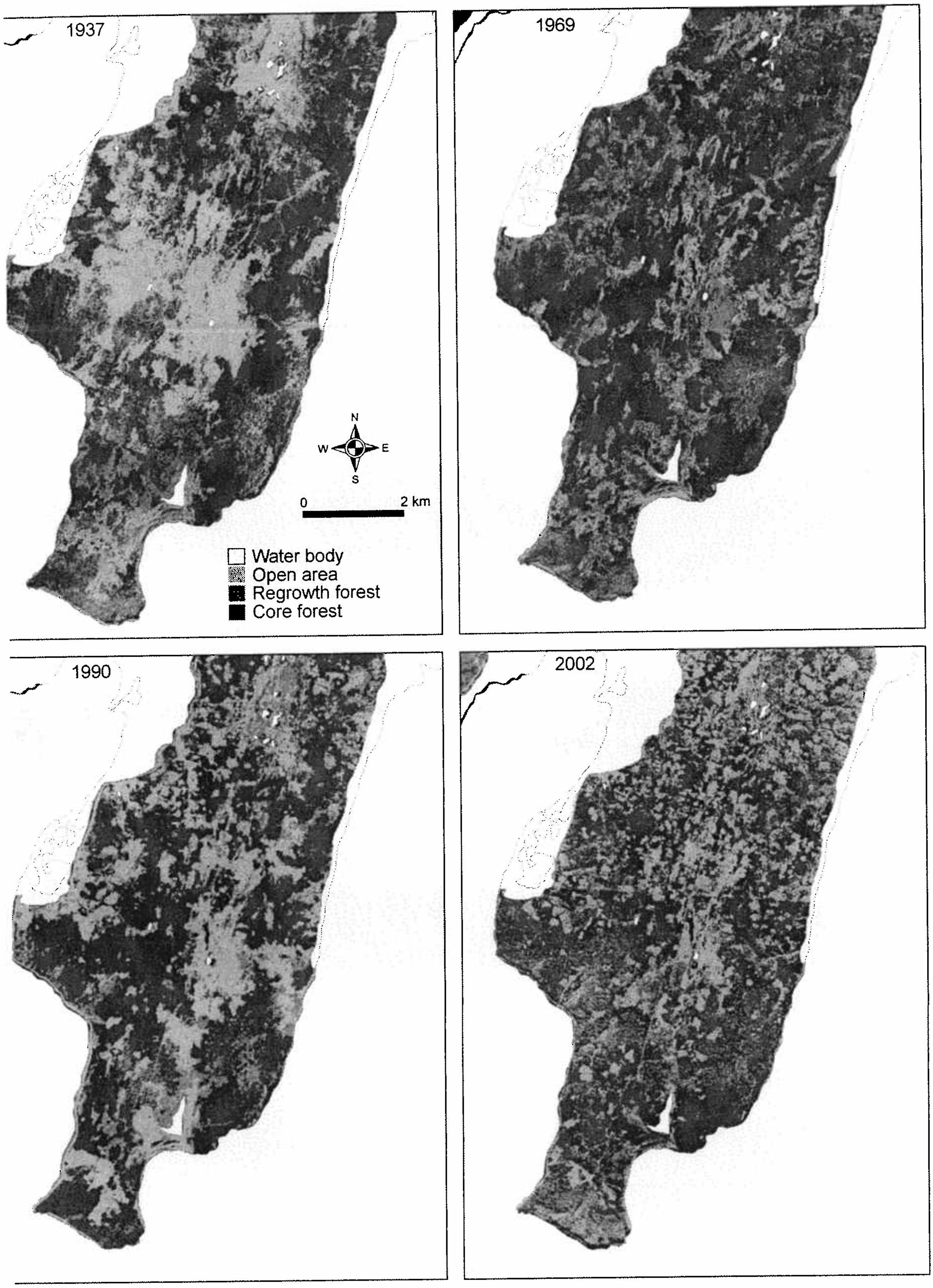

Figure 2: The four maps, selected to represent the overall changes in the land cover types of core forest, regrowth forest and open area on the KwaNibela Peninsula from 1937 to 2002

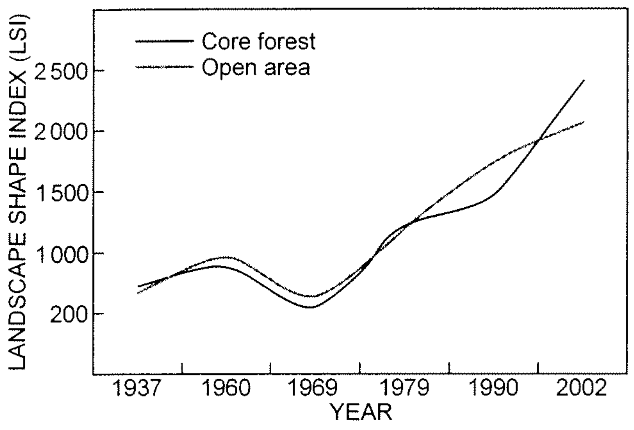

Figure 3: The Landscape Shape Index (LSI) values for KwaNibela Peninsula from 1937 to 2002, which are a measure of the fragmentation of the landscape and can be attributed to human activities

of forest resource use, extent and intensity of clearing for crop cultivation) has not yet been quantified and is largely unknown, both historically and presently.

In other areas of indigenous forest, such as the Soutpansberg, bush encroachment also resulted in a shift from non-forest to forest areas, with mostly indigenous species becoming established in the grassland-woodland-forest transitions (Geldenhuys and Venter 2002). It is possible that extensive areas of forest existed on KwaNibela before 1937, in which case forest has merely recovered after being disturbed. However, this viewpoint cannot be substantiated based on the available evidence. The earliest aerial photographs date back to 1937 and clearly show small, discrete patches of forest in a large open woodland matrix. Weisser (1978) inspected aerial photographs from 1937 in the Richards Bay–uMfolozi area and found that *Acacia karroo* woodland, Secondary Dune Scrub and plantation forests had replaced the grasslands over the years. Only 14% of the grassland area of 1937 remained in 1974. Soil isotope analysis revealed the presence of ancient grasslands under the existing forests and woodlands of Hluhluwe (West et al. 2000) and this supports the notion that grassland/woodland predated the forest as the dominant vegetation type on KwaNibela.

The results obtained from the pixel analyses of the aerial photographs were expected to show greater differences in cover type percentages between 1937 and 2008 based on the considerable visual changes in the maps. However, due to certain limitations of the study, such as differences in aerial photograph quality and the inability to distinguish open woodland from anthropogenically altered areas, the pixel analyses results should be considered in conjunction with the LSI results for fragmentation as well as a visual interpretation of the maps. There are other notable shortcomings of the interpretations of land-cover change, which deserve mention. For instance, if the percentages of core forest cover remain the same for two successive analyses, it is assumed that no change has occurred and the core forest at any given point has not changed, when in reality this may not be the case. The core forest at one point may have decreased considerably and at another point it may have increased. The methodology used did not allow for detailed analysis of cover changes at that level. Due to a lack of detailed archival data on the human history in the peninsula, it was also impossible to infer definitive anthropological reasons for the landscape changes.

Conclusion

This study describes three land-cover types: core forest, which is old-growth established forest vegetation; dense regrowth forest vegetation; and open areas, consisting of woodland vegetation and anthropogenically altered land. The changes in the distribution of these land-cover types are shown to be variable with core forest expanding and open areas contracting slightly between 1937 and 2008. The nature of the land-cover types has changed significantly, with fragmentation of both the core forest and open areas increasing overall.

From the LSI results and the maps, one can extrapolate that humans had a notable effect on the landscape from 1990 onwards and that the core forest areas expanded but became more fragmented as human population pressure increased. This suggests that the exclusion of fires and the reduction in herbivory have resulted in a shift from a previously grassland/woodland-dominated landscape to forest, as was also shown by Weisser (1978) for the Richards Bay–uMfolozi area. However, the resource use by the people inhabiting the peninsula appears to influence the dynamics of the system and the interaction between forest regeneration and resource use may be to the 'benefit' of forest and the detriment of grassland/woodland.

Acknowledgements — The authors wish to express their gratitude to Professor Harold Annegarn of the Geography, Environmental Management and Energy Studies (GEMES) Unit at the University of Johannesburg for the use of the GIS facilities as well as his advice on technical aspects of the paper and encouragement throughout the study. Thanks to all the students at the GEMES unit for their technical assistance and advice. We are very thankful to Sarel and Melani van der Westhuizen and all the staff at Nibela Lake Lodge for providing accommodation during site visits. We acknowledge Professor Mike Laing for advice on historical military activities in the area, the Surveyor-General in Mowbray for access to the series of aerial photos and the South African Weather Service for providing the historical climatic data. Finally, thank you to Goodenough Mdluli, *Induna* Mdluli and the community of KwaNibela for their technical assistance and enthusiasm for the study.

References

Acocks JPH. 1953. Veld types of South Africa. *Memoirs of the Botanical Survey of South Africa* 28: 1–192.

Bond WJ, Midgley GF, Woodward FI. 2003. What controls South African vegetation—climate or fire? *South African Journal of Botany* 69: 79–91.

Boudreau S, Lawes MJ. 2005. Small understorey gaps created by subsistence harvesters do not adversely affect the maintenance of tree diversity in a sub-tropical forest. *Biological Conservation* 126: 279–286.

Boudreau S, Lawes MJ, Piper SE, Phadima LJ. 2005. Subsistence harvesting of pole-size understorey species from Ongoye Forest

Reserve, South Africa: species preference, harvest intensity, and social correlates. *Forest Ecology and Management* 216: 149–165.

Bowman DMJS, Walsh A, Milne DJ. 2001. Forest expansion and grassland contraction within a *Eucalyptus* savanna matrix between 1941 and 1994 at Litchfield National Park in the Australian monsoon tropics. *Global Ecology and Biogeography* 10: 535–548.

Bruton MN, Smith M, Taylor RH. 1980. A brief history of human involvement in Maputaland. In: Bruton MN, Cooper KH (eds), *Studies on the ecology of Maputaland.* Grahamstown: Rhodes University; Durban: Natal Branch of the Wildlife Society of Southern Africa. pp 12–17.

Bürgi M, Russell EWB, Motzkin G. 2000. Effects of postsettlement human activities on forest composition in the north-eastern United States: a comparative approach. *Journal of Biogeography* 27: 1123–1138.

Eckhardt HC, van Rooyen N, Bredenkamp GJ. 1997. Plant communities of the forests, woodlands and thickets in northern KwaZulu-Natal. *Koedoe* 40: 91–112.

Eeley HAC, Lawes MJ, Piper SE. 1999. The influence of climate change on the distribution of indigenous forest in KwaZulu-Natal, South Africa. *Journal of Biogeography* 26: 595–617.

Egan D, Howell EA. 2001. *The historical ecology handbook: a restorationist's guide to reference ecosystems.* Washington, DC: Island Press.

Everard DA, van Wyk GF, Midgley JJ. 1994. Disturbance and the diversity of forests in Natal, South Africa: lessons for their utilization. In: Huntley BJ (ed.), *Botanical diversity in southern Africa. Strelitzia* 1. Pretoria: National Botanical Institute. pp. 275–285.

Fairbanks DHK, Thompson MW, Vink DE, Newby TS, van den Berg HM, Everard DA. 2000. South African land-cover characteristics database: a synopsis of the landscape. *South African Journal of Science* 96: 69–82.

Feely JM. 1980. Did iron age man have a role in the history of Zululand's wilderness landscapes? *South African Journal of Science* 76: 150–152.

Feely JM. 1986. The distribution of Iron Age farming settlement in Transkei: 470 to 1870. MA thesis, University of Natal, Pietermaritzburg, South Africa.

Ferrier S. 2002. Mapping spatial pattern in biodiversity for regional conservation planning: where to from here? *Systematic Biology* 51: 331–363.

Gaugris JY, Matthews WS, van Rooyen MW, du P Bothma J. 2004. The vegetation of Tshanini Game Reserve and a comparison with equivalent units in the Tembe Elephant Park in Maputaland, South Africa. *Koedoe* 47: 9–29.

Gaugris JY, van Rooyen MW. 2007. The structure and harvesting potential of the sand forest in Tshanini Game Reserve, South Africa. *South African Journal of Botany* 73: 611–622.

Gaugris JY, van Rooyen MW, du P Bothma J. 2008. Growth rate of selected woody species in northern Maputaland, KwaZulu-Natal, South Africa. *South African Journal of Botany* 74: 85–92.

Geist HJ, Lambin EF. 2002. Proximate causes and underlying driving forces of tropical deforestation. *BioScience* 52: 143–150.

Geldenhuys CJ. 1992. Richness, composition and relationships of the floras of selected forests in southern Africa. *Bothalia* 22: 205–233.

Geldenhuys CJ. 1993. Observations of the effects of drought on evergreen and deciduous species in the Eastern Cape forests. *South African Journal of Botany* 59: 522–534.

Geldenhuys CJ. 2004. Concepts and process to control invader plants in and around natural evergreen forest in South Africa. *Weed Technology* 18: 1386–1391.

Geldenhuys CJ, Venter S. 2002. Plant communities and biodiversity of the Limpopo province forests: relevance and management options. In: Seydack AHW, Vorster T, Vermeulen WJ, van der Merwe IJ (eds), *Multiple use management of natural forests and savanna woodlands: policy refinement and scientific progress.* Pretoria: Department of Water Affairs and Forestry. pp 23–37.

Goodman PS. 2003. Assessing management effectiveness and setting priorities in protected areas in KwaZulu-Natal. *BioScience* 53: 843–850.

Hudak AT, Wessman CA. 1998. Textural analysis of historical aerial photography to characterize woody plant encroachment in the South African savanna. *Remote Sensing of Environment* 66: 317–330.

Izidine S, Siebert S, van Wyk AE. 2003. Maputaland's Licuati forest and thicket, botanical exploration of the coastal plain south of Maputo Bay, with an emphasis on the Licuati Forest Reserve. *Veld and Flora* 89: 56–61.

Kirkwood D, Midgley JJ. 1999. The floristics of Sand Forest in northern KwaZulu-Natal, South Africa. *Bothalia* 29: 293–304.

Kotze DJ, Lawes MJ. 2007. Viability of ecological processes in small afromontane forest patches in South Africa. *Austral Ecology* 32: 294–304.

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke G et al. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11: 261–269.

Lawes MJ, Macfarlane DM, Eeley HAC. 2004. Forest landscape pattern in the KwaZulu–Natal midlands, South Africa: 50 years of change or stasis? *Austral Ecology* 29: 613–623.

Lawes MJ, Lamb BCC, Boudreau S. 2005. Area- but no edge-effect on woody seedling abundance and species richness in old Afromontane forest fragments. *Journal of Vegetation Science* 16: 363–372.

Lawes MJ, Joubert R, Griffiths ME, Boudreau S, Chapman CA. 2007a. The effect of the spatial scale of recruitment on tree diversity in afromontane forest fragments. *Biological Conservation* 139: 447–456.

Lawes MJ, Griffiths ME, Boudreau S. 2007b. Colonial logging and recent subsistence harvesting affect the composition and physiognomy of a podocarp dominated afrotemperate forest. *Forest Ecology and Management* 248: 48–60.

Limpitlaw D, Woldai T. 2004. Patch analysis of Landsat datasets for assessment of environmental change in the Zambian Copperbelt. *Proceedings of the IEEE International: Geoscience and Remote Sensing Symposium* 4: 2290–2293.

Mast JN, Veblen TT, Hodgson ME. 1997. Tree invasion within a pine/grassland ecotone: an approach with historic aerial photography and GIS modeling. *Forest Ecology and Management* 93: 181–194.

Matthews WS. 2005. Contributions to the ecology of Maputaland, Southern Africa, with emphasis on Sand Forest. PhD thesis, University of Pretoria, South Africa.

McCracken DP. 1986. The indigenous forests of colonial Natal and Zululand. *Natalia* 16: 19–38.

Mckenzie P. 1998. Weapons testing: its impact on people and the environment. In: Cock J, Mckenzie P (eds), *From defence to development: redirecting military resources in South Africa.* Cape Town: David Philip Publishers. pp 85–96.

Mladenoff DJ, White MA, Pastor J, Crow TR. 1993. Comparing spatial pattern in unaltered old growth and disturbed forest landscapes. *Ecological Applications* 3: 294–306.

Mucina L, Rutherford MC. 2006. *Vegetation of South Africa, Lesotho and Swaziland. Strelitzia* 19. Pretoria: South African National Biodiversity Institute.

Natal Parks Board. 1979. *St Lucia.* Petermaritzburg: Natal Parks Board.

Obiri JAF, Lawes MJ. 2002a. Attitudes of coastal-forest users in Eastern Cape province to management options arising from new South African forest policies. *Environmental Conservation* 29: 519–529.

Obiri JAF, Lawes MJ. 2002b. Regeneration in canopy gaps: implications for selective tree harvesting in coastal scarp forests of the Eastern Cape province. In: Seydack AHW, Vorster T, Vermeulen WH, van der Merwe IJ (eds), *Multiple use management of natural forests and savanna woodlands: policy refinement and scientific progress*. Pretoria: Department of Water Affairs and Forestry. pp 397–410.

Obiri JAF, Lawes MJ. 2004. Community attitudes and perceptions towards forest conservation. In: Lawes MJ, Eeley HAC, Shackleton C, Geach B (eds), *Indigenous forests and woodlands in South Africa: policy, people and practice*. Pietermaritzburg: University of Natal Press. pp 257–259.

Obiri JAF, Lawes MJ, Mukolwe M. 2002. The dynamics and sustainable use of high-value tree species of the coastal Pondoland forests of the Eastern Cape province, South Africa. *Forest Ecology and Management* 166: 131–148.

Pitman WV. 1980. Hydrology of the coastal lakes of Maputaland: with special reference to St Lucia and Sibaya. In: Bruton MN, Cooper KH (eds), *Studies on the ecology of Maputaland*. Grahamstown: Rhodes University, Grahamstown; Durban: Natal Branch of the Wildlife Society of Southern Africa. pp 12–17.

Pooley ES. 1980. Some notes on the utilization of natural resources by the tribal people of Maputaland. In: Bruton MN, Cooper KH (eds), *Studies on the ecology of Maputaland*. Grahamstown: Rhodes University; Durban: Natal Branch of the Wildlife Society of Southern Africa. pp 467–479.

Prins FE, Lewis H. 1992. Bushmen as mediators in Nguni cosmology. *Ethnology* 31: 133–147.

Ripple WJ, Hershey KT, Anthony RG. 2000. Historical forest patterns of Oregon's central coast range. *Biological Conservation* 93: 127–133.

Robertson J, Lawes MJ. 2005. User perceptions of conservation and participatory management of iGxalingenwa forest, South Africa. *Environmental Conservation* 32: 64–75.

Sisk TD, Launer AE, Switky KR, Ehrlich PR. 1994. Identifying extinction threats: global analyses of the distribution of biodiversity and the expansion of the human enterprise. *BioScience* 44: 592–604.

South African Weather Service. 2008. Climate statistics: St Lucia Lake Research Centre (No.: 0339731A7). [data requested 21 November 2008].

Shi H, Singh A, Kant S, Zhu Z, Waller E. 2005. Integrating habitat status, human population pressure, and protection status into biodiversity conservation priority setting. *Conservation Biology* 19: 1273–1285.

StatsSA. 1996. South African Census. South Africa: Statistics South Africa – producer; South African Data Archive – distributor.

StatsSA. 2001. South African Census. South Africa: Statistics South Africa – producer; South African Data Archive – distributor.

Swetnam TW, Allen CD, Betancourt JL. 1999. Applied historical ecology: using the past to manage for the future. *Ecological Applications* 9: 1189–1206.

Thunberg CP. 1779. *Travels in Europe, Africa, and Asia, performed between the years 1770 and 1779. Volume I: Voyage to the southern parts of Europe, and to the Cape of Good Hope in Africa in the years 1770, 1771, 1772, 1773*. London: Richardson, Corneill and Egerton.

von Maltitz GP. 1991. Prospects for future research on dune forest dynamics. In: Everard DA, von Maltitz GP (eds), Dune forest dynamics in relation to land-use practices. Pretoria: Environmental Forum Report, FRD. pp 128–136.

von Maltitz GP, van Daalen JC, MacDevette DR, Jacobs CJ. 1991. The woody dune vegetation at Eastern Shores. In: Everard DA, von Maltitz GP (eds), Dune forest dynamics in relation to land-use practices. Pretoria: Environmental Forum Report, FRD.

von Maltitz GP, Mucina L, Geldenhuys CJ, Lawes MJ, Eeley H, Aidie H, Vink D, Fleming G, Bailey C. 2003. Classification system for South African indigenous forests. An objective classification for the Department of Water Affairs and Forestry. Unpublished report no. ENV-P-C 2003-017. Pretoria: Environmentek, CSIR.

Walker C. 2005. Land of dreams: land restitution on the eastern shores of Lake St Lucia. *Transformation: Critical Perspectives on Southern Africa* 59: 1–25.

Weisser PJ. 1978. Changes in area of grasslands on the dunes between Richards Bay and the Mfolozi River 1937 to 1974. *Proceedings of the Grassland Society of South Africa* 13: 95–97.

Weisser PJ, Muller R. 1983. Dune vegetation dynamics from 1937 to 1976 in the Mlalazi-Richards Bay area of Natal, South Africa. *Bothalia* 14: 661–667.

Weisser PJ, Garland IF, Drews BK. 1982. Dune advancement 1937–1977 at the Mlalazi Nature Reserve, Mtunzini, Natal South Africa, and a preliminary vegetation-succession chronology. *Bothalia* 14: 127–130.

West AG. 1999. Hunting for humans in forest ecosystems: are the traces of Iron-Age people detectable? MSc thesis, University of Cape Town, South Africa.

West AG, Bond WJ, Midgley JJ. 2000. Soil carbon isotopes reveal ancient grassland under forest in Hluhluwe, KwaZulu-Natal. *South African Journal of Science* 96: 252–254.

Whateley AM, Wills AJ. 1996. Colonization of a sub-tropical woodland by forest trees in South Africa. *Lammergeyer* 44: 19–30.

Wilcox BA, Murphy DD. 1985. Conservation strategy: the effects of fragmentation on extinction. *American Naturalist* 125: 879–887.

Wilson M. 1959. The early history of the Transkei and Ciskei. *African Studies* 18: 167–179.