A geomorphic and soil description of the long-term fire experiment in the Kruger National Park, South Africa

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In 1954, the experimental burning programme into fire research was initiated in the Kruger National Park (KNP), South Africa. It is viewed as one of the last remaining long-term landscape fire experiments in Africa. Throughout the more than five decades of fire treatments in the experiment, numerous surveys (expanding various spatial and temporal scales), research projects (covering biotic and abiotic components) and analyses have been conducted with the aim to assess the impacts of different fire regimes on the savannah biome. The design of the experiment intended to test the effect of season and frequency of burning on vegetation within four major landscapes in the KNP. However, these effects have been partly obscured by factors not fully taken into account by the experimental design, namely, herbivory, artificial water provision and soil variation. Soil variation between replicates in the same landscape, as well as within individual replicates, has raised the issue of the representivity of the trial. This paper provided a description and ranking of the experimental burning trial according to the geomorphic and soil characteristics of each plot in comparison to the surrounding landscape.

Conservation implications: The KNP burn plots are one of the largest and longest-running fire experiments on fire ecology in African savannahs. However, studies need to consider the underlying geomorphic and soil template when designing experiments and interpreting results. This work describes the representivity of the plots across, and within, treatments.

Introduction

Fire has long been recognised as an essential determinant of the structure and function of African savannahs (Higgins *et al*. 2007; Sankaran, Ratanam & Hanan 2008; Scholes & Walker 1993; Trollope 1982) and is often used as a management tool within conservation agencies. The application of appropriate fire regimes is usually informed and adapted by the findings of ongoing research, which is undertaken on the experimental application of selected fire regimes on fixed areas (see e.g., Andersen, Cook & Williams 2003; Knapp *et al*. 1998), with treatments often repeatedly applied for many decades. The changing attitudes towards fire management within South African conservation areas – from the orthodox equilibrium theory (fixed rotational fire regimes) to one that embraces a dynamic savannah system based on non-equilibrium theory (patch mosaic fires over space and time) (Bond & Archibald 2003; Mentis & Bailey 1990; Van Wilgen *et al*. 2000; Van Wilgen, Biggs & Potgieter 1998) – has questioned the validity of results from historical long-term fixed fire experiments in influencing fire management policies (Van Wilgen *et al*. 2004; Van Wilgen, Govender & Biggs 2007). A recent critical review of the long-term fire experiment in bringing about changes in the fire management policy at the Kruger National Park (KNP) found that it had little direct influence. However, the experiment has had numerous other unforeseen benefits, particularly its support and use in ongoing key research projects undertaken on the experiment to improve our understanding of fire as a key driver of savannah dynamics (Van Wilgen *et al*. 2007).

The spatio-temporal scale and the underlying template of various fire experiments often brings into question the representivity of the results from these plot-based experiments when scaling up to landscape processes. The KNP long-term fire experiment (Biggs *et al.* 2003) is often criticised regarding the difficulty in separating the effects of the experimental fire treatments from other factors that might be causing the observed differences. The Experimental Burn Plot (EBP) trial was designed with the initial aim of testing the effects of different seasons and frequencies of burning on the vegetation of the KNP. These effects have been partly obscured by factors not fully taken into account by the experimental design, most importantly, herbivory, artificial water provision and soil variation (Biggs *et al.* 2003).

The response of the vegetation and animal population to the template presented by the geology (which is reflected by the soils) and the changes caused by the ecosystem drivers such as rainfall, hebivory and fire, have led to a complex patch mosaic template within the park (Venter, Scholes & Eckhart 2003). To quantitatively assess the effect that the varying fire regimes have on the dominant vegetation communities, it was envisioned that vegetation surveys would be conducted annually, whilst animal life would be observed periodically (Nel 1953). A comprehensive baseline vegetation (woody and herbaceous) survey was conducted prior to establishment of all treatments in 1954. Vegetation re-surveys were undertaken in the late 1990s and early 2000s (Van Wilgen *et al*. 2007). During the 50-year lifespan of the experiment, various researchers conducted surveys (which were predominantly of vegetation) on the experiment (Govender, Potgieter & Biggs 2003; Van Wilgen *et al*. 2007). Webber (1979) was the first to investigate the soil characteristics on the Skukuza plots; thereafter, other work looking at soil characteristics was undertaken by Mills and Fey (2004a, 2004b), whilst the majority of research pertaining to soils on the experiment focused on the nutrient content, cycling and variation in nutrient levels with different fire regimes (Coetsee 2007; Feig 2004; Otter 1992; Shackleton & Scholes 2000; Van Wilgen *et al.* 2007).

Analysis, understanding and incorporation of the results from the experiment of the effects of fire on savannah systems have only been undertaken in the past decade. The Van Wilgen *et al.* (2007) paper outlines, in detail, the contribution that the experiment had to effect change in management actions and policy in the park. Key findings on the biota studied on the experiment include the following (Van Wilgen *et al.* 2007):

- Woody tree and shrub density are unresponsive to fire regimes and fire is not critical for the maintenance of woody plant richness and composition. Exclusion of fire promotes an increase in woody biomass, with the most marked effects on woody vegetation in the extreme treatments (annual burning, burning in summer or wet season, or long periods of fire exclusion). These effects were also greater in areas of higher rainfall.
- Manipulation of fire regimes is not critical for the maintenance of herbaceous plant species diversity. Herbaceous composition changed little with fires in the dormant season, but changes were significant in the wet, growing season and with fire exclusion. Impacts caused by fire were most marked in wetter areas and increased grazing pressure on the plots after the treatments influenced the grass diversity at drier sites.
- There were noticeable effects of fire on small mammal communities, with unburnt sites supporting the most species and highest densities of small mammals.
- Bird species richness and composition did not respond to the different fire regimes.
- No significant effect on ant species composition and diversity between the fire treatments but significant differences in ant assemblage composition were found between the extreme fire treatments (burnt vs unburnt plots).
- Regardless of fire treatment, nitrogen loss is replenished soon after the fire. Frequent, annual burning increases soil crusting on the plots. Mycorrhizal colonisation increases with root branching and fine root development decreases with decreasing fire frequency, allowing for optimal acquisition of resources under different fire frequencies.
- Fire intensity varies as a result of changes in fuel moisture content rather than post-fire age, particularly because of the seasonal differences in fuel moisture content that override those of fuel load.

Since the inception of the experiment in the 1950s, our understanding of the role that fire plays within savannah ecosystems continues to improve. Therefore, current and future fire management policies implemented in the KNP will continue to be supported by the best available science that promotes appropriate adaptive fire management.

Owing to the lack of baseline soil surveys or soil characterisation of the EBPs, this paper provides a soil and geomorphic description of the experiment in order to determine which replicate or individual plots within replicates are not representative of the land types in which they are set. It is well known that differences in soil types cause significant differences in vegetation in the KNP (Venter 1990) and knowledge of the variation and extent of different types of soil and geomorphology on the EBPs is therefore necessary, in order to make future studies on the plots more relevant and representative of the surrounding landscape.

Study site

The KNP was proclaimed in 1926, and covers approximately 1 948 528 ha within the low-lying savannahs of north-eastern South Africa. The vegetation is characterised by savannahs within 37 landscapes (Gertenbach 1983), with the dominant trees being knobthorn (*Acacia nigrescens*), marula (*Sclerocarya birrea*), leadwood (*Combretum imberbe*), red-bush willow (*Combretum appiculatum*), silver cluster leaf (*Terminalia sericea*) and mopane (*Colophospermum mopane*). Mean annual rainfall varies from 350 mm in the north to over 700 mm in the south. Geologically, the KNP is underlain by granites in the west, whilst the eastern sector is underlain predominantly by basalt (Venter 1990). The flora of the park comprises 1983 species, including more than 400 tree and shrub species and more than 220 grass species.

Experimental burn plots

Fire research formally began in the KNP in 1954 with the establishment of one of the few long-term fire ecology research experiments in Africa (Van der Schijff 1958). The experiment consisted of the application of fires at varying return intervals and seasons, as well as protection from fire, on a series of plots approximately 7 ha in area within specific vegetation types represented by four of the major ecological regions in the Park (Pretoriuskop: Sourveld vegetation; Skukuza: *Combretum* vegetation; Satara: Knobthorn and Marula vegetation; Mopane: Mopane vegetation) (Figure 1). The treatments were replicated four times in each of these ecological regions. Within each ecological region, four different replicates or strings were scattered within 20 km of each other. A double firebreak road surrounds the individual replicates (with the area between the firebreak roads burnt annually in autumn) to ensure protection from wild fires.

The treatments originally included annual (B1) winter fires in August and biennial (B2) and triennial (B3) fires in August (winter), October (after first spring rains), December (early summer), February (late summer) and April (autumn). In 1976, further treatments to examine the effects of fires every four (B4) and six (B6) years in October were added to selected landscapes (Satara and Mopane). Full details and history of the experimental design and application of treatments are available from Biggs *et al*. (2003). Description of the areas in which the KNP's fire experiment was replicated within is outlined in Table 1. The associated fire treatments and plots numbers for each replicate is given in Online Appendix 1a–d.

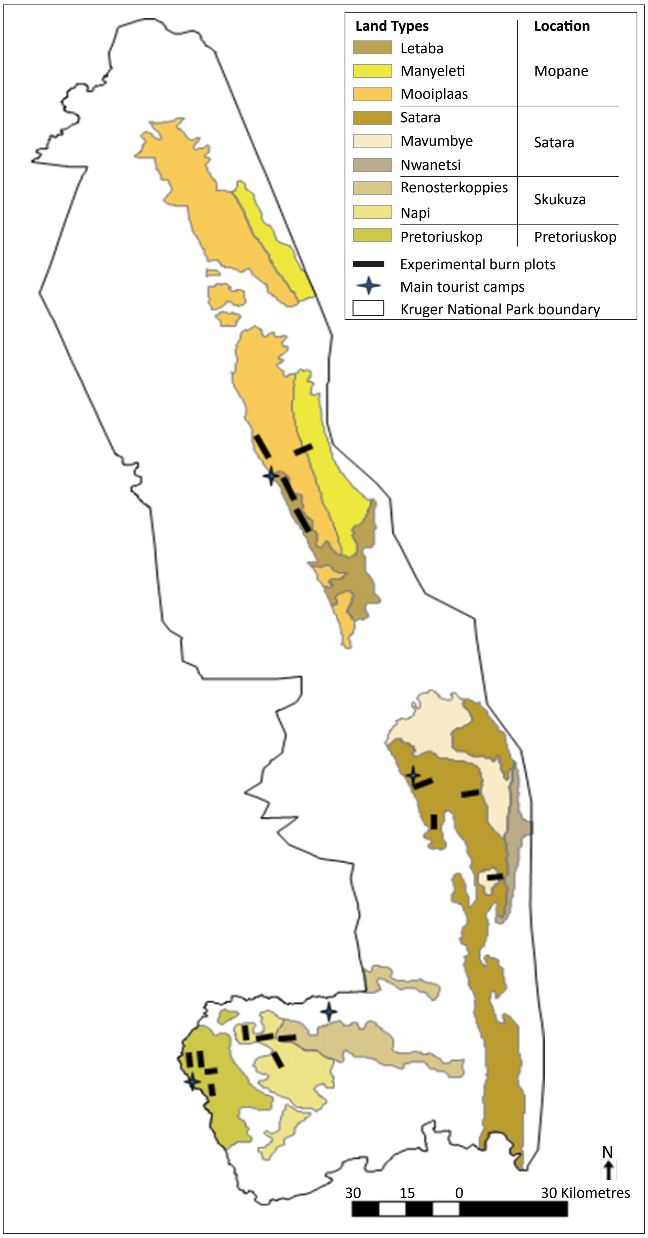
Methods

A series of aerial photographs (digital, colour, shutter speed: 1/800, scale: 1:50 000, altitude: 914.4 m, aircraft speed: 185.2 km/h) taken in April 2000 and field surveys were used to map the land units with their associated soil and vegetation patterns on each of the plots. Sections that are atypical of the specified norm were delineated and assigned a score according to the system described below (Table 2). However, the survey was not conducted to identify, in detail, all soil types or to give detailed descriptions of vegetation within the plots. Reference made to land types in this report is according to the definitions and descriptions of Venter (1990).

Soil differences usually cut through individual plots so that part of the plot may score 5, whilst another part may have a score of 1. The plot as a whole was scored depending on the dominant soil types found on it and how representative it is of the environmental parameters within each particular replicate was assessed visually.

Assumptions

The following assumptions were made with regard to this survey:



Source: Venter, F.J., 1990, 'A classification of land for management planning in the Kruger National Park', PhD thesis, Department of Geography University of South Africa.

FIGURE 1: Location of the experimental burn plots within the land types as described by Venter (1990), in the Kruger National Park.

TABLE 1: Salient features of the four major vegetation types in which the Kruger National Park's fire experiment was replicated.

Geology	Location	Annual rainfall (mm)	Dominant tree species	Replicate	Land Type†
Granite	Pretoriuskop	705	*Terminalia sericea*, *Dichrostachys cinerea*	Numbi	Pretoriuskop
				Shabeni	Pretoriuskop
				Kambeni	Pretoriuskop
				Fayi	Pretoriuskop
	Skukuza	572	*Combretum collinum*, *Combretum zeyheri*	Skukuza	Napi and Renosterkoppies
				Napi	Napi
				Mbyamiti	Napi
				N'waswitshaka	Napi
Basalt	Satara	507	*Acacia nigrescens*, *Sclerocarya birrea*	Satara	Satara
				Marheya	Satara
				Nwanetsi	Satara
				Lindanda	Satara, Mavumbye and Nwanetsi
	Mopane	451	*Colophospermum mopane*	Tsende	Letaba and Mooiplaas
				Mooiplaas	Letaba and Mooiplaas
				Nshawo	Mooiplaas and Manyeleti
				Dzombo	Mooiplaas

†, Land Types as described by Venter, F.J., 1990, 'A classification of land for management planning in the Kruger National Park', PhD thesis, Department of Geography, University of South Africa.

TABLE 2: The allocated representivity scores and description of each score assigned to plots and replicates.

Allocated score†	Description of the scoring system
1	Plots located at the valley bottoms of the catena and not representative of the surrounding landscape.
2	Plots located at the foot slopes of the catena and slightly representative of the surrounding landscape.
3	Plots located at the mid-slopes of the catena and moderately representative of the surrounding landscape.
4	Plots located on atypical crests of the catena and well representative of the surrounding landscape.
5	Plots located on typical crests on the catena and totally representative of the surrounding landscape.

†, Scores were linked to specific pedo-geomorphological conditions and how representative each plot was to the surrounding landscape.

- When the EBPs were laid out in the 1950s, the initiators attempted to locate the different replicates on the crests in order to avoid too much soil variation. This assumption is based on the layout of the replicates in both granitic and basaltic areas, where minor portions of mid-slope and foot-slope areas are represented in some of the plots.
- The presence or absence of roads influenced the layout of the EBPs as they were only laid out alongside existing roads. This negatively influenced the attempt to restrict the EBPs to upland areas, so that certain portions of plots occur in foot-slope areas.

This scoring system was used as a means to investigate the following questions:

- How representative of the broad ecological region or landscape is each group of four replicates and series?
- How comparable is each of the four replicates? This is to test if one or more of the replicates in a series are outliers, why it is regarded as outliers and whether it is enough of an outlier to warrant complete exclusion from analyses under certain circumstances.
- How comparable is each the individual plots in one replicate? Are there particular outliers based on any geological, geomorphologic or soil criteria?

Results

Pretoriuskop

The Pretoriuskop replicates of the EBPs are all fairly well representative of the Pretoriuskop Land Type (Venter 1990). The Fayi replicate generally has more sandy and yellow soils with patches of Avalon–Clovelly and shallow Hutton–Glenrosa–Kroonstad forms (Soil Classification Working Group 1991) dominant with many *T. sericea* trees (Figure 2a). The downstream part of some of the plots on the Shabeni replicate are influenced by seepage areas and duplex soils, namely deep Clovelly form (Soil Classification Working Group 1991) (Figure 2b). This replicate seems to have less tall grass species than the other Pretoriuskop plots. The Numbi replicate features deep, red, sandy loam soils with minor areas of duplex soils (usually on the foot slope of plots), shallow soils (steep areas) or clay soils associated with intrusions of dolerite or gabbro. A clayey area caused by the presence of some gabbro may occur, for example on plot 4 (fire treatments – Online Appendix 1a–d) of the Numbi replicate (Figure 2c). The Kambeni replicate has been deeply incised by a stream (plot 11) but the influence of this is limited and is characterised by very shallow soils (Escourt form) (Soil Classification Working Group 1991), caused by the steep slope in this area (Figure 2d). Table 3a and 3b illustrates the overall representivity scores for each replicate and individual plot within Pretoriuskop.

Skukuza

Huge granite rock outcrops and boulders occur on some of the Biyamiti plots. The soils within these plots are usually hydromorphic and therefore slightly different from the rest of the plots. The south-western plots (plots 9–12) feature more clayey soils as a result of the presence of dolerite dykes in this area. These plots are generally quite different from the other plots in this replicate, as well as the series, as they are dominated by Estcourt–Swartlands–Kroonstad and Hutton–Clovelly–Fernwood forms (Soil Classification Working Group 1991) (Figure 3a). The Skukuza replicate of the EBPs is characterised by quite large areas of sodic and duplex soils that occur on the foot slopes of parts of plots 6 and 7. These sodic soils have relatively thin A horizons (< 15 cm), which makes these areas completely different from the other areas in the plots. Serious erosion within firebreaks is already evident where the firebreaks cross into sodic soils. Unfortunately, the control or no burn plot (plot 7) (see Online Appendix 1a–d for treatments) at this replicate is one of those most seriously affected by the sodic soils, which covers more than half of the no burn treatment (Figure 3b). The N'washitshaka replicate is characterised by reddish soils (Glenrosa–Hutton forms), but plot 6 is almost completely associated with hydromorphic or duplex soils (Kroonstad–Estcourt forms) (Soil Classification Working Group 1991) (Figure 3c). The Napi replicate also has some duplex soils (Fernwood–Kroonstad and Hutton–Clovelly–Fernwood forms), as well as granite boulders or rocky outcrops (Figure 3d). Table 4a and 4b illustrates the overall representivity scores for each replicate and individual plot within Skukuza.

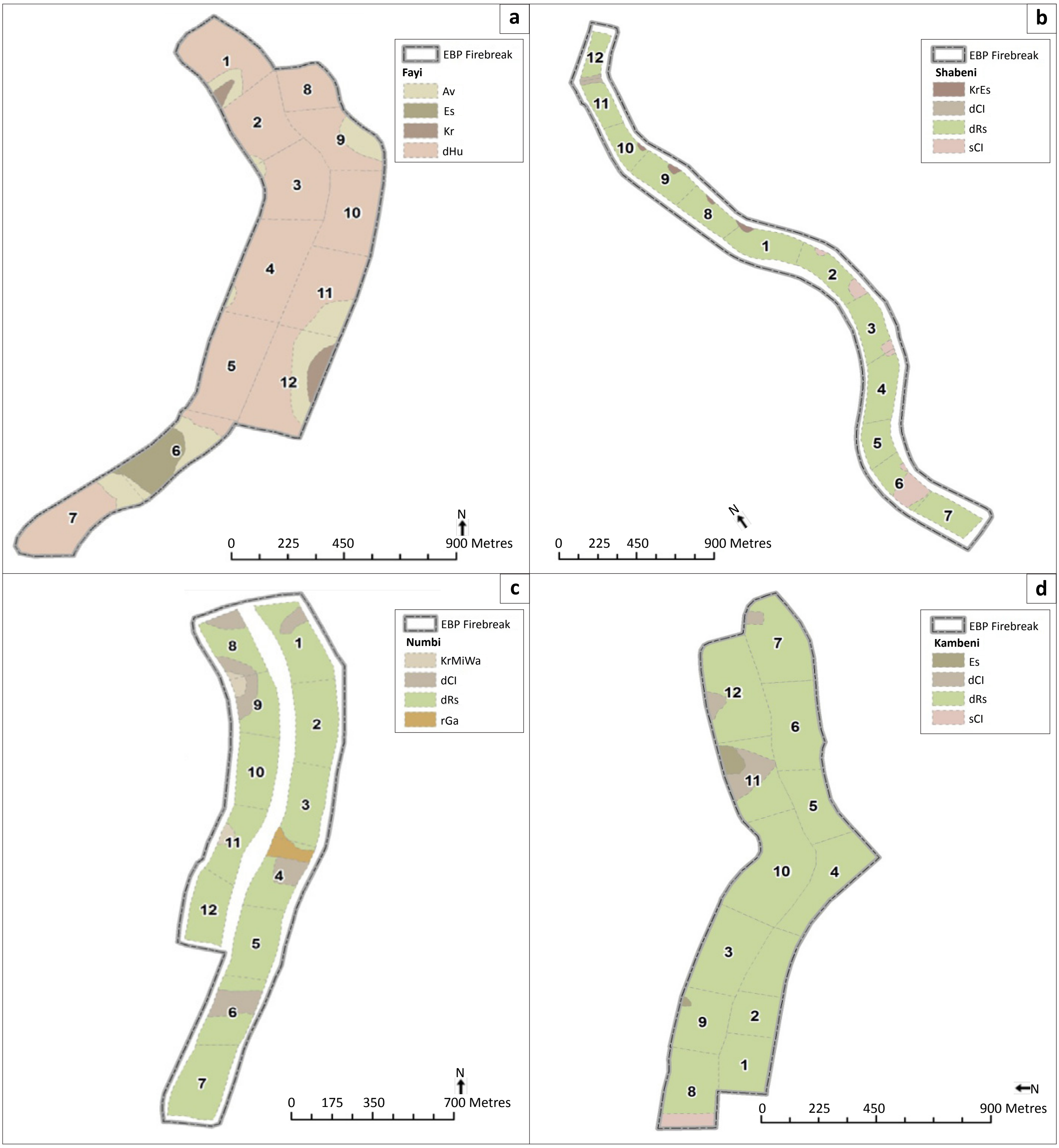
Satara

It is assumed that these replicates were located to represent the *S. birrea*–*A. nigrescens* savannah of the central basalt plains. The soils and general vegetation of this zone are described as the Satara Land Type by Venter (1990).

The Satara replicate occurs on a very flat part of the basalt plains. The geology is Sabie River Basalt Formation with dolerite dykes and the soils are mainly moderately deep Shortlands–Swartland soil (Soil Classification Working Group 1991), that are red structured clays. Because of the flatness of this area, a number of shallow pans and associated black vertic soils occur. Some thin, elongated, rocky outcrops associated with

TABLE 3a: The overall representivity scores for each replicate within Pretoriuskop.

Replicate	Overall score	Comments
Numbi	5	Representative
Kambeni	5	Representative
Shabeni	5	Representative
Fayi	4	Soils are slightly more sandy and yellowish



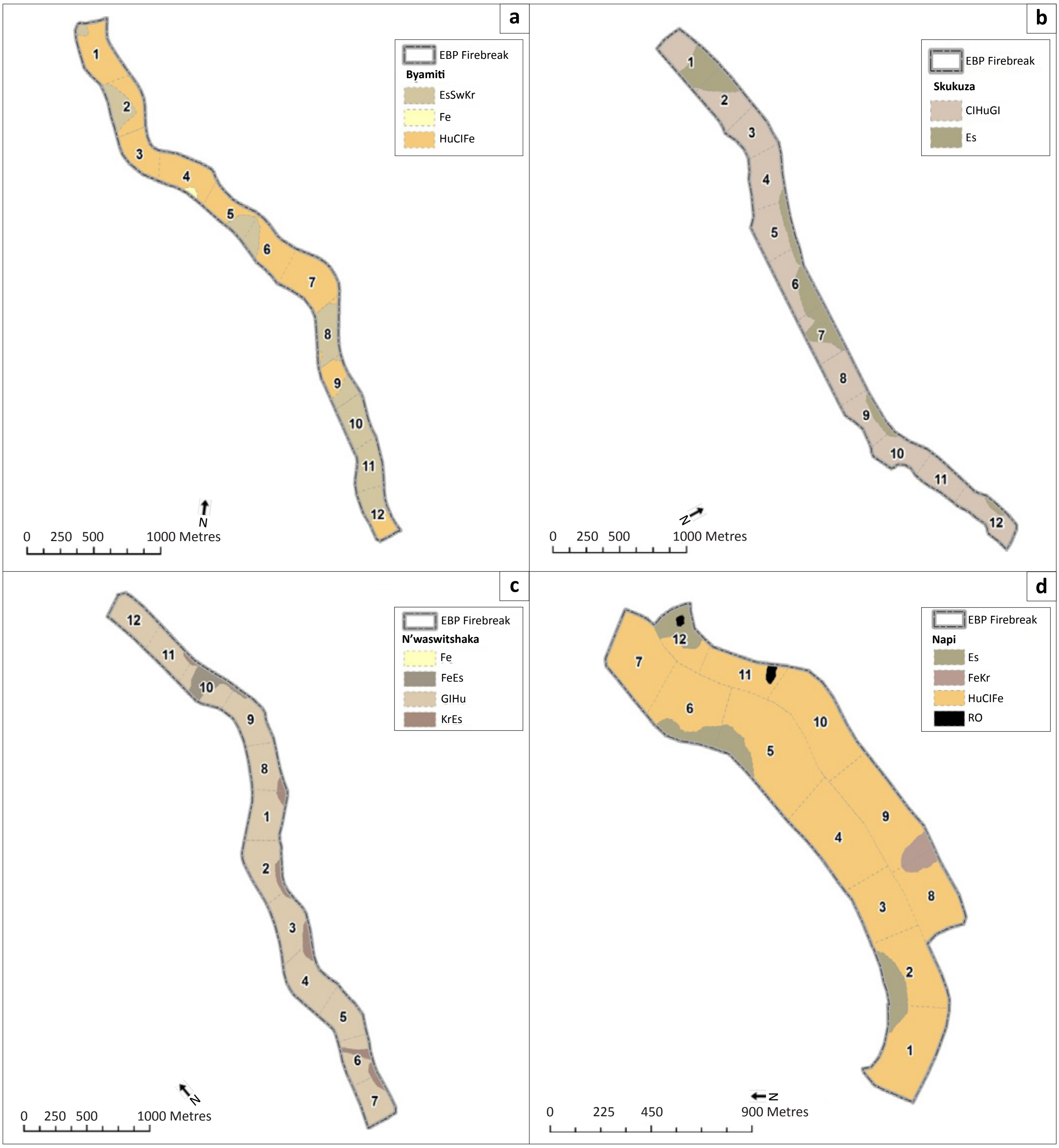
EBP, Experimental Burn Plot; Av, Avalon–Clovelly and shallow Hutton–Glenrosa–Kroonstad; Es, Estcourt; Kr, Kroonstad; dHu, Deep Hutton; KrEs, Kroonstad–Estcourt; dCl, Deep Clovelly; dRs, Deep red sand; sCl, Shallow Clovelly; KrMiWa, Kroonstad–Glenrosa–Wasbank; rGa, Red Gabbro.

FIGURE 2: Description of the soils types on the Pretoriuskop replicates (a) Fayi (b) Shabeni (c) Numbi and (d) Kambeni. For the complete list of soils names and abbreviations see Online Appendix 2.

dolerite dykes also occur (Figure 4a). The Lindanda replicate (Figure 4b) is representative of soils and vegetation of three different land types, namely Satara, Mavumbye and Nwanetsi (Venter 1990), as it is characterised by soils associated with both the Sabie River Basalt Formation and the Letaba Basalt Formation. It has been influenced by colluviation from the Lebombo Hills. This colluvium has influenced soils in the north-eastern corner of the replicate (portions of plots 5 and 6 and plot 7). The occurrence of more clayey soils along the south-western part of the replicate (plots 8, 9, 10, 11, 12 and 14) is ascribed to the occurrence of picrite basalts of the Letaba Basalt Formation. This area is characterised by very clayey soils of the Bonheim and Arcadia forms. Stunted *A. nigrescens* dominates this area and no *S. birrea* occurs. A drainage line through plot 2 is the cause of alluvial soils (Bonheim and Swartland) (Soil Classification Working Group 1991) and

TABLE 3b: The overall representivity scores for each plot within the four replicates in Pretoriuskop.

Replicate	Plot number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
Numbi	4	5	5	4	5	4	5	4	4	5	4	5	-	-	4.50
Kambeni	5	5	5	5	5	5	4	4	5	5	4	4	-	-	4.67
Shabeni	4	5	5	5	5	4	5	4	5	5	5	5	-	-	4.71
Fayi	4	5	5	4	5	3	4	5	5	5	4	4	-	-	4.29



EBP, Experimental Burn Plot; EsSwKr, Estcourt–Swartland–Kroonstad; Fe, Fernwood; HuClFe, Hutton–Clovelly–Fernwood; ClHuGl, Clovelly–Hutton–Glenrosa; Es, Estcourt; FeEs, Fernwood–Estcourt; GlHu, Glenrosa–Hutton; KrEs, Kroonstad–Estcourt; FeKr, Fernwood–Kroonstad; RO, Rocky outcrop.

FIGURE 3: Description of the soils types on the Skukuza replicates (a) Biyamiti (b) Skukuza (c) N'waswitshaka and (d) Napi. For the complete list of soil names and abbreviations see Online Appendix 2.

TABLE 4a: The overall representivity scores for each replicate within Skukuza.

Replicate	Overall score	Comments
Skukuza	3	Sodic footslopes, especially control plot
Napi	5	Partly incised, sloping land with shallow soils
Mbyamiti	3	Flat and relatively homogenous soil pattern
N'waswitshaka	4	Diverse soils and vegetation pattern, especially control

typical associated dense vegetation. The influence of the valley bottom and foot-slope extends about 50 m on either side of the drainage line. The area to the west of the drainage line, covered by plot 1 and part of plot 2 corresponds to a transition between the red, medium clayey soils associated with Sabie River basalt and the black very clayey soils associated with Letaba basalt. The woody vegetation on parts of plots 5 and 6 and all of plot 7 indicates that sodic soil conditions occur, for example Sterkspruit, with *Acacia welwitschii* as the dominant tree. Some pans also occur in this area. These plots are therefore not completely representative of the Lindanda replicate or the Satara series. The area covered by significant portions of plot 2 and plots 3, 4, 5, 6 and 13 of the Lindanda replicate is characterised by soils of the Swartland and Shortlands forms and features woody plants such as *S. birrea*, *A. nigrescens*, *Acacia tortilis*, et cetera; it is comparable with the rest of the series. The western part of the replicate is associated with Letaba basalt. The Marheya replicate is considered to be representative of the Satara Land Type, but a drainage line through plot 9 also influences plots 8 and 10 with darker, calcareous soils representative of very shallow Mispah–Glenrosa–Maya forms (Soil Classification Working Group 1991) (Figure 4c). The Nwanetsi replicate is regarded as very representative of the Satara Land Type, as most of the area is flat and characterised by red, structured, clay soils, which are characterised as moderately deep Shortlands–Swartland forms (Soil Classification Working Group 1991) (Figure 4d). Table 5a and 5b illustrates the overall representivity scores for each replicate and individual plot within Satara.

Mopane

Three of the four replicates are situated in the mopane shrub vegetation, with relatively shallow, calcareous, dark, clay soils associated with the picrite lavas of the Letaba Basalt Formation. The Dzombo replicate is regarded as the best replicate as it is very homogeneous with respect to soils and slope and is characterised by soils from deep Milkwood and shallow Bonheim forms (Soil Classification Working Group 1991) (Figure 5a).

Two of the replicates – Mooiplaas (Figure 5b) and Tsende (Figure 5c) – have parts that represent slightly incised, sloping land where soils are shallower and the mopane has a tendency to grow taller. Sometimes, drainage lines or depressions represent deeper and vertic clay soils, for example Arcadia (Soil Classification Working Group 1991). On the shallow or rocky areas, different vegetation may be found, namely trees or shrubs such as *Terminalia prunioides*, *C. apiculatum* and *Acacia exuvialis*, as well as grasses such as *Heteropogon contortus* and *Aristida* spp.

The Nshawo replicate is located in an area where three types of parent material occur and where the soils and vegetation are therefore fairly heterogeneous over the replicate as a whole. The Nshawo replicate is located on the interface of the Letaba Basalt and Sabie River Basalt Formations, as well as on the edge of the Shawu vlei area where very deep alluvial soils occur. Soils associated with the Letaba Basalt Formation are dark, calcareous clays, often shallow as on the western side of the replicate, whereas those associated with the Sabie River Basalt Formation are reddish and usually not calcareous. On the reddish soils, trees or shrubs such as *Combretum imberbe* and *Albizia harveyi* may be dominant. On the shallow calcareous clays, mopane may dominate and on the alluvial clay deposits thickets of mopane occur (Figure 5d). Table 6a and 6b illustrates the overall representivity scores for each replicate and individual plot within Mopane.

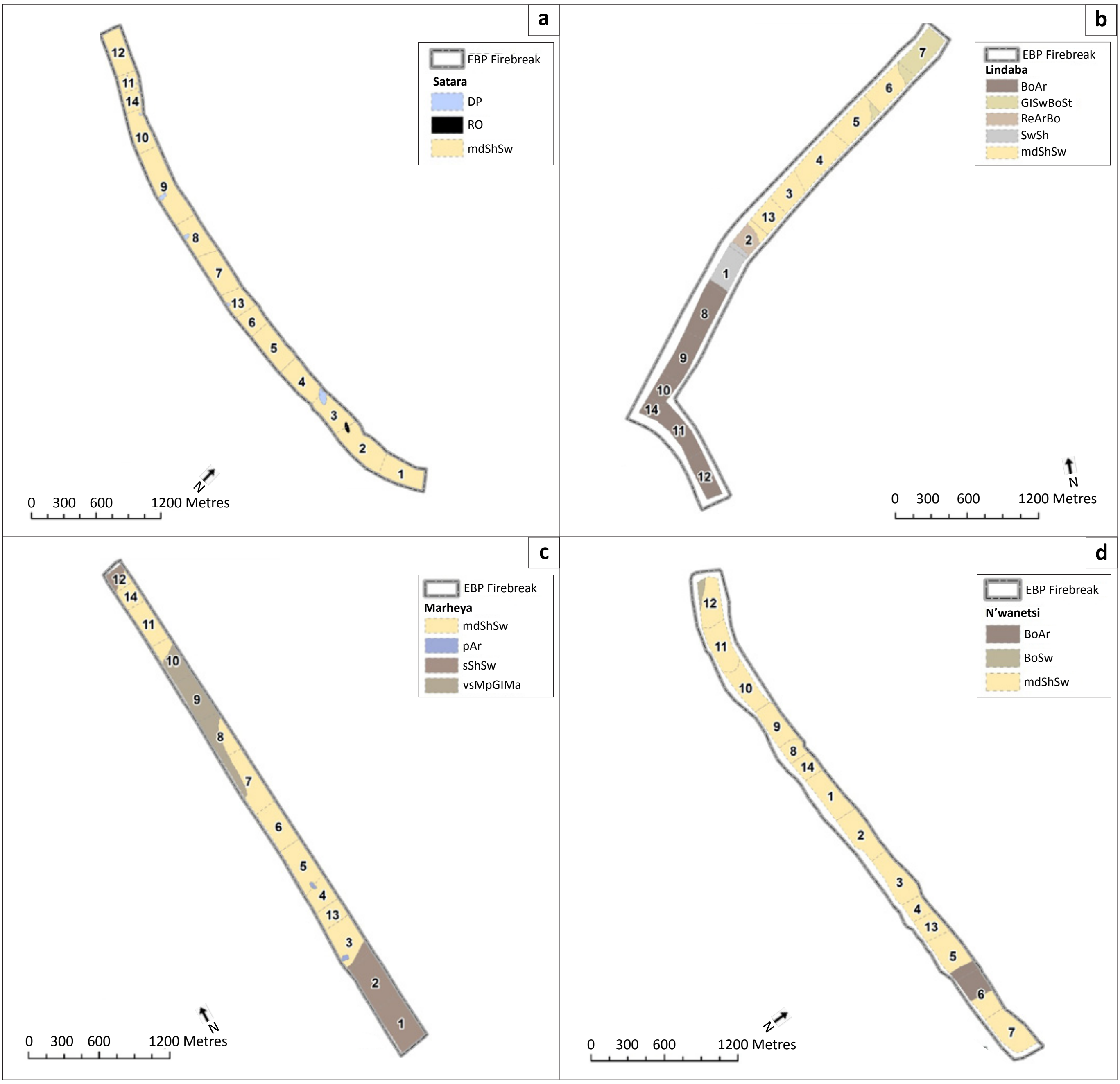
Discussion

Present long-term studies, such as those in the Serengeti (Stronach & McNaughton 1989), the KNP (Van Wilgen *et al.* 2007), and Yellowstone National Park (Romme *et al.* 2011) usually begin as short-term academic projects and are not envisioned to continue for decades. However, they progress over time as new events lead to further research, with the combined data and results leading to insights that were unintended and support additional questions and projects for further understanding (Sinclair *et al.* 2007). The few long-term ecological experiments in South Africa are crucial to understanding and interpreting the complex ecosystem behaviour involving slow and rapid changes at multiple ecosystem states which only became apparent over a period of several decades (Thirgood *et al.* 2007).

As previously outlined, the original objective of the experiment was to determine the effect of fire frequency and season on four of the major vegetation types in the KNP (Biggs *et al*. 2003) and therefore were spaced across the landscape to maximise the representivity of the landscape, particularly with reference to the underlying soils (Van der Schijff 1958). The results from this geomorphic and soil

TABLE 4b: The overall representivity scores for each plot within the four replicates in Skukuza.

Replicate	Plot number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
Skukuza	3	3	5	5	3	2	1	5	3	5	5	4	-	-	3.67
Napi	5	3	5	5	4	4	5	4	4	5	5	2	-	-	4.25
Mbyamiti	4	2	5	4	3	4	4	2	3	2	2	3	-	-	3.17
N'waswitshaka	3	4	4	4	5	4	5	4	5	3	4	5	-	-	4.17



EBP, Experimental Burn Plot; DP, Depressions and pans; RO, Rocky outcrop; mdShSw, Moderately deep Shortlands–Swartland; BoAr, Bonheim–Arcadia; GlSwBoSt, Glenrosa–Swartland–Bonheim–Sterkspruit; ReArBo, Rensburg–Arcadia–Bonheim; SwSh, Swartland–Shortlands; pAr, Pans with Arcadia; sShSw, Shallow Shortlands–Swartland; vsMpGlMa, Very shallow Mispah–Glenrosa/Maya; BoSw, Bonheim–Swartland.

FIGURE 4: Description of the soils types on the Satara replicates (a) Satara (b) Lindanda (c) Marheya and (d) Nwanetsi. For the complete list of soil names and abbreviations see Online Appendix 2.

description of the individual plots and replicates in the experiment has indicated that not all plots within replicates and not all replicates within the landscape can be considered homogeneous treatments. It is for this reason that researchers undertaking their projects within the EBPs, can, for statistical analyses, exclude any outlier replicates (based on the soil and geomorphic description) from their sampling protocol. However, it must also be noted that it is the outlier replicate (least representative of the surrounding landscape) that encompasses the variation and heterogeneity that is inherent within KNP ecosystems and therefore it should not be completely ignored.

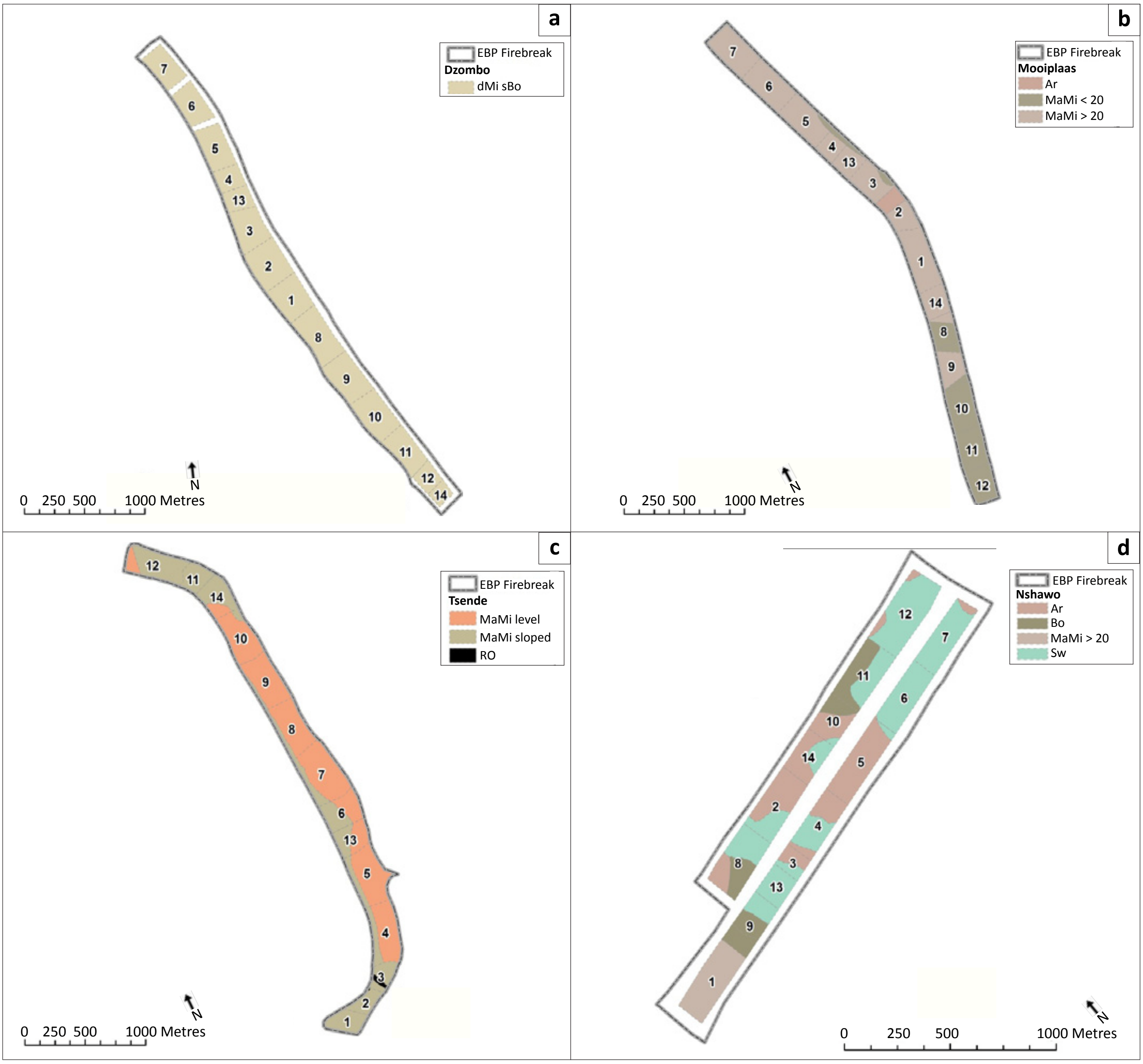
Finally, the KNP's long-term fire experiment has been instrumental in highlighting that ecosystems are not static and management should not aim to maintain the status quo; rather, it should allow natural change to take place within an adaptive management framework. This understanding could not have been achieved without the array of research

TABLE 5a: The overall representivity scores for each replicate within Satara.

Replicate	Overall score	Comments
Satara	5	Few rocky dykes and pans – not significant influence
Marheya	4	Partly incised, sloping, shallow soils
Nwanetsi	5	Flat and relatively homogenous soil pattern
Lindanda	3	Diverse soils and vegetation pattern, especially control

TABLE 5b: The overall representivity scores for each plot within the four replicates in Satara.

Replicate	Plot number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
Satara	5	5	4	4	5	5	5	4	5	4	3	5	4	4	4.43
Marheya	4	4	4	5	5	5	4	3	3	3	5	4	5	5	4.21
Nwanetsi	5	5	5	5	5	4	5	5	5	5	5	5	5	5	4.93
Lindanda	4	3	5	5	3	3	1	3	3	3	3	3	5	3	3.36



EBP, Experimental Burn Plot; dMi sBo, Deep Milkwood and shallow Bonheim; Ar, Arcadia; MaMi < 20, Maya–Milkwood (< 20 cm); MaMi > 20, Maya–Milkwood (> 20 cm); MaMi level, Maya–Milkwood (> 20 cm) – level; MaMi sloped, Maya–Milkwood (< 20 cm) – sloping; RO, Rocky outcrop; Bo, Bonheim; Sw, Swartland.

FIGURE 5: Description of the soils types on the Mopane replicates (a) Dzombo (b) Mooiplaas (c) Tsende and (d) Nshawo. For the complete list of soil names and abbreviations see Online Appendix 2.

and projects that have been undertaken on the EBPs over the past five decades (Van Wilgen *et al*. 2007).

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TABLE 6a: The overall representivity scores for each replicate within Mopane.

Replicate	Overall score	Comments
Tsende	4	Partly incised, sloping, shallow soils, rocky outcrops
Mooiplaas	4	Partly incised, sloping, shallow soils, rocky outcrops
Nshawo	2	Diverse soils and vegetation pattern
Dzombo	5	Flat and homogenous soil

TABLE 6b: The overall representivity scores for each plot within the four replicates in Mopane.

Replicate	Plot number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Average
Tsende	4	4	3	4	4	3	4	5	5	5	3	4	3	4	3.93
Mooiplaas	5	3	5	4	5	5	5	4	4	3	4	4	5	4	4.29
Nshawo	4	3	5	2	3	2	2	3	3	3	3	2	2	3	2.86
Dzombo	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5.00

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Competing interests

The authors declare that they have no financial or personal relationship(s) which may have inappropriately influenced them in writing this article.

Authors' contributions

F.J.V. (Kruger National Park) undertook the geomorphic and soil survey on the experiment. He also developed the scoring system for plot and replicate representivity. The initial project report was prepared by F.J.V. (Kruger National Park), whilst N.G. (Kruger National Park) wrote the manuscript for publication.

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