Experimental burn plot trial in the Kruger National Park: history, experimental design and suggestions for data analysis

R. Biggs, H.C. Biggs, T.T. Dunne, N. Govender and A.L.F. Potgieter

Biggs, R., H.C. Biggs, T.T. Dunne, N. Govender and A.L.F. Potgieter. 2003. Experimental burn plot trial in the Kruger National Park: history, experimental design and suggestions for data analysis. *Koedoe* 46(1): 1-15. Pretoria. ISSN 0075-6458.

The experimental burn plot (EBP) trial initiated in 1954 is one of few ongoing long-term fire ecology research projects in Africa. The trial aims to assess the impacts of different fire regimes in the Kruger National Park. Recent studies on the EBPs have raised questions as to the experimental design of the trial, and the appropriate model specification when analysing data. Archival documentation reveals that the original design was modified on several occasions, related to changes in the park's fire policy. These modifications include the addition of extra plots, subdivision of plots and changes in treatments over time, and have resulted in a design which is only partially randomised. The representativity of the trial plots has been questioned on account of their relatively small size, the concentration of herbivores on especially the frequently burnt plots, and soil variation between plots. It is suggested that these factors be included as covariates in explanatory models or that certain plots be excluded from data analysis based on results of independent studies of these factors. Suggestions are provided for the specification of the experimental design when analysing data using Analysis of Variance. It is concluded that there is no practical alternative to treating the trial as a fully randomised complete block design.

Key words: burn plots, fire, policy, experimental design, season, frequency.

R. Biggs, CSIR Environmentek, P.O. Box 395, Pretoria, 0001, Republic of South Africa; T.T. Dunne, Statistical Sciences, University of Cape Town, Rhodes Gift 7707, Republic of South Africa; H.C. Biggs, N. Govender and A.L.F. Potgieter, South African National Parks, Private Bag X 402, Skukuza, 1350, Republic of South Africa.

Introduction

The experimental burn plot trial initiated in 1954 in the Kruger National Park is one of few long-term fire ecology research projects in Africa. Although attracting much energy and attention during its first decade, scientific interest in the trial declined considerably between the mid-1960s and the late 1990s. This was largely due to a perception that the trial was irrevocably confounded by 'unnaturally' high levels of herbivory (Trollope *et al*. 1998).

Following a management review in 1997, the possibility of closure of the trial prompted a surge of scientific activity on the plots. The ensuing analysis of data has raised questions about the experimental design of the trial and how the design should be specified in Analysis of Variance (ANOVA). In the hope of uncovering the original documentation describing the design of the trial, a detailed search of archival documentation was undertaken. This paper outlines the history of the EBP trial and describes the current experimental design. Suggestions for the appropriate specification of explanatory models in ANOVA are provided. The paper also discusses confounding factors in the trial, such as herbivory and soil variation, and suggests approaches for taking these into account.

History of the EBP trial

The trial was started in 1954 by the newly formed Biological Section of the Kruger National Park in response to a lack of information on the role of burning in the preser-

vation of fauna and flora (National Parks Board 1953). The objectives of the trial were to assess the influence of fire on what were perceived as the four most important veld types (landscapes) and their associated biotic populations in the Kruger National Park (National Parks Board 1954). It was envisaged that vegetation surveys would be conducted annually, while animal life would be observed from 'time to time'. The intention was that the investigation would, in due course, be expanded to other important vegetation landscapes (Nel 1953).

Prior to the commencement of the trial, veld burning had become a highly contentious management practice in South Africa, and a negative attitude towards controlled burning had developed (Trollope *et al.* 1998). The effects of the fire suppression policy applied in the Kruger National Park between 1948 and 1956 (Van Wilgen *et al.* 2000), led to concerns about bush encroachment, deterioration of grazing and fuel accumulation (Trollope *et al.* 1998). In 1953, approximately one quarter of the Kruger National Park burnt in uncontrolled wild fires (Van der Schijff 1958; Brynard 1971), raising significant concern about the impacts of fire on the wild plants and animals the park was mandated to protect and preserve. While the need for research on fire impacts had been a primary reason for the appointment of the first Biologist in 1951, the fires of 1953 provided the impetus for drawing up the park's first concrete fire research proposal (Nel 1953).

The original proposal was based on recommendations for a fire research programme in the Kruger National Park, emanating from a special visit in 1950 by Dr. Turpin, Dr. Rowland and Mr. Bonsma of the Department of Agriculture. The proposal was that the trial consist of the following six fully randomised treatments in each of the four major veld types: a fire exclosure, an annual and triennial burn in winter, an annual and triennial burn in spring after the first rains, and a triennial burn in late summer (Nel 1953). However, the actual plots laid out between 1954 and 1957 consisted of the following seven treatments: a fire exclosure, an annual burn in August and biennial burns in August, October, December, February and April (Van der Schijff 1958). Each treatment was replicated four times within each landscape, with replicates (strings of treatment plots) spaced across the landscape to maximise their representativity of the landscape (Van der Schijff 1958). The reason for the departure from the original six, carefully considered treatments was not recorded.

During 1955, the Board approved the expansion of the experiment to include annual and triennial treatments in each of the five existing treatment seasons (i.e., February, April, August, October and December) (National Parks Board 1955a). The triennial treatments were added between 1956 and 1958 by demarcating five additional plots at one end of each of the existing replicates. Where this was not feasible, the additional plots were laid out parallel to the existing replicates (National Parks Board 1956; Van der Schijff 1958). The reason why the additional annual treatments were never laid out is not mentioned in the archival material, but probably relates to the physical limitations of burning annually in seasons other than winter. In addition, the fire policy was changed in 1957 to a formal system of burning once every three years in spring (Van Wilgen *et al.* 2000), so that the effects of triennial burns would have been of greater interest than those of annual burns.

The meaningfulness of certain treatments was questioned early on in the trial (National Parks Board 1962). According to this report, an investigation into the background of the trial clearly showed that a number of treatments were included to illustrate or prove the damaging impacts of natural and artificially ignited fires, rather than to meet the original objectives. The report concludes that this value-loaded agenda resulted in the inclusion of certain unnecessary treatments and the exclusion of some crucial treatments, such as treatments with a lower burning frequency or a treatment directly after the first spring rains which was not coupled to a specific calendar month (National Parks Board 1962).

Following detailed vegetation surveys conducted during the early 1970s, it was concluded that the February treatments did not differ significantly from the fire exclosure (National Parks Board 1976). A decision was taken to divide the February plots in half and change the treatments on the resulting four subplots to four- and six-year burns, both before and after the first rains of the season (National Parks Board 1976). This decision accompanied an amendment of the park's fire policy in 1975, which allowed for longer periods between fires in drier areas (Van Wilgen *et al.* 2000). The decision to abandon the February treatments was, however, recalled soon after on the basis that mid-summer burns were practised as part of the general fire policy (National Parks Board 1976) and should therefore be retained in the trial (National Parks Board 1981). Where plots had already been subdivided, one half retained the original treatment (February biennial or triennial) and the other half was intended to receive respectively a four- or six-year treatment before the spring rains. These four- and six-year treatments were soon modified to being applied after the first spring rains because it was felt that, since the general fire policy was to burn after the spring rains, treatments with this timing would yield more useful information.

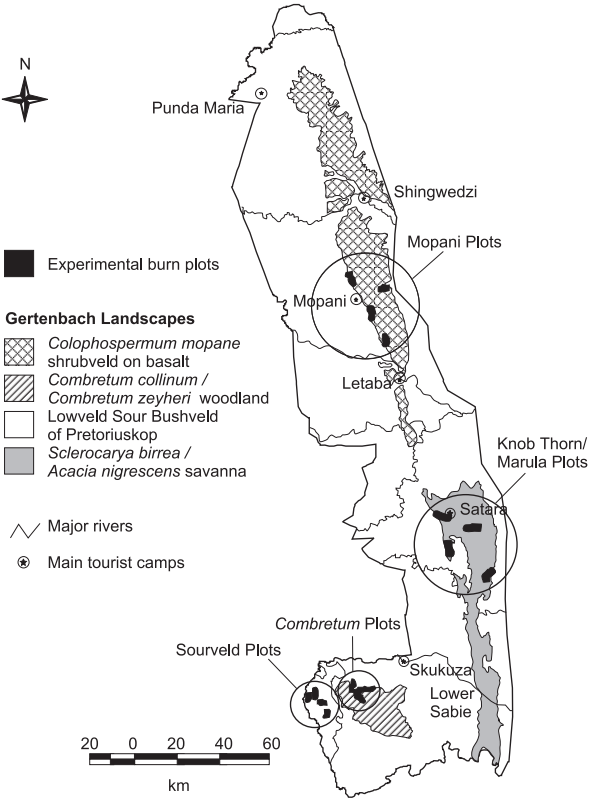

Fig. 1: The trial consists of four replicates (strings of plots) in each of four major vegetation landscapes in the park. Each replicate consists of 12 (Sourveld and Combretum replicates) or 14 (Knobthorn/Marula and Mopani replicates) plots, each of which receives a unique fire treatment (see Table 2).

Various soil, vegetation and animal surveys were carried out during the first 30 years of the trial (National Parks Board 1984). Botanical surveys were conducted on a regular basis from the inception of the trial until the 1980s and narrative-style summaries of results generally recorded in the annual reports of the Biological Section. These reports may provide a qualitative means of investigating the rate of vegetation change in the trial. Survey methods were of particular concern (National Parks Board 1960; National Parks Board 1962) and were addressed by a number of studies (Brynard *et al.* 1960; Von Broembsen 1964; National Parks Board 1974). Several studies investigated treatment-induced soil changes on the plots (National Parks Board 1971; National Parks Board 1978; Webber 1979). Further details of studies conducted on the EBPs, including the detailed half-hectare vegetation surveys conducted during the early 1970s and the 'wrap-up' surveys conducted in the late 1990s, are given by Trollope *et al.* (1998) and Govender *et al.* (2003). Details of more recent studies can be found

in the Annual Project Reports compiled by the Scientific Services Division of the park.

Current experimental design

In statistical terms, the EBP trial is a fractional factorial, partly randomised, complete block design. The experimental design terminology used in this paper is defined in Table 1. The trial is referred to as a fractional factorial design as all treatment frequencies do not occur in combination with all treatment seasons (Table 2). It is a complete block design as all treatments are applied once within each replicate. The trial is only partly randomised as described below.

The trial currently consists of 16 replicates (strings of plots), made up of four replicates in each of the four major Gertenbach (1983) landscapes: Lowveld Sour Bushveld of Pretoriuskop (sandy granitic soils), *Combretum collinum/Combretum zeyheri* woodland (sandy granitic soils), *Sclerocarya birrea/ Acacia nigrescens* savanna (clay basaltic soils), and *Colophospermum mopane* shrubveld on basalt (clay basaltic soils) (Fig. 1). Each replicate consists of 12 full plots, each of which receives a different fire treatment. In the Knobthorn/Marula and Mopani landscapes, October four and six year treatments were introduced in the late 1970s by respectively dividing the February biennial and triennial treatments in half; these landscapes therefore have 14 plots per replicate (Table 2). The plots within each replicate are not fully randomised, but consist of two adjacent randomised sections (Fig. 2). Each full plot is approximately 7 ha in size (370 m x 180 m) and protected by a double firebreak.

Only four treatment randomisations were constructed and each randomisation applied once in each landscape. A replicate in, for example, the Lowveld Sour Bushveld of Pretoriuskop, will have a different plot layout to all other replicates in the Sourveld, but an identical layout to one replicate in each of the other three landscapes. It appears that the four treatment randomisations were not randomly allocated to the replicates in a particular landscape, but were assigned starting at either the most southerly or most northerly replicate.

Table 1
Experimental design terminology as used in this paper

Term	Definition
Treatment	A combination of fire season and frequency (e.g. annual burn in August) applied to a specific plot.
Plot	The smallest experimental unit, approximately 7 ha in size. Plots are grouped together in replicates (Fig. 2).
Replicate	A string of 12 or 14 plots. There are four replicates in each landscape (Fig. 1).
Trial	The full set of 16 replicates, or 208 plots, spaced across four landscapes.

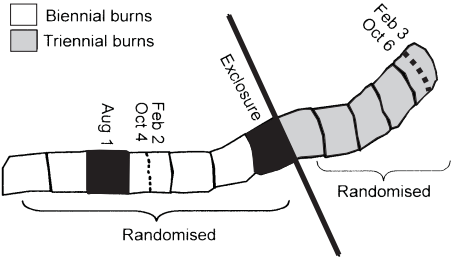

Fig. 2: Each replicate consists of two randomised sections of plots. The first section consists of the fire exclosure, August annual and the five biennial treatments. The second, adjoining section consists of the five triennial treatments. The four- and six-year treatments (only on the Mopani and Knobthorn/Marula replicates) were created by dividing the February biennial and triennial treatments respectively in half.

Table 2
Current fire treatments applied in each replicate of the EBP trial. Treatments were started between 1954 and 1958. The four- and six-year treatments were started between 1976 and 1979

			Season		
Frequency (years)	February (late summer)	April (autumn)	August (late winter)	October (after first spring rains)	December (mid-summer)
1			x		
2	x	x	x	x	x
3	x	x	x	x	x
4				x[a]	
6				x[a]	
>45	Fire Exclosure				

[a]Only on the Knobthorn/Marula plots (Landscape 17) and Mopani plots (Landscape 23)

Confounding factors

Confounding refers to a situation where the effects of experimental treatments cannot be separated from other factors that might be causing the observed differences. The EBP trial was designed with the aim of testing the effects of different seasons and frequencies of burning. 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.

Herbivory and artificial water provision

It was realised from the outset that the trial would be characterised by strong fire-herbivory interactions. Herbivore numbers typically increase for a period following fire (Scholes & Walker 1993). The small size of the plots (approximately 7 ha) compared to the scale of fires in the Kruger National Park (average fire size approximately 2500 ha and median fire size approximately 1000 ha, Van Wilgen *et al.* 2000) result in 'unnaturally high' concentrations of herbivores on the plots (Van der Schijff 1958; Gertenbach & Potgieter 1975; Van Wyk 1975). This problem is mentioned in almost every annual report and highlights the concern it raised, especially with regard to frequently burnt plots. The implication that the plots are therefore not representative of processes in the wider landscape is one of the main reasons for a widely-held perception (Trollope *et al.* 1998) that the trial is of little relevance. The large plot size (in experimental terms) (Nel 1953) and the intended practice of burning veld in the immediate vicinity of the plots when applying treatments (Van der Schijff 1958) were measures aimed at reducing the impacts of herbivory.

Post-fire herbivory has been exacerbated by the introduction of artificial, permanent waterholes into the areas surrounding certain replicates (Gertenbach & Potgieter 1975). Recently Gorman (*in prep*.) compared herbivore numbers on the plots to those in the adjacent non-experimental areas. Initial results indicate that there are significantly more herbivores on the plots than in the adjacent areas, as well as significant variations in herbivore numbers between different treatments. In response to the herbivory problem, herbivore exclosures were erected during the 1970s in the three southern landscapes in which the trial was being conducted to determine the effect of fire in the absence of herbivory (National Parks Board 1972-1974; National Parks Board 1988-1990). Each exclosure contained a number of treatment plots that were significantly smaller than the

Table 3

Suggestions for model specification when analysing EBP data using Analysis of Variance (ANOVA). These model elements apply more broadly to the specification of generalised linear models, such as log-linear and logistic models. The suggestions below relate to the analysis of data from a single landscape. When analysing data from multiple landscapes, model specification becomes more complex (see text)

Issue	Problem	Suggested approach
Blocking	In heterogeneous environments, background variation may obscure treatment effects. Such variation can be reduced by grouping experimental units (plots) into 'blocks' with similar background conditions.	Replicates should be specified as blocks in the model to remove the between-replicate variation from the overall variation in the data, thereby allowing more powerful tests of treatment effects. Replicates should be specified as a random factor, as they represent a subset of the landscape about which conclusions are being drawn.
Pseudoreplication	Repeated measurements on individual plots are incorrectly treated as independent replicates in the model. A very common mistake in ecological field experiments (Hurlbert 1984; Crawley 1993).	1) Calculate the mean value of observations on each plot, and use the single mean value for each plot as input into the model. This, however, excludes the possibility of testing for interactions between factors. If interactions are likely to be important, calculate two mean values for each plot by randomly dividing the observations on each plot into two halves. 2) Individual observations (instead of plot means) can be included in the analysis by specifying 'plot'as an additional blocking factor nested within 'replicate'. This does not change the analysis results. The simpler approach of using mean values as input is therefore recommended.
Estimation of fire season and frequency effects	As a result of the season and frequency factors not being fully crossed or complete factorials (i.e. not all fire frequencies are applied across all seasons, see Table 2), the separate effects of season and frequency of burn can only be examined for biennial and triennial treatments. For the other treatments (August annual, October four and six yearly treatments), only the combined influence of season and frequency can be investigated.	Where all treatments are included in a study, and it is of interest to separate the effects of season and frequency, a possible approach is to run two separate analyses (see Enslin *et al*. 2000): 1) an analysis which includes all treatments without separating the effect of season of burn from that of frequency (i.e. one explanatory variable 'treatment' with 12 or 14 levels), and; 2) a second analysis which includes only the biennial and triennial treatments, with season and frequency specified as independent explanatory variables (season with five levels, and frequency with two levels). Results should be adjusted for multiple testing using the Bonferroni procedure or other suitable multiple comparisons adjustment (Quinn & Keough 2002). Treatment should be specified as a fixed factor in the model.

Table 3 (continued)

Issue	Problem	Suggested approach
Herbivory	'Unnaturally high' herbivory on certain plots, particularly frequently burnt plots and plots in the vicinity of artificial waterpoints.	1) Include 'distance to nearest permanent water' as a covariate (see Enslin *et al*. 2000). 2) Use the herbivore density data of Gorman (*in prep*.) as a covariate in the model.
Soil variation	Certain plots are located on soils that are not representative of the general landscape.	Use the findings of Venter (*in prep.*) as a basis for excluding certain plots or replicates as unrepresentative of the landscape in which they are located. This could also be done using multivariate analysis.
Pre-treatment variation between plots	Current differences between plots may reflect not only the effect of differing treatments, but may also be partly related to variation between plots prior to the start of the trial.	1) Include the 1954 baseline vegetation data as a covariate in analyses. 2) Define the response variable as the change between 1954 and present (if baseline data were collected for the variable of interest) Including a baseline covariate may partly correct for soil variation e.g. local depressions along a replicate string.

EBPs (exclosure plot size 0.04 ha; total exclosure size 2 ha). No results were compiled from these herbivore exclosures, and treatments in the last of these camps, the Makhohlola Exclosure, were stopped during the early 1990s.

Soil variation

Soil variation between replicates in the same landscape, as well as within individual replicates, also raises the issue of representativity of the trial (National Parks Board 1971; Van Wyk 1975; Trollope *et al.* 1998). Webber (1979) concluded that the plots in his study area (the *Combretum* woodland) were not fully representative of the area and that the original siting of the plots should have been preceded by a soil survey. Replicates in the granites are mainly located on the relatively homogenous watersheds (crests), which comprise the majority of the area in these landscapes. This implies that the effects of fire on the low-lying parts of the drainage basins cannot be inferred from the trial. The geomorphic and soil representativity of the plots has been investigated by Venter (*in prep.*), who rated each plot for representativity of its own replicate, as well as of the landscape in which it lies. Each replicate was also rated as a whole for representativity of the landscape in which it is located. The conclusion was that the majority of plots are fair to good representatives of the geomorphic and soil characteristics of their landscapes, but that there are a few outliers.

Treatment compliance

More than 80 % of the total number of scheduled burns that should have taken place to date have been applied. Appendix 1 tabulates the treatment history in each of the four landscapes in which the trial is being conducted. The main reason for deviation from the planned schedule was that certain plots could not be burnt in specific years because the vegetation cover was either too sparse

(due to drought and/or herbivory impact) or conditions were too moist for burning. A number of accidental burns have occurred, either from fires outside the plots jumping the firebreaks or due to fires jumping between plots during treatment applications. Many of the accidental burns occurred during the first few years of the trial before the firebreaks were widened (National Parks Board 1956), and led to the swapping around of several treatment plots during the early years of the trial (National Parks Board 1955a). Other deviations from the original plot layout resulted from plots being damaged by roadworks during the initial demarcation (National Parks Board 1955b). A number of accidental burns have recently occurred on the fire exclosure plots (Napi, Satara, Mbyameti and N'shawu replicates) due to the accumulation of biomass resulting from several years of good rain (Appendix 1).

Suggestions for sampling and data analysis

The design of the EBP trial poses a number of challenges for sampling and analysing data from the trial. While the nature of these problems will vary depending on the specific study, several issues are likely to crop up in almost all studies.

Sampling

The sequence of rainfall-fire interaction on different plots is likely to have an effect on many parameters of interest (Mentis & Bailey 1990; Oelofse *et al.* 1999), and raises the question of comparable periods of observation. Rather than sampling across different treatments at the same point in time, it may be more appropriate to sample certain responses at a set period after a burning treatment has been applied. However, as treatments are applied in different years, such sampling would need to account for interannual variation in factors such as rainfall. By sampling in this manner, it may be possible to conduct specific analyses to determine the generality of post-burn phenomena such as herbivory across treatments.

Data analysis

Data from the EBP trial typically consist of observations (e.g. tree height, termite counts) collected from a selected number of treatments in a specific landscape. Usually multiple observations are made on each plot, and all observations are made at a single time period (i.e. the aim is to detect differences between treatments at a specific point in time, rather than to observe changes on a specific treatment over a period of time). Such data are typically analysed using Analysis of Variance (ANOVA). It is important that the design be correctly specified in the ANOVA, in order to ensure that the correct error term is used in hypothesis testing. Table 3 provides suggestions for model specification where data have been collected from several replicates in a single landscape. Herbivory and soil differences between plots can be accounted for to some extent by making use of results from independent studies of these factors. Where data have been collected from multiple landscapes, 'landscape' should be specified as an additional explanatory factor, and 'replicate' should be specified as nested within 'landscape'.

The lack of full randomisation within replicates (each replicate consists of two separate randomised sections of plots (Fig. 2)), could be accounted for by regarding the trial as having a split-plot design. 'Section' would be specified as nested within 'replicate', and 'plot' as nested within 'section'. In this interpretation, frequency (biennial or triennial) is applied per section, and season of burn applied to the plots within each section. Specifying the analysis in this way is, however, likely to be unnecessarily complicated, and would be largely theoretical as treatment frequency is not in reality applied separately from treatment season.

Where multiple observations on specific plots are conducted over a period of time, and this generates time series data, observations cannot simply be regarded as indepen-

dent. In some cases, a repeated measures form of ANOVA could be used, with time specified as either an explanatory or blocking factor. In other cases, specific time series analysis techniques may be necessary. Three sets of detailed vegetation surveys are available for quantitatively investigating the rate and direction of vegetation change: i) the baseline surveys conducted prior to the start of the trial, ii) the surveys conducted in the early 1970s, and iii) the 'wrap-up' surveys conducted in the late 1990s. The survey method used in the 1970s survey, however, differs substantially from the method used in the baseline and wrap-up surveys and limits the use of this data.

Inference

The small size of the plots in comparison to the typical area burnt by a fire in the park (Van Wilgen *et al.* 2000), implies that inference about scale-dependent processes should be approached with caution. The lack of randomisation in the experiment has resulted in a number of treatments nearly always being adjacent, which may have implications for parameters that are sensitive to edge effects. For example, all triennial treatments are located next to at least one other triennial treatment, 75 % of exclosure plots lie adjacent to a December biennial treatment, and all October four-year treatments lie next to a February two-year treatment. Edge effects may be important especially on the half-size plots (February two- and three-year and October four- and six-year treatments on the basalts). The responses on the half-size October four- and six-year treatments should be interpreted as the composite effect of 25 years of a February two- and three-year treatment, followed respectively by 20 years of an October four- and six-year treatment.

Conclusions

The EBP trial is one of few ongoing long-term fire ecology projects in Africa and provides a basis for valuable research. The trial has several inferential complications. Statistically, the most serious is the lack of full randomisation; other complicating factors are herbivory and soil variability between plots. While the lack of randomisation should be kept in mind, there seems no practical alternative to treating the trial as a fully randomised block design. As argued by Trollope *et al.* (1998) the trial should be interpreted as a fire-herbivory interaction study. The results of Venter (in prep.) can be used to investigate soil-vegetation relationships under different treatment regimes, while the data of Gorman (in prep.) can be used to test for the additional effects of herbivory. The scale of the plots, and hence their representativity of especially scale-dependent processes, is an issue as plot size fires are infrequent in the park and account for only a small proportion of the total area burnt (Van Wilgen *et al.* 2000).

If the trial is to continue in the long-term, it may be worth considering several adjustments. For example, the closure of waterholes within a certain radius of the EBP replicates would remove some of the variation in herbivory. The idea of erecting herbivore exclosures within specific plots, or of entirely fencing certain plots, could be re-explored. If particular treatments are to be suspended or changed (e.g. as proposed by Trollope *et al.* 1998), and the separate effects of season and frequency of burn are of interest, it is essential that these factors be fully crossed (i.e. a minimum of four treatments are needed, consisting a combination of two seasons by two frequencies). The timing of burning should be related to specific conditions (e.g. after the first spring rains), rather than to specific calendar months, and named accordingly. Any modifications should, however, be thoroughly and carefully considered to avoid loss of the long-term value of the trial.

Acknowledgements

Beukes Enslin explicitly pointed out to the current community of researchers that the trial is not fully randomised. The two reviewers are thanked for their insightful contributions. Sandra MacFadyen and

Don Ntsala are thanked for their assistance in the preparation of the map.

References

BRYNARD, A.M., R.L. DAVIDSON, P. GILLARD, G. LECATSAS & J. LEIGH. . 1960. Calibration of the belt transect method in *Combretum* woodland in the KNP. Annexure 'C', Annual Report of the Biological Department, April 1959 - March 1960. Report, Skukuza, South African National Parks.

BRYNARD, A.M. 1971. Controlled burning in the Kruger National Park: History and development. Proceedings of the Annual Tall Timbers Fire Ecology Conference. *Tallahasee, Tall Timbers Research Station* 11: 219-232.

CRAWLEY, M.J. 1993. *GLIM for Ecologists*. London: Blackwell.

ENSLIN, B.W., A.L.F. POTGIETER, H.C. BIGGS & R. BIGGS. 2000. Long term effects of fire frequency and season on the woody vegetation dynamics of the Sclerocarya birrea/Acacia nigrescens savanna of the Kruger National Park. *Koedoe* 43(1): 27-37.

GERTENBACH, W.P.D. & A.L.F. POTGIETER. 1975. Veldbrandnavorsing in die Knoppiesdoring-Maroelaveld van die sentrale distrik, Nasionale Krugerwildtuin. Unpublished Memorandum, Skukuza, South African National Parks.

GERTENBACH, W.P.D. 1983. Landscapes of the Kruger National Park. *Koedoe* 26: 9-121.

GOVENDER, N., A.L.F. POTGIETER & H.C. BIGGS. (*In press*). Scientific value of research conducted on the experimental burn plots in the Kruger National Park. *Proceedings of the International Rangelands Conference.* 26 July - 1 August 2003, Durban, South Africa.

HURLBERT, S.H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54(2): 187-211.

MENTIS, M.T. & A.W. BAILEY. 1990. Changing perceptions of fire management in savanna parks. *Journal of the Grassland Society Southern Africa* 7(2): 81-85.

NATIONAL PARKS BOARD. 1953. Jaarverslag van Bioloog 1951. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1954. Jaarverslag van Bioloog 1953. Item 37, Appendix "N" of the Agenda of the Board meeting held on 25/26 June 1954. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1955b. Jaarverslag van Bioloog 1954. Item 4, Appendix "C" of the Agenda of a Board Meeting held on 21/22 November 1955. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1955a. Veldbrandproewe. Letter from the Director of National Parks to the Warden of the Kruger National Park informing him of decisions regarding the Experimental Burning Trial taken at a Scientific Steering Committee meeting. Reference K.1/14/2(37). Typescript, Skukuza, South African National Parks.

NATIONAL PARKS BOARD.1956. Jaarverslag: Biologiese Afdeling 1955. Item 4, Appendix "C" of the Board Meeting held on 22/23 June 1956. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1960. Jaarverslag: Biologiese Afdeling April 1959 - Maart 1960. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD.1962. Jaarverslag: Departement Natuurbewaring April 1961 - Maart 1962. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD.1971. Afdeling Natuurbewaring Jaarverslag 1970 - 1971. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD.1972. Afdeling Natuurbewaring Jaarverslag 1971 - 1972. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1973. Afdeing Natuurbewaring Jaarverslag 1972-1973. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD.1 974. Afdeling Natuurbewaring Jaarverslag 1973-1974. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1976. Jaarverslag: Departement Natuurbewaring Apr 1975 - Mar 1976. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1978. Department of Nature Conservation KNP: Six-monthly report April - September 1978. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1981. Jaarverslag: Departement Navorsing en Inligting April 1980 - Maart 1981. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1984. NBP Research Report 1983 - 1984. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1988. Jaarverslag: Afdeling Navorsing 1987 - 1988. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1989. Jaarverslag: Afdeling Navorsing 1988 - 1989. Report, Skukuza, South African National Parks.

NATIONAL PARKS BOARD. 1990. Jaarverslag: Departement Natuurbewaring April 1989 - Maart 1990. Report, Skukuza, South African National Parks.

NEL, T.G. 1953. Verslag oor veldbrand. Typescript, Skukuza, South African National Parks.

OELOFSE, J., B.H. BROCKETT, H.C. BIGGS & C. EBERSOHN. 1999. The effect of drought and post-fire grazing on the herbaceous layer of Shrub-Mopane Veld on Basalt in the Kruger National Park, South Africa. *In*: ELDRIDGE, D. & D. FREUDENBERGER (eds.). *People and rangelands - building the future.* Proceedings of the VIth International Rangeland Congress, 19-23 July, Townsville, Australia.

QUINN, G.P. & M.J. KEOUGH. 2002. *Experimental Design and Data Analysis for Biologists*. Cambridge: Cambridge University Press.

SCHOLES, R.J. & B.H. WALKER. 1993. *An African savanna. Synthesis of the Nylsvley study*. Cambridge: Cambridge University Press.

TROLLOPE, W.S.W., A.L.F. POTGIETER, H.C. BIGGS & L.A. TROLLOPE. 1998. Report on the Experimental Burning Plots (EBP) trial in the major vegetation types of the Kruger National Park. Unpublished report no. 9/98, Skukuza, South African National Parks.

VAN DER SCHIJFF, H.P. 1958. Inleidende verslag oor veldbrandnavorsing in die Nasionale Krugerwildtuin. *Koedoe* 1: 60-93.

VAN WILGEN, B.W., H.C. BIGGS, S.P. O'REGAN & N. MARE. 2000. A fire history of the savanna ecosystems in the Kruger National Park, South Africa between 1941 and 1996. *South African Journal of Science* 96: 167-178.

VAN WYK, P. 1975. Memorandum: Veldbrand in die Krugerwildtuin. 14pp. Typescript, Skukuza, South African National Parks.

VON BROEMBSEN, H.H. 1964. Report on two visits to the Kruger National Park. Annexure 'B' of the Annual Report: Nature Conservation KNP Nov 1963 - Oct 1964. Report, Skukuza, South African National Parks.

WEBBER, C.N. 1979. The effects of fire on soil-plant ecological relationships in the southern part of the Kruger National Park: a study in soil geography. M.Sc thesis, University of Pretoria, Pretoria.

Appendix 1

Treatment history and compliance in the EBP trial. For each treatment, the tables reflect the replicates burnt according to schedule in a particular year. Where deviations from the schedule occurred, the reasons and specific plots involved are indicated. Where treatment reports are missing or incomplete, and probable treatment compliance could be inferred with certainty from the rainfall conditions in the particular year and expert knowledge of the plots in question, the inferred treatments are indicated. For example, treatment reports are consistently missing for all the major drought years (1964-65, 1983, 1992-94), and it was assumed that no treatments were applied in these years.

→

Appendix 1 (continued)
Sourveld (Pretoriuskop) Landscape

	Aug 1	Feb 2	Apr 2	Aug 2	Oct 2	Dec 2	Feb 3	Apr 3	Aug 3	Oct 3	Dec 3	Exclosure
1954	√			√	√	√						
1955	√	√	√									
1956	√			√	√	√						
1957	√	?	√									
1958	√			√	√	√	√	√	√	√	√#S	
1959	√	√	√									
1960	√			√	√	√						
1961	√	√	√				√	√	√	√	√	
1962	√	#K		√	√	√						
1963	√	FKNS	√									
1964	√			√	√	FKNS	√	√	√	√	FKNS	
1965	√	√	√									
1966	√			√	√	FKNS						
1967	√	FKNS	?				?	?	√	√	√	
1968	√			√	√	√						
1969	√	?	√									
1970	√			√	√	√	√	√	√	√	√	
1971	√	F	FKNS									
1972	√			√	√	√						
1973	√	√	√				√	√	√	√	√	
1974	√			√	√	√						
1975	√	FKNS	KNS									
1976	√			√	√	√	?	√	√	√	√	
1977	√	N	√									
1978	√			√	√	√						
1979	√	?	√				?	√	√#S	√	√	
1980	√			√	√	√						
1981	√	S	FKNS				(N)					
1982	√			√	√	FS		√	√	√	√#K	
1983	FKNS	√	FKNS									
1984	√			√	FKNS	FKNS	F					
1985	√	?	√					√	√	F	F	
1986	√			√	F	FKNS						
1987	FKNS	√	√				√					
1988	√			√	√	√		√	√	√	√	
1989	√	√	√									
1990	√			√	√	√#S	√					
1991	√	√	√	#F	#F			√	√	√	√	#F
1992	FKNS			√	N	FKNS						
1993	√	FKNS	FKNS				?					
1994	FKNS			S	FKNS	?		FKNS	√	FKNS	FKNS	
1995	√	?	?									
1996	√			√	?	?	FKNS					
1997	√	√	√					√	√	√	√	
1998	√			√	√#K	√						
1999	√	FKNS	√				FKNS					
2000	F			F	F	F		√	√	√	√	
2001	√	FN	F									

(F) Fayi, (K) Kambeni, (N) Numbi, (S) Shambeni

Shaded cells indicate planned treatment schedule. Brackets indicate starting year of a modified treatment schedule.

(√) Plots on all four replicates burnt according to schedule. Where treatments could not be applied on certain replicates due to sparse vegetation or overly moist conditions, the specific plots NOT burnt in the particular year are indicated (remaining plots burnt according to schedule)

(#) Accidental burn on indicated plot (?) Reports missing.

Appendix 1 (continued)
Combretum (Skukuza) Landscape

	Aug 1	Feb 2	Apr 2	Aug 2	Oct 2	Dec 2	Feb 3	Apr 3	Aug 3	Oct 3	Dec 3	Exclosure
1954	√			√	√	√						
1955	√	√	√									
1956	√			√	√	√						
1957	√	√	√									
1958	√			√	√	√	√	√	√	√	√	
1959	√	√	√									
1960	√			√	√	SW						
1961	√	W	MNSW				W	MW	√	√	√	
1962	√			√	√	S						
1963	√	MNSW	√									
1964	MNSW			MNSW	MNSW	MNSW	MNSW	MNSW	MNSW	MNSW	MNSW	
1965	MNSW	MNSW	MNSW									
1966	√			√	√	?						
1967	√	MNSW	MNSW				MNSW	MNSW	√	√	√	
1968	√			√	√	√						
1969	√	MNSW	√									
1970	√			√	√	√	√	√	√	√	√	
1971	√	MNSW	MNSW									
1972	√			√	√	√						
1973	√	√	√				√	√	√	√	√	
1974	√			√	√	√						
1975	√	MNSW	MNSW									
1976	√			√	√	√	?	√	√	√	√	
1977	N	N	W									
1978	√			√	√	√						
1979	√	?	√				?	√	√	√	√	
1980	√			√	√	NSW						
1981	√	M	MNSW				(MNSW)					
1982	√			S	M	MNSW		√	√	√	MNSW	
1983	MNSW	MNSW	MNSW									
1984	√			√	MNSW	?	MNSW					
1985	√	?	√					√	√	√	√	
1986	√			√	√	?						
1987	MNSW	W	S				W					
1988	√	#S		√	√	√		S	√	√	M	
1989	S	MNS	√									
1990	√			√	√	MNSW	√	#M				
1991	S	MNSW	√					√	√	MW	MS	
1992	MNSW			MNSW	MNSW	MNSW						
1993	MNSW	MNSW	MNSW				MNSW					
1994	S			W	MNSW	?		MNSW	MS	MNSW	MNSW	
1995	√	MNSW	MNSW									
1996	√	#S		√	√	?	MNSW		#W	#W	#W	
1997	√	S	√					√	√	√	√	
1998	N	#S		√	SW	SW						
1999	√	MNSW	√				MNSW					
2000	√			M	NS	NS		√	√	N	√	#N
2001	√#N	NS	?	#N	#MS	#S		#M	#M	#M		#M

(M) Mbyameti, (N) Napi, (S) Skukuza, (W) N'waswitshaka

Shaded cells indicate planned treatment schedule. Brackets indicate starting year of a modified treatment schedule.

(√) Plots on all four replicates burnt according to schedule. Where treatments could not be applied on certain replicates due to sparse vegetation or overly moist conditions, the specific plots NOT burnt in the particular year are indicated (remaining plots burnt according to schedule)

(#) Accidental burn on indicated plot (?) Reports missing.

Appendix 1 (continued)
Knobthorn / Marula (Satara) Landscape

	Aug 1	Feb 2	Apr 2	Aug 2	Oct 2	Dec 2	Feb 3	Apr 3	Aug 3	Oct 3	Dec 3	Oct 4	Oct 6	Exclosure
1954														
1955														
1956	√			√	√	√								
1957	√	√	√											
1958	N			√	√	√	√	√	√	√	√			
1959	√	S	√											
1960	√			√	√	√								
1961	L	√	√				√	√	√	√	√			
1962	√			√	LM	LMNS								
1963	LMNS	LMNS	LMNS											
1964	LMNS			LMNS	LMNS	LMNS	LMNS	LMNS	LMNS	LMNS	LMNS			
1965	LMNS	LMNS	LMNS											
1966	LM			S	LM	?								
1967	√	?	?				?	?	L	L	√			
1968	LMN			√	√	MS								
1969	√	LMNS	√											
1970	LMN			L	L	L	L	L	L	L	L			
1971	√	LMN	LMNS											
1972	√			√	√	√								
1973	MN	√	√				L	L	L	L	√			
1974	√#L			√	√	LMNS								
1975	√	?	LMNS											
1976	√			√	√	√	LMNS	√	√	√	√			
1977	M	LMNS	√									√		
1978	√			√	√	√								
1979	√	?	√				N	√	√	√	√		√	
1980	L			√	L	L								
1981	√	LS	LMNS				(LS)					?		
1982	√			√	√	L		√	√	√	L			
1983	LMNS	LMN	LMNS											
1984	S			√	?	LMNS	LMNS							
1985	√	LMNS	√					L	√	L	√	√	√	
1986	LNS			√	√	LMNS								
1987	LMNS	√	M				L							
1988	L			L	L	M		L	L	L	L			
1989	MNS	LMNS	M									?		
1990	√			LS	L	LMNS	LMNS							
1991	LM	√	√					L	L	L	√		L	
1992	LMNS			LMNS	LMNS	LMNS								
1993	LMNS	LMNS	LMNS				LMNS					?		
1994	LMNS			LMNS	LMNS	LMNS		LMNS	LMNS	LMNS	LMNS			
1995	LMNS	LMNS	LMNS											
1996	√			L	?	?	?#S							
1997	√	√	√					√	√	√	√	√	√	
1998	LMNS			M	√	M								
1999	√	S	LM				LMNS							
2000	√			√	√	√		L	√	√	√			#S
2001	√	√	√						#L			LMNS		

(L) Lindanda, (M) Marheya, (N) N'wanetsi, (S) Satara

Shaded cells indicate planned treatment schedule. Brackets indicate starting year of a modified treatment schedule.

(√) Plots on all four replicates in the landscape burnt according to schedule. Where treatments could not be applied to certain replicates due to sparse vegetation or overly moist conditions, the specific plots NOT burnt in the particular year are indicated (remaining plots burnt according to schedule)

(#) Accidental burn on indicated plot (?) Reports missing

Appendix 1 (continued)
Mopani Landscape

	Aug 1	Feb 2	Apr 2	Aug 2	Oct 2	Dec 2	Feb 3	Apr 3	Aug 3	Oct 3	Dec 3	Oct 4	Oct 6	Exclosure
1954														
1955														
1956														
1957	√			√	√	√			√	√	√			
1958	√	√	√				√	√						
1959	T			√	√	√								
1960	D	N	DMNT						√	√	√			
1961	√			√	√	DMT	√	N						
1962	√	T	√											
1963	√			√	√	DMNT			√	√	DMNT			
1964	DMNT	DMNT	DMT				DMNT	DMNT						
1965	DMNT			DMNT	DMNT	DMNT								
1966	√	DMNT	DMNT						√	√	?			
1967	√			√	√	√	?	DMNT						
1968	√	√	MN											#T
1969	√			√	√#T	√		#M	√	√	√#T			
1970	MT	√	√				√	M						
1971	√			T	T	DMT								
1972	√	DMNT	√						√	√	√			
1973	DT			√	√	DMNT	N	√						
1974	√	DMNT	√#D						#T					
1975	DMN			√	√	√			√	√	√			
1976	√	?	√				?	N				√		
1977	NT			T	√	N#M								
1978	√	?	√						√	D	√			
1979	DMNT			√	M	M	?	√					√	
1980	√		MT									D		
1981	√	(√)	#M	√	√	√	(√)	#M	√	D	√			
1982	M		M					DM						
1983	DMNT	DMNT		DMNT	DMNT	DMNT								
1984	DMNT		DMNT				DMNT		DMNT	DMNT	DMNT	?		
1985	√	?		√	√	√		√					√	
1986	DMNT		NT											
1987	DMNT	T		DMNT	DMNT	?	NT		MT	T	DMNT			
1988	T		NT					MT				√		
1989	DMN	√	(√)	T	DMNT	?								
1990	MN						DMNT		√	DMNT	DMNT			
1991	DMNT	DMNT	√	DMN	MN	DMNT		?					NT	
1992	DMNT											?		
1993	DMNT	DMNT	DMNT	DMNT	DMNT	DMNT	DMNT		DMNT	DMNT	DMNT			
1994	DMNT							DMNT						
1995	DMNT	DMNT	DMNT	DMNT	DMNT	?								
1996	DMNT						?		D	?	?	?		
1997	√	√	√	√	DT	√		√					DT	
1998	DMNT													
1999	M	MN	√	√	√	√	MT		√	√	√			
2000	√							√				√		
2001	√	√	N	√	√	√								#N

(D) Dzombo, (M) Mooiplaas, (N) N'shawu, (T) Tsendi

Shaded cells indicate planned treatment schedule. Brackets indicate starting year of a modified treatment schedule.

(√) Plots on all four replicates in the landscape burnt according to schedule. Where treatments could not be applied to certain replicates due to sparse vegetation or overly moist conditions, the specific plots NOT burnt in the particular year are indicated (remaining plots burnt according to schedule)

(#) Accidental burn on indicated plot (?) Reports missing