An investigation of macro-charcoal production and deposition in the experimental burn plots of Hluhluwe-Umfolozi Park, South Africa

By: Liliyane I.J. Mendel[a],

Supervisor: Dr Lindsey Gillson[ab]

[a]*Department of Botany, University of Cape Town, Private Bag X1, Rondebosch 7701, South Africa.*

[b] *Plant Conservation Unit, Botany Department, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa*

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I am unsure what your predictions were & consequently your conclusions are unclear

Abstract

There is a lack of analyses of charcoal from contemporary fire events, which would help interpret paleoecological charcoal records. Savannas are especially vulnerable to changes in disturbance regimes and therefore a better understanding of these disturbance regimes is essential for its conservation. Fire, an important large disturbance in mesic savannas, needs to be managed correctly in order to conserve the savanna and for this a better understanding of past regimes is essential. This investigation looks at how a contemporary fire and the burning ? vegetation, in a South African savanna, are reflected in the macro-charcoal. To investigate this, traps ~~are~~ were countersunk into the ground within and around experimental burn plots in Hluhluwe-Umfolozi Park. The charcoal ~~is~~ was sieved into two size classes and then counted. Small (150 - 500μm) and large (500 - 2000μm) charcoal abundance drop~~s~~ped drastically within the first 10 m of burn, after which there ~~is~~ was no relation with distance. Small and large charcoal particle abundance ~~is~~ was to what? significantly different and with what? positively correlated. Tree density ~~is~~ was negatively correlated with small charcoal particle abundance and grass density ~~is~~ was positively correlated with large charcoal particle abundance. There ~~is~~ was an increase in charcoal abundance downwind of the predominant winds during and after the fire. The ratio of small to large particles does not reflect the distance from the burn. Although there ~~are~~ were high levels of spatial variability, especially in terms of particle size distribution, despite this there ~~are~~ were clear differences between burned and unburned areas. The clear differences between burned and unburned areas can be used to interpret palaeorecords. To confirm the relationship with vegetation and charcoal abundance more studies are needed to strengthen these findings and use this for interpretation of palaeorecords.

Key-words: Charcoal abundance, dynamic ecosystems, fire, grass density, palaeoecology, savanna, tree density.

Abbreviations: Disk pasture method (DPM), Hluhluwe-Umfolozi Park (HUP), Hluhluwe Game Reserve (HGR), spring burn (SP), standard error (SE), winter intense burn (WI), winter mild burn (WM)

Introduction

There is a growing emphasis on the ecological role of fire and its role in preserving and managing present biodiversity (Conedera *et al.*, 2009; Archibald *et al.*, 2005). Fire is one of the large infrequent disturbances that can have a lasting and significant effect on shaping an ecosystem's development (Gillson, 2006). Fires do not only reflect climatic and biological factors, but also anthropogenic activities and thus cultural background of how ecosystems and fires were managed in the past (Conedera *et al.*, 2009). Fire is a critical driver in mesic savanna ecosystems (Archibald *et al.*, 2005; Bond *et al.*, 2005). Analysis of charcoal in lake sediments has been used to understand fire history over long time periods (Whitlock & Larsen, 2001). The incomplete combustion of organic matter produces particulate charcoal, which provides direct evidence of burning (Conedera *et al.*, 2009). Charcoal analysis can extend and complement previous dendrochronological and historical work (Whitlock & Larsen, 2001). To reconstruct fire regimes, historical data have been used from the geosphere, biosphere, anthroposphere and palaeoecology (Conedera *et al.*, 2009). Such records are often difficult to interpret, however, because of the complex interplay between fire intensity, area, distance and type of vegetation with charcoal abundance (Gardner & Whitlock, 2001; Whitlock & Larsen, 2001). There are three primary sources used for fire reconstruction based on lake-sediment records: pollen evidence, particulate charcoal and ~~lithologic~~ lithological evidence (Whitlock & Larsen, 2001). However, analysis on modern charcoal deposition and transport is rare and is also needed to calibrate historic charcoal data (Whitlock & Larsen, 2001).

NP

Climate plays a large role in determining global vegetation types and has been strongly correlated with global vegetation patterns (Bond *et al.*, 2003; O'Brien *et al.*, 2009). In turn, accumulation of vegetation contributes to fire frequency and intensity (Bond *et al.*, 2003; Carcaillet *et al.*, 2001). In Hluhluwe-Umfolozi Park, for example, the lower lying southern areas i.e. Umfolozi Park, receive less rain therefore having less grass and experience less intense fires compared to the wetter northern Hluhluwe Park with its tall grass swards (Bond *et al.*, 2001). The northern portion of the park (Hluhluwe) supports a mesic savanna with an average rainfall of approximately 750 mm of rain per annum increasing to approximately 1000 mm/pa on the higher hilltops some of which support closed forest, reflecting the higher rainfall conditions at these altitudes (Waldram *et al.*, 2008). The southern portion of the park (Umfolozi) supports a semi-

spelling

spelling

poor sentence construction

v. long sentence

600 mm per annum is not semi-arid by any stretch of the imagination!

arid savanna with rainfall approximately 600mm/pa (Waldram *et al.*, 2008). However it is not climate alone that controls vegetation and fire. Even if the weather is not conducive to fire ignition and spread, fires can occur if the vegetation is highly flammable as a result of fuel accumulation/ and low or moisture content (Carcaillet *et al.*, 2001). CO_2 concentrations a~~e~~ffect rates of successional recovery (Bond *et al.*, 2003). High CO_2 allows trees to outgrow fire height within fire intervals and thus affects the location of ecosystem boundaries (Bond *et al.*, 2003). Direct climate control of vegetation is overridden by fire in some parts of the world and it is these vegetation types that are therefore very sensitive to both climatic and human control of the disturbance regime (Bond *et al.*, 2003). In many grassy ecosystems, fire limits trees and a Sheffield Dynamic Global Vegetation Model (SDGVM) simulation of South African vegetation indicates that ecosystem structure at higher rainfall sites are strongly influenced by burning (Bond *et al.*, 2003). Hence a better understanding of past fire regimes and vegetation switches is important for the management of such parts of the world. The four components referred to by fire regime include the type, intensity, season and frequency of burning and a further component, which is of particular interest when considering the influence of fire at a landscape level, is the spatial aspect (Balfour & Howison, 2001). To understand these four components of fire regimes in the past by looking at palaeorecords, a better understanding of macro-charcoal production and deposition is necessary.

reference should be Woodward

confusing sentence! What are you trying to say?

Savannas are an example of a largely disturbance controlled biome (Bond *et al.*, 2005; Gillson, 2004). Savannas are highly dynamic mixtures of trees and grass, which are influenced by site conditions, variation in rainfall, fire and herbivory (Scholes & Archer, 1997). Savannas have been pinpointed as a vegetation type vulnerable to whole ecosystem changes with global climate change (Bond *et al.*, 2003). However, it is not as simple as an increase in tree density with global climate change; other variables such as herbivore density also play a role (Bond *et al.*, 2001; Waldram *et al.*, 2008). There are interactions between fire and grazers too, which need to be understood (Archibald *et al.*, 2005). It is not possible to manage soils and rainfall; However, it is possible to manage fire and to use fire to manage animal-movements and vegetation dynamics (Archibald *et al.*, 2005). In order to confirm suggestions that landscape scale changes in grass cover and forest encroachment are caused by changes in the relative importance of fire and herbivory (Bond *et al.*, 2001), we need to investigate past fire regimes and changing vegetation types in combination. Grazers have the ability to alter fire regimes, for example by grazing grasses short enough that they create biologically induced barriers to the spread of fire (Waldram *et al.*, 2008). Bond *et al.* (2001) suggested that Hluhluwe has changed from a grazing to fire-dominated system during the 20th century. Where higher rainfall prevails fire-dominated systems are more likely to exist and grazer-dominated systems where rainfall is lower, however in areas of intermediate rainfall both types of systems can be supported (Waldram *et al.*, 2008). Hluhluwe is supposedly an area of such intermediate rainfall (Waldram *et al.*, 2008; Bond *et al.*, 2001); a better understanding of the palaeorecords would be able confirm this interplay.

The use of stratigraphic charcoal data to interpret combustion at a range of spatial and temporal scales is based on the assumption regarding how charred particles are transported to and deposited in sedimentary basins. Furthermore, how the variance in structure of stratigraphic – incomplete sentence profiles are affected by transport (Clark & Patterson, 1997). Palaeorecords such as sediment samples from lakes are analyzed for charcoal and charcoal density in order to reconstruct local fire history (Carcaillet *et al.*, 2001). Fire reconstructions can be based on charcoal measurements form lake sediments, peats, soils, or dune sediments (Carcaillet *et al.*, 2001). Such palaeorecords may be used to determine fire return intervals as well as fire and vegetation-recruitment dynamics (Brubaker *et al.*, 2009). Paleoecological data are commonly used to determine what the 'natural' state of an ecosystem is (Heyerdahl & Card, 2000). To interpret charcoal layers in palaeorecords a better understanding of how charcoal reflects fire and vegetation characteristic is necessary.

In order to interpret past patterns of fire in the charcoal record to manage savannas, knowledge on the relationship between production and transport of charred particles during fires is required (Clark *et al.*, 1998; Ohlson & Tryterud, 2000). Ohlson and Tryterud (2000) showed that macroscopic charcoal is reliable evidence of local fire influence. In an attempt to investigate the past fires of the HUP we need to understand how the present vegetation and fires are reflected in charcoal.

Aims

In this study, we analyze charcoal samples collected from traps set within and at set distances from experimental burn-plots. We investigate how charcoal abundance varies with distance, tree abundance and grass density. Charcoal traps were set within and at increasing distances from experimental burn plots, in order to examine:

a) The relationship between charcoal abundance and distance from the burn plot
b) How differences in vegetation (standing biomass, tree: grass composition) within plots are reflected in the charcoal signal
c) The relationship between wind direction and charcoal distribution
d) How the ratio of small to large particles changes with distance from the burn

ah hah! At last I see what you should have put in the Abstract

Clark *et al.* (1998) found that particle flux to the ground declines sharply within 5m of the burn edge and has variable distribution without trend to a distance of 60m. Therefore we expect to find a sharp decline in charcoal collected per trap with distance from the burn plots. The traps within the burn sites are expected to have the highest amount of charcoal and it is expected to decrease with increasing distance from the burn site (Gardner & Whitlock, 2001). Since vegetation plays a large role in contributing to the fire intensity and extent, as well as frequency, (Carcaillet *et al.*, 2001; Enache & Cumming, 2004), we expect a positive/negative? relationship between vegetation and charcoal abundance. The structure and size of charcoal particles are a function of the pyrolysis regime and wood characteristics (Enache & Cumming, 2004). Tinner and Hu (2003) found that shrub tundra species had on average larger charcoal particles than the forest samples. Thus, we might expect the only one! plot with lower tree density to have a higher fraction of larger charcoal particles. It is well established in the literature that charcoal fragments are transported by wind (Pisaric, 2002; Enache & Cumming, 2004). However, the effect of aerial transport ~~in~~ savanna fires is not as well understood. We expect a significantly larger amount of charcoal in front of the predominant winds. The ratio of small to large particles is expected to increase with distance from the burn as the smaller lighter particles can be carried further in the air (Ohlson & Tryterud, 2000).

What does this mean?

in one sentence you say it is well known & in the 2nd you say it isn't!

We haven't heard yet how many plots you had and how they differed in tree and grass density.

This study aims to help interpret future palaeoecology studies of lake sediment cores from Hluhluwe-Umfolozi Park. As suggested by Archibald *et al.* (2005) the park has the potential for large-scale vegetation changes; although the ~~however~~ what causes of these large-scale vegetation changes is not clear. Perhaps it is due to CO_2 fertilization, which alters post-burn recovery rates (Bond *et al.*, 2001). — incomplet sentence In order to better understand this we need to examine ~~look at~~ past vegetation changes and the what role that fire played in this. This calibration exercise involves setting charcoal traps around the Hluhluwe burn plots in order to determine how charcoal abundance varies with distance and prevailing wind. Results of the study will be used in later palaeoecological research comparing vegetation change, fire history and climate in Hluhluwe-Umfolozi. These data will then be considered in terms of the implications for interpretation of charcoal records in pollen preparations.

Materials and Methods

Study site

The study was conducted in Hluhluwe Game Reserve (HGR), part of the Hluhluwe-Umfolozi Park (HUP) in the northern Kwa-Zulu Natal, South Africa (28°00'-28°26'S; 31°43'-32°09'E, Figure 1). HUP is a mesic savanna system that which covers an area of 90 000 ha with a varied topography (Bond *et al.*, 2001; Archibald *et al.*, 2005). The park is very hilly and altitude ranges from 40m to 750m above sea level, with mean annual rainfall ranging from 600-1000mm, generally increasing with altitude (Balfour & Howison, 2002). Within HUP, there are three broad vegetation types: the grassland and forested hilltops, riverine forest strips (Acocks, 1975). you say 3 and then describe only 2! The majority of the park is dominated by fine-leaved Acacia (italics) savanna trees scattered in the grassland, with some areas of closed broad-leaved woodland in riverine forest strips (Acocks, 1975). In accordance with savanna ecosystems, the HUP Acacia savanna ranges from open through to closed canopy patches. what does this mean? The dominant grass species is *Themeda triandra* Forsk (no italics), a tall, bunch-grass, which forms part of the grasslands within the park and is highly flammable (Balfour & Howison, 2002; Bond *et al.*, 2001; Archibald *et al.*, 2005). The park has a wide array of mammal species (Bond *et al.*, 2001). Through the last century, mammal populations in HUP have fluctuated greatly due the effects of disease, culling and other management inventions (Waldram *et al.*, 2008). HUP has been the last refuge for white rhinoceros Ceratotherium simum Rhino since the beginning of the 20th century and the park also supports a full complement of predators, browsers and other grazers (Waldram *et* *al.,* 2008). In comparison with other conservation areas, the herbivore biomass in HUP is high (~12,500 kg/km^2; Waldram *et al.*, 2008).

The fire history of HUP is well documented post 1950s. Prior to this information, knowledge on fire regimes in the area is scarce, however, there are accounts of anthropogenic use of fires by early travelers (Balfour & Howison, 2002). Since the 1950s, ~~when fire records were first collected~~, fire regimes have been very variable (Balfour & Howison, 2002; Archibald *et al.*, 2005). Thickets and forests probably represent the climatic potential for plant growth, within the HUP, in the absence of top-down control by fire and herbivory and once established they seldom burn (Bond *et al.*, 2001). what are you trying to say?

~~The opportunity to do this study in HUP arose because~~ I used of experimental burn plots under close surveillance and with a monitored fire regimes and vegetation since 2005. There are four plots (500m x 500m), each undergoing a different treatment for the past 4 years. There is a control plot (NB), which has not been burnt since the start of the experiment, a winter intense (WI) burn plot which has been burnt at the end of winter every year since the start of the experiment and there is the winter mild (WM) plot which ~~is~~ has been burned at the beginning of winter each year since the start of the experiment. Lastly there is the spring burn (SP) plot, which is burned in spring every year. For this investigation, however, it was the last year of the experiment and it was decided that all plots except the control will be burned at once with one fire. This project is being run by ZLTP (Zululand Tree Project). relevance The Gontshi North plots (Figure 2) were used for this investigation as their burn time fell within the time of this project and were all at a similar altitude, 830-890m, with little topographic variation.

note difference in spelling!

Figure 1: Kwa-Zulu Natal, South Africa, showing the location of the Hluhluwe-Umfolozi Park.

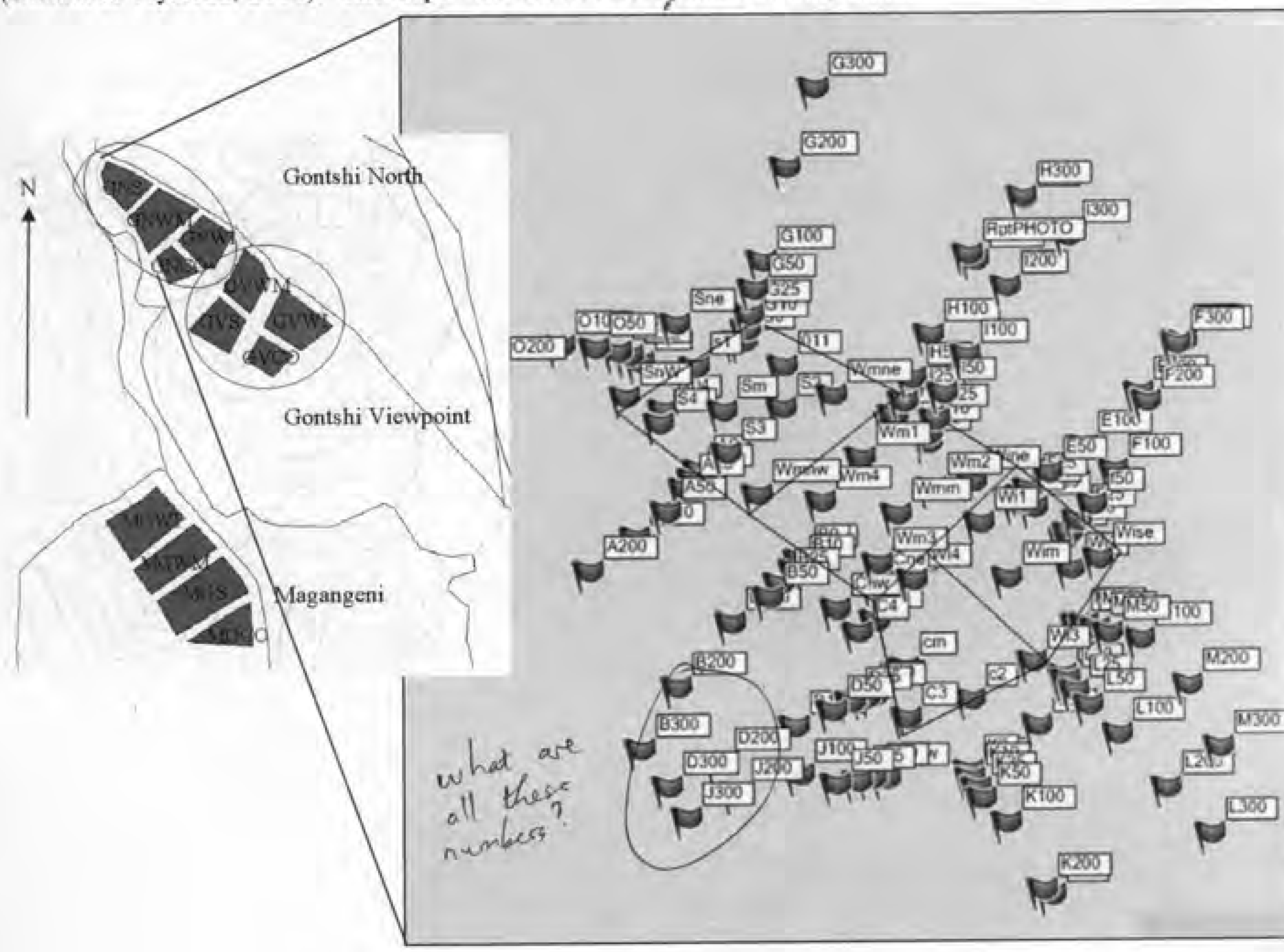
Field work

A total of 119 aluminium baking tins, were used to trap charcoal produced by fires (Ohlson & ? Tryterud, 2000). Each trap was 11 cm? x 22 cm and depth was 5.5 # cm (photo on cover page). Traps were located both inside and outside of the planned burn area. 'Inside traps' refer to traps which were directly burn~~t~~ed over, whether inside or outside the planned burning plot, and all other traps that were not burn~~t~~ed over are referred to as 'outside traps'. Outside traps were arranged in transects with different orientation from the burn edge (Figure 2). A trap was placed in the centre and at each corner of each plot and then another trap half way from the point to each corner of the plot (Figure 3). Transects were run from the edge of the plots at approximately 90° to the edge of the plot. A trap was placed on the edge of the plot at the beginning of the transects, then 10, 25, 50, 100, 200 and 300 metres away from the edge of the plot. The distances were measured by my

what does this mean?

relevance? #

calibrated number of steps, which was done according to the number of steps within 10m. The containers were dug into the dry soil next to the tallest shrub or tree closest to the point ~~needed~~ used, the shrub/tree was marked with danger tape ?meaning? and a GPS co-ordinate meaning? was taken. The traps were countersunk into the soil so that the rim was in line with the soil surface, with the intention that the organic surface soil would not burn down to a level lower than the brim of the charcoal trap (Ohlson & Tryterud, 2000). The traps were set out from ~~the~~ 21-23 July 2009.



what are all these numbers?

Figure 2: The burn plots in Hluhluwe Game Reserve, showing the location of particle-traps within and around the Gontshi North burn plots. How big is this area?
GNS – Gontshi North spring burn, GNWM – Gontshi North winter mild burn, GNWI – Gontshi North winter intense burn, GNCO – Gontshi North control/no burn, GVS – Gontshi Viewpoint spring burn, GVWM – Gontshi Viewpoint winter mild burn, GVWI – Gontshi Viewpoint winter intense burn, GVCO – Gontshi Viewpoint control/no burn, MGS – Magangeni Spring, MGWM – Magangeni winter mild, MGWI – Magangeni winter intense burn, MGCO – Magangeni control/no burn.

Because of weather and the delay in the burn schedule of HiP the plots were only burnt on the 1 September 2009 and traps were collected from the 3-4 September. The traps were closed by folding the brim together and transported in labeled Ziploc bags. Large charred wood structures, i.e. twigs, were cut in line with the brim of the trap. Some traps were burnt and others were found outside their hole, therefore the analysis is based on data from 70 traps (17 inside and 53 outside). During collection tree density was measured at set distances along the transects using closest individual method as described by Cottam and Curtis (1956). Within plot tree density and grass density (DPM for details of method see Archibald *et al.*, 2005) was obtained from the ZLTP September 2009 Research Database. Each fire plot contains one rectangular tree sampling plot of 100m by 15m, in which the species name for all trees encountered was recorded. DPM (disk pasteur method) was used to obtain grass density readings in the vicinity of the tree sampling plot before the fire, in order to calculate fuel load.

2009, I presume?

of what?

to when?

what does this mean?

?

I presume that you were not pasteurizing milk! I guess this should read "pasture"?

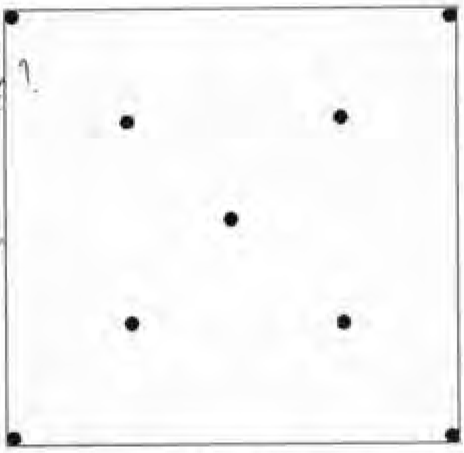


Figure 3: Layout of inside traps for all plots, black points indicate trap location.

Is this a useful figure? How big is this area? What is the distance between traps?

Charcoal analysis

The samples were dry-sieved in a 2.0mm, 0.5mm and 150μm mesh to obtain three size classes, namely small (150μm-0.5mm) and large (0.5-2.0mm), the micro-charcoal (<150μm) was stored in plastic bottles for later analysis. This method of charcoal preparation has been shown to be the least likely to fragment or destroy charcoal particles during preparation (Rhodes, 1998). The analysis of large charcoal fragments (>150μm) is considered to be the most reliable technique to why "thus"?

reconstruct past forest fires with lake sediments (Whitlock & Larsen, 2001), thus we analyzed these size-classes.

The sieved samples were then weighed and of the total sample collected a subsample was poured into a petri dish and weighed. This proportion of sample was suspended in 10% Hydrogen peroxide (H_2O_2) overnight to bleach the organics excluding the charcoal (Stevenson & Haberle, 2005; Rhodes, 1998), thus facilitating the identification of charcoal. The charcoal particles of the subsample, which were treated with H_2O_2 overnight, were counted under a stereoscope (Leica Zoom 2000, model EZ4) in a petri dish which ~~was placed~~ on a pie graph the diameter of the petri dish (Figure 4). Six widely distributed of the 16 slices of the petri dish pie chart were counted in order to account for uneven particulate dispersion (Rhodes, 1998). The charcoal particles were identified on the basis of including fragments that were of angular form, opaque and black (Rhodes, 1998) as the error incurred through misidentification is insignificant when using this method (Blackford, 2000).

i.e.

not sure what this means

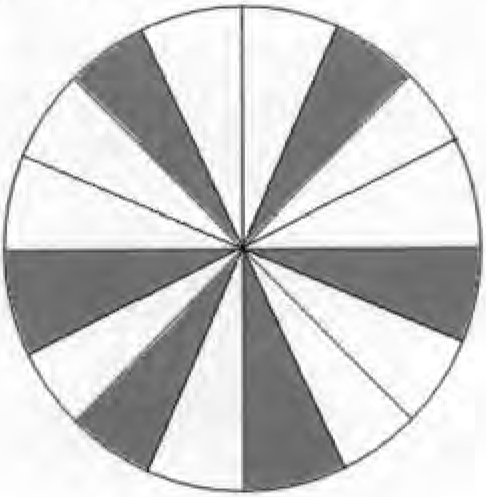


Figure 4: Pie chart, like that placed under the petri dish, and the shaded areas indicate sections counted (not actual size).

Statistical analysis

not relevant

STATISTICA 8 was used for all statistical tests and Microsoft Office Excel 2007 was used to plot graphs. The data was not normally distributed and thus nonparametric tests were used for why didn't you rather transform the data? There is more statistical power in a parametric test

statistical analysis. The average number of small and large charcoal particles were tested for difference using a sign test and then using a Spearman Rank Order Test the relationship between the two size classes was tested. A Spearman Rank Order correlation was used to test the relationship between both large and small charcoal particle abundance with distance from the burn plots. A Kruskal-Wallis test was used to test for significant differences in charcoal abundance, tree density as well as grass density between the different plots. A *post hoc* multiple Mann-Whitney ~~Us~~ test was performed if a significant difference was found. To test the relationship between tree density as well as grass density and charcoal abundance, a Spearman Rank Order correlation was used. In order to test the difference in charcoal abundance of transects in front of versus behind the predominant winds, a Mann-Whitney U test was performed. In testing for a relationship between charcoal size ratios and proportion of? versus distance a Spearman Rank Order correlation was used.

l.c.

l.c.

italicize

did you perform a Bonferroni adjustment of alpha?

Results – You obtained the results; hence, use past tense throughout

The number of small charcoal particles per trap within and outside burn plots ~~is~~ was positively correlated (R = 0.8698, p <0.05, Spearman Rank Order correlation) with the number of large charcoal particles within and outside burn plots. The average number of small charcoal particles is significantly different to the average number of large charcoal particles (Z = 5.480, p = 0.00, sign test), for both inside and outside traps. As the number of large charcoal particles decrease, so do the small particles.

2 units after decimal is sufficient

never is exactly 0. Suggest writing $p < 0.001$

I presume that you lumped these data?

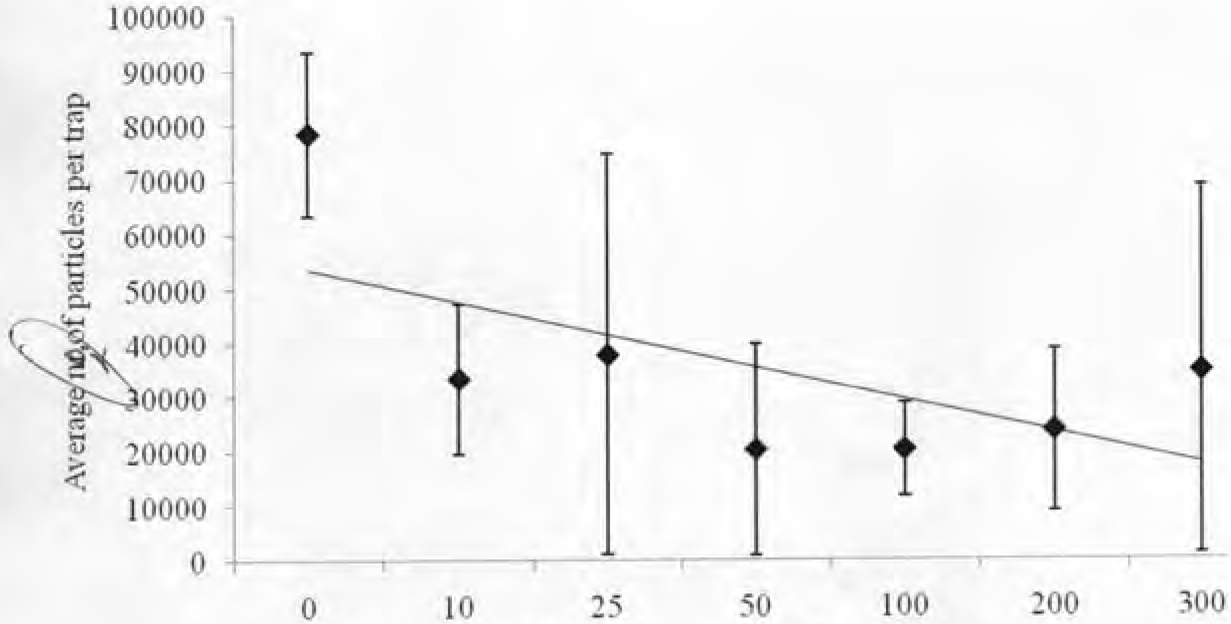


Figure 5: Average number of small particles (±SE) per trap according to distance from edge of burn plot, showing a linear trend (R = -0.0379, p <0.05, Spearman Rank Order correlation).

A correlation of -0·04 is a very weak trend. An r value >0·6 is considered large.

Small (150 – 500 µm) charcoal particle abundance declined steadily with increasing distance from the burn plots (R = -0.3787, p <0.05, Spearman Rank Order correlation, Figure 2). There ~~is~~ was a sudden decrease in small particle charcoal abundance between 0 # m and 10 # m (p =0.002, t = 3.1725, df = 67, independent t-test). Although there ~~is~~ was a significant negative relationship between small charcoal fragment abundance and distance from edge of burn plot it is important to note that there is a large standard error (SE) associated with many of the points. After the first 10 # m, excluding 0 # m, there ~~is~~ was no significant relationship between distance from burn and charcoal abundance (R = - 0.173, p >0.05, Spearman Rank Order correlation).

I thought that you were only using non-parametric tests?

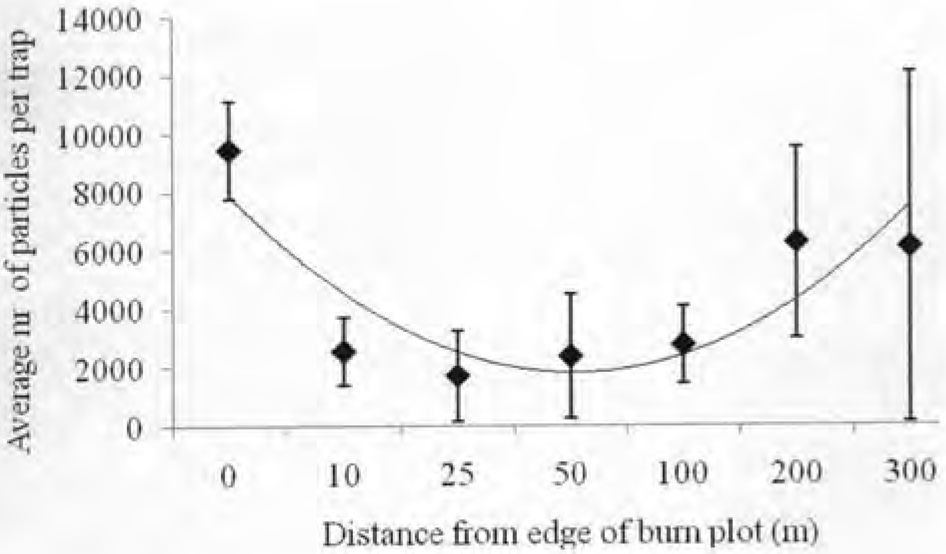


Figure 6: Average number of large particles (±SE) per trap according to distance from edge of burn plot, showing a polynomial trend (R = -0.3~~284~~, p <0.05, Spearman Rank Order correlation).

unaware that you can do this with a Spearman Rank

There ~~is~~ was a significant relationship between distance from burn and large (500 – 2000 μm) charcoal particle abundance (R = -0.328, $p < 0.05$, Spearman Rank Order Correlation, Figure 6), ~~h~~However, from Figure 6, one can see that it is a very different pattern that emerges compared to that of small particle abundance (Figure 5). The large particle~~s~~ abundance also decline~~s~~d significantly between 0m and 10m from the plots (p = 0.0126, t = 2.5625, df = 68, parametric test independent t-test). Once again it is important to note the large SE associated with some points. After the first 10m, excluding 0m, there ~~is~~ was no relationship between distance from burn and charcoal abundance (R = - 0.156, p <0.05, Spearman Rank Order correlation).

this indicates that there was a significant relationship!

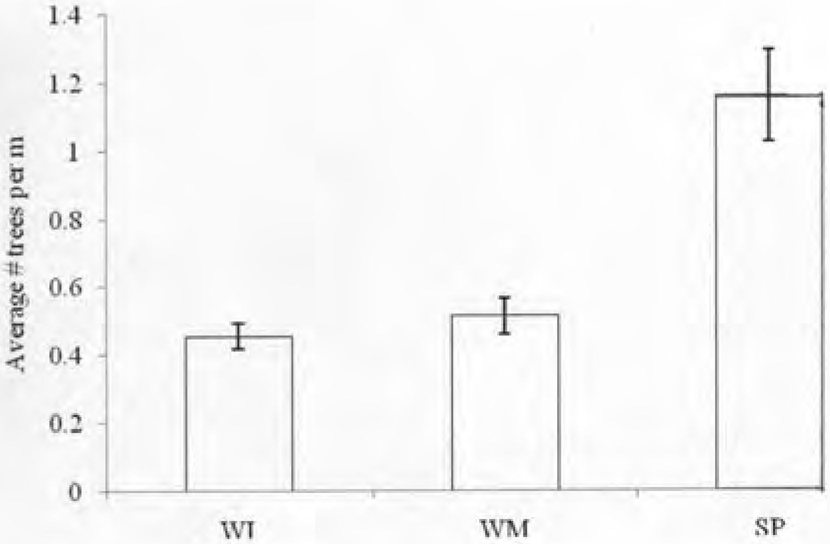


Figure 7: Average tree density for burn treatments ($H_{(2)}$ = 15.153, p = 0.0005, Kruskal-Wallis test). WI = winter intense, WM = winter mold and SP = spring burn.

italics test ?

Table 1: Post hoc multiple Mann-Whitney Us of tree density within plots with different burn treatments, values in bold are significant (p <0.05).

what are these numbers

	SP	WM	WI
SP		**0.009214**	**0.000737**
WM	**0.009214**		1.000
WI	**0.000737**	1.000	

remind us what these acronyms mean

The tree density of the SP plot is approximately double that of the WM and WI plots. The WI and WM have very similar tree densities (Figure 7).

Rather messy

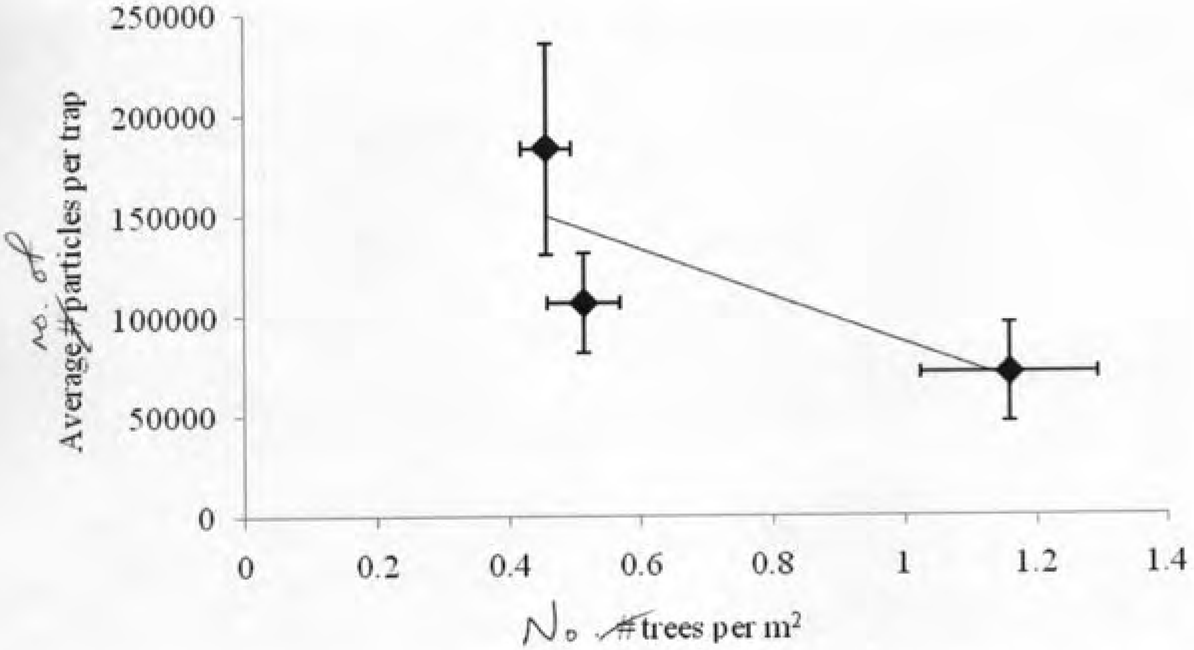


Figure 8: Average number of small charcoal particles per trap (SE) within plots in relation to tree density within plots, showing linear trend (R = -0.596940, $p < 0.05$, Spearman Rank Order correlation).

As tree density increases the number of small charcoal particles per trap decreases. There ~~is~~ was a strong negative relationship between small charcoal particle abundance and tree density (stats?)

Rather messy - write into text

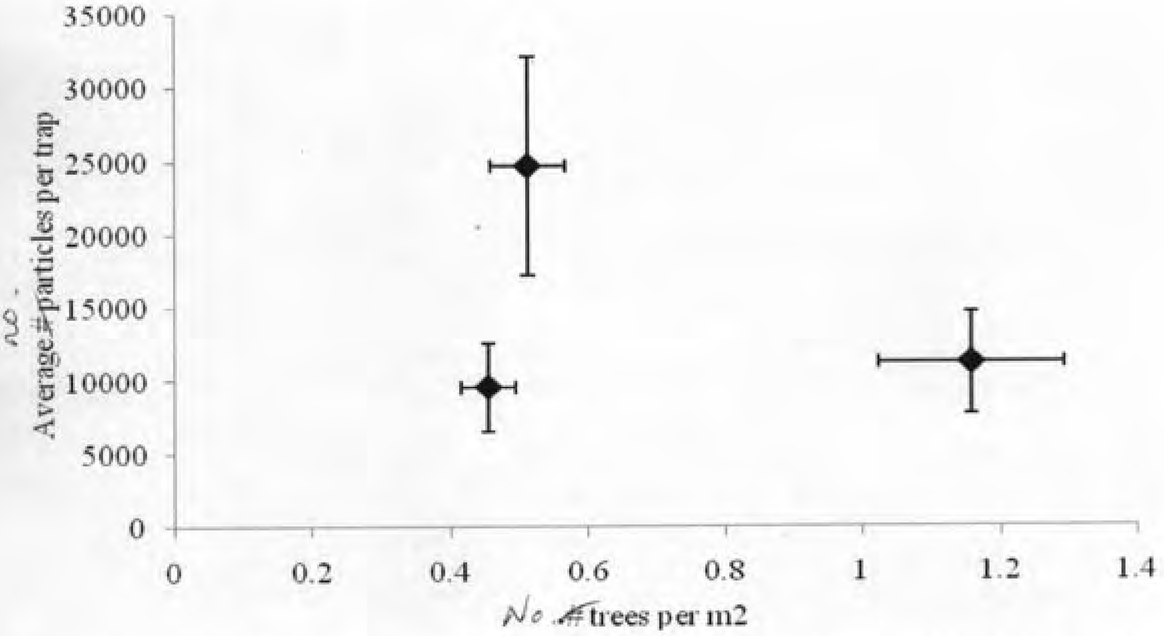


Figure 9: Average number of large charcoal particles per trap (SE) within plots in relation to tree density within plots ($R = 0.218393$, $p > 0.05$, Spearman Rank Order correlation).

There ~~is~~ was no relationship between tree density and large charcoal particle abundance. (stats?)

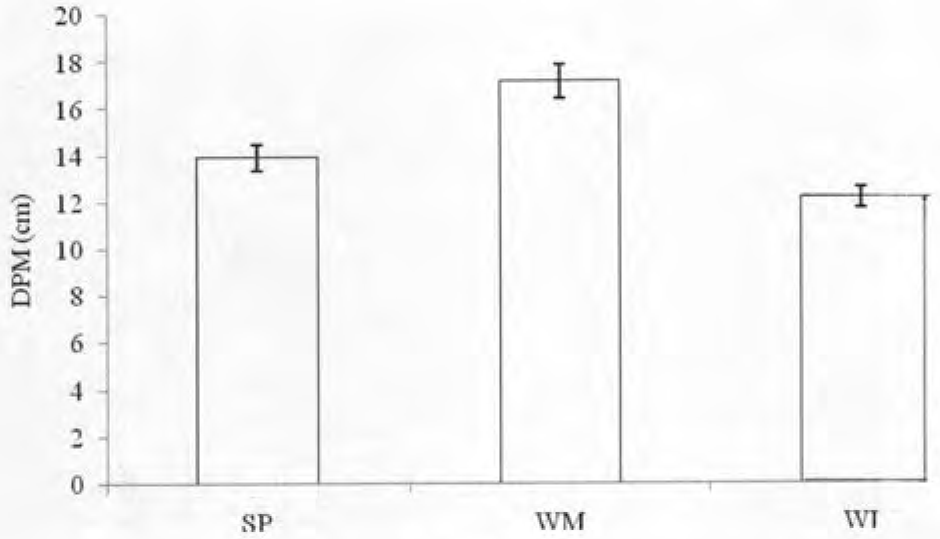


Figure 10: Average grass density (DPM) of plots with different burn treatments ($H_{(2)} = 24.729$, $p = 0.000$, Kruskal-Wallis ~~T~~test)

what is this?

Are these U values? Bonferroni adjustments of α ?

Table 2: *Post hoc* multiple Mann-Whitney ~~Us~~ test results of grass density results within plots with different burn treatments, values in bold are significant (p <0.05). invalid to use this because every extra test gives you an extra 5% chance of a significant result for the wrong reason, ie there is a high probability of Type I error

	SP	WM	WI
SP		**0.016224**	0.090507
WM	**0.016224**		**0.000002**
WI	0.090507	**0.000002**	

The plot with winter mild burn treatment had a higher grass density than the spring burn plot and the winter intense burn plot. There ~~is~~ was no difference in grass density between the spring and winter intense burn plots.

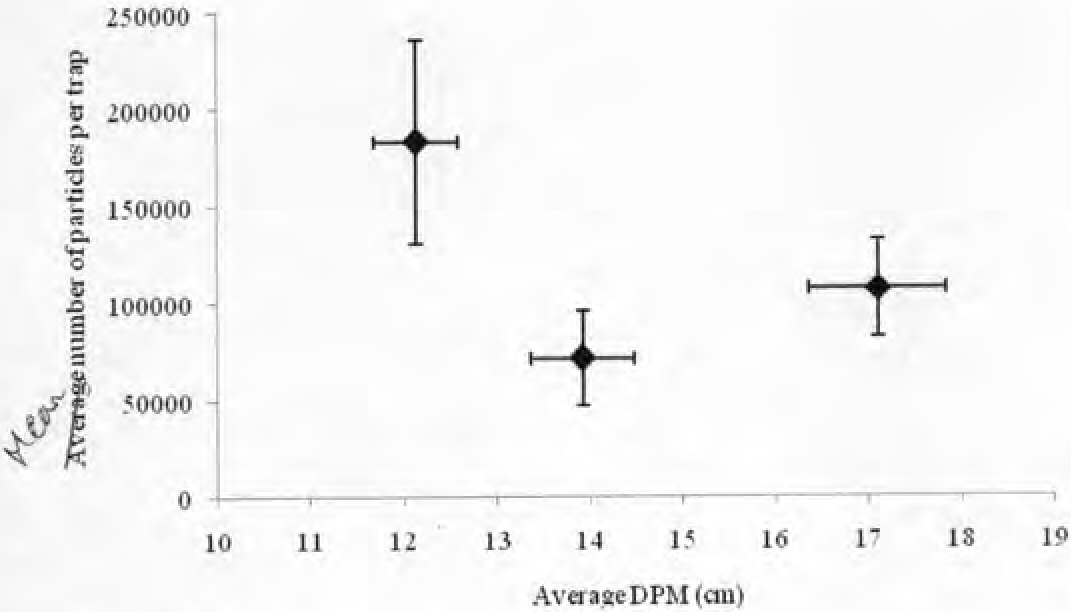


Figure 11: ~~Average~~ Mean number of small charcoal particles per trap (SE) within burn plots in relation to grass density (DPM) ? of burn plots (R r = -0.38~~73~~, p >0.05, Spearman Rank Order correlation).

There ~~is~~ was no significant relationship between the small charcoal particle abundance and grass density.

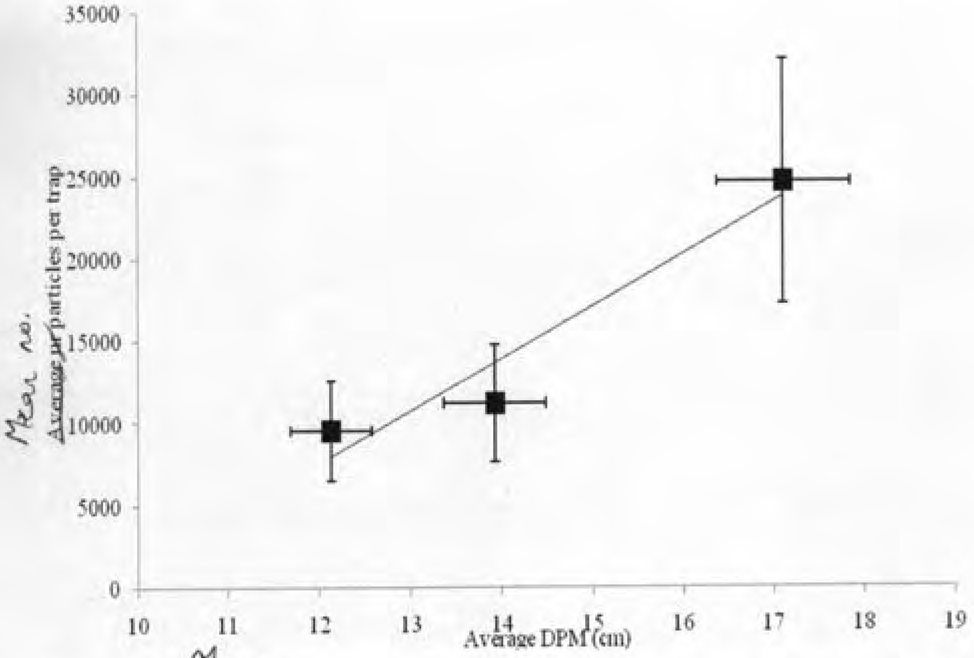


Figure 12: ~~Average~~ Mean number of large charcoal particles per trap (SE) within burn plots in relation to grass density (DPM) ? of burn plots, showing linear trend ($R = 0.61$~~44~~, $p < 0.05$, Spearman Rank Order correlation).

There ~~is~~ was a significant positive relationship between large charcoal particle abundance and grass density. Note the small interval error ? in which the grass density falls.

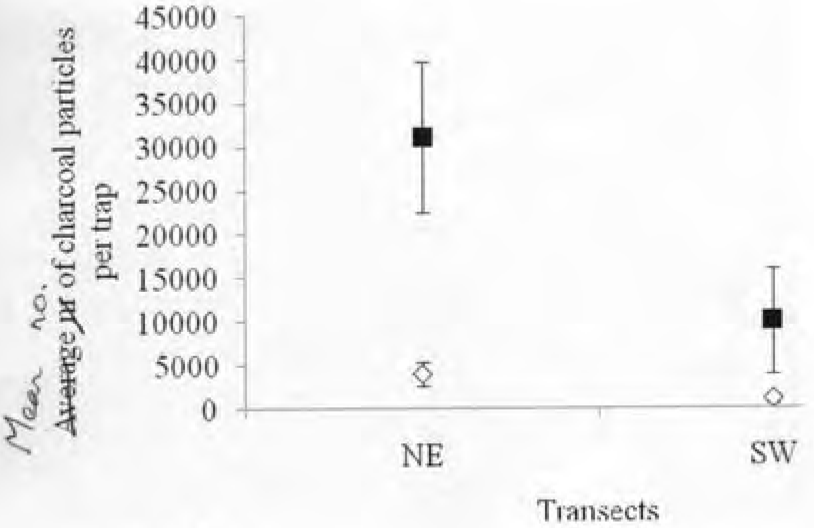


Figure 13: Mean ~~Average~~ number of small (solid black) and large (white) charcoal particles per trap (with SE bars) along transects to north-east (NE) versus transects to south-west (SW) of plots (small: $Z = 2.6475, p = 0.008$; large: $Z = 1.8417, p = 0.066$, Mann-Whitney U t~~T~~est).

The winds during and after the fire were predominantly NE and hence there ~~are~~ were more small charcoal particles in transects downwind from the burn. The small charcoal deposition head burn ? in front of the predominant winds ~~is~~ was double that of the small charcoal deposition backburn ? behind the wind.

The large charcoal particles show the same pattern as the small charcoal particles: with more large particles in the traps from transects downwind of the burn plots. The large charcoal deposition in front of the predominant winds ~~is~~ was more than double that behind the wind.

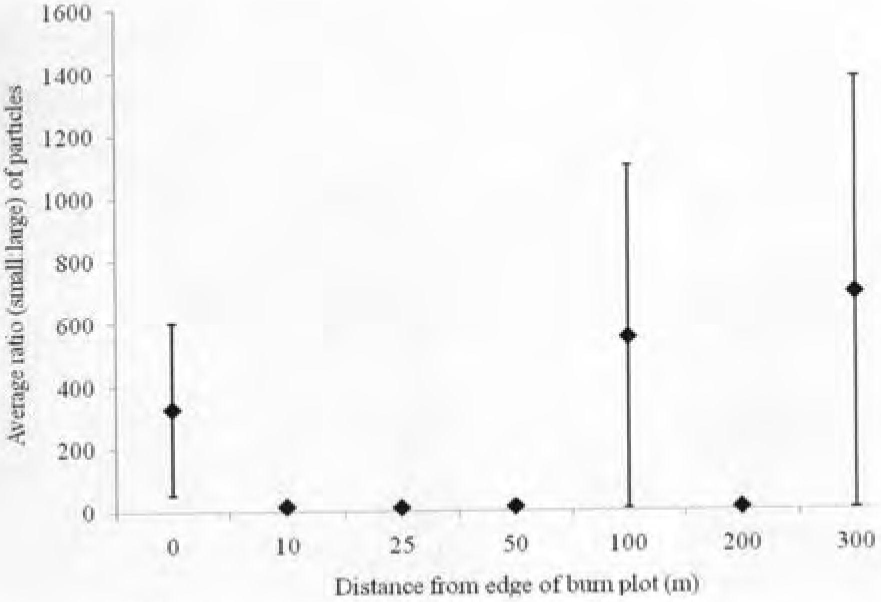


Figure 14: Mean ~~Average~~ ratio of small to large charcoal particles (SE) related to distance from burn plots ($R = -0.2$~~063~~, $p > 0.05$, Spearman Rank Order correlation).

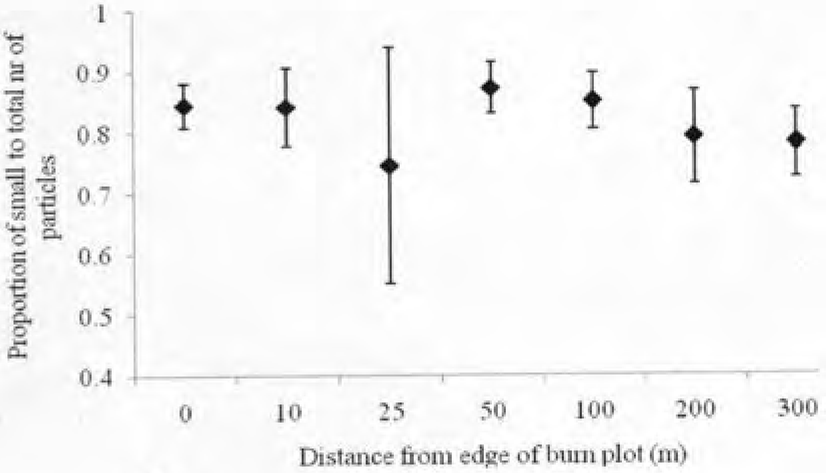


Figure 15: Mean ~~Average~~ proportion of small charcoal particles per trap ± (SE) related to distance from burn plots ($R = -0.21$~~46~~, $p > 0.05$, Spearman Rank Order correlation).

There was ~~is~~ no significant relationship between either ratio or proportion of charcoal particles and distance from burn plots. Note the standard error bars ~~SE~~ were ~~is~~ very large.

Discussion

Like any other single burn the Gontshi North, Hluhluwe-Umfolozi Park, burn cannot be taken as 'representative' of all burns within the park (Clark *et al.*, 1998), however it does reveal charcoal deposition characteristics, which aid in the interpretation of palaeorecords. This was a quick (15min), small scale and controlled burn. The results are proxies, which by definition are more or less a rough approximation of the reality (Conedera *et al.*, 2009). Generally the fires in Hluhluwe are spatially limited by numerous streams with riverine vegetation compared to flatter and less divided landscapes such as the Etoscha National Park (Balfour & Howison, 2001). Thus when interpreting paleoecological data for the Park it is important to keep in mind that fires are very fragmented and findings could be evidence of only a localized events. A better understanding of the history of fire and grazing in the Hluhluwe-Umfolozi Park is necessary (Archibald *et al.*, 2005). Fire is an influential 'herbivore' over large parts of the globe (Bond & van Wilgen, 1996) and within the small area of the Hluhluwe-Umfolozi Park there is a large spatial diversity in the fire regime, about which little is known (Balfour & Howison, 2001). Knowledge of production and transport of charred particles is required for the interpretation of palaeorecords of biomass burning (Clark *et al.*, 1998). This study looks at the primary fallout of charcoal during and shortly after the fire. It is this primary charcoal which is said to make up most of the sedimentary charcoal compared to secondary and redeposited charcoal, which is relatively minor in component (Blackford, 2000). In this way we hope to attain a better understanding of paleoecological charcoal investigations.

what doe
this mean

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sentence construction

high

a) The relationship between charcoal abundance and distance from the burn plot

The small charcoal particle abundance shows the expected relationship of charcoal deposition with distance from the burn (Figure 5) although there is a large standard error. Model predictions show a decrease in charcoal abundance with distance from the source (Whitlock & Larsen, 2001), as do our results for the small particles. The large standard error (SE) associated with transect charcoal abundance could be due to the canopy cover i.e. that in some areas the denser canopy cover decreases the amount of charcoal reaching the ground. Outside the plots the vegetation was not controlled for and is very patchy from open lawn patches to closed thicket. Blackford (2000) found that canopy cover can have a significant effect on the penetration of charcoal to the ground. Furthermore, turbulence can have an effect on deposition of particles, suspending them long enough for extended transport (Clark *et al.*, 1998; Gardner & Whitlock, 2001) and thus resulting in uneven distribution of charcoal.

The large charcoal particle abundance decreases drastically within the first 10m and then at approximately 50m starts increasing again (Figure 6). Perhaps this is due to the 'skip distance' mentioned in the literature (Whitlock & Larsen, 2001; Peters & Higuera, 2007). Skip distance is the zone at the base of the convective column of the fire, where no charcoal deposition takes place; perhaps this could explain the decrease and then increase in charcoal abundance with distance. Theoretical models suggest that skip distance applies mainly to charcoal particles smaller than 200µm (Whitlock & Larsen, 2001). According to this theory, it is unlikely that skip distance can explain the pattern observed in the larger particles as the smaller particles would be expected to show the same pattern and perhaps even in a more exaggerated form. Four out of ~~twelve~~ 12 transects lay in areas that had already been burnt before the experimental burn and perhaps this contributed significantly to the variance and discontinuity of charcoal abundance outside the plots. The charcoal of the previous burn that was already there when the traps were put out might have contaminated samples. Then, however the question would remain: What caused the large particles to show this pattern and not the small particles? Perhaps larger charcoal particles are more easily lifted off the ground again after they are deposited, and the animal activity in the vicinity of these traps disturbed the large charcoal particles so that they were wind swept into the traps. Small particles, on the other hand, which are windswept and disturbed by passing animals, will travel greater distance because they are lighter (Whitlock & Larsen, 2001; Peters & Higuera, 2007). Thus the smaller particles would not land in the traps which are so close by, but rather are deposited further away and thus perhaps sampling at further distances would have revealed the same pattern for small particles. In order to investigate whether the pattern of charcoal abundance is due to skip distance it would be necessary to know the exact location of the convective column of the fire because the drop-off in charcoal deposition is directly related to this (Whitlock & Larsen, 2001). Furthermore the unexpected delay in the experimental burn could have influenced these results, increasing the chances of charcoal from other fires and surroundings to contaminate traps.

The large decrease in charcoal abundance within the first 10 # m of the burn is consistent with previous research (Clark *et al.*, 1998). Charcoal deposition outside ~~of~~ the burnt areas does not show a reliable and even distribution pattern (Figure 5, Figure 6).

b) How differences in vegetation are reflected in the charcoal signal can never be exactly 0

Looking at the charcoal abundance within the plots there is no significant difference between charcoal abundance and experimental burn treatments (small: $H_{(1)} = 26.754$, $p = 0.00$; large: $H_{(1)} = 29.783$, $p = 0.00$). As a result of previous fire regimes we expect a change within the system which would be reflected in the charcoal of subsequent burns. The expected result of the experimental burns is different why? vegetation i.e. different tree and grass densities (Bond *et al.*, 2005). Accordingly the next step was to investigate whether there was a difference in vegetation and whether this is reflected in the charcoal.

? ?

There are significantly more trees in the SP plot than in either the WI or WM plots (Figure 7). Burns in winter seem to kill off trees more than burns in spring. ~~Winter is the~~ dry season and thus perhaps the fires are more intense due to the lower moisture content (Bond *et al.*, 2001; Carcaillet *et al.*, 2001), thus killing off more trees. Tree and shrub cover are reduced by higher intensity fires (Duffin, 2008). As tree density decreases the small charcoal particles become more abundant (Figure 8), and there ~~is~~ was no significant relationship with large charcoal particles (Figure 9). Assuming that as tree density increases grass density decreases, a reduced less fuel load will accumulate on the ground and perhaps as a result there will be less intense fires, which also means less charcoal (Forbes et al., 2006; Keeley, 2009). Furthermore, since grass is said to produce larger charcoal whereas trees form smaller charcoal (Enache & Cumming, 2004), the decrease in grass density as a results of increase s in tree density means that large charcoal particles play a less important role (Enache & Cumming, 2004; Tinner & Hu, 2003). The decrease in small charcoal abundance is expected according to Tinner and Hu (2003), who found that forest (i.e. tree) samples produce less large charcoal than more herbaceous vegetation. how do you know this?

? ? unclear

The grass density in the WM is significantly greater than either the WI or SP plots (Figure 10). The fires at the end of the dry season (WI) or during spring kill ~~off more~~ grass than those at the beginning of the dry season (WM). The difference in grass density was only reflected in the larger charcoal particle abundance (Figure 12). The small charcoal abundance showed no relationship with grass density (Figure 11). Grass is expected to be more closely associated with large charcoal particles as it produces larger particles because of less fracturing due to the elongate morphology of the grass vascular bundles (Umbanhowar & McGrath, 1998). Furthermore, grass is also more resistant to pyrolysis and combustion due to its thicker call walls and higher lignin content (Umbanhowar & McGrath, 1998). Grass that occurs in more heavily grazed areas may accumulates silica in their leaf blades (McNaughton & Tarrants, 1983). ~~Since~~ Because there is a large herbivore population in HUP (Archibald *et al.*, 2005), perhaps the grass there has higher silica content and thus cells are further strengthened, reducing fracturing during combustion. Grass charcoal is longer and narrower than charcoal from leaves or wood (Umbanhowar & McGrath, 1998). Fire has a different effect on different vegetation types and the degree of combustion and fragmentation varies considerably (Pisaric, 2002), forming charred fragments of different morphology and structure (Enache & Cumming, 2004).

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should have begun the paragraph with this statement

c) The relationship between wind direction and charcoal distribution

It is well-established in the literature that charcoal is carried by wind and depending on the size and density of the charcoal, as well as the force of the fire plume; the charcoal fragments can be transported several metres to tens of kilometers in the air (Pisaric, 2002). Such long-distance transport of charcoal over kilometres, is however, usually associated more with intense forest fires (Pisaric, 2002). The effect of the predominant winds (NE) during and after the burn is clearly visible from looking at both large and small particle charcoal abundance (Figure 13). The small and large particles are carried further by the wind, resulting in a higher abundance of charcoal downwind versus behind the wind as expected from previous research (e.g. Gardner & Whitlock, 2001;). Thus, wind transport of charcoal can blur the distinction between burned and unburned sites.

awful sentence - what are you trying to say?

? missing reference!

surely unburned sites have no charcoal?

d) How the Ratio of small to large particles ~~changes with~~ and distance from the burn

Neither the ratio nor the proportion of small charcoal particles showed any pattern in relation to distance from source area. This could be due to the high variability of the charcoal abundance, which in turn could be due to many uncontrolled variables. Due to a delay in burning the plots, the traps were out long before the fire thus allowing for the accumulation of material, including

Sorry, this was my 21 month-old daughter!

charcoal from other nearby fires, which could have significantly affected the results. Furthermore, these traps were placed unprotected ~~in an area~~ were many animals roam free. Thus, therefore animals walking past could have ~~knocked traps or kicked up~~ matter which then landed in the traps and altered the results. Our results do not support the idea that larger particles are swamped by small particles or vice versa and ~~there is a correlation between small~~ and large particles, the large particles appear to be especially important when ?unclear source is nearby and grass density is high (Figure 6, Figure 12).

sentence is far too long & very clumsy

If the concentrations of charcoal are maintained as the current surface becomes buried by further organic debris accumulation, this would suggest a 'charcoal peak', distinguishable from lower background levels. Although variability within the given small plots is high, differences between burned and unburned zones are still apparent (Blackford, 2000). Large and small charcoal abundance ~~is~~ were positively correlated, confirming their close relationship and common origin.

The data presented here are limited by the fact that they result from a single fire event. Every fire event will be different, with charcoal production and dispersal depending on the size, temperature, speed and duration of the fire, the available material for combustion, antecedent meteorological conditions, weather patterns during the fire and the efforts of people to either maintain or extinguish it (Blackford 2000).

Particles are most abundant where the fire burnt and sharply declined at edge of burn. Therefore, the assumption that large particles are indicative of local fires remains valid. The assumption that sieving charcoal series should be used as a proxy for local fire history is confirmed by these findings, whereas to detect regional trends in fire history the pollen-slide charcoal analysis is more suitable (Carcaillet *et al.*, 2001). Our findings confirm the complex interplay of fire, charcoal deposition and temporal as well as spatial effects, as suggested by Gardner and Whitlock (2001) and Whitlock and Larsen (2001).

explanation

This study has demonstrated characteristics of a real fire event in HVP that are of interest to palaeoecologists, and the variability of charcoal deposition is once again confirmed. Future research should record surface charcoal concentrations before a planned fire, ~~look at~~ examine long-term differences between burned and unburned areas as well as the change that happens to charcoal deposited over time. Post-depositional processes have not been studied, however it is most likely that the smallest particles are eroded and larger particles break down (Blackford 2000). The current study has not followed the path of subsequent charcoal redistribution, hence a further study investigating this could supplement this study in paleoecological interpretations of charcoal. Charred particles can continue to accumulate for several years after a fire (Whitlock & Larsen, 2001).

Conclusion

The data show a number of points directly relevant to the interpretation of subfossil charcoal remains:

1. Small (150 - 500μm) charcoal abundance drops drastically within the first 10 m of the burn, after which there is no relationship with distance.
2. Large (500 - 2000μm) charcoal particle abundance drops drastically within the first 10m of the burn, after which there is no significant relationship with distance. why not say this in one sentence
3. Tree density is reflected in the small charcoal particle abundance and grass density is reflected in the large charcoal particle abundance. Tree density is negatively correlated with small charcoal abundance. Grass density is positively correlated with large charcoal abundance. – do you really know this? You had no direct measure of this
4. There is an increase in charcoal abundance downwind of the predominant winds blowing during and after the fire. – Surely this is expected?
5. The ratio of small to large particles does not reflect the distance from the burn. – move to point 2
6. There are high levels of spatial variability, especially in terms of particle size distribution. Despite this there were clear differences between burned and unburned areas, such as . . . ?

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