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The Influence of Range Fire on Soil Fungi, Microbial Activity and Soil Properties along the Boro Route of the Okavango Delta

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ABSTRACT

The influence of burning on soil microbial dehydrogenase activity, nitrogen content and fungal population along the Boro route in the Okavango Delta was assessed in the flood and dry seasons. Soil samples from the burnt plots and the adjacent control un-burnt plots were cultured on agar plates using dilution methods. *Fusarium* spp. were dominant while *Aspergillus* species were low in burnt plots. The other fungi such as *Drechslera* sp., *Exophiala jeanselmmei*, *Penicillium compactum* and *Chrysosporium merdarium* were only in the burnt plots as compared to unburnt control plots. However, fungal diversity and soil dehydrogenase activity reduced after 6 months of burning showing significant increase in *Chrysosporium merdarium* in almost all the burnt plots. The influence of burning on soil nitrogen was insignificant instead flooding had a stronger influence on nitrogen content than burning. The results indicate that burning increased fungal diversity and biomass, however reduces overall microbial enzyme activity after burning without influencing soil nitrogen and pH.

Keywords: burning, fungal diversity and density, microbial biomass, dehydrogenase

INTRODUCTION

Sometimes fire has been described as an essential factor for the maintenance of savannas and their typical appearance (Vijver *et al*. 1999; Govender *et al*. 2006; Aleper *et al*. 2008; Peterson and Reich 2008). Although fire may have some desired effects such as clearance of unwanted vegetation, it also has negative transient effects such as changing the vegetation diversity by favouring species which are resistant and those with early post recovery (Paul and Clark 1996; Heinl *et al*. 2007b). Burning lowers species richness and diversity of plants (Heinl 2001). Burning of vegetation deprives the soil organisms of the much needed organic material required to form organic matter (Certini 2005) which influences nutrient mineralization and in turn plant nutrient uptake (Paul and Clark 1996; Raynaud *et al*. 2006). Fire may negatively affect soil microbial biomass and soil microorganisms' capacity to carry out many of their nutrient cycling activities (Giardina *et al.* 2000; Jensen *et al.* 2001; Michelsen *et al*. 2004; Chu and Grogan 2009) and also influences nutrient cycling through their enzyme activities. Decomposition of organic residues in soil involves many reactions among which is dehydrogenation, a process catalysed by the dehydrogenase enzyme mostly of microbial origin and is an integral part of the microbial community structure (Ceasar-TonThat and Cochran 2001; Mubyana-John *et al*. 2007). Any disturbance in the soil microbial community is likely to influence the dehydrogenase activity of the soil and its activity is an indicator for microbial activity (Ross 1971; Skujins 1973; Tabatabai 1994; Araújo *et al*. 2009). Thus, soil fungi concentrate in the subsoil and play a major role in organic matter buildup by decomposition and degradation of resistant organic components such as cellulose, lignin, keratin and chitin (Kara and Bolat 2007). They also participate in the stabilization of soil aggregates due to their filamentous nature and thus may prevent soil erosion (Packham *et al.* 2002; Osono *et al.* 2003).

The Okavango Delta, in northwestern Botswana, a semi arid to arid country with very low rainfall, serves as the major source of water for flora and fauna in the area. Although the Delta is a protected area, wild fires do occur there. These fires may be caused by lightening or by human activities (Heinl 2001; Kgathi *et al*. 2005; Heinl *et al*. 2007a). The Okavango Delta has a savanna biome with occasional swamps in the floodplains, Mopane and shrub woodland type of vegetation as distance from the riverbed increases. In the floodplains although sedges and grasses form the main vegetation layer they are extremely effective at suppressing regeneration of other growth forms (Ellery and McCarthy 1998). The grasses exhibit rapid growth after sprouting at the onset of floods and rains and they become highly flammable due to human activities and veld fires after the floods recede. There have been several studies conducted in the Delta on the effects of fire on vegetation and wildlife. However, very few documented studies address the

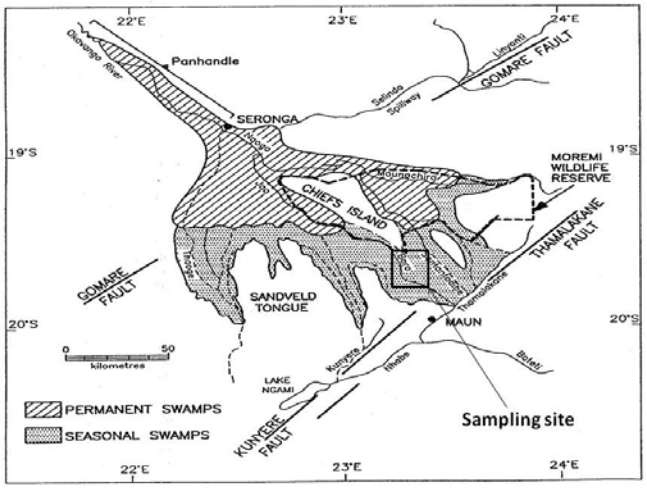

Fig. 1 Map of the Okavango Delta in north-western Botswana, sampling area indicated by a square. Source Harry Oppenheimer Okavango Research Centre, Cartographic unit. Maun, Botswana.

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Original Research Paper

Table 1 Location of the sampling plots in the Okavango Delta.

Plot	GPS coordinates	Vegetation	Burning history
6b	34K0742339 (7804766)	Short Mopane and grass	Burnt in 2000
6ub	Adjacent to above	Short Mopane and grass	Unburnt
6(01)b	34K0742806 (7804507)	Short Mopane and grass	Burnt in 2001/2
51ub	34K0743743 (7805587)	Short Mopane and grass	Unburnt control for 6(01)b
03(1)b	34K0747118 (7805803)	2° floodplain grassland	Burnt July 2003
03(1)ub	Adjacent to above	2° floodplain grassland	Unburnt
03(2)b	34K0738281 (7807176)	3° floodplain mostly *Cynodon dactylon*	Burnt July 2003
03(2)ub	Adjacent to above	3° floodplain mostly *Cynodon dactylon*	Unburnt
03(3)b	34K0737916 (7807693)	2° floodplain mostly *Panicum repens*	Burnt August 2003
03(3)ub	Adjacent to above	2° floodplain mostly *Panicum repens*	Unburnt
03(4)b	34K0737260 (7808591)	2° floodplain grassland	Burnt August 2003
03(4)ub	Adjacent to above	2° floodplain grassland	Unburnt
03(5)b	34K0736861 (7809169)	2° floodplain grassland	Burnt August 2003
03(5)ub	Adjacent to above	2° floodplain grassland	Unburnt

b: burnt, ub: no record of burning since 2000, 1° - primary, 2° - secondary, 3° - tertiary

effect of fire on below ground microbial communities, nutrient cycling and other activities. The main objective of this study was to assess the effect of burning on soil microbial activities as reflected by microbial enzyme, fungal density and diversity.

MATERIALS AND METHODS

Site and sampling

Sampling was undertaken along the Boro route in the Okavango Delta (23 24°E, 19-24°S) (**Fig. 1**). The plots (**Table 1**) were located in the floodplains and bordering riparian woodlands, as these are the areas most susceptible to fire. The selected plots had documented history of burning since 2000. Adjacent unburnt plots were used as controls. The floodplains were dominated by grasses such as *Panicum repens*, *Setaria sphacelata* in the lower flood plains and *Cynodon dactylons* in higher floodplains bordering the Mopane riparian woodlands. The riparian woodlands consisted mostly of scattered Mopane (*Colophospermum mopane*) with patches of grasses.

Sampling was carried out in September 2003, less than 2 weeks after the onset of fire season in the Delta and also in February 2004. September is characterised by dry soil spells in the tertiary floodplains and the riparian woodlands. While in February, the soils are mostly wet from the surface floods characteristic of the Okavango (Ellery and McCarthy 1998). For each plot, three replicate soil samples located at least 20 m apart and each consisting of 5 sub-samples of approximately 30 cm apart were collected from seven burnt plots and their corresponding unburnt control plots. The samples were taken from the A1 horizon (about 5 cm deep) using a clean core borer. Representative samples of approximately 500 g each were then transferred into four polyethylene bags with Ziploc closure. In all a total of 42 samples each composing of five sub samples were collected at each sampling time. These were packed in cooler boxes and transported to the laboratory immediately.

Fungal density and diversity

Fungal populations in the soil samples were estimated by plate count method by making soil dilutions in sterile physiological solution (8.0 g NaCl/L) and then plating out on malt extract agar (MEA, Oxoid medium CM57, Oxoid Ltd. Basingstoke, Hampshire UK) amended with 0.3 mg/L streptomycin sulphate (Parkinson and Paul 1982). Three replicates per sample were made. The agar plates were incubated at 30°C for a week. Population counts and diversity were determined and corrected for moisture content in order to express them on dry weight basis. The given percentage values were calculated from the total number of fungal species isolated from the burnt and unburnt plots. After isolation different fungi were purified by transferring mycelia disks from the different colony types on to fresh MEA amended with streptomycin sulphate. Identification of the isolates was based on macroscopic fungal colony morphology and microscopic reproductive features as described by Domsch *et al.* (1993) and other reference books (Ellis 1971, 1976; Carmichael *et al.* 1980; Sutton 1980; Hanlin 1990; Klich 2002). *Fusarium* spp. were identified according to Nelson *et al.* (1983) and Domsch *et al.* (1993). For sterile fungi, sporulation was induced by growing them on water agar supplemented with carnation leaves (Fisher *et al.* 1982; Kirk *et al.* 2001) and incubating the plates under ultra-violet light (short wave length-340 nm) at 25°C until the fungi sporulated. When induction of sporulation was not successful, isolates were recorded as 'unidentifiable sterile mycelia'.

Dehydrogenase activity

Dehydrogenase activity was determined using the method outlined by Tabatabai (1994) and Friedel *et al.* (1994). Replicate 20 g portions of air-dried and soil sieved through a 2 mm sieve, samples were extracted with methanol and colorimetric determination of 2,3,5-triphenyl formazan (TPF) produced by reduction of 2,3,5-triphenyl tetrazolium chloride (TTC) by the soil enzyme. The red colour intensity developed by the TTC was measured at 485 nm using a spectrophotometer (Spectronic instrument 20D+) and TPF was used as a reference standard.

Microbial biomass

The fumigation re-inoculation method was used to determine microbial biomass carbon (Jenkinson and Paulson 1976; Parkinson and Paul 1982). To differentiate soil fungal biomass from bacterial biomass selective inhibition technique (Anderson and Domsch 1978; Baath and Anderson 2003) was used. The method involved substrate-inhibition respiration using antibiotics selective against bacterial or fungal respiration. Streptomycin sulphate (2%) plus chlorophenicol (1%) were used to inhibit bacterial respiration while cyclohexamide (0.05%) was used to inhibit fungal respiration. Triplicate 100 g fresh soil samples were used in the determination of CO_2 evolved (Parkinson and Paul 1982). Controls consisted of soils to which no inhibitor had been added. Microbial biomass was calculated by subtracting CO_2-C evolved from amended samples from the non-amended and then dividing by 0.5. The factor 0.5 used was based on the calculated fraction of biomass C mineralised to CO_2 over the 10-day incubation period (Jenkinson and Paulson 1976; Bailey *et al.* 2002b).

Soil properties

Soil moisture content was determined gravimetrically from weight loss after 10 g of each soil sample was oven dried at 105°C overnight (Anderson and Ingram 1993). Soil texture (% sand, silt and clay) was determined by the hydrometer (*Bouyoucos* method (Anderson and Ingram 1993). The soil textural class was then determined by using the soil textural triangle (Anderson and Ingram 1993). The other soil was air dried and passed through a 2 mm mesh sieve to determine total N using an automated N analyser (LECO Model FP 328). Ethylenediaminetetraacetate (EDTA) was used as the standard. Active soil acidity was determined in a soil:

Table 2 Fungal species isolated from the unburnt and burnt plots of the Okavango Delta soils in September 2003. (Values given are means of three replicates)

No. of Genera	Fungal genera/species	CFU/g soil in unburnt plots	CFU/g soil in burnt plots
1	*Absidia corymbifera*	10	4
2	*Acroconidiella tropaeoli*	0	1
3	*Alternaria alternata*	5	3
4	*Aspergillus candidus*	0	1
	Aspergillus clavatus	146	2
	Aspergillus flavus	1	0
	Aspergillus fumigatus	18	31
	Aspergillus japonicus	1	6
	Aspergillus niger	10	7
	Aspergillus parasiticus	0	27
	Aspergillus wentii	98	213
	Aspergillus spp.	137	122
5	*Chalara elegans*	2	3
6	*Chlamydomyces palmarum*	1	0
7	*Chrysosporium merdarium*	0	5
8	*Cochliobolus lunatus*	0	68
	Cochliobolus sativus	1	4
9	*Drechslera* sp.	0	15
10	*Exophiala jeanselmei*	0	7
11	*Fusarium equiseti*	11	246
	Fusarium oxysporum	3	8
	Fusarium sp.	0	4
12	*Mucor* sp.	0	2
13	*Oidiodendron echinulatum*	2	4
	Oidiodendron sp.	1	0
14	*Penicillium brevicompactum*	0	1
	Penicillium compactum	0	2
	Penicllium funiculosum	7	1
	Penicillium rugulosum	0	9
	Penicillium spinulosum	0	1
	Penicillium steckii	74	13
	Penicillium vulpinum	1	2
	Penicillium spp.	58	171
15	*Pithomyces* sp.	1	1
16	*Phoma medicaginis*	14	5
17	*Pseudeurotium zonatum*	9	0
	Pseudeurotium sp.	11	0
18	*Rhizopus oryzae*	1	0
	Rhizopus stolonifer	1	1
19	*Sporothrix schenckii*	13	6
20	*Stachybotrys chartarum*	25	0
21	*Trichocladium asperum*	4	0
22	*Trichoderma* sp.	7	7
23	*Verticillium* sp.	2	0
	Unidentified fungi	276	169

water (1: 2) suspension as outlined by Anderson and Ingram (1993). The pH of the supernatant was measured using an Accumet®/Fisher Scientific Model 50 pH meter (London, UK) with a combination glass electrode and readings were recorded to two decimal places.

Statistical analysis

Analysis of variance was performed using the SPSS 11.0 package. *Post Hoc* analyses were performed using Tukey's test ($P \leq 0.05$) (Elston and Johnson 2008). In the analyses group separation was based on burning history, habitat (whether grassland or riparian woodland).

RESULTS

Fungal diversity

In all there were 23 different genera of fungi consisting of many species isolated from the Boro region of the Okavango Delta (**Table 2**). There were many unidentifiable species i.e., more than 35 species isolated from both the burnt and the unburnt plots during the first sampling period. Although there were many genera isolated from the burnt plots, many could not be identified to species level. In all, the burnt plots had more unidentifiable species. There were also many unidentifiable fungal colonies, of which 13% were from the unburnt plots and 8% were from the burnt plot (**Table 2**). Macroscopic and microscopic observations revealed that there were usually few of each species among the unidentifiable. *Aspergillus* and *Penicillium* spp. comprised the major genera and made up 39 and 16% of the total isolates, respectively. Only about 0.7% of the total isolates were *Fusarium* species isolated from the unburnt plots, while 12% of the isolates from the burnt plots were *Fusarium* species.

Table 3 Fungal species isolated from the unburnt and burnt plots of the Okavango Delta soils in February 2004. (Values given are means of three replicates)

No. of genera	Fungal genera/species	CFU/g soil in unburnt plots	CFU/g soil in burnt plots
1	*Absidia corymbifera*	3	7
2	*Alternaria alternata*	0	4
3	*Aspergillus fumigatus*	130	92
	Aspergillus japonicus	1	12
	Aspergillus niger	11	10
	Aspergillus parasiticus	31	71
	Aspergillus wentii	175	127
	Aspergillus spp.	113	136
4	*Chalara elegans*	16	1
5	*Chrysosporium merdarium*	0	19
6	*Cochliobolus sativus*	2	7
7	*Fusarium equiseti*	9	217
	Fusarium oxysporum	3	21
	Fusarium sp.	14	3
8	*Mucor* sp.	9	2
9	*Penicillium brevicompactum*	3	0
	Penicillium steckii	19	1
	Penicillium vulpinum	18	0
	Penicillium spp.	16	8
10	*Pithomyces* sp.	0	2
11	*Phoma medicaginis*	12	2
12	*Rhizopus oryzae*	7	7
	Rhizopus stolonifer	1	1
13	*Sporothrix schenckii*	1	9
14	*Trichoderma* sp.	1	1
	Unidentified fungi	45	8

During the second sampling, in February, only 14 genera consisting of 19 known species were isolated from the unburnt and the burnt plots (**Table 3**). The total number of isolates from the second sampling was much lower than those obtained from the first sampling. Unidentifiable fungi from the unburnt plots made up 3% of the total isolates and only 0.6% of the total isolates could not be identified in the burnt plots. However, species diversity was slightly, but non significantly, higher in the burnt plots during both sampling periods.

Figs. 2 and **3** show fungal population in the plots in September shortly after burning and in February. Only six plots were sampled during the second sampling period. Of these four burnt plots all of which were under grassland indicated a higher population than that of the control plots. The increase in fungal population observed in grassland was not observed in Mopane riparian woodland plots. The earliest burnt plot, 6, and the latest burnt plot, 03(5), showed a slightly lower population than that of the unburnt plots. The February sampling i.e., 6 months after the fire results indicated non significant differences in fungal population due to burning. Also there were no differences between the riparian woodland (6b, 6ub, 51ub) plots and the floodplain grassland plots (03). Results from the first sampling showed that the fungal population in the burnt plots were slightly higher or equal to that in the unburnt plots in five of the seven sampled plots. A slightly lower population

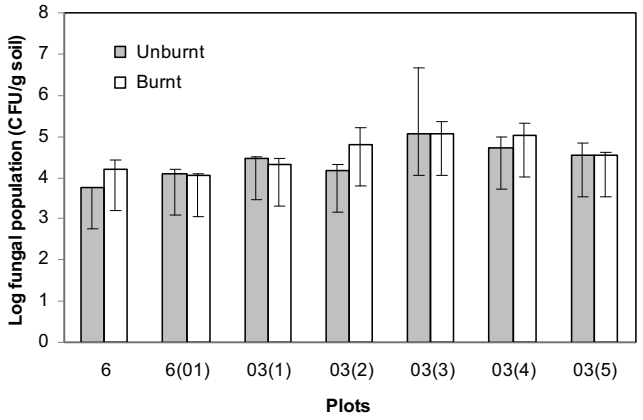

Fig. 2 Soil fungal populations in September 2003.

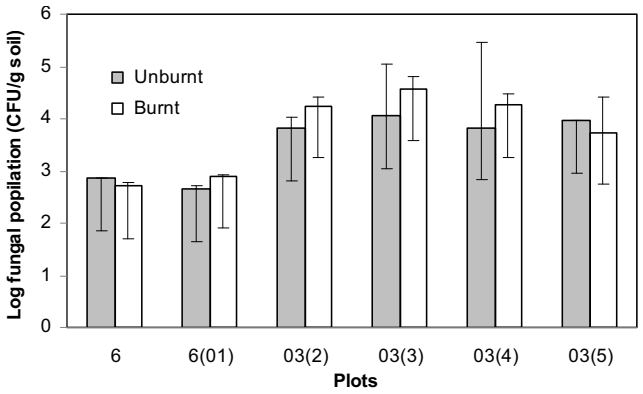

Fig. 3 Soil fungal population in February 2004.

than that of the unburnt plots was observed in plots 6(01) and 03(1).

Fungal and bacterial biomass

The results from the first sampling showed a fungal biomass which ranged from 98.27 mg C/g soil to 167.20 mg C/g soil in the burnt plots, while that in the unburnt plots ranged from 67.47 mg C/g soil to 167.93 mg C/g soil. Significantly higher fungal biomass in burnt plots than in the respective controls plots were recorded in five plots during the first sampling period. After 6 months from the last burning, the fungal biomass in the burnt plots ranged from 56.47 mg C/g soil to 168.67 mg C/g soil, while fungal biomass in the unburnt plots ranged from 60.13 mg C/g soil to 127.60 mg C/g soil (**Tables 4, 5**). Riparian woodland plots (6, 6(01) generally had lower fungal biomass compared to grassland plots (03). There was variability among plots on the influence of burning on bacterial biomass C as some plots indicated an increase while others did not. Immediately after the fire there was an increase in bacterial biomass C (**Table 4**), however, this increase was not maintained but declined after 6 months (**Table 5**). Overall, bacterial biomass C was higher immediately after the fire in September than in February in both the burnt and unburnt plots.

Tables 6 and **7** show total soil nitrogen levels in the burnt and unburnt plots in September and February. In all the studied plots there was no significant difference in total soil N content between the burnt and unburnt plots. The active soil pH of the plots ranged from 5.8 to 8.4 but did not differ significantly between the burnt and unburnt plots (**Tables 6, 7**). Soil texture also did not differ between the burnt and unburnt plots at both sampling times (**Tables 6, 7**).

Dehydrogenase activity

Soil dehydrogenase activity during the first sampling period ranged from 132 to 241 μg/g soil in the burnt plots (**Tables 6, 7**). Much wider variations were recorded in the unburnt plots (112 to 281 μ/g soil). In four of the plots, the dehydrogenase activity was significantly higher compared to the corresponding unburnt plots, the other three plots showed a dehydrogenase activity, which was lower than the unburnt adjacent plots. Similar results were obtained during the second sampling, except for the 03(5) plot in which the dehydrogenase activity was almost the same as that of the control (**Table 7**).

DISCUSSION

The soils of the Okavango Delta along the Boro route showed high fungal diversity. In all, in the unburnt plots they were more than 35 fungal species, which could be identified. These belonged to more than 23 different genera. Burning influenced fungal genera diversity more than it influenced fungal population (**Table 2; Figs. 2, 3**). There was also a shift in fungal diversity with burning.

Table 4 The influence of fire on fungal/bacterial biomass C ratio in soil sampled from unburnt and burnt plots along the Boro route in the Okavango Delta in September 2003. (Values given are means of three replicates).

Plots	Fungal biomass C (mg C/100 g soil)		Bacterial biomass C (mg C/100 g soil)		Fungal/bacterial biomass	
	Unburnt	Burnt	Unburnt	Burnt	Unburnt	Burnt
6	67.47 ± 27	98.23 ± 33	15.04 ± 2.3	22.00 ± 1.9	4.38	4.47
6(01)	129.80 ± 20	104.87 ± 40	22.30 ± 4.1	2.20 ± 0.3	5.82	47.67
03(1)	111.47 ± 25	167.20 ± 12	27.10 ± 3.0	37.40 ± 3.2	4.11	4.47
03(2)	105.60 ± 19	109.27 ± 25	17.80 ± 1.9	81.40 ± 5.2	5.93	1.34
03(3)	132.73 ± 34.9	139.33 ± 22	19.10 ± 2.1	24.20 ± 1.9	6.95	5.76
03(4)	167.93 ± 8	151.07 ± 9	28.60 ± 2.6	28.60 ± 1.9	5.87	5.28
03(5)	145.93 ± 27	163.53 ± 17	25.10 ± 2.1	30.80 ± 2.4	5.81	5.30

Table 5 The influence of fire on fungal /bacterial biomass C ratio in soil sampled from unburnt and burnt plots along the Boro route in the Okavango Delta in February 2004. (Values given are means of three replicates).

Plots	Fungal biomass C (mg C/100 g soil)		Bacterial biomass C (mg C/100 g soil)		Fungal/bacterial biomass	
	Unburnt	Burnt	Unburnt	Burnt	Unburnt	Burnt
6	93.87 ± 30	86.53 ± 19	20.53 ± 1.8	9.53 ± 2.7	4.57	9.08
6(01)	60.13 ± 22	56.47 ± 13	41.80 ± 4.8	12.10 ± 3.6	1.44	4.67
03(2)	112.20 ± 20	88.73 ± 15	6.60 ± 0.7	22.00 ± 2.9	17.00	4.03
03(3)	119.53 ± 8	168.67 ± 16	15.40 ± 1.2	17.60 ± 5.2	7.76	9.58
03(4)	127.60 ± 23	140.80 ± 12	6.60 ± 0.9	1.30 ± 0.2	19.33	108.31
03(5)	121.00 ± 23	151.80 ± 14	3.20 ± 0.1	2.20 ± 0.5	37.81	69.00

Table 6 Soil dehydrogenase activity, total nitrogen, active acidity and texture in unburnt and burnt plots along the Boro route of the Okavango Delta in September 2003.

Plot texture	Treatment	Dehydrogenase (µg TPF/g soil)	Total soil N (%)	Active acidity (pH)	ψSoil class
6	Unburnt	112 ± 56	0.01 ± 0.01*	7.00 ± 0.00	S
	Burnt	206 ± 10	0.03 ± 0.00	7.00 ± 0.00	S
6(01)	Unburnt	169 ± 29	0.00 ± 0.00	5.96 ± 0.09	S
	Burnt	144 ± 21	0.00 ± 0.00	6.50 ± 0.26	S
03(1)	Unburnt	152 ± 38	0.24 ± 0.05	5.84 ± 0.20	SL
	Burnt	148 ± 19	0.29 ± 0.01	6.37 ± 0.33	SL
03(2)	Unburnt	189 ± 51	0.05 ± 0.01	7.99 ± 0.92	S
	Burnt	222 ± 13	0.12 ± 0.02	7.76 ± 0.38	S
03(3)	Unburnt	281 ± 16*	0.11 ± 0.02***	8.38 ± 0.11 ***	SL
	Burnt	132 ± 30	0.36 ± 0.01	6.14 ± 0.01	SL
03(4)	Unburnt	209 ± 25	0.39 ± 0.02	6.02 ± 0.06	SL
	Burnt	241 ± 11	0.39 ± 0.04	6.04 ± 0.09	SL
03(5)	Unburnt	173 ± 63	0.11 ± 0.02	7.00 ± 0.00	S
	Burnt	174 ± 2	0.11 ± 0.01	6.48 ± 0.26	S

Values given are means of three replicates; ψ S = Sandy, SL = Sandy loam
Significance is indicated by asterisks: *, $\alpha < 0.05$; **, $\alpha < 0.01$; ***, $\alpha < 0.001$; where α is the probability of type I error; blank = not significant.

Table 7 Soil dehydrogenase activity, total nitrogen, active acidity and texture in unburnt and burnt plots along the Boro route of the Okavango Delta in February 2004.

Plot texture	Treatment	Dehydrogenase (µg TPF/g soil)	Total soil N (%)	Active acidity (pH)	ψSoil class
6	Unburnt	98 ± 6 **	0.03 ± 0.01	6.24 ± 0.07 ***	S
	Burnt	151 ± 7	0.34 ± 0.15	7.00 ± 0.00	S
6(01)	Unburnt	123 ± 17	0.02 ± 0.00	6.35 ± 0.07 **	S
	Burnt	112 ± 11	0.01 ± 0.00	5.82 ± 0.02	S
03(2)	Unburnt	157 ± 2 *	0.05 ± 0.01 ***	8.00 ± 0.69	S
	Burnt	198 ± 13	0.12 ± 0.00	7.00 ± 0.00	S
03(3)	Unburnt	134 ± 7 ***	0.38 ± 0.01 *	5.84 ± 0.08	SL
	Burnt	72 ± 2	0.35 ± 0.01	5.77 ± 0.07	SL
03(4)	Unburnt	115 ± 2	0.31 ± 0.00	5.69 ± 0.21	SL
	Burnt	149 ± 14	0.30 ± 0.00	5.70 ± 0.15	SL
03(5)	Unburnt	137 ± 23	0.21 ± 0.01	6.17 ± 0.42	S
	Burnt	137 ± 4	0.20 ± 0.01	6.02 ± 0.09	S

Values given are means of two replicates; plot 03(1) not sampled; ψ S = Sandy, SL = Sandy loam
Significance is indicated by asterisks: *, $\alpha < 0.05$; **, $\alpha < 0.01$; ***, $\alpha < 0.001$; where α is the probability of type I error; blank = not significant.

Other researchers in the field have also observed a shift in soil fungal diversity due to burning (Suzuki and Bärlocher 2009). Burnt plots tended to promote higher species diversity. Species such as *Aspergillus wentii*, *Fusarium equiseti* and *Penicillium* spp. increased significantly in the burnt plots. On the contrary burning seemed to contribute to the disappearance of some species such as *Pseudeurotium* sp., *Pseudeurotium zonatum*, *Rhizopus oryzae*, *Stachybotrys chatarum*, *Trichocladium asperum* and *Verticillium* sp. while others such as *Aspergillus clavatus* and *Penicillium steckii* only declined. The burnt plots seemed to have a higher diversity of genera than the unburnt. Trappe *et al.* (2005) reported similar findings. Irrespective of having more genera there were fewer species per genus and fewer individuals per species in contrast to the unburnt plots where there were many species per genus and more individuals per species. Overall in September after burning the results indicated an increase in fungal diversity. Fungal diversity was generally low in the February sampling. Many species observed during the dry September sampling were not detected in the February samples irrespective of whether the plot had been burnt or not (**Tables 2, 3**). This was attributed to high moisture content during the February sampling, as the high floodwaters might have reduced soil oxygen available for microbial respiration (Trappe *et al.* 2005). Soil fungi are mostly aerobic and thus increased soil moisture may reduce their population.

In this study, fire may also have resulted in species dominance change as reflected by the appearance of new species in the burnt plots, a trend also observed by other researchers (Lygis *et al*. 2010). Species such as *Chrysosporium merdarium*, *Acroconidiella tropaeoli*, *Aspergillus candidus*, *Cochliobolus lunatus*, *Drechslera* sp., *Exophiala jeanselmei*, *Penicillium spinulosum* and *Penicillium rugulosum* were observed in the burnt plots and yet none of these taxa were isolated from the unburnt plots. Some species were more affected by fire than others. Results from both sampling periods indicated that the genus *Aspergillus* was negatively affected by fire while *Fusarium* sp. showed an increase with burning initially as reflected by *F. equiseti* and *F. oxysporum* which still maintained increased populations in the burnt plots. Deka and Mishra (1984) also made a similar observation. Generally there was a return to original species composition after 6 months, an indication of recovery of species. Whether these species had become accustomed to the fire circle or reintroduced from surrounding unburnt areas was not clear. A shift in species diversity resulting in an increase in the *Fusarium* species may negatively affect the plant population in the burnt site as some *Fusarium* species are plant pathogens causing root and stem rot, vascular wilt, fruit rot or ear diseases (Domsch *et al*. 1993). These results are in accordance with other investigations that have also shown changes in the fungal species after fire (Yibarkuk *et al*. 2001; Wuthrich *et al.* 2002; Lygis *et al*. 2010).

The results from this study generally showed an increase in the fungal species and population in plots where grasses were the dominant vegetation as opposed to riparian Mopane woodland 6 months after the fire. This trend has also been observed in other areas (McMullan-Fischer *et al*. 2002; Mubyana-John *et al*. 2007), although shortly after the fire fungal population may decline as shown by Liu *et al*. (2001) who found a decrease in the soil fungal population one month after fire. Both heat and ash modify soil chemical and physical status (Diaz-Ravina *et al.* 1992; Certini 2005). With burning and death of the above ground matter in grasslands, there is usually a lot of below ground material that will likely die and serve as substrate for soil organisms

such as fungi and actinomycetes who play major roles in decomposition of organic residues. This has also been suggested as a possible explanation by other researchers (Vazquez *et al*. 1993; Liu *et al.* 2001). Fungi play a major role in decomposition of organic residues, thus on a short term basis, in grasslands it is likely there would be an increase in fungal activities due to increased substrate (Kara and Bolat 2007). Although fire may produce a sharp increase in soil microbial populations, the groups are affected differently. In this study however, soil bacterial biomass also showed significant increase shortly after burning but decreased 6 months later probably because of declining substrate levels. Increases in fungal biomass were also observed shortly after burning in the grassland plots indicating possibly the substrates were still available, as all the roots may not have been decomposed after 6 months. Young shoots will also result in more root exudates when compared to older plants.

Both fungal and bacterial biomass may have been temporarily higher in the burnt plots because of the readily available substrates. Michelsen *et al.* (2004) and Albrecht *et al.* (1995) also observed increased fungal biomass in burnt plots. Expectedly, fungal biomass was much higher than the bacterial biomass values as indicated by the high fungal/bacterial ratios as fungi play a much more active role in the degradation of organic residues, whereas bacteria are more involved in nutrient cycling. However, some authors have also indicated that the selective inhibition method may not be the best measurement for biomass, as it only provides information about respiratory activity of the fungal and bacterial components of the total biomass (Bailey *et al*. 2002a).

Plots with mostly Mopane (6b, 6b(01) showed a decrease in fungal biomass with burning (**Table 5**). Generally the riparian Mopane plots had lower fungal biomass than the grassland plots. Grasslands are more susceptible to fires, even less intense fires, than riparian Mopane vegetation, thereby contribute more to below ground nutrients for the soil organisms. As such frequent fires may alter plant diversity due to the death of grasses but may leave tree species unaffected thus altering the structure of the ecosystem (McMullan-Fischer *et al*. 2002; McIver and McNeil 2006). The change in the structure of the ecosystem can decrease the range of substrates present. Frequent or repeated burning can result in less litter and less substrate for the soil organisms (McIver *et al*. 2007). The fungi community responds better to a wide range of substrates than a narrow range. The loss of substrates due to fire could be responsible for the low species diversity observed in the riparian Mopane woodland plots (plots 6 and 6(01) (Packham *et al*. 2002; Mlambo *et al*. 2007; Siele *et al*. 2008).

Soil dehydrogenase assay indicated an increase in activity in some burnt plots and not others (**Table 6**). Within each plot, there were variations in soil dehydrogenase activity between the burnt and unburnt plots without any clear pattern. Six months after burning soil dehydrogenase activity values declined compared to shortly after the fire. The correlation factor between burning and dehydrogenase was very low indicating another factor probably influenced soil dehydrogenase activity more than burning (Hamman *et al*. 2008; Garcia-Villaraco Velasco *et al*. 2009). Based on this study we hypothesize that soil moisture was likely the factor that resulted in increased soil dehydrogenase activity as it coincided with the onset of the floods.

In this study, soil nitrogen levels (**Tables 6, 7**), did not seem to be influenced by burning probably because nitrogen in the Delta is mostly replenished by the floodwater (Omari *et al*. 2004).

CONCLUSION

Fires in the Okavango Delta, along the Boro route affected microbial populations differently. Changes took place in fungal diversity with many genera and species observed but with fewer individuals per species. This was however contrary to unburnt plots where there were few genera and species but with many individuals per species. Increases in fungal biomass were observed 6 months after burning, but not immediately. This increase depended more on vegetation than any other factor as the effects were more pronounced in grassland than riparian Mopane woodland. The effect of burning on soil dehydrogenase showed a considerable variation possibly because the different microbial groups producing the enzyme were affected differently. So far burning did not seem to affect soil pH and nitrogen. The above results are based on short-term effects of fire; however, continued study may reveal long-term effects.

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