THE IMPACT OF COMMUNAL LAND USE ON DAMBOS IN LOWER GWERU, ZIMBABWE

by
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ABSTRACT

The study investigated how the exploitation of dambos changes their vegetation composition, soil properties and how that will in-turn affect the water quality. Species diversity and evenness ware higher in Madikane (H' = 2.52, E = 0.69) than Dufuya H' = 2.14, E = 0.63). There was a significant difference in species composition between Madikane dambo, a protected area and Dufuya dambo, an area impacted by communal agriculture and grazing. Species that were present in Madikane indicated a permanent or semi-permanent wetness compared to species tolerant to arid conditions and indicating disturbance that were present in Dufuya. The arid condition in the outer region of Dufuya indicates a shrinking in size of that dambo. Dambo utilization also indicated a change in dominance from perennials to annuals and an increase in exotic species. There was no significant difference in the physical structure of the soil (% clay and % silt, $p > 0.05$). A significant difference was recorded in the chemical properties of the soil. There was a wide pH range in Madikane (4.98 – 10.15) than Dufuya (5.26 – 7.86). The organic carbon content was positively correlated with moisture content in Madikane ($r = 0.74$) and Dufuya ($r = 0.88$). Organic carbon content was significantly different ($p < 0.05$) Madikane (3.58 %; 17.67 %) than Dufuya (2.38 %; 7.38 %) both in the outer and central zones respectively. There was a significant difference ($p < 0.05$) in phosphorus and nitrogen concentrations. Nitrate-N and ammonium-N were higher in the surface zone (0 -20 cm) than the subsurface zone (20 -100 cm) for both dambos indicating leaching of nutrients from the surface zone. Nitrate-N and ammonium-N were higher in Madikane than Dufuya which is a characteristic of soils with more organic matter. Higher levels of phosphorus in Dufuya than Madikane indicates additions through fertilizer application. Phosphorus from soil was exported more readily into water in Dufuya ($r^2 = 0.52$) than Madikane ($r^2 = 0.24$). Leaching of soil nutrients was also shown by an increase in calcium ions in the water in Dufuya (2.23 mg L^{-1}) than Madikane (1.21 mg L^{-1}) which in-turn caused a high conductivity in Dufuya (287 $\mu S\ cm^{-1}$) than Madikane (125 $\mu S\ cm^{-1}$).

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INTRODUCTION AND LITERATURE REVIEW

Definition and distribution of dambos in Zimbabwe

The complexity of wetland ecosystems has led to various definitions by different authors (Mitsch and Gosselink, 1993) but an internationally accepted definition, which encompasses most of the wetland characteristics found in different regions is given in Articles 1.1 and 2.1 of the RAMSAR Convention as ‘‘areas of marsh, fern, peatland, or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh or brackish or salt, including areas of marine water the depth of which does not exceed six meters’’ (Ramsar Convention Bureau, 1997). Of all the different types of wetlands that occur in Africa, inland valleys commonly known, as dambos are the predominant type found in Zimbabwe (Whitlow, 1985a). Dambos exhibit a range of different features and this has led various authors to suggest definitions emphasizing features specific to the *dambos* they had studied (Rattray *et al*., 1953; Thompson, 1972, Ivy, 1981; Whitlow, 1984a).

The distribution of dambos in Zimbabwe is influenced by factors such as relative relief, bedrock characteristics and climatic conditions (Whitlow, 1984b). In Zimbabwe, dambos cover about 1.28 million ha or 3.6 % of the country’s land area and 84% of them are located towards the north of the country on the undulating highveld plateau above 1200 m where the mean annual rainfall is above 800 mm. Individual dambos are generally small, ranging from 0.1-1.0 km wide and 0.5-5.0 km long (Dambo Research Unit, 1987), which means that they have been overlooked in development plans despite the fact that in total area they are more important than other land classes.

Characteristics of dambos

Dambos in Zimbabwe are generally defined as seasonally waterlogged valley grasslands distinguished by a characteristic grass and sedge flora, and a general absence of woody species

(Whitlow, 1984a). The lack of trees and shrubs in dambos has been attributed to the inhibiting effects of seasonal water-logging and occasional but intensive fires (Rattray, 1957). The vegetation typically consists of a mosaic of plant communities which changes in character from the margins to the central zone depending on the degree and duration of water-logging (Whitlow, 1985b). Three zones determined by the moisture content can be identified: (1) the dambo margin, the driest zone, (2) the middle zone and (3) the central zone with the highest water content (Whitlow, 1984a). The margin includes shrubs and woody species that are typically found in sites adjacent to the dambo. Grasses are the dominant species in the middle zone where conditions become progressively wetter while the central zone, which may be permanently waterlogged, is dominated by sedges.

In Zimbabwe, most dambo soils are non-calcic hydromorphic soils that cover more than one million hectares of dambo (Whitlow, 1984b). They are generally characterized by well-defined organic surface horizons which increase in depth from the margin to the central zone (Whitlow, 1985b). Organic matter accumulates because microbial activity is limited by the acidic and waterlogged conditions, and there is little mixing of humic horizons with mineral soils because of the absence of earthworms which favor better drained and less acid soils. Calcic hydromorphic soils are found in some dambos, and they comprise dark grey or black clays with a high base status. The dominant clay mineral in these soils is montmorillonite, hence these soils resemble vertisols in their behaviour with respect to expansion and contraction during wetting and drying phases.

Dambo utilization

The dispersed distribution pattern of dambos has made them accessible to a high proportion of the rural population (Dambo Research Unit, 1987) and cultivation and grazing in dambos because of the growing population and economic pressures on the rural population

(Whitlow, 1983). In Zimbabwe's communal lands dambos are important for the supply of water, for grazing and for the cultivation of gardens (Whitlow, 1985a).

Dambos generally provide a reliable source of water for animals and humans because they remain moist during the dry season (Thompson, 1972; Whitlow, 1984a). The moist conditions also provide a favorable environment for plant growth. Dambos are also important in areas where alternative water sources are remote or prone to drying up because shallow wells can be easily sunk in them (Adreini *et al*., 1995). The moist conditions also enable rural populations to cultivate vegetables during the dry season using traditional water management techniques (Lovell *et al*., 1995; Murata *et al*., 1995).

Dambo cultivation is a well-established tradition amongst peasant farmers in Zimbabwe. Peasant farmers' gardens provide a regular supply of crops (Whitlow, 1983; Acres, 1985), which is especially important during drought years. Furthermore, dambos become excellent farming land once they have been drained because of their high organic matter content. This has attracted many marginalized communal farmers. The grazing of cattle and other livestock is a common form of *dambo* land use because dambos support a vigorous growth of grasses when other grazing is in short supply since the residual reserves of soil moisture can support new plant growth during the dry season.

Impacts of cultivation and grazing on dambo ecosystems

The conversion of wetlands to agricultural land has implications on all of their components, especially the soils that are the physical foundation of their ecosystems (Stolt *et al*., 2000). Cultivation of dambos requires the drainage of excess water to enable proper root development and soil aeration. The most common method used by peasant farmers is to cut deep ditches in them (Roberts, 1983). The concentration of runoff in the ditches leads to the development of gullies. These lower water table levels and cause dambos to dry out

(Whitlow, 1985a). Drainage of dambos also leads to loss of organic matter and soil nutrients. It also causes subsidence (Lilly, 1981; Whitlow, 1983), while the tillage of wetland soils increases soil compaction (Brady and Weil, 1999; Braekke, 1999).

Wetland soils are characterized by low nutrient availability and low rates of soil processes as a result of anoxic conditions in the soil (McLatchey and Reddy, 1988; Aerts *et al*., 1999). Upon conversion to agricultural land, soils that were once subjected to reducing conditions and low rates of decomposition become subjected to oxidizing conditions and high rates of decomposition (Armentano and Menges, 1986). Decomposition is further increased by liming, which raises the pH of the soil and elevates its base cation content (Simmons *et al.*, 1996; Braekke, 1999; Compton and Boone, 2000).

In Zimbabwe, grazing pastures becomes more intense after they have been burnt beginning in about late August through to October (Whitlow, 1985a). Burning is done to get rid of moribund, coarse grasses and sedges and to stimulate new growth. Little thought has been given to the impact of this activity on nutrient fluxes in the system. Burning particularly causes loss of nitrogen stored in the biomass (Brady and Weil, 1999), while other nutrients are reduced to ash and lost through wind erosion and surface runoff during early rainstorms (Whitlow, 1985a).

Hydrology is a primary factor in soil formation because it drives the formation of hydric soils from the existing substrate (Fennessy and Mitsch, 2001). Wetland agriculture is characterized by networks of drainage ditches which lower the water table, promote rapid drainage during and after precipitation and create conditions of continuous surface flow (Bruland *et al*., 2003). Prior to ditching, the water table is higher, drainage slower, and only intermittent flow normally occurs (Richardson and Gibbons, 1993). The water content controls the redox status, pH, nutrient cycling and community composition of plants (Brigham and Richardson, 1993). The draining of wetlands has a negative impact on these processes as flooding alters the availability of plant nutrients (Ponnamperuma, 1984; Hossner and Baker, 1988).

Clearing land for agriculture has triggered some of the most rapid losses of biodiversity on earth (Pimm *et al*., 1995; Vitousek *et al*., 1997). Wetlands are a rich source of macrophyte biodiversity (Mitsch and Gosselink, 1993). The rapid loss of species from wetlands has led to a decline in productivity, nutrient retention and resistance to invasion by introduced plant species (Tilman, 1996; Loreau, 2000; Naeem *et al*., 2000). The extinction of species is thought to alter the way solar energy is captured and the rate at which matter is cycled in an ecosystem (Chapin *et al*., 2000; Cardinale *et al*., 2002).

Importance of wetlands in hydrobiology

Wetlands are natural filters that improve the quality of the water that flows through them (Kadlec and Kadlec, 1979). Good water quality allows a rich assemblage of plant and animal life to develop. The presence of a dense growth of vegetation and high plant productivity, together with considerable contact between water and sediments through sheet-flow promotes anaerobic and aerobic processes that can remove pollutants and enable organic matter to accumulate in the soil (Kadlec and Kadlec, 1979; Hammer, 1992; Mitsch and Gosselink, 1993). Sediment accumulation of 6 to 20 mm per year have been reported in United States of America and deposits of up to 50 % of the suspended load have been reported in New- Zealand (Mitsch and Gosselink, 1993).

Nitrogen and phosphorus loading to wetlands comes from runoff and leaching from fertilized croplands (Hemond and Benoit, 1988; Djodjic *et al*., 1999; Djodjic and Bergstrom, 2005) but excess nutrients can be filtered out as water flows through the wetland. Nitrogen is removed by vascular plants and microorganisms, denitrification and ammonia volatilization (DeLaune *et al*., 1986; Howard-Williams, 1985) although denitrification by anaerobic bacteria is the primary mechanism by which nitrogen is removed from wetland waters (Mitsch, *et al*., 2000). A continuous supply of nitrates to the anaerobic zone of the wetland sediments allows high denitrification rates to occur in most wetlands. This process is enhanced further in wetlands that are alternatively wet (anaerobic) and dry (aerobic) (Reddy and Patrick, 1984). Phosphorus is removed from wetlands mainly through adsorption onto mineral sediments (Richardson, 1985; Cooper and Gilliam, 1987), but it is also removed through uptake by plants and by precipitation as insoluble phosphates of iron, aluminum or calcium (Nichols, 1983).

Organic pollutants such as pesticides and herbicides may reach wetlands through agricultural activity but are removed through sorption onto sediments (Hemond and Benoit, 1988). Since water is generally shallow in wetlands, they provide an ideal opportunity for photo-degradation of pesticides (Zafiriou *et al*., 1984).

In Zimbabwe, the ecological value of dambos has been taken for granted because of incorrect public perceptions, poor legislation and conservation strategies that are not backed by adequate scientific research (Matiza, 1994). Although much is known about wetlands elsewhere (Finlayson and Moser, 1992; Dugan, 1994), little work has been done in Zimbabwe and much of what is known about local dambos relates to their agricultural uses (Whitlow, 1985b). There is a need for continued research on dambos and their biodiversity, especially in view of the growing level of human impacts that are contributing to their destruction.

Objectives and research questions

The maintenance of species diversity ensures natural functioning (Tilman, 1996). This investigation will test the hypothesis that the impact of humans leads to decrease in the diversity of macrophytes in dambos. It will provide information on changes in plant diversity and how it may influence the functioning of dambo ecosystems. These data could develop into policies that promote the sustainable utilization of dambos in Zimbabwe.

The first objective of this study is to compare plant communities in a relatively undisturbed dambo with those in one heavily affected by communal agriculture. This was done by determining the plant cover, species richness and species abundance. The second objective was to determine the physical and chemical characteristics of the soil in these dambos by determining soil texture, pH, total organic carbon, total nitrogen, nitrate nitrogen, total phosphorus and plant available phosphorus (P_2O_5). The third objective was to assess the water quality in the dambos by measuring the physical and chemical variables (dissolved oxygen, pH, conductivity, total nitrogen, ammonium nitrogen, total phosphorus, total dissolved solids, calcium and chloride) of their water.

The principal research questions were: (1) Are there any differences between the plant communities in a dambo subjected to communal agriculture and one that is relatively undisturbed? (2) How has the soil been affected by these different land uses? (3) Do changes in the characteristics of the soil affect the quality of water in the dambos?

THE STUDY AREA

The study area is located 90 km west of Gweru in the Zimbabwean Midlands. It is an area overlaid by Kalahari Sands with gentle relief that has allowed the extensive development of dambos. The natural vegetation consists of *Phragmites australis*, *Thelypteris confluens* and *Typha capensis* although much of it has now been cleared for agriculture. The soil in the wetter parts of the dambos tends to be waterlogged and rich in organic matter and they support areas of grassland interspersed amongst the woodland. Many of them have been extensively cultivated and are heavily grazed. The average rainfall of the area is 650 mm and, as it is throughout Zimbabwe, rainfall is strongly seasonal with one rainy season lasting from

November to March. The dambos often support perennial streams and are therefore an important source of water during the dry season.

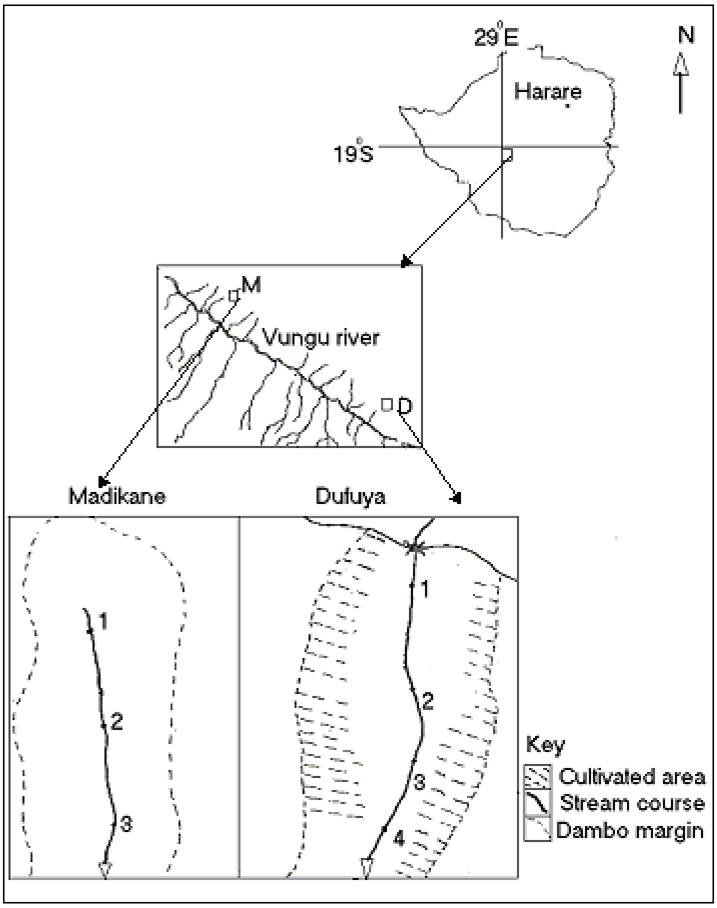

Figure 1: The location of the study sites showing the spatial relationship of the dambos Madikane (M) and Dufuya (D) and sampling stations.

The Dufuya system is located at $19^0$16'S, $29^0$19'E at an altitude of 1 274 m next to Dufuya Primary School along the Sogwala road and drains into the Somkamba stream, a tributary of the Vungu River. The dambo area is 63.3 ha in extent, 28.2 ha is cultivated with about 212 gardens (mean area = 0.127 ha). Water drains into the dambo from a large spring (locally known as a sponge), which is covered by a dense growth of vegetation. An intermittent stream meanders southwards from the spring creating a perennially damp marshy strip that bisects the system with two similar sets of gardens flanking either side of the open marshy strip. The gardens near the central drainage area are wetter than those towards the edge of the dambo that are drier and have sandier soils.

Madikane dambo is located at $19^0 14$'S, $29^0 15$'E at an altitude of 1 256 m and is about 15 km from the Dufuya dambo and it also drains into the Somkamba stream. It is protected by the Department of Natural Resources as well as by the local villagers to whom the area is sacred and therefore cultivation is not permitted. Water drains from a spring into the dambo and meanders south into Somkamba stream.

METHODS

Sampling methods

Plots which covered the outer dambo zone and the central zone were selected for the sampling of macrophytes. Plants were sampled by means of the quadrat technique. Line transects of 80 m were laid at 15 m intervals in Madikane dambo and at 50 m intervals in Dufuya. This was done so as to have an equal number of quadrats from both dambos. Plants were sampled along each transect by laying a 25 cm x 25 cm quadrat at 10 m intervals and recording the species composition, species abundance, and percentage cover in each quadrat. Species that could not be identified were labelled, preserved in a plant press and taken to the National Herbarium in Harare for identification.

Soil sampling was done in November 2004. Soil samples were taken with a soil corer measuring 5 cm in diameter and 20 cm in depth. Fifteen surface (0-20 cm) and five subsurface (20-100 cm) cores were taken from each dambo. The samples were placed into self-sealing plastic bags and stored in a cooler until they could be taken to the laboratory for analysis.

The pH of the soil was determined with a Philips digital pH meter (PW 9419) in a 2:1 water to soil ratio. The soil samples intended for the determination of total organic carbon were air dried, homogenized with a pestle and mortar and passed through a 2mm sieve. The samples were then oxidised with a mixture of 1N potassium dichromate ($K_2Cr_2O_7$) and concentrated sulphuric acid (H_2SO_4) and the soil digest was titrated against a 0.2 M ferrous ammonium sulphate solution (Schnitzer, 1982).

Exchangeable ammonium was determined from undried samples by extracting with 0.5M solution K_2SO_4, and filtration through Whatman 42 filter paper followed by colorimetric estimation. A similar procedure was used for the determination of nitrate-nitrogen except that filtration was followed by cadmium reduction (Keeney and Nelson, 1982). Total nitrogen and total phosphorus were determined by digestion of soil at 110 ^{0}C for 1 hour in concentrated sulphuric acid followed by colorimetric estimation. Plant available phosphate was determined by the Bray method (Bray and Kurtz, 1945) in which 2.5 g of air dried soil was extracted with Bray P2 solution (0.03 N NH_4F and 0.1 N HCl) followed by colorimetric estimation. Particle size distribution was determined by the hydrometer method in which 50 g of air dried soil was saturated with distilled water. The soil suspension was mixed with 300 ml tap water in a graduated cylinder where hydrometer readings and the temperature of the suspension were taken after 40 seconds and after 2 hours (Gee and Bouder, 1986).

Water samples were taken in November 2004, January 2005 and March 2005 from 5 sampling points in Dufuya dambo and 3 sampling points in Madikane dambo (Figure 1). Dissolved oxygen, pH, temperature, conductivity, turbidity, chloride and calcium were measured in duplicate samples on site using a Horiba U-23 multi-meter water quality monitor. Duplicate samples were taken at a depth of 10 cm with a plastic water sampler and placed in 1L polyethylene bottles and stored in an icebox at 4^{0}C. The samples were transferred to the laboratory for the determination of total nitrogen, total phosphorus and ammonium nitrogen. The samples were analysed within 24 hours using HACH ER/ 04 kits. Total phosphorus was determined by the acid persulfate digestion method which measured soluble reduced phosphate in the digested solution (method 8190). Total nitrogen was determined by alkaline persulfate digestion (method 10071) while ammonia was determined by the salicylate method (method 10023).

Data Analysis

Differences in the plant diversity of the two dambos was evaluated with Shannon's Diversity Index (H'):

$$H' = -\sum pi\ In\ pi$$

where H' = Shannon's Diversity Index of species diversity and pi = proportional abundance of species i. This index is a measure of the average degree of uncertainty in predicting to what species an individual chosen at random from a collection of S species and N individuals will belong. Species evenness, a measure of how abundance is distributed among species was calculated using Shannon index of evenness (E_H)

$$E_H = \frac{H}{H\max} = \frac{H}{InS}$$

where S = Total number of species in that particular site. H' = Shannon Index, a measure of species diversity.

The Sorenson similarity index was used to compare the similarity in species composition between the two dambos. It is an index which is limited to presence/absence data, and it is given by:

$$D = \frac{2a}{2a + b + c}$$

where a is the number of species shared between the two sampling units, b is the number of species only found in the first unit and c is the number of species found only in the second unit.

Analysis of variance (Minitab version 13.0) was used to determine any significant differences in water quality and soil variables between the two *dambos* and data that were not normally distributed were logarithmically transformed. Spearman's Rank Correlation was used to examine the relationships among the measured variables and identify those that covaried significantly.

RESULTS

Plant communities

A total of 51 species were recorded in the two dambos (Table 1). Madikane had 39 species belonging to 17 families, while Dufuya had 29 species belonging to 10 families. Thirty one percent of the species occurred in both dambos. Most species were herbs but grasses made up 18 % of the total in Madikane and 14 % in Dufuya and only one tree species, *Ficus thonningii*, was recorded (in Madikane). Exotic species were present in both dambos but they were more numerous in Dufuya where five species, amounting to 17 % of the total, compared to Madikane with only three species, or 5 % of the total.

Species diversity and evenness was higher in Madikane (H' = 2.52, E = 0.69) than in Dufuya (H' = 2.14, E = 0.63). The dominant species in Madikane were *Thelypteris confluens, Kyllinga erecta, Carex cognata, Cyperus rotundus,* and *Cyperus articulatus*, which made up 75 % of the total. In Dufuya, the dominant species were *Fimbristylis dichotoma, Kyllinga erecta* and the unidentified asteracean Species A, which made up 70 % of the total.

Table 1: The relative abundance (%) of each species in two different regions of the two dambos. (O = outer, C = central, M = Madikane, D = Dufuya). Species marked * are exotics and † are herbs.

Family	Species	MO	MC	DO	DC
Acanthaceae	*Hypoestes forskalei* †			0.44	0.05
Amaranthaceae	*Amaranthus hybridus** †			3.51	
Anacardiaceae	*Pyroides pyroides*		0.11		
Apiaceae	*Hydrocotyle bonariensis** †	3.37	3.42		
Asteraceae	*Conyza welwitschii* †	1.35	0.15		
	Pseudognaphalium album †	0.03			
	Osteospermum monocephalum	0.38		0.08	0.32
	Senecio strictifolius †		0.04		
	Blumea solidaginoides †	0.10			
	*Conyza sumatrensis** †			0.65	
	Lactuca indica †			0.13	0.11
	Bidens pilosa †			1.30	
	Otomeria elatior †			4.75	
	Species A	10.73	1.75	19.36	23.02
	Species B	0.75			
Capparidaceae	*Cleome gynandra* †			1.19	
Cyperaceae	*Cyperus rotundus*	19.34		0.43	
	Kyllinga alba	4.76		4.54	2.95
	Fuirena pubescens	0.02			
	Kyllinga erecta	14.08	2.33	35.10	29.79
	Carex cognata	7.63	12.89	0.08	3.46
	Fimbristylis dichotoma	0.10		13.65	22.40
	Cyperus articulatus	8.82	36.08	0.15	0
Fabaceae	*Tephrosia* spp. †	0.02			
Fumariaceae	*Chironia palustris* †	0.03			
Malvaceae	*Sida rhombifolia* †		0.04		
Moraceae	*Ficus thonningii*		0.07		
Musaceae	*Musa caventish**				0.03
Onagraceae	*Epilobium salignum* †	0.10			
	Ludwigia stolonifera †	0.13			
Orobanchaceae	*Cycnium tubulososum* †	0.48	0.55	0.79	3.17
Poaceae	*Panicum repens*	5.37		1.23	7.76
	Cynodon dactylon	1.87		7.34	0.99
	Eragrostis inamoena	0.38			
	Paspalum scrobiculatum	0.25			1.29
	Andropogon eucomus	0.02		0.32	0.35
	Sporobolus pyramidalis	0.01		0.87	
	Eragrostis cylindriflora			0.08	
	Eriochloa macclounii †			0.08	
	Eragrostis heteromera			2.60	
	*Paspalum urvillei**			0.43	3.14
	Phragmites australis	1.47	15.84		
	Species C		4.88		
	Species D	4.27	3.39		
	Species E	0.15		0.22	0.24
Rosaceae	*Potentilla* spp.* †		0.07		
Rubiaceae	*Richardia scabra* †		0.22		
Solanaceae	*Physalis peruviana* †		0.11		
Thelypteridaceae	*Thelypteris confluens* †	13.06	15.87		
Tyhaceae	*Typha capensis* †	0.92	2.22	0.65	0.91
Verbenaceae	*Lantana camara**	0.01		0.02	
Species diversity (H')		2.48	1.92	2.09	1.88
(E_H)		0.72	0.65	0.63	0.66

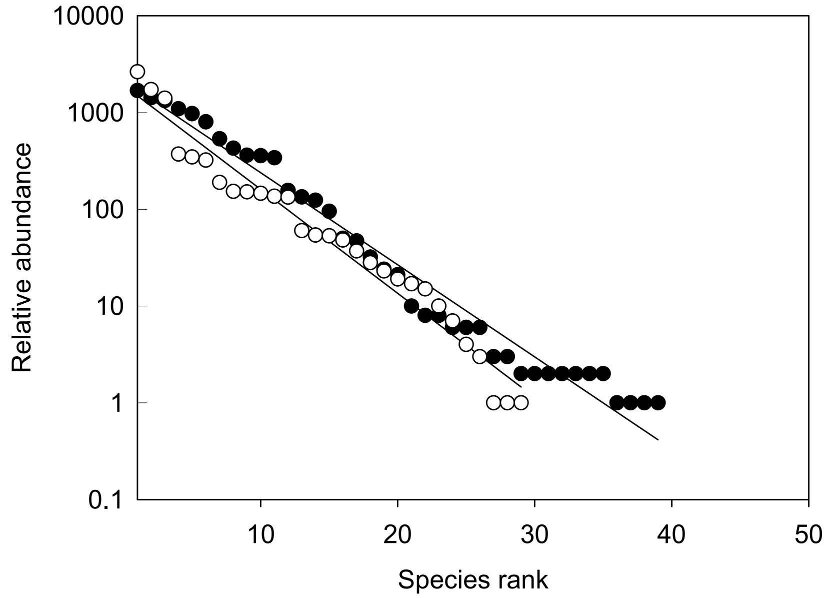

Figure 2: Species importance curves for Madikane (●) and Dufuya (○) dambos. Regression lines were fitted as follows: $y = 3.38 - 0.09x$, $r^2 = 0.97$ (Madikane) and $y = 3.23 - 0.10x$, $r^2 = 0.96$ (Dufuya).

There was a significant difference in species composition between Madikane and Dufuya (Spearman rank correlation, $p < 0.05$). Species were more evenly distributed in Madikane than Dufuya. The ranking of species in the dambos differed and the rank of a species increased as its relative abundance increased (Figure 2). Species that were important in Dufuya were at times absent in Madikane and vice-versa. For example, *Thelypteris confluens* that had a second rank in Madikane was absent in Dufuya.

In both dambos, the central regions had a relatively low species diversity and evenness compared to the outer regions (Table 1). The dominance of a few species in the central regions suggests a competitive interference and or adaptation by the plant species to survive in waterlogged conditions. The differences in species composition between the outer and central regions were significant (Spearman Rank Correlation, $p < 0.05$). The central region of Madikane was dominated by *Thelypteris confluens* (15.87 %), *Phragmites australis* (15.84 %) and the *Cyperus articulatus* (36.08 %) while the central region of Dufuya was dominated by

Kyllinga erecta (29.79 %), *Fimbristylis dichotoma* (22.4 %) and the asterecean Species A (23.02 %). The Sorensen similarity index for the central regions was 11 % so they were not similar in terms of their species composition.

The outer region of Madikane was dominated by *Cyperus rotundus, Kyllinga erecta* and *Thelypteris confluens* while the comparable regions of Dufuya were characterized by species of disturbed ground, *Cleome gynandra* (2 %), *Bidens pilosa* (1 %), *Amaranthus hybridus* (4 %) and *Cynodon dactylon* (7 %) a species that occurs widely in overgrazed areas. The Sorensen similarity index for the outer regions was 18 % so they were not similar in terms of their species composition.

A cluster analysis of species composition separated the dambos into three distinct clusters with Madikane and Dufuya being distinctively separated (Figure 3). The outer zone of Madikane was widely separated from the central zone and was rather closer to the Dufuya cluster. This was a result of 22 species that were present in Madikane but absent in Dufuya, 12 species present in Dufuya but absent in Madikane and 10 species that were common to Dufuya and the outer region of Madikane. The central region of Madikane was separated from the rest of the regions because it was dominated by *Thelypteris confluens* and *Phragmites australis* suggesting a wet environment in that region.

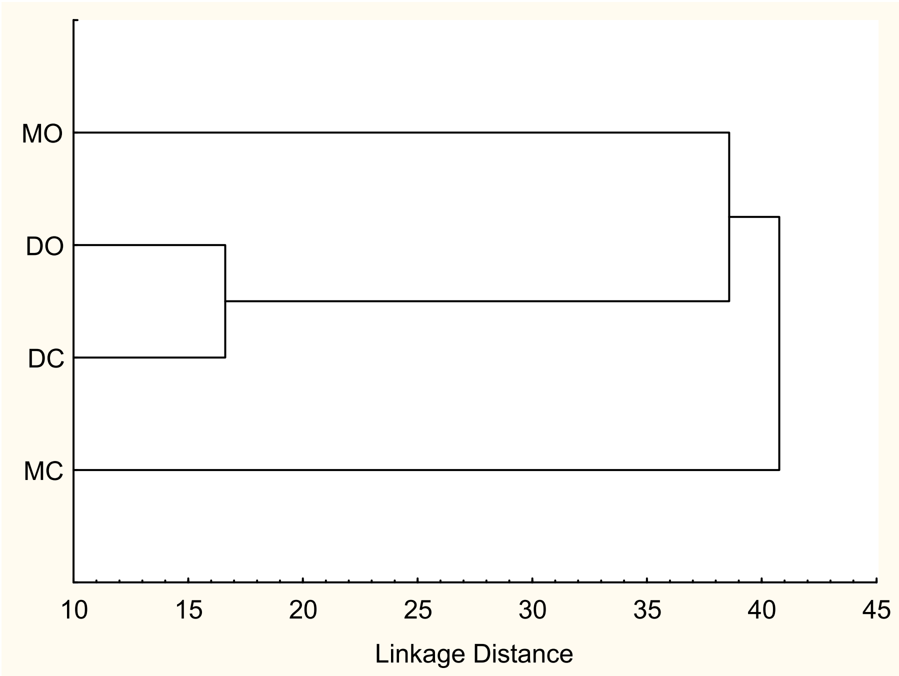

Figure 3: A dendrogram of species composition in the study areas (O = Outer and C = central; M = Madikane and D = Dufuya)

Soil properties

The concentrations of ammonia, nitrate-nitrogen and total nitrogen in the soil was significantly higher in the surface layers of Madikane than in Dufuya (Figure 4). This was also true for ammonium and total nitrogen in the deeper layers but nitrate-nitrogen was much higher in the deeper layers of Dufuya, which was the opposite to the situation in the surface layers. The differences between the two dambos were significant ($p < 0.05$) in each case. Presence of nitrogen in deeper layers suggests leaching from the surface layer.

Table 2: Mean concentration of total phosphorus (P), plant available phosphorus (P_2O_5) and pH in Madikane and Dufuya with significantly different ($p < 0.05$) values highlighted in bold

	Madikane	Dufuya
PH	6.9	6.3
P (%)	0.03	0.04
P_2O_5 ($\mu g\ g^{-1}$)	**66.48**	**79.25**

The concentration of phosphorus was higher in Dufuya than Madikane (Table 2). The slightly higher level of phosphorus in Dufuya suggests the influence of external sources. Soil pH was relatively higher in Madikane than Dufuya with a range of 4.98 – 10.15 and 5.26 – 7.86 respectively. The slight acidity of the soil in some parts of Dufuya and Madikane suggest the release of humic acids from organic matter decomposition.

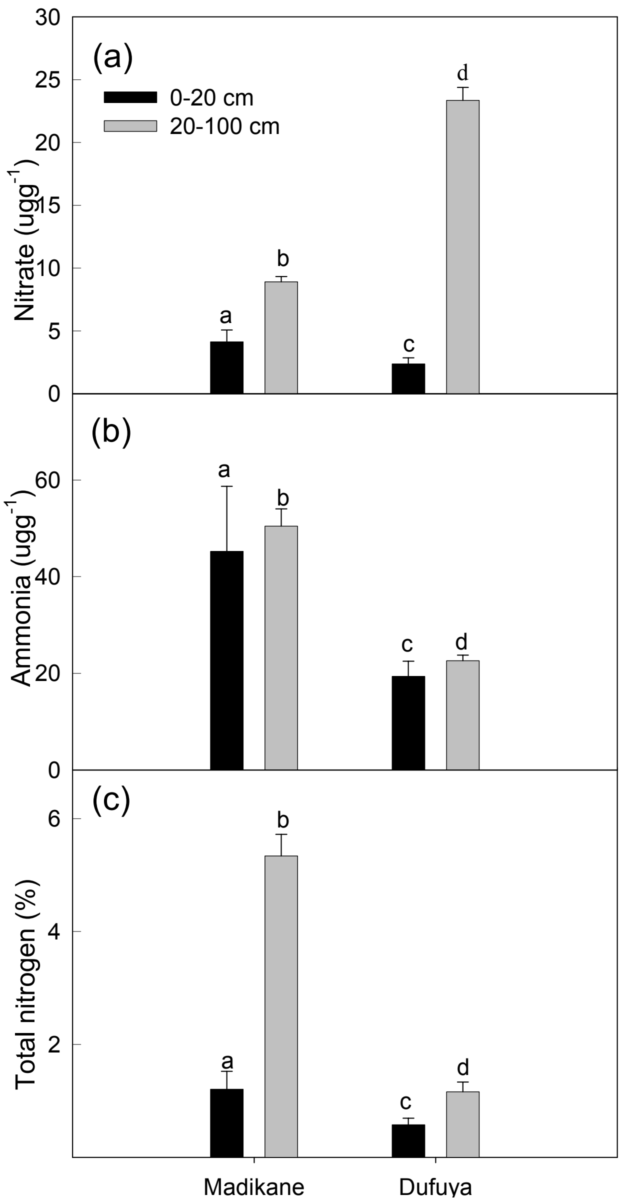

Figure 4: Mean concentrations of (a) nitrate nitrogen (μg NO_3 g^{-1} soil), (b) ammonium nitrogen (μg NH_4^+ g^{-1} soil) and (c) total nitrogen (%), in surface (0-20 cm) and subsurface (20-100 cm) samples. Values presented are means ± standard deviation. Values with the same superscript are not significantly different ($p > 0.05$).

The concentration of organic carbon in both dambos was higher in the central zone than in the outer zone although it was significantly lower in Dufuya (Figure 5). The concentrations in the drier outer zones were much lower than in the central zones and although the differences between the two dambos were relatively small they were still significant. Moisture content in the central and outer zones ranged between 60 – 90 % and 1 – 45 % respectively.

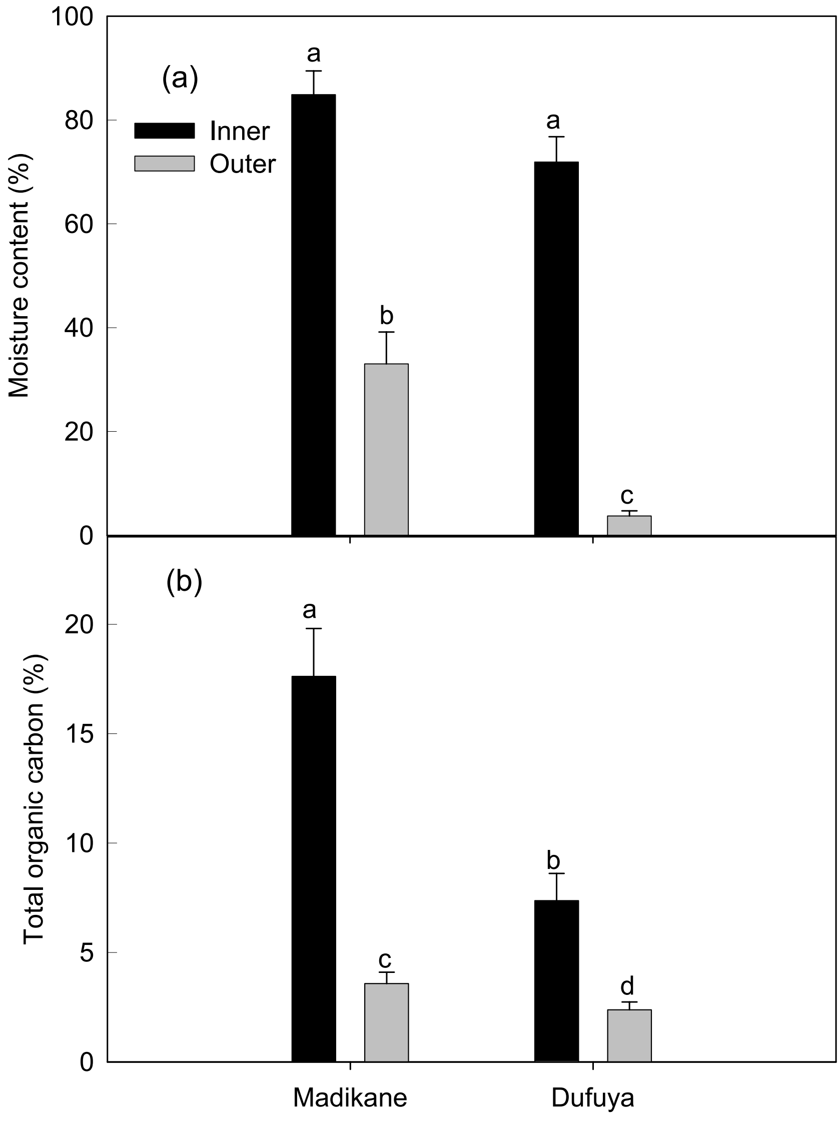

Figure 5: Mean content of (a) moisture (%) and (b) total organic carbon in the outer and in the central zone of Madikane and Dufuya. Values presented are mean ± standard deviation. Values with the same superscript are not significantly different (ANOVA: $p > 0.05$).

There was a significant correlation between the amount of total organic carbon and moisture content in Madikane (Pearson correlation, r = 0.74) and Dufuya (r = 0.88). The amount of total organic carbon significantly increased with the increase in moisture content (Figure 6) suggesting the importance of moisture in the decomposition of plant matter. The increase in organic carbon with moisture content was more pronounced in Madikane (r^2 = 0.78) than Dufuya (r^2 = 0.54).

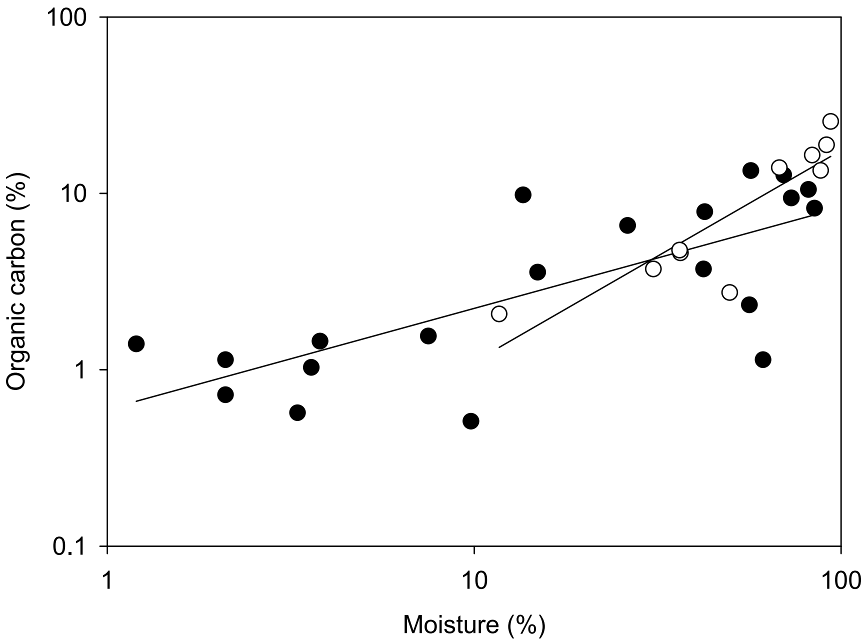

Fig 6: The relationship between moisture content and organic carbon in Dufuya (●) and Madikane (○). Regression lines were fitted as follows: y = -0.22 + 0.57*x*, r^2 = 0.54 (Dufuya) and y = -1.15 + 1.20*x*, r^2 = 0.78 (Madikane).

The majority of soils sampled in the two *dambos* were loamy sand or sandy loam with clay content ranging from 3 -29 % in Dufuya and 5 – 19 % in Madikane (Table 3). Clay loam soils were only present in two sites in Dufuya. There were no significant differences detected in particle size composition between the two *dambos*, % silt (t - test, $p > 0.05$) and % clay ($p > 0.05$). The amount of clay and silt were significantly positively correlated with the amount of phosphorus in Dufuya (Pearson correlation, r = 0.5) as opposed to the negative correlation in Madikane (r = -0.3) (Figure 7). There was no correlation between the amount of clay and silt with the amount of nitrogen in Madikane (r = 0.02) and Dufuya (r = 0.01).

Table 3: The physical structure of soil in Madikane and Dufuya. Values presented are means ± standard deviations. Values with the same superscript are not significantly different (t - test: p > 0.05).

	Sand	Clay	Silt
Dufuya	72.2 ± 14.75^{a}	13.0 ± 7.01^{b}	14.8 ± 9.34^{c}
Madikane	77.8 ± 9.19^{a}	10.7 ± 4.33^{b}	11.5 ± 6.82^{c}

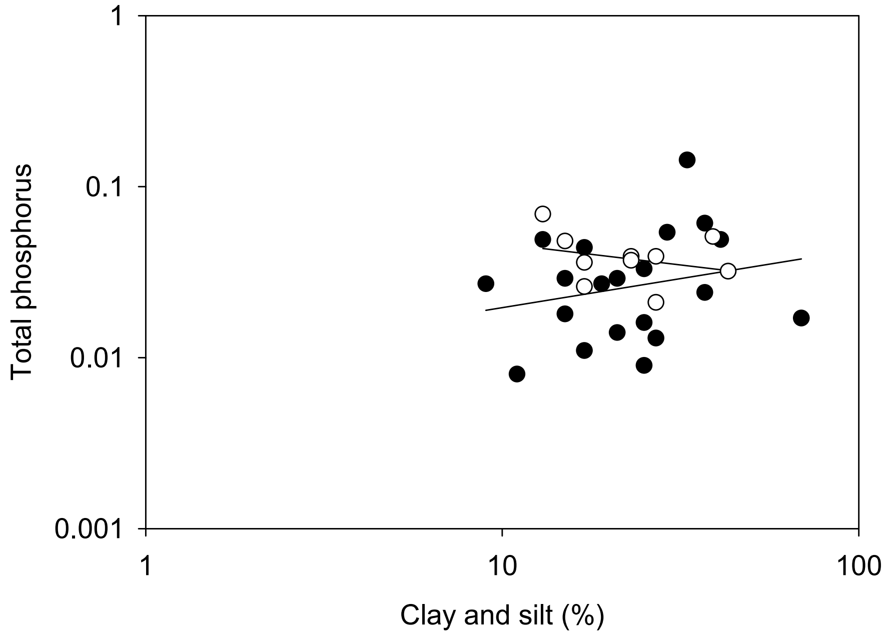

Figure 7: The relationship between the physical structure of soil and phosphorus in Dufuya (●) and Madikane (○). Regression lines were fitted as follows: y = 0.0004 + 0.002*x*, r^2 = 0.05, p > 0.05 (Dufuya) and y = 0.0004 + 0.04*x*, r^2 = 0.09, p > 0.05 (Madikane).

Water Quality

The concentration of total nitrogen was relatively low in both dambos (1.30 ± 0.23 mg L^{-1} in one dambo and 1.17 ± 0.25 mg L^{-1} in the other) but there was no significant difference between them (ANOVA, $p > 0.05$). The concentrations of ammonium nitrogen levels ranged from 0.01 to 0.05 mg L^{-1} in both dambos and the differences between them were also not significant (Table 4). The concentration of phosphorus was significantly higher ($p > 0.05$) in Dufuya (1.30 ± 0.26 mg L^{-1}) than in Madikane (0.66 ± 0.12 mg L^{-1}). Calcium was significantly higher in Dufuya than in Madikane but no significant difference ($p > 0.05$) in the concentration of chloride. The pH of water in Madikane varied with a pH ranging from 6.71 to 10.0 while it was nearly neutral in Dufuya (6.70 to 7.07). The conductivity was significantly ($p < 0.05$) higher in Dufuya (287 ± 36.18 µS cm^{-1}) than in Madikane (125 ± 3.61 µS cm^{-1}) but the concentration of dissolved solids was the same in both wetlands with a range of 0.1 to 0.2 g L^{-1}. The concentration of dissolved oxygen in Madikane ranged from 4.8 - 6.3 mg L^{-1} and in Dufuya from 6.6 - 8.1 mg L^{-1}.

Table 4: The mean values ± standard deviation of various water quality variables from Madikane and Dufuya.

	Madikane	Dufuya
AN (mg L^{-1})	0.05 ± 0.01	0.03 ± 0.02
TDS (g L^{-1})	0.13 ± 0.05	0.12 ± 0.03
N (mg L^{-1})	1.30 ± 0.23	1.17 ± 0.25
P (mg L^{-1})	0.66 ± 0.12	1.30 ± 0.26
Ca (µg L^{-1})	1.21 ± 0.42	2.23 ± 0.34
Cl (mg L^{-1})	1.77 ± 0.17	2.05 ± 0.25
pH	6.76 ± 0.04	7.01 ± 0.04
Conductivity (µS cm^{-1})	125 ± 3.61	287 ± 3.18
DO	5.66 ± 0.54	7.11 ± 0.38

Soil and water relationships

In Dufuya, the pH in water rapidly increased as the soil pH increased. This suggests a loss of Ca^{2+} and other cat-ions from the soil. Lime ($CaCO_3$) that is used to control soil pH act as a source of Ca^{2+}. The effect of liming is also indicated by the small range of water pH in Dufuya than in Madikane. The increase of Ca^{2+} from is also shown by a high conductivity of water in Dufuya than Madikane (Table 4). In Madikane, there was a gradual decrease in the pH of water as soil pH increased.

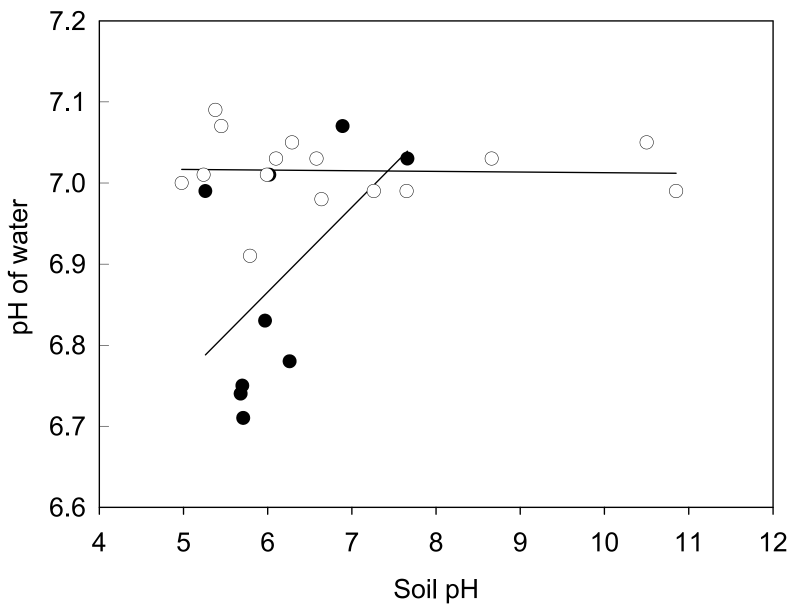

Figure 8: The relationship between soil and water pH in Dufuya (●) and Madikane (○). Regression lines were fitted as follows: $y = 6.23 + 0.11x$, $r^2 = 0.28$, $p > 0.05$ (Dufuya) and $y = 7.02 – 8.32x$, $r^2 = 0.21$, $p > 0.05$ (Madikane)

The concentration of nitrogen in water slightly decreased with an increase in soil nitrogen of both dambos. A significant decrease was recorded in Madikane than Dufuya. Cultivation of soil in Dufuya suggests a negative impact on nitrifying bacteria that is responsible for the loss of nitrogen through nitrification compared to Madikane where there is little disturbance. The concentration of phosphorus in water of Dufuya rapidly increased with an increase in soil pH. The increase was significant and it suggests leaching of phosphorus from the cultivated areas, as dambos tend to act as sources of nutrients applied in excess of crop uptake. In Madikane, there was a slight increase of phosphorus in water with an increase in soil phosphorus and the increase was not significant. This suggests removal of phosphorus by the rapidly growing macrophytes in the dambo.

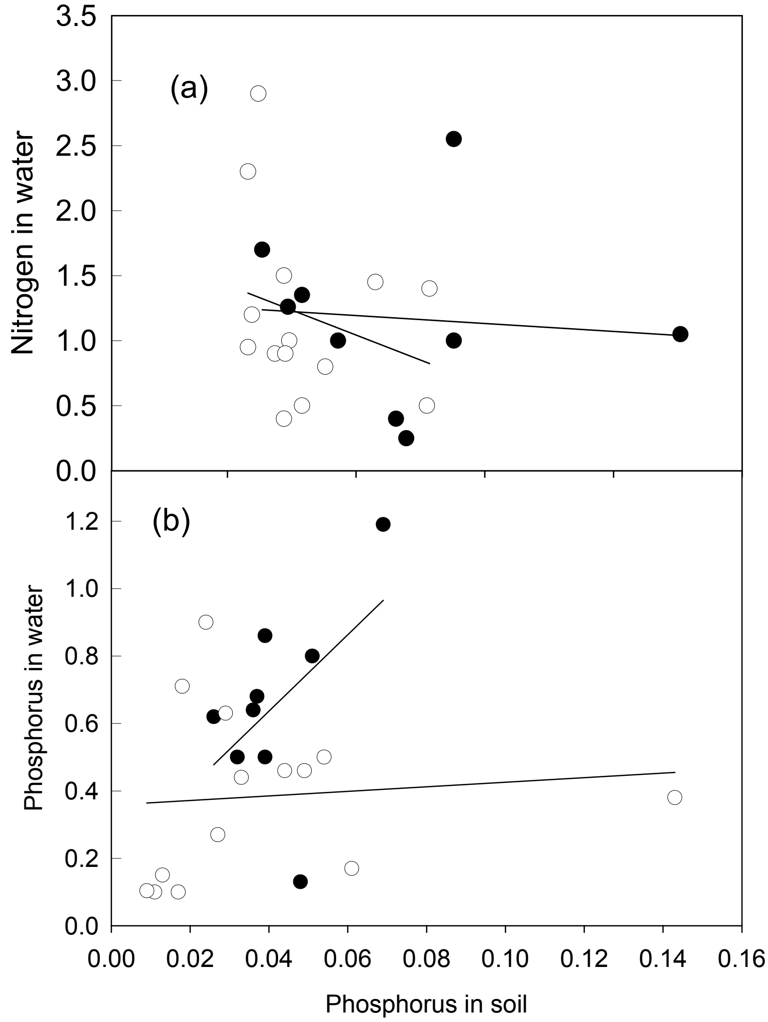

Figure 9: The relationship between (a) nitrogen in soil and water and (b) phosphorus in soil and water in Madikane (○) and Dufuya (●). Regression lines were fitted as follows: (a) $y = 1.42 – 0.38x$, $r^2 = 0.07$ (Madikane), $y = 1.25 – 0.06x$, $r^2 = 0.01$ (Dufuya) (b) $y = 0.36 + 0.68x$, $r^2 = 0.24$ (Madikane), $y = 0.18 + 11.34x$, $r^2 = 0.52$ (Dufuya),

DISCUSSION

The exploitation of dambos changes their vegetation composition as in other ecosystems (Vitousek *et al*., 1997). This was reflected by the differences in species composition between Madikane and Dufuya. The species that were present in Madikane indicate a permanent or semi – permanent wetness (*Phragmites australis*, *Ludwigia stolonifera, Cyperus articulatus, Carex cognata, Typha capensis, Epilobium salignum* and *Thelypteris confluens*) (Everett, 1982a, 1982b) compared to species that that requires well drained soils and can tolerate arid environments (*Amaranthus hybridus*, *Cleome gynandra and Hypoestes forskalei*) that were present in Dufuya. The dominance of species adapted to an arid environment especially in the outer region of Dufuya indicates shrinking in size of Dufuya dambo. A continuous cultivation in Dufuya would result in its disappearance.

The central regions of the two dambos were characterized by low species abundance but a different species composition. Competitive interference by *Phragmites australis* and *Cyperus articulatus* in the centre of Madikane, *Kyllinga erecta* and *Fimbristylis dichotoma* in the centre of Dufuya could be strong and hence contribute to the low species diversity. These species tend to grow and colonize rapidly in areas they are found (Everett, 1982a, 1982b). The low species diversity in the central regions can also be attributed to high moisture content in these regions (Acres, 1985). Few species are adapted to survive in areas where the soil is permanently waterlogged since waterlogged areas have less habitat variation. *Cyperus articulatus, Phragmites australis* and *Fimbristylis dichotoma*, the most dominant species in Madikane and Dufuya respectively are strongly associated with moist conditions and sandy soils (Everett, 1982a). These species form dense stands in the normal rain season.

Dambo utilization replaces the natural growing species with introduced and exotic species. Dufuya had a high proportion of exotic species (17 %) than Madikane (5 %) (Table

1). *Cleome gynandra* and *Amaranthus hybridus* are weeds that indicates disturbance (Everett, 1982a) in form of cultivation and these were only present in Dufuya.

The use of dambos can also change the vegetation structure. This was shown by the presence of species indicating disturbance in Dufuya. *Cynodon dactylon* is a perennial species which indicates grazing. It has high cover abundance but no dominating effect because of its short growth form. *Cynodon dactylon* had low cover abundance in Dufuya compared to Madikane. *Panicum repens*, a species which grows in the transition zone between land and water is also preferred by herbivores (Sharpe, 1997). In Madikane, *Panicum repens* had a low relative abundance but with a height greater than 100 cm whilst in Dufuya it had a high relative abundance but a height of less than 10 cm in most cases.

A shift of species composition from perennials to annuals due to dambo utilization in Dufuya was observed in Dufuya dambo. The annual species that dominated in Dufuya especially the outer regions were *Eragrostis cylindriflora*, *Paspalum urvillei, Cleome gynandra*, *Amaranthus hybridus, Panicum repens* and *Bidens pilosa*. In Madikane, there was a mixture of annual and perennials.

The levels of soil nitrogen were generally higher in Madikane than Dufuya (Figure 4). This is not an unusual feature in peat soils as it is explained by decomposition and mineralization of plant material which releases nitrogen back into the soil (Zedler, 2000). Fertilization of agricultural land lead to an accumulation of phosphorus and nitrogen (Compton and Boone, 2000). In this study, Dufuya was enriched with phosphorus than Madikane. The low levels of phosphorus in Madikane are also explained by uptake with rapidly growing dambo vegetation (Bruland *et al*., 2003) since flooded soils are associated with reducing conditions which increase the solubility and mobility of phosphorus (Zedler, 2000). Although the soil data could not be analysed at the same degree of detail as floristic data, a change in the levels of nitrogen and phosphorus shift the composition of a plant community by promoting a rapid growth of species that are best adaptable to that environment. Low nutrients and high base concentrations have been found to be responsible for higher plant diversity in wetlands (Wheeler and Shaw, 1995). Hence some of the observed differences in species composition are explained by the differences in nutrient composition.

Agricultural activity in hydric soils does not always result in the depletion of soil organic carbon (Shaffer and Ernst, 1999). In this study, it was shown that the wetness of the soil which was influenced by the position in the dambo had an effect on total organic content (Figure 6) since organic carbon increased with an increase in moisture content. Few microorganisms that can breakdown organic matter are adaptable to live in relatively wet environments (Mclatchey and Reddy, 1988). The slight differences in organic carbon between Madikane and Dufuya may be attributed to cultivation since organic carbon is assumed to be 58 % total of organic matter.

Table 5: The concentration of total nitrogen and total phosphorus (mg L^{-1}) in water from peat soils of Madikane and Dufuya (this study) compared to that of Carolina bay complex (Bruland *et al*., 2003) and Coastal plain wetlands (Walbridge and Richardson, 1991). R = reference site and I = impacted site.

	Total nitrogen		Total phosphorus	
	R	I	R	I
This study	1.30	1.17	0.66	1.30
Carolina Bay	1.65	1.60	0.05	0.16
Coastal wetlands	1.08		0.08	

There was a significant difference in the water quality between Madikane and Dufuya as evidenced by the differences in nutrient concentrations of phosphorus and nitrogen. The ability to improve water quality is often high in the presence of species like *Phragmites australis* and *Typha capensis* (Kadlec and Knight, 1996), which were dominant in Madikane than Dufuya. The high concentrations of total nitrogen recorded in water from both dambos (Table 4) are not an unusual feature as it is a characteristic of water from peat soils. The levels of nitrogen recorded in this study are close to those reported in Carolina and coastal wetlands (Table 5).

Most of the nitrogen recorded in water could have been derived from peat soils through nitrification of ammonia produced from organic matter decomposition (Avinmelech *et al*., 1978) as evidenced by the high levels of nitrogen in the soil (Figure 4). The high levels of phosphorus recorded in Dufuya than Madikane are explained by the disturbance of a natural ecosystem through fertilizer application (Djodjic *et al*., 1999). The increase of phosphorus in the disturbed ecosystem is a result of export of phosphorus from cultivated areas and the inability of these systems to serve as sinks of fertilizer applied in excess of plant uptake (Djodjic *et al*., 2000; 2005; Walbridge and Richardson, 1991). The high conductivity in Dufuya (287 $\mu S\ cm^{-1}$) compared to Madikane (125 $\mu S\ cm^{-1}$) is also explained by nutrient loading. Lime ($CaCO_3$) that is used to control soil pH act as a source of calcium. Leaching of calcium ions and other cat – ions tend to increase the conductivity of water. A long term monitoring of the physical and chemical variables is needed so as to assess the extent of the impact of agriculture.

The question on dambo utilization is whether or not they should be used by how they should be used in a sustainable way. Dambo cultivation has to be fully recognized as an economic activity especially in the rural community. The current policy on dambo utilization has to be changed since it has allowed degradation to progress unchecked. Dambo farming under proper management emphasizing on community responsibility can be of sustainable use since dambos are a common property with no specific person responsible for their use or misuse. The management strategy has to be ecologically sound, economically viable, socially just, humane and adaptable.

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