UNIVERSITY OF ALBERTA

Effects of Prescribed Burning on the Grassland Vegetation of the Makgadikgadi Pans National Park, Botswana

by

© Isaac K. Theophilus

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Effects of Prescribed Burning on the Grassland Vegetation of the Makgadikgadi Pans National Park, Botswana** submitted by **Isaac K. Theophilus** in partial fulfillment of the requirements for the degree of **Master of Science** in **Wildlife and Rangelands Resources.**

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Dedication

This work is dedicated to my mother, Uanee Margaret, and my father, Theophilus Hangero, for all the love and devotion.

ABSTRACT

In the grassland vegetation of the Makgadikgadi Pans National Park in north-central Botswana (20° 23' S, 24° 49' E), dry season fires are a common phenomenon. Government has, with little succcess, tried to suppress all uncontrolled fires. Increasing human encroachment into conservation areas has led to perpetual conflicts between wildlife and the livestock sector. As a result of reduced wildlife mobility to areas of natural migration, management was forced to seek viable alternative means to provide high quality forage for the wildlife. Prescribed burning, for management purposes, was identified as a possible tool. A study was initiated in 1992 to test the hypotheses that season of burning did not have effects on (i) forage productivity, (ii) forage quality, and (iii) changes in vegetative cover and species composition.

Following burning, forage productivity was significantly lower in the Burn treatments than in the No Burn, forage moisture was higher in the newest burn than the No Burn. By the second growing season the Burn treatments had recovered their productivity to the No Burn levels. Lower productivity in the Burn treatments after a fire is indicative that forage may be a limiting factor after a fire. Fire intensity had no effect on total productivity, extended leaf height and seedhead numbers of the three main grass species.

Prescribed burning resulted in increased digestibility and crude protein content of the forage. However, these increases were short-lived. Higher crude protein was found in the young, actively growing forage at the onset of growth while maximum digestibility values were found during the mid-growing season. Both variables were very low during the dry season indicating that low forage quality will likely negatively affect animals during the dry season. Of the three species studied, *Schmidtia pappophoroides* was highly palatable, *Stipagrostis*

uniplumis was good when young but became lower in quality as it reached maturity. *Odyssea paucinervis* was a poor forage species. Rainfall induced rapid growth in the Burn treatments resulting in more digestible forage.

In the growing season following burning, there was reduced foliar cover but by the second growing season *Schmidtia* and *Odyssea* had recovered to pre-burn levels. Bare ground was highest in the newest burn compared to the No Burn. By the second growing season, the Dry season burn treatments had higher total vegetative cover and live vegetative component than the Early wet season burn treatment. Burning removed the dead component thereby making the regrowth forage more available to the herbivores.

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CHAPTER 1 INTRODUCTION

Prescribed burning is an important and essential range management practise in both livestock and wildlife management systems in Africa. Fire is utilised for the manipulation of natural vegetation either for pasturage, game management, timber production, or for a combination of two or more of these objectives (Trapnell 1959, Van Wyk 1971, Harrington and Ross 1974, Trollope 1982). Historically, fires caused by lightning and man have been a major force affecting forest and grassland ecosystems (Stoddart et al. 1975, Crowder and Chheda 1982). Whenever fuels were sufficient and there was an ignition source, fires have consumed trees and shrubs thus maintaining grassland and savanna type vegetation. The existence of a large proportion of the savannas has been attributed to periodic fires (Ewusie 1980).

In the African savannas, fire is recognised as having an important ecological role in the development and maintenance of productive and stable, savanna communities (Phillips 1965, Lemon 1968, Austein 1971, Gillon 1971, Skovlin 1971, Van Wyk 1971, Vesey-Fitzgerald 1971, West 1971, Afolayan 1978). The driest savannas burn when above average rainfall has allowed production of sufficient contiguous fuel to carry a fire. Intermediate savannas burn more often and more intensively, while the wettest savannas only burn when there has been an extended dry season causing the grass to dry up (Skarpe 1992, Trollope 1984, van Wilgen, Everson and Trollope 1990). Thus each moisture regime and vegetation type has its own potential fire regime (Hodgkinson et al. 1984).

Having evolved with fire as a natural periodic phenomenon in the ecosystem, many shrubs and trees of the semi-arid savanna are fire tolerant. There is consensus that in a predominantly grassland vegetation, fire will kill the woody plant seedlings and juveniles, preventing their development to a mature fire resistant stage (Animal Production Research Unit 1980, Sweet and Tacheba 1985). However, once the woody species have become dominant and are suppressing grass growth, there is no longer sufficient grass fuel to support an intense fire.

Fire is one of the most controversial tools in range management (Pratt and Gwynne 1977, Tainton et al. 1978). Even among the scientific community there is an apparent disagreement that fire can control bush encroachment since most woody species growing in the savannas are relatively tolerant to fire, and have evolved under the influence of regular burning. Another reason often given is that the precise effects of fire at different times of the year and different frequencies is poorly understood. The long term nature of this type of research often compounds the problem.

Fire is a major factor maintaining tropical savannas and grasslands, and its utilization is deeply rooted in African cultures. The reasons commonly given for burning are to: 1) stimulate fresh growth of grass, 2) attract wildlife for hunting or to improve areas for cattle, and 3) eliminate tall dry grass which can hide predators. The above traditional reasons for burning were restated by Trollope (1989) as follows: i) to remove moribund and/or unacceptable grass material, and ii) to eradicate and/or prevent the encroachment of undesirable plants.

In developing a burning program, it is important to consider the reasons for burning and the appropriate fire regime to be applied. The effectiveness of a burning regime is influenced by several factors. Key factors include the intensity of a burn, which depends on climatic and fuel load conditions (Norton-Griffith 1979), season of burning (van Rensburg 1971, Harrington and Ross 1974, Afolayan 1978, Trollope 1983, Trollope 1984, Edroma 1984), and frequency of burning (Eltringham 1976, Trollope 1983, Novellie 1987).

On grasslands, fire is used to remove the old or senescing unutilized herbaceous material of previous years in order that new growth may develop unhindered by the accumulation of dead material and thus be readily available to the grazing animals. Removing dead grass with fire results in more uniform utilization of the forage. This is especially important in tropical and sub-tropical humid climates where herbaceous growth is rank and coarse (Stoddart et al. 1975).

Burning grasslands generally decreases yield, but this is not always the case (Heady 1975). Forage production may be lower on burned plots in some years and not in others. This is because the increase in the preferred species might lead to overgrazing by the herbivores in the burned areas. The result is that management programs should take into account the size of the area to be burned to avoid localized overgrazing. It is essential to burn the entire range or to burn large areas and base stocking rates on the acreage burnt, since some wildlife prefer burned range (Mentis and Tainton 1984, Child et al. 1987, Novellie 1987, Moe, Wegge and Kapela 1990). Otherwise severe overgrazing will occur on the burned area to the detriment of the better plants causing changes in species composition (van Rensburg 1971). Rangelands are said to be deteriorating when there is more bare ground, more woody plants, more undesirable grass species than it had previously. African grasslands have evolved in association with a wide variety of wild ungulate species favouring grasses of different heights (Bell 1970, Grobler 1983).

Quality of forage may be increased or decreased by burning. Forage quality following burning is affected by changes in plant composition, which vary with time of burning. An adequate index of forage quality may be provided by measuring crude protein (CP) content which is expressed as a percentage

(%) of dry matter. In Botswana, the Animal Production Research Unit (1986) found that crude protein, and to a lesser extent digestibility of grasses consumed, had a major effect on cattle live-weight gains. Most herbivores are grazers and need a higher crude protein content in their diet because herbivores are limited by poor quality forage. It is generally thought that for livestock maintenance, forage consumed should have a minimum crude protein content of 7% and for meat production the crude protein should be at least 10% (Animal Production Research Unit 1980).

In Botswana, the present policy is to prevent all uncontrolled range fires. Persons wishing to burn their own land may do so after obtaining permission from the authorities, but if fire spreads into neighbouring land the licenced person is liable to heavy fines. Despite the fact that legislation is in place, it is estimated that up to 20% of Botswana burns annually (Animal Production Research Unit 1980). When considering the official legislation and the widely accepted reasons for rangeland burning; i.e. removal of moribund and/or unacceptable grass material and to prevent the encroachment of undesirable species; the question then arises whether an important part of the ecosystem is not being eliminated to the detriment of the ecological stability of the system. Mentis and Bailey (1990) discuss the role of changing perceptions regarding the use of fire in the management of savanna parks. They mention that fire is no longer viewed as an undesirable evil but an important tool of park management programs.

Makgadikgadi Pans National Park was unmanaged since the park was established in 1970. Vegetation and wildlife management programs were non-existent because of the adopted policy of non-interference. Also, managers did not see the need for intensive management because of the availability of vast areas of land for wildlife. Now, following increased human and livestock populations, there is pressure on the land and thus a need for more active management. When this conservation area was established the potential impact the park would have on the communities was overlooked. These settlements have grown rapidly and so have their demands for increased land for livestock grazing. People view the park as some form of reserved grazing areas for their livestock. However, even with increased pressure by the livestock production sector, Makgadikgadi has become a more economically valuable conservation area.

With the adoption of the National Tourism Policy of 1992 by the Botswana government, plans are under way to develop the Makgadikgadi Pans National Park and the adjacent Nxai Pan National Park into the same management unit. The two most important goals for the management of the unit are: (i) to maintain and preserve biological diversity and essential life support systems in both parks, and (ii) to provide facilities and opportunities for research and monitoring to further understanding of physical and biological processes within the management unit. It is hoped and believed that revenue accruing from tourism would benefit the local communities around the park periphery for them to realise the values of wildlife conservation.

In Botswana, management of wildlife areas has followed a basic policy of non-interference. This policy will surely change with increased pressure on the land by several competing land uses. The Makgadikgadi Pans National Park is surrounded by human settlements on all sides except the northern part where it links with Nxai Pan National Park. Conflicts arise between wildlife conservation and the livestock sector. The Wildlife Conservation Policy, passed by Parliament in 1986, emphasizes the role that wildlife utilization and proper management of Botswana's wildlife habitats must play in the management of the renewable natural resources. The country's national conservation strategy stresses a balance between animals and their habitats through proper and effective management which must be based upon sound scientific research findings (Anon 1989).

Wildlife conservation areas are not complete ecological units. Hence there is a need for seasonal and natural movement of the herbivores outside of the parks in search of high quality food and water. However, rapid human population growth, about 3.4% per annum (Government of Botswana 1985), has led to reduction in the mobility of the migratory animals to their traditional migration areas. This calls for effective management of these areas to protect the important habitats (Government of Botswana 1986). The need for a pro-active policy is evident.

Fire has been used for the management of wildlife areas in many parts of Africa while Botswana has had a fire suppression policy. Hence, little information is available on the effects of fire within the country. As a result it is important to investigate the effects of prescribed burning on grasslands such as those of the Makgadikgadi Pans National Park. It is for this reason that the use of fire as a possible tool for the management of the Makgadikgadi Pans National Park was investigated. This justifies the study for the assessment of the effects of fire on the grassland vegetation of the area. On the basis of knowledge gained, it might be important to review the current policy and develop, through the appropriate channels of communication and administration, an updated policy and mechanisms to implement it.

There has been no previous comprehensive study of the effects of fire on vegetation in Botswana. The limited number of studies that have been carried out include that of Skarpe (1980) who worked in the western Kalahari sandveld while Sweet (1982) and Sweet and Tacheba (1985) examined the effect of fire on controlling brush in the eastern hardveld of Botswana. They found that fire favoured the development and maintenance of a predominantly grassland vegetation.

The current study was aimed at investigating and developing an understanding of the effects of fire on the grassland vegetation of the Makgadikgadi Pans National Park. The study was restricted to grasslands because large numbers of herbivores are dependent upon them for sustenance.

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CHAPTER 2 EFFECTS OF SEASON OF BURNING ON PRODUCTIVITY OF GRASSLANDS

2.0 INTRODUCTION

Botswana is one of the few countries in Africa that still possesses an abundance and diversity of wildlife. This has come about largely because wildlife has been recognized by government as a valuable natural resource that needed proper conservation, protection and management for the benefit of the nation. In this regard the National Parks and Game Reserves cover about 17% of the country. However, the conservation areas are not complete ecological units. They cannot sustain animals within them throughout the year, hence the need for seasonal migrations. These migrations usually lead to areas outside the conservation areas resulting in conflicts with human settlements around the parks.

One of the major problems facing wildlife conservation in Botswana, as in other parts of Africa, is the increasing human population, encroachment of human settlements and their livestock production systems around the periphery of parks. This results in the unending conflicts between wildlife conservation and the livestock sectors. The Makgadikgadi Pans National Park is representative of such problems. The park is surrounded on all sides by human settlements, except the northern part where it links with Nxai Pan National Park. There is severe pressure on the park from human encroachment. Livestock grazing on the periphery and within the park is a serious problem confronting wildlife conservation in the area. These human activities curtail natural wildlife migrations. Hence, there is need for management to explore options that cater for the needs of the wildlife within the park throughout the year. One such vegetation management tool that has been used elsewhere in Africa, Australia and North America is prescribed burning.

Vegetation management focuses on naturally occurring dynamics and practical manipulation of rangeland. Several management tools exist and the choice of any one tool depends on the objectives and the costs of the implementation. The controlled use of fire is a tool that has been used in the management of African savannas. Prescribed burning can be used to remove unwanted herbage from the range (van Rensburg 1971). When used under optimal conditions, and depending on the management objectives of the area, fire can be an effective and inexpensive tool in controlling brush encroachment resulting in increased herbage production during subsequent rainy seasons. Accessibility of herbage to the herbivores declines with the aging of the sward after a fire and hence the need for constant removal of old growth and stimulation of new tillers. Fire is a part of nearly all rangeland ecosystems (Child et al. 1987, Odum 1993).

Fire has long influenced the development, maintenance and productivity of African savannas, and as such African grasslands have developed under the impact of fire and grazing (Heady 1975, Stuart-Hill and Mentis 1982). Savanna areas are important for both livestock and wildlife grazing. Fire is not as selective as grazing, and it does not often occur during periods of active plant growth. However, it is a defoliating agent, and as such plants have had to adapt to it in order to survive. There has been a strong selection for grass plants to deter and tolerate herbivory and tolerate fire (Bailey 1988, Heady and Heady 1982).

The productivity of forage is increased or decreased by different burning regimes including season of burning, and other factors such as area to be burned and growth stage of plants (Heady 1975). Trollope (1982) found that burns applied in mid-winter and immediately after the first spring rains had no significant effect on the grass sward. However, burns applied during the early summer when grass was actively growing had a disastrous effect on the productivity and the basal cover of the grass sward. Thus, physiological state of the grass plant, rather than season of burning, is the most important factor. West (1971) reported that early winter burning in the sourveld of Natal resulted in earlier and more seed production of the grass species. Hadley and Kieckhefer (1963), working in the more moist Tallgrass Prairies of Kansas, found a significant increase in living shoot and flowering stalk production and a more rapid rate of phenological development in recently burned areas compared to unburned areas.

The time required for increased herbage production to occur depends upon species composition present at the time of burning and climatic conditions at the time and following burning. Biomass production of some perennial grasses has been reported to increase up to 24% the first year after the fire. In some studies, however, two or more years were required before herbage production increased to pre-burn levels (Shackleton 1991). In arid areas there is a general reduction in biomass production immediately following a fire (Mentis and Tainton 1984) and the period of increased productivity varies with habitat type and may last for many years. Hodgkinson et al. (1984) also found that total biomass produced following a fire was usually lower even though forage quality was high.

Dry season removal of accumulated dead herbage by fire has relatively less effect on grass production than does removal of green growth (van Rensburg 1971, Child et al. 1987). However, dry-season burning can alter plant species composition in natural ecosystems by damaging or killing plants. Fire damage to individual plants depends upon the temperatures reached in the plant tissue, the length of time the critical temperatures are maintained, and the physiological state of the plant at the time of the burn (Child et al. 1987). Growth stage, growth form and size of plant influence the susceptibility of live tissue damage by heat. Afolayan (1978), working in the Kainji Lake National Park, Nigeria, found that late season burns had the highest standing grass crop compared to the unburned plots, with early burning showing some intermediate results. He recommended early burning for narrow strips along game-viewing roads to improve visibility and promote the new flush of grass. This would allow animals to concentrate along the tracks for better game-viewing. Edroma (1984), working in the Queen Elizabeth National Park, Uganda also found that late burns rather than early burns promoted increased dry matter production and stimulated growth and increase in species numbers in a *Hyparrhenia-Themeda* grassland. Exclusion of fire led to a decline in species composition and productivity of the grassland and also encouraged the establishment of shrubs.

Herbage produced on rangeland is usually related to soil moisture availability. Season of burning is also related to soil moisture because it affects amount of herbage produced following a fire. Any range management practices that adversely affects moisture levels will usually reduce yield. Season of burning, therefore, becomes as critical as moisture conservation practise, the longer a soil remains bare after burning, the greater the potential for losing the surface soil to the forces of erosion. Herbage produced after a prescribed burn will depend on the amount of rainfall immediately following a burn.

In summary, burning has a marked effect on the potential for dry matter production. Whether the area is grazed or not, burning stimulates uniform sprouting and growth of grassland, and the surbordinate species contribute more towards total herbage production. Herbage yield reductions due to burning are primarily associated with time of burning, soil type and climate. In wetter grasslands, burns properly timed may increase herbage production or at least not reduce it but as normal rainfall diminishes, burning generally temporarily reduces herbage yield.

Despite the foregoing information on the wide use of prescribed burning in other parts of Africa, Botswana has had a fire suppression policy and the management of wildlife areas has followed a basic policy of non-interference. However, even with the policy in place, it is estimated that about 20% of Botswana's rangelands burn annually. This policy will surely change with the increased pressure on the land by the several competing land uses. It is evident that wildlife conservationists need a proactive policy to manage wildlife resources within Makgadikgadi Pans National Park. It is for these reasons that the effect of prescribed burning on the herbaceous productivity of the Makgadikgadi Pans was evaluated.

The study was conducted to test the hypothesis that the season of burning does not have any effects on the productivity of the herbaceous grassland vegetation in the Makgadikgadi Pans National Park.

2.1 STUDY AREA

2.1.1 Location

The Makgadikgadi Pans National Park (MPNP), formerly Makgadikgadi Pans Game Reserve (MPGR), lies between 20° 10.0'S, 24° 15.0'E and 20° 50.0'S, 25° 05.0'E in north-central Botswana (Appendix 1). The park, which is about 4900 km^2, was established in 1970 to preserve the western part of the Makgadikgadi Pans ecosystem and the adjacent open plains as well as the bush country between Nxai Pan to the north and the Boteti River to the southwest (von Richter 1976). In 1992 the park was increased in size by incorporation of some areas of the northern statelands. The park forms part of the ancient Makgadikgadi lake-bed (Hutton 1974).

2.1.2 Geology and Soils

The Makgadikgadi Pans is an enormous flat area covered with salt-bearing fine white sand and clay (Hutton 1974). The Makgadikgadi pans complex occupies a basin that is the lowest point in a drainage system extending from Botswana into Namibia, Angola and Zimbabwe (Baillieul 1978). It is the desiccated remnants of a huge lake into which the Letlhakane, Okwa and Mmono Rivers used to flow from the south; the Nata, Semowane, Mosetse and Lephashe Rivers from the east; and into which the Boteti River used to drain via the Okavango Delta from southeast Angola to the west. The origins of the basin and pans are closely tied to complex climatic and tectonic changes that occurred in the Kalahari region during the late tertiary period, about three million years ago, and in quaternary time (Cooke 1979). Grove (1969) estimated that lake Makgadikgadi covered 34000 km^2 at its maximum extent, with a volume of about 500-1000 km^3. Climatic changes have caused the lake to fluctuate in size. As the climate became drier, the rivers ceased to flow and the water in the lake began to recede, leaving the old beach as evidence of its previous extent (Hutton 1974). In some places vegetation has encroached on the pan while in others wind action has prevented vegetation growth.

The western part of the Makgadikgadi basin consists of lacustrine, fluvial and aeolian landforms (Blair-Rains et al. 1967, Blair-Rains and McKay 1968, Cooke and Verstappen 1984). Quaternary deposits of aeolian, fluvial and lacustrine origin, forming part of the of the Pliocene, about two million years ago, and recent Kalahari beds, are underlain by rocks of the Karoo system

(Field 1978, Jones 1980, Jones and Key 1987).

The sedimentary material overlying this basin includes sands of the Kalahari type, pan sediments, calcrete and silcrite. Sands of the Kalahari type have been carried by wind and water into the basin at varying times during the tertiary and subsequent periods, though some material may have been derived from the underlying rocks of the Stromberg series (Blair-Rains et al. 1967, Cooke and Verstappen 1984).

In addition to the soils derived from sandy parent material, riverine or lucastrine alluvial materials, there are areas of lithosols derived from basalt and vertisols either of lithomorphic origin or occurring in depressions. These soils are found in the north-east of the park (Blair-Rains et al. 1967). Soils are developed on the deep sheet of Kalahari type sand. These soils are structureless, mildly acid to neutral in reaction and of low fertility. They are usually porous and free draining although relatively impermeable soils occur in topographic depressions.

Tectonic and climatic changes have affected the sedimentation in the drainage basin (Blair-Rains and McKay 1968, Cooke and Verstappen 1984). As a result of sub-aerial exposure, some of the sedimentary materials, has become silcified and calcified. Within the basin of an extensive earlier lake, and around the present Makgadikgadi depression, outcrops of calcrete and silcrete are common. Such soils are generally poorly developed and have a poor nutrient status. The sands are prone to erosion by wind, especially where vegetation is sparse (Dutch Consulting Engineers 1980).

2.1.3 Climate

The climate of the Makgadikgadi area is sub-tropical with distinct winter and summer seasons (Blair-Rains and McKay 1968). Temperatures are low during the winter months, minimum of about 5 °C in June, and frosts may occur. In summer temperatures can be extremely high during the day for example there may be maximum temperatures of about 35 °C in October. Extreme temperatures recorded were -4.4 °C in August and 43.3 °C in November (Blair-Rains, Child and McKay 1967).

During the wet season, wind direction is variable especially in the mornings and afternoons. However, winds tend to be northeasterly. During the winter, winds are generally easterly. The relative humidity (RH) is highest during the late half of the wet season (January-April), up to about 76% in March, and low for the rest of the year. From August to October, relative humidity is particularly low, going down to 19-22% (Blair-Rains and McKay 1968).

Southern Africa is periodically visited by severe and sometimes prolonged droughts (Schulze 1972). The degree of surface aridity in Southern Africa is not only a function of precipitation, but also of evaporation. Potential evaporation exceeds the total rainfall and this creates water deficit for plant growth. Herbage grows on soil moisture, and soil moisture essentially reflects the difference between precipitation and evapotranspiration.

Precipitation over the region follows an annual cycle and is entirely a summer phenomenon (Tyson 1986). More than 80% of the annual rainfall in this region occurs between October and March. However, there are great variations from both the monthly and yearly rainfall averages (Blair-Rains and McKay 1968). The total rainfall for any one year may vary from half to nearly double the average, and monthly variations are even more extreme than yearly fluctuations. Years of less than average rainfall are more frequent than years of above average rainfall (Appendix 2). The mean annual rainfall for the Makgadikgadi area is 450 mm (Pike 1971, Field 1978, van Zon 1984) with a variation of about 35% (Bhalotra 1985) and a standard deviation of 200 mm and the intensity is highly variable (Mbano 1984). The general rainfall pattern can be divided into two periods. October to December constitute the early wet period whilst January to April constitute the late wet period. Most of the rain in Makgadikgadi falls during the late wet period. The study area lies between two rainfall recording stations located in Maun (about 160 km west of the study area) and Gweta (50 km east of the study area). The longest recorded rainfall is that of Maun (1922 to 1990) (Appendix 2).

Total seasonal rainfall for the period preceding and during the study is shown in Figure 2.1. Annual precipitation was generally below normal except for the 1990/91 and the 1993/94 season when the total rainfall exceeded the 450 mm mean annual rainfall. The rainfall for the 1991/1992 season was extremely low, only 270 mm, which is below the mean annual rainfall of 450 mm. Effective precipitation for plant growth was considerably higher in January 1994 (275 mm) compared with that of the same period in 1993 (67 mm) (Figure 2.2).

2.1.4 Topography

The Makgadikgadi Pans form part of the depression which extends further north to Mababe. Makgadikgadi Pans consists of the Sua Pan and the western Ntwetwe Pan and is the main focus of drainage in the area. The Makgadikgadi area is generally flat or gently undulating at a general elevation of about 914 m above sea level (Blair-Rains and McKay 1968, Cooke 1979, Verstappen 1981, Cooke and Verstappen 1984). The comparative flatness is broken by isolated sand ridges, and in some places by linear or crescent shaped dunes.

2.1.5 Vegetation

The vegetative cover of Botswana consists of an herb layer composed of a mixture of grasses and forbs with an upper layer of scattered trees and shrubs. The density of trees or shrubs varies from location to location but it is closely associated with the annual rainfall and local drainage conditions (Animal Production Research Unit 1980). The vegetation is classified into the following three main types: i) Tree savanna in which the taller woody species are mainly trees, ii) Shrub savanna in which there are no or very few trees and many scattered shrubs and, iii) Grassland savanna in which there are very few or no trees or shrubs and the vegetative cover is a mixture of grasses, sedges and herbs.

The vegetation of the Makgadikgadi has been documented by Blair-Rains and McKay (1968), Child (1968), Weare and Yalala (1971) and Mbano (1984). The area is described as predominantly delta grassland savanna. However, various vegetation types can be identified within the park. The southwestern part of the park is riverine vegetation dominated by *Acacia* spp. with little or no herbaceous understory because of overgrazing by livestock from nearby settlements. The western part of the park is scattered wooded savanna (park woodland) also dominated by *Acacia* spp. and with a lot of brush encroachment. The herbaceous layer is dominated by *Stipagrostis uniplumis* (Licht) de Wint., *Eragrostis* and *Aristida* spp.

Open grassland savanna occurs in the central part of the park and to the east and southeast where bare pans become common. Extensive grassland occurs on the slightly higher ground away from the sparse vegetation of the pan fringes. The pans are surrounded by extensive short grassland in which the principal species are *Aristida meridionalis* Henr., *Heteropogon contortus* (L.) Beauv., *Odyssea paucinervis* Stapf., *Digitaria* spp., *Cynodon dactylon* (L) Pers.

and *Cenchrus ciliaris* (L). East of the pans these grasslands occur in narrow belts, in some cases not more than 1 km wide and give way abruptly to tree savanna (Dutch Consulting Engineers 1980). Trees and shrubs are absent, although there may be scattered or fringing groups of *Hyphaene* sp. and *Acacia* spp., and on raised hummocks stands of *Albizia* sp. and *Terminalia* spp.. Among the grasses are *Cenchrus ciliaris*, *Panicum* sp., *Schmidtia pappophoroides* Stend., *Cymbopogon* sp., *Eragrostis* sp., *Aristida* sp. and *Odyssea paucinervis*. The grassland zone of Makgadikgadi is dominated by the following grass species; *Schmidtia pappophoroides*, *Eragrostis rigidor* Pilger., *Stipagrostis uniplumis*, *Odyssea paucinervis* and *Cenchrus ciliaris*. The upper layer is dominated by scattered groups of *Hyphaene* sp. and shrub to tree savanna dominated by *Albizia* sp. and several *Acacia* sp.

2.1.6 Wildlife

A principal feature of the Makgadikgadi ecosystem is the migration of Burchell's zebra (*Equus burchelli* Gray) and blue wildebeest (*Connochaetes taurinus* Burchell) populations. During the wet season, usually in November to April, animals graze the short grass plains along the western edge of Ntwetwe pan (Dutch Consulting Engineers 1980). As this region dries out, the animals migrate westwards to the Boteti River where they spend the entire dry season usually from May to October, moving out to the plains again as soon as it rains. In the wet season when surface water is widely available, animals tend to be dispersed in smaller groups but during the dry season animals concentrate in large groups within reach of the permanent water source, the Boteti River.

Approximately 80% of the total animal biomass in the Makgadikgadi Pans National Park is composed of the more migratory herbivores: zebra and wildebeest (Kgathi and Kalikawe 1993). Other species found in the area are hartebeest (*Alcelaphus buselaphus* G. Cuvier.), gemsbok (*Oryx gazella* L.), eland (*Taurotragus oryx*), springbok (*Antidorcas marsupialis*), hippopotamus (*Hippopotamus amphibius* L.), giraffe (*Giraffa camelopardalis* L.), kudu (*Tragelaphus strepsiceros* Pallas) and impala (*Aepyceros melampus* Lichtenstein). Elephant (*Loxodonta africana* Blumenbach), roan (*Hippotragus equinus* Harris) and buffalo (*Syncerus caffer* Sparrman) are occasionally seen during years of above average rainfall. Many other smaller mammals occur in the area including many rodents.

The main predators found within Makgadikgadi are lion (*Panthera leo* L.), leopard (*Panthera pardus* L.) and hyaena (*Hyaena brunnea* Thunberg). Movement of the predators is usually tied to the movement of the prey. Developments on the periphery of the park, such as human settlements and livestock grazing on all sides except the north, have affected the impending free migration of wildlife. These have led to conflicts between wildlife conservation and the livestock production sector, because of predator depredation on livestock.

Another factor of importance to the livestock sector is the transmission of certain diseases between wildlife and livestock. There have been past outbreaks of Foot and Mouth disease in northern Botswana. African buffalo are known carriers of the virus that causes the disease even though the disease is not apparent in them. The main concern is the mixing of cattle and buffalo. Another disease that is likely to be transmitted when cattle and wildebeests are in contact is malignant catarrh.

2.2 METHODS

2.2.1 Experimental design

The study was conducted using a randomized complete block design with four blocks (sites). Each of the four sites was divided into six equal-sized plots (100m by 100m). The least representative plot (that is, plot with heavy termite mounds or rodent burrows etc.) was rejected leaving only five plots per site. One plot at each site was randomly selected as ~ Control plot (No Burn) leaving four plots per site for the burning treatments. The remaining four plots at each site were then randomly selected as either 1992 or 1993 burning plots (2 plots per year) and further distinguished as Dry season (September) or Early wet season (November) burning plots for the two years, respectively.

2.2.2 General Procedures for Burning

Prescribed burning was conducted in the Makgadikgadi Pans National Park in September and November of 1992 and 1993, respectively, following the guidelines of Bailey (1988). Firebreaks, about five metres wide, were constructed around each site to prevent wild fires from entering the study sites before or after the prescribed burns were implemented. The firebreaks also ensured maximum fire control during the prescribed burns. At each burning time one 100m x 100m plot was burned at each of the four sites. Prior to burning, in five randomly located 1m x 1m quadrats, fuel load was harvested by clipping in both the Burn and No Burn treatment plots. During the Early wet season burns (November) all clipped materials were sorted into live and dead components. Only the dead material was considered to constitute the fuel. If there was any precipitation prior to conducting the burns, sufficient drying time was allowed before burning.

On the day of the burn, prior to ignition, the relative humidity (%RH), wind speed (km h^{-1}) and direction were obtained at the site. Most of the burning was conducted in the afternoon when the relative humidity was at its lowest and wind speed was considered optimal (less than 20 km h^{-1}) for burning. The first task was to widen firebreaks prior to the actual burning of the study plots. At times the burning of the firebreaks proved to be a formidable task because of the poor distribution of the fuel. All of the burning was started near the firebreak on the leeside (downwind). All sites were burned using strip head-fires.

During the burning process five visual estimates of flame lengths per replication were made and these were used for the calculation of energy output of the fire using the method of Alexander (1982). Flame length was defined as the distance between the tip of the flame and the ground mid-way in the zone of active combustion. Frontal fire intensity (I) was determined from the function:

$$I = 259.83\,(L)^{2.174}\ \text{kW m}^{-1} \qquad \text{where } L = \text{flame length in meters}$$

In areas with complete burns and for the control plots, five clusters per treatment were randomly located and marked with 0.5m stakes. Clusters were used for both destructive (productivity determination) and non-destructive sampling (species composition and ground cover). Field sampling was carried out starting in December 1992 for two treatments (No Burn and Dry season burns), in February for three treatments (No Burn, Dry and Early wet season burns) and in July for all three treatments. More burns were instituted in September and November of 1993. Sampling was continued in December 1993 and concluded in February 1994. Only the February 1994 sampling period yielded results for all the treatments and for the two years of study.

2.2.3 Vegetation sampling

Herbaceous material was hand-harvested to a height of 2 cm above the ground using sheep shears (Cook and Stubbendieck 1986). At each harvesting period two randomly selected 1m x 1m quadrats were harvested at each cluster (10 quadrats per treatment). Quadrats were only harvested once during the project and hence were marked after harvesting to prevent resampling. Prior to harvesting, extended leaf height of the non-reproductive tillers were measured from two tufts for each species in the quadrat during the December and February sampling, and also for the sampling in February, the total number of seedheads per species was also counted. Extended leaf height was measured by extending the longest leaf against a metre ruler in each of the two quadrats to be harvested. Seedhead numbers were only counted in one of the two quadrats.

All harvested material was sorted into live and dead components and weighed fresh to obtain wet weights. The materials were then air-dried for five days and re-weighed. Samples were dried in brown paper bags that allowed free circulation of air. Total Standing Crop was obtained by adding together the live and the dead material (litter). The percentage moisture content was obtained by the function: % Moisture Content = {(Wet wt.-Dry wt.)/Wet wt.} * 100

2.2.4 Data Analysis

Significant effects for herbage productivity were detected using the General Linear Model (GLM) procedure of the SAS program. Least Square Means for the fresh and dead components as well as moisture content of the vegetation were generated and analyzed using GLM procedures for the two years of the study (1992 and 1993). Anova table for productivity is in Appendix 3A.

GLM procedures were also used to test for significant differences for the extended leaf height and the seedhead numbers for the sampling periods of December and February for both years of the study. Where least square means could not be computed, general means were used and the standard error of the means computed using the square root of error mean square divided by the number of observations. All analysis followed the convention as outlined in the SAS User's Guide (SAS 1985). Treatment means were separated by the Student-Newman-Keuls Multiple Range Test ($p<0.05$).

2.3 RESULTS

2.3.1 Fire Effects

Fuel loading, weather conditions and fire parameters are presented in Table 2.1 for both Dry and Early Wet season burns. The fuel comprised herbaceous material that had accumulated for at least four years. Higher fire intensities were associated with higher fuel loads. The Early Wet season burn in 1993 yielded a fire with the highest flame length compared with the Dry season burn of the same year. Flame lengths also appear to be related to the amount of fuel available during a prescribed burn. Wind speed, relative humidity and fuel moisture content all appeared to be relatively constant for all burns. Wind speed and relative humidity were similar in all the burns.

Fire intensities were higher in 1993 burns than in 1992 burns. This appeared to be related to the amount of fuel available for the prescribed burns. Flame lengths were greatest in the most intense fires (Figure 2.3). The Early Wet season burn was more intense (2109 kW m^{-1}) than the Dry season burn (1839 kW m^{-1}) in 1993 despite the fuel having a slightly higher moisture content. The 1992 burns were of very low intensity, 627 and 289 kW m^{-1}, for the

Dry season and the Early Wet season burns, respectively.

The response of the grass sward to fire was assessed in terms of the standing herbaceous vegetation that had accumulated on the burned plots by February 1993 and by February 1994. The effects of the prescribed burn on the above-ground standing crop, extended leaf height and the number of seedheads are presented in Table 2.2. Above-ground standing crop was higher in the unburned plots than in the burned plots at three and five months after the burns. Above-ground standing crop was higher in the more intense fires. Mean standing crop was significantly reduced by burning at any time compared to the unburned plots. There were no significant differences between the burn treatments in any particular year and also no significant differences were detected between years (Table 2.2). Yield from the 1993 intense burns was comparable to the 1992 less intense treatment burns.

Extended leaf height for *Schmidtia pappophoroides* and *Odyssea paucinervis* were significantly reduced by the burns for both treatment years compared to the No Burn treatment burn (Table 2.2). However, no significant differences were detected between the Dry season and the Early Wet season burns. Significant differences were also detected between the No Burn and the burn treatments for *Stipagrostis uniplumis* for both treatment years.

Seedhead numbers for *Schmidtia pappophoroides* were favoured by the low intensity burns of 1992 whilst in 1993 no significant differences were detected between the No Burn and the Burn treatments. Seedhead numbers for *Stipagrostis uniplumis* were reduced by fire during the year of burning.

2.3.2 Season of Burn

The No Burn (NB) treatment had the highest total above-ground standing crop throughout the study compared to the Burn treatments (Figure 2.4, Table

2.3). However, the differences were mainly decreasing and had disappeared by February of the second growing season after burning. In the first twelve months following burning, the mass of standing crop was described by an almost bell-shaped curve, increasing from December to February and then decreasing by July through December at the onset of the growing season. As a result of the different seasons of burns, the Early wet season burn plot initially lagged behind the Dry season burn plots. However, by February there were no significant differences between the Dry season and Early wet season burns (Figure 2.4). In February 1993, at five months after the Dry season and three months after the Early wet season burns there were no significant differences between treatments in live aboveground biomass (Table 2.3). For the 1993 burning treatments, by February 1994, there differences between No Burn and Burn treatments.

In July 1993, standing crop was composed of predominantly dead material in each burn treatment (Figure 2.5). However, we observed some growth between February and July sampling thus February did not necessarily constitute the peak production period. Between July and December and well into the growing season, senescence of the standing material continued at a moderate pace, as judged by the amount of dead material present at the sampling in December 1993 (220 g m^{-2} in July and 164 g m^{-2} in December). However, between December and February 1994, senescence was very rapid resulting in little standing dead material at the sampling period in February 1994.

During the sampling period of December 1993, which constituted 15 and 13 months post-treatment for the 1992 Dry and Early Wet season burns respectively, there were no significant differences between the No Burn and the Burn treatments (Table 2.3). No significant differences were also detected among the Burn treatments. Similar results were obtained for the 1993 burn treatments. The yield was 21 g m^{-2} for the Dry season 1993 burned compared with 28 g m^{-2} for the Dry season 1992 treatment. The No Burn treatment also yielded similar results for 1992 and 1993, 167 g m^{-2} and 164 g m^{-2} respectively. The extended dry period into the 1993/94 growing season seems to have had the depressive effect on growth and hence this could have had an effect on the 1993 Dry season burns.

A direct comparison was made of the effects of season of burn on the 1992 and 1993 treatments for the early growing period (December) and the mid-growing period (February) (Figure 2.6). No significant differences were detected between the years for either sampling period, however, there were differences between the No Burn and the Burn treatments. Three months after burning, productivity in the Dry season burns remained low whereas the above-ground standing crop in the No Burn treatment was dominated by standing dead material. After the Dry season burns the area remained bare for one or two months before the onset of the rains in late October or early November thereby making it more susceptible to wind erosion which is prevalent in the area.

Sampling during the mid-growing season (February) yielded results which were not significantly different between the Dry season (five months regrowth) and Early Wet season (three months regrowth) but both Burn treatments were significantly different from the No Burn. The 1993 treatments seemed to yield higher than the 1992 treatments. This may be related to the above normal rainfall in January 1994 (275 mm) and the overall total seasonal rainfall which was higher for the 1993/1994 season compared with the 1992/1993 season which was below normal. The Early Wet season burn treatment was more productive than the Dry season burn, three months after the burns, it yielded similar results to the Dry season burn and again the area did not remain bare for longer periods before the onset of growth.

2.4 DISCUSSION

2.4.1 Fire Effects

Fire behaviour is an important factor to consider when evaluating vegetation responses to prescribed burning. This important aspect has largely been ignored on grassland fires. Fire intensity, the release of heat energy per unit time per unit length of fire front, is deemed as a useful tool for predicting the effect of fire on vegetation. Response of vegetation to burning has been studied intensively, but few studies relate this to fire intensity (Engle et al. 1989). The current study has shown that high fire intensities did not result in significant suppression of herbaceous productivity. Higher fire intensities during the 1993 Dry and Early Wet season burns did not result in significantly different biomass production (Table 2.2). However, both burn treatments did suppress live biomass production for several months (Table 2.3). This rapid recovery reveals a vegetation well adapted to burning. By 15-18 months after the fire, sufficient recovery had occurred that there was no difference in live biomass between No Burn and Burn treatments.

The rate of energy release is affected by fuel moisture content, wind, heat transfer, fuel size and arrangement Byram (1959). The most important contributory factor to lower heat energy release in this study, especially the 1992 treatments, might have been the fuel size and its distribution. Fuels consisted predominantly of fine herbaceous materials which were poorly distributed. The uneven distribution of low fuel loads resulted in fires with very low rate of spreads, lower flame lengths and therefore very low energy released and hence low fire intensities. This is likely related to the very low rainfall (Figure 2.1) which preceded the treatments. Rainfall during the 1991/92 season was only 270 mm. The early wet season burns were also complicated by some early rainfall showers in November (40 mm) (Figure 2.2) and hence the fuel might not have been dry enough to carry a fire despite having allowed sufficient time for the fuel to dry (up to five days). However, the opposite is true for the 1993 treatments. These were preceded by above average rainfall which resulted in high accumulated fuels with better distribution.

The current study has shown that even in the arid climates of Makgadikgadi Pans, fire intensity itself has not been demonstrated to have an effect on grassland productivity, extended leaf height and seedheads numbers. Extended leaf height for *Stipagrostis uniplumis* was significantly different between the No Burn and the Burn treatments. Skarpe (1980) observed that *Stipagrostis uniplumis* was heavily damaged by intense fires while *Schmidtia* increased its production and flowering. Roberts et al. (1988) looking at the effects of fire on tobosa grass and weeping lovegrass found no effects of fireline intensity on both species with respect to yield, extended leaf height and the number of seed stalks. Similar results were reported from Australia. This is contrary to Trollope (1982) who reported that burning had a marked effect on flowering of grasses. Early winter burning resulted in an earlier and greater seeding of the different grass species than burning after spring rains. However, his study was located in a high rainfall area of the Sourveld of Natal. Sabiiti and Wein (1989), also working in a high rainfall area of south-western Uganda, reported that high fire intensities promoted maximum grassland productivity. They found annual late burns to stimulate vigorous grass growth and grass seed germination. Early burns were not as effective. Even though our results from Makgadikgadi are slightly different from these, the differences in the rainfall might be the main factor. The current study was in an arid climate and so soil moisture could have been a limiting factor in the early regrowth following the burns and thus we would expect productivity to be lower than in the more moist areas.

The lack of any significant effect of fire intensity on grassland production is important from the point of view of using fire for various management objectives. Range managers can apply intense fires to meet a variety of objectives without fear of reduced vigour and yields of grasses. It is incumbent upon the manager to choose between exposing the bare land for extended periods (Dry season burn) where it is subject to possible wind erosion or to burn using high intensity fires after the first rains. The latter will suit the objective of controlling brush encroachment. This is because high intensity fires are generally required for this purpose and if they have no negative effects on grassland production it makes the method more acceptable to the land manager. As such, knowledge of fire behaviour is fundamental to an understanding of the procedures which should be adopted when using fire as a management tool in range.

2.4.2 Effect of season of burn on productivity

The effect of the season of burn on productivity has received considerable attention. Wright and Bailey (1982), Wright (1985), Trollope (1982), and Shackleton (1991) have discussed the effects of season of burn on productivity . Others have discussed the combined effects of fire and grazing on productivity (Eltringham 1976, Afolayan 1978, Edroma 1984). The common factor for all is that in the higher rainfall areas there is an increase in overall productivity of the grasslands whilst in more arid areas there is a short term decline in the productivity of the burned areas. This short term decline in arid areas like Makgadikgadi may lead to shortage of forage during the critical times. Heady (1975) stated that burning usually lowered forage production in mixed prairies and other dry grasslands and also burning in different seasons resulted in different effects on production in these grasslands. Grass biomass dynamics depend on rainfall, grazing pressure and veld fires with rainfall being the most important factor affecting grassland recovery.

In Makgadikgadi, no significant differences were found between the Dry and Early wet season treatment burns for the two years of the study when sampling was done three and five months after the burns. Significant differences were detected for the No Burn treatments relative to the Burn treatments. The No Burn was in general more productive than the Burn treatments for the two years of the study. Lower above-ground standing crop in the burned swards contributed to a low total above-ground standing crop which indicated that absolute amounts of forage may be a limiting factor for several months after a fire. This is especially important for the dry season burn when the area is made more susceptible to wind erosion and less forage is available to the herbivores within the park. However, within 12 months of the burns there was no significant differences between the burned and the unburned areas. Vegetation in burns conducted after the early rains generally recovered faster than the dry season burns. There were no differences in productivity between the dry season and the early wet season burns when sampled during the mid-growing period and by the second growing season there were no significant differences between the Burns and the No burns. Thus an area burnt during the early wet season recovers faster than that burned during the dry season and this recovery may be complete by the second growing season. Our results are contrary to Tainton et al. (1977) whose study in the Tall Grassveld of Natal showed very little difference in the pattern of recovery growth of range burned in late winter or early spring. This being a high rainfall area, moisture might not have been a limiting factor for grassland recovery.

Burning has a marked effect on the potential for dry matter production. Whether grazed or not, burning stimulates uniform sprouting and growth of the grassland and the less dominant species contribute more towards the total herbage production (Edroma 1984). At the sampling period of February 1994, no significant differences were detected between the 1992 and 1993 Burn treatments, however, there were significant differences between the 1993 Burns and the No Burn treatment. It is speculated that the above normal rainfall in January 1994 (275 mm) and the above normal seasonal rainfall for the 1993/94 (460 mm) contributed more to the total above-ground standing crop which in this case consisted of live biomass only.

Results from this burning experiment are compounded with utilization by the herbivores and/or rodents and insects (harvester termites) and hence they are not a true reflection of the effects of burning. In Africa, the decomposition rates that have been documented are variable, depending upon climate and whether litter-eating termites were present. Morris et al. (1982) reported that 70% of litter was decomposed in 16 months in a semi-arid savanna in South Africa. Intensity of grazing and trampling by the herbivores is also said to reduce quantities of litter accumulation. Litter is lowest during the rainy season when presumably moisture conditions are optimal for decomposition (Button et al. 1988). In semi-arid environments, decomposition is negligible during most of the year due to lack of water, which limits microbial activity. Physical and chemical degradation and consumption by termites may predominate (Moorhead and Reynolds 1989, Noy-Meir 1985).

It has been stated that season of burning and vegetation type are important in determining the effect of burning. Season of burning selected will depend upon the objectives for the application of fire. In the Makgadikgadi, we have found that in terms of production there are no differences between fires applied in the Dry season and the Early wet season. Results from the Makgadikgadi study indicated no differences in the recovery rates for both Dry and Early wet season burns. However, Early wet season burns would be favoured if one is to meet a number of objectives. This is supported by results from the University of Fort Hare which indicated that there were no differences in effects of season of burn between burns applied in mid-winter and immediately after the first spring rains (Trollope 1982, 1990). West (1965) and Van Rensburg (1971) also stressed the importance of burning when the grass sward was still dormant and advocated burning just prior to spring rains when fire was to be used for control of brush. These agree with the results from Makgadikgadi in that Early Wet season burns were intense and thus could check brush regrowth. At 17 and 15 months post-treatment for the Dry and Early Wet season respectively, there were no significant differences in terms of total above-ground standing crop between the two burn treatments.

Makgadikgadi is an arid area with erratic and unreliable rainfall and prevailing winds in the easterly direction during the dry season and hence it is inherent that any prescribed burning program should take into account the susceptibility of the area to possible erosion and availability of forage to the numerous herbivores inhabiting the park.

2.4.3 Conclusions

1) Fire intensities had no effect on herbage production.

2) Burning temporarily reduced herbage production but it recovered to pre-burn levels by the second growing season.

3) Herbage production from Early Wet season burns are not significantly different from the Dry season burns by the mid-growing period and both are not significantly different from the No Burn by the second growing season.

Table 2.1 Fuel loading, weather conditions, flame length and fire intensity for Dry season and Early wet season prescribed burns in 1992 and 1993 (S. E. refers to Standard Error of the Mean).

Year of Burn	1992		1993	
Season	Dry Season	Early Wet	Dry Season	Early Wet
Parameter	Mean	Mean	Mean	Mean
	S.E.	S.E.	S.E.	S.E.
Wind Speed ($km\ h^{-1}$)	13.0	14.4	12.6	14.4
	0.9	1.1	0.5	2.0
Relative Humidity (%)	22	34	29	34
	2	4	4	2
Fuel Load (gm^{-2})	81	121	228	203
	21	21	9	19
Fuel Moisture (%)	10	11	11	13
	2	3	1	1
Flame Length (m)	1.5	1.0	2.5	2.6
	0.2	0.1	0.2	0.4
Fire Intensity ($kW\ m^{-1}$)	627	289	1839	2109

Table 2.2 Effects of burning on first year forage productivity, extended leaf height and seedhead numbers in February 1993 and 1994, respectively.

	1992 Burn			1993 Burn		
Season/ Parameter	No Burn	Dry Season	Early Wet	No Burn	Dry Season	Early Wet
Fire Intensity ($kW\ m^{-1}$)	–	627	289	–	1839	2109
Biomass ($g\ m^{-2}$)	239 a	122 b	101 b	309 a	121 b	127 b
Leaf Ht (mm)						
Schmidtia	409 a	329 b	330 b	364 a	277 b	270 b
Odyssea	296 a	182 b	186 b	227 a	148 b	165 b
Stip -agrostis	670 a	417 b	595 a	641 a	365 b	430 b
Seedhead/ m^{-2}						
Schmidtia	21 b	44 a	34 ab	39 a	34 a	29 a
Odyssea	0	0	0	0	0	0
Stip -agrostis	16 a	1 b	2 b	8 a	1 b	0 b

(means within a row within the same year with the same letter indicates no significant difference at $p<0.05$).

Table 2.3 Mean productivity for the above-ground standing crop (g m^{-2}) for herbaceous components at different sampling dates for various burning treatments.

Sampling Date	Burning Treatment	Live Biomass (g m^{-2})	Standing Dead (g m^{-2})	Total Standing Crop(gm^{-2})
December 1992	1. No Burn	49 a	118 a	167 a
	2. Dry Season[1]	28 b	0 b	28 b
February 1993	1. No Burn	150 a	89 a	239 a
	2. Dry Season	122 a	0 b	122 b
	3. Early Wet	101 a	0 b	101 b
July 1993	1. No Burn	0	220 a	220 a
	2. Dry Season	0	159 b	159 b
	3. Early Wet	0	178 b	178 b
December 1993	1. No Burn	0 b	164 a	164 a
	2. Dry Season	0 b	132 a	132 a
	3. Early Wet	0 b	142 a	142 a
	4. Dry Season'(93)	21 a	0 b	21 b
February 1994	1. No Burn	309 a	N	309 a
	2. Dry Season	247 ab	N	247 ab
	3. Early Wet	223 ab	N	223 ab
	4. Dry Season'(93)	121 b	N	121 b
	5. Early Wet '93	127 b	N	127 b

(means within a column within the same year with the same letter are not significantly different at $p<0.05$)
(N = litter negligible, [1] All burning conducted in1992 except as noted).

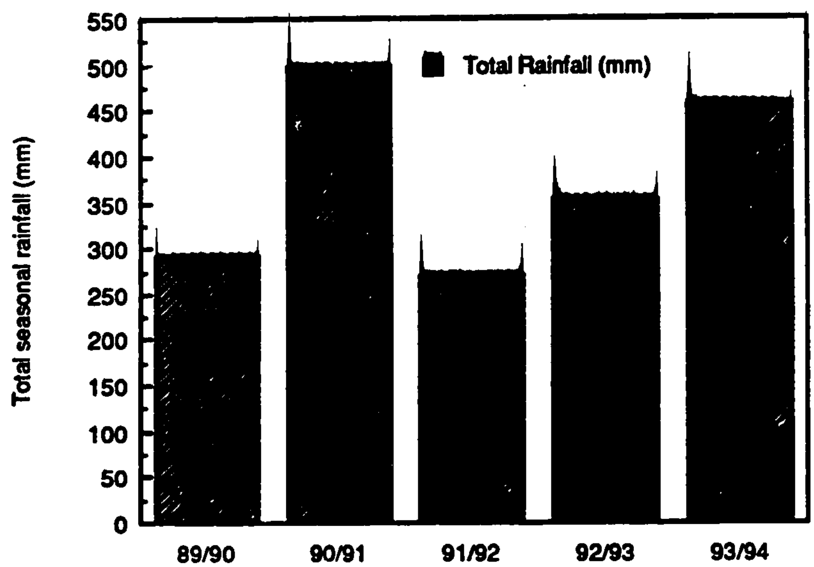

Figure 2.1 Annual rainfall (July to June) for Maun, Botswana from 1989 to 1994 (long term seasonal rainfall is 450 mm).

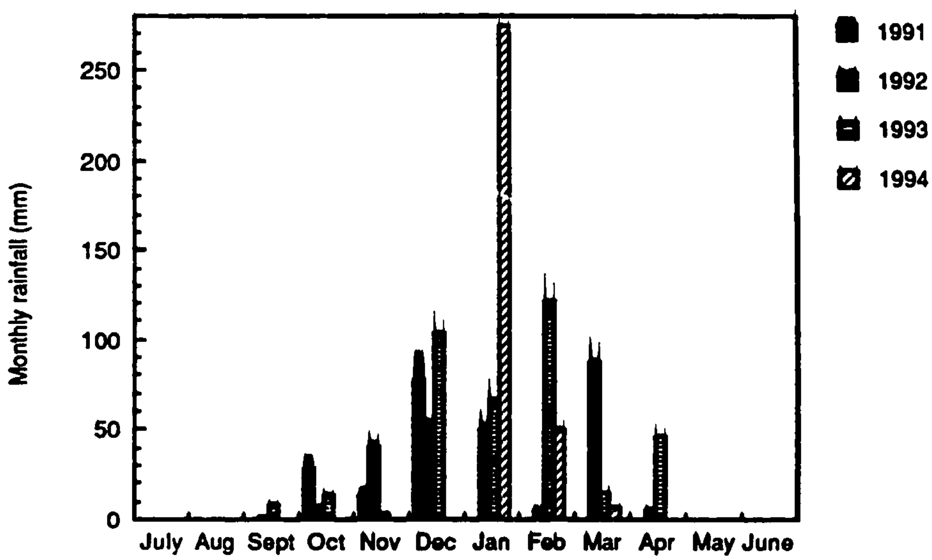

Figure 2.2 Total monthly rainfall for Maun, Botswana for the period July 1991 to June 1994.

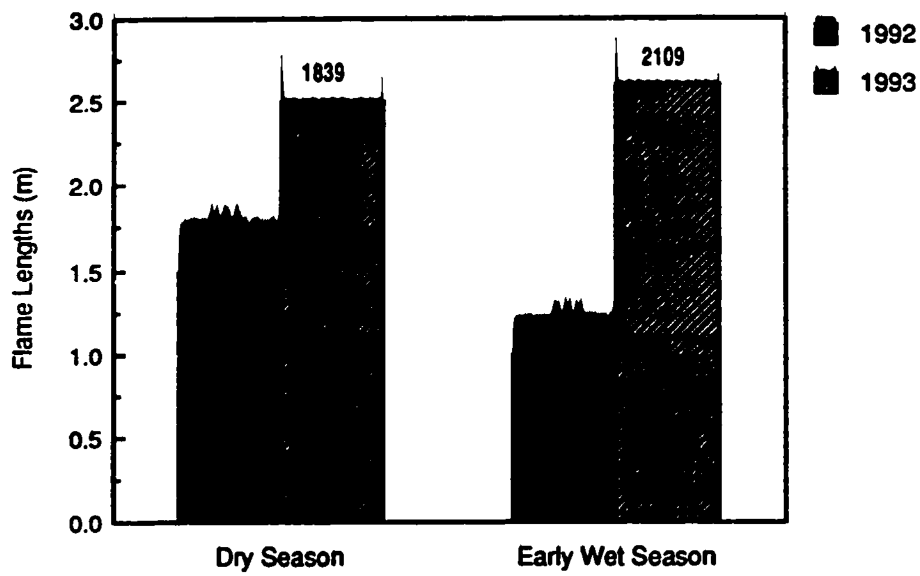

Figure 2.3 Fire Intensities for the 1992 and 1993 prescribed burns at Makgadikgadi Pans National Park, Botswana (numbers on each bar refer to fire intensity, kW m^{-1})

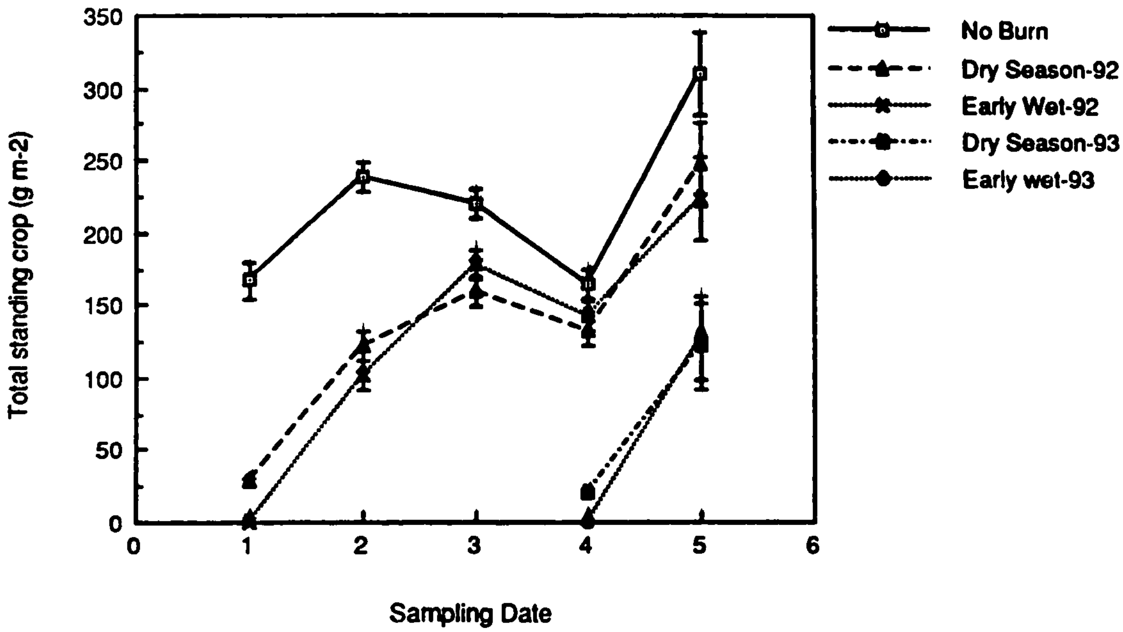

Figure 2.4. Total above-ground standing crop for treatments applied in 1992 and 1993 and sampled during 1) December 1992, 2) February 1993, 3) July 1993, 4) December 1993, and 5) February 1994 (bars are standard errors of the mean).

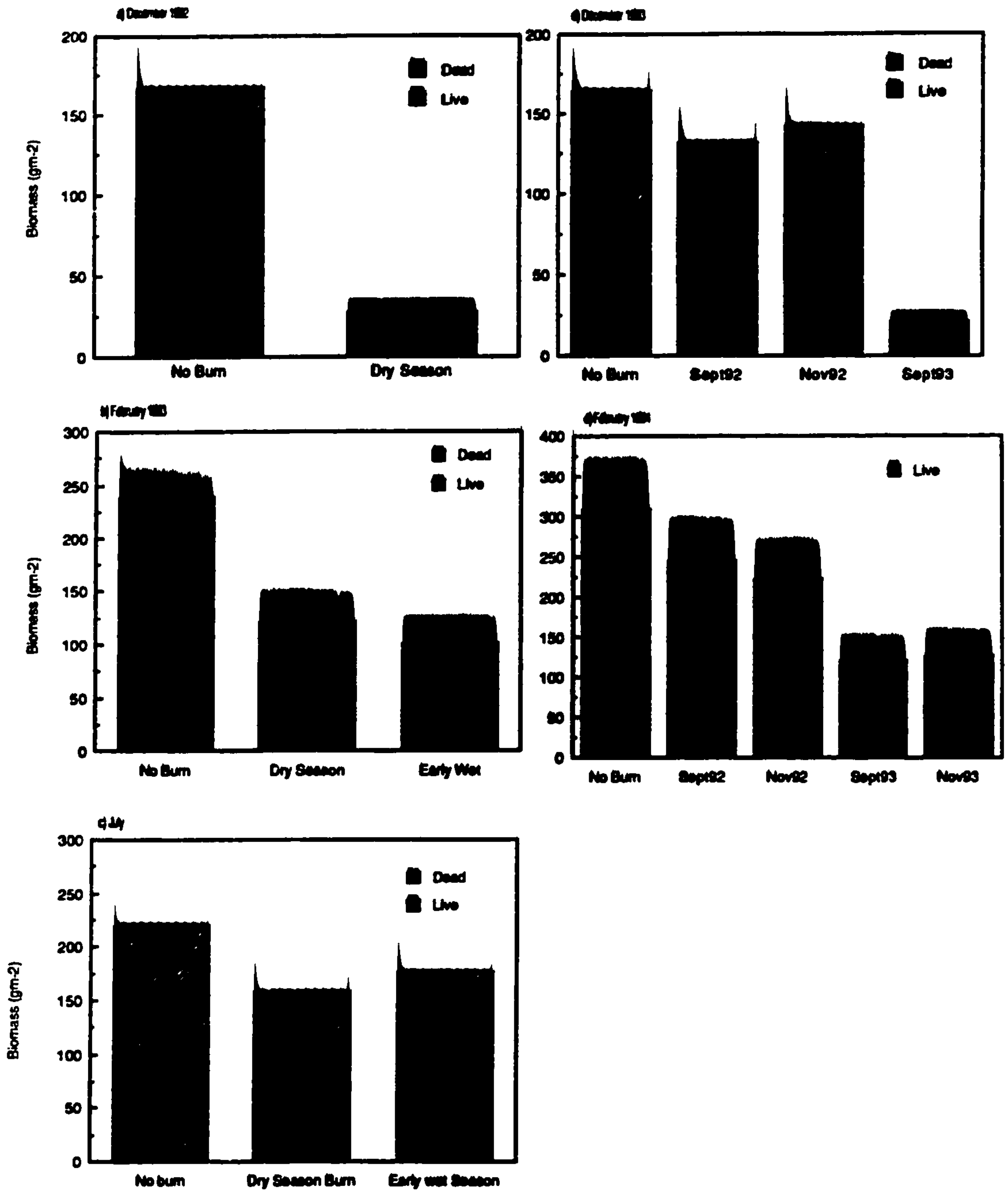

Figure 2.5 Components of the herbaceous vegetation during the different sampling periods .

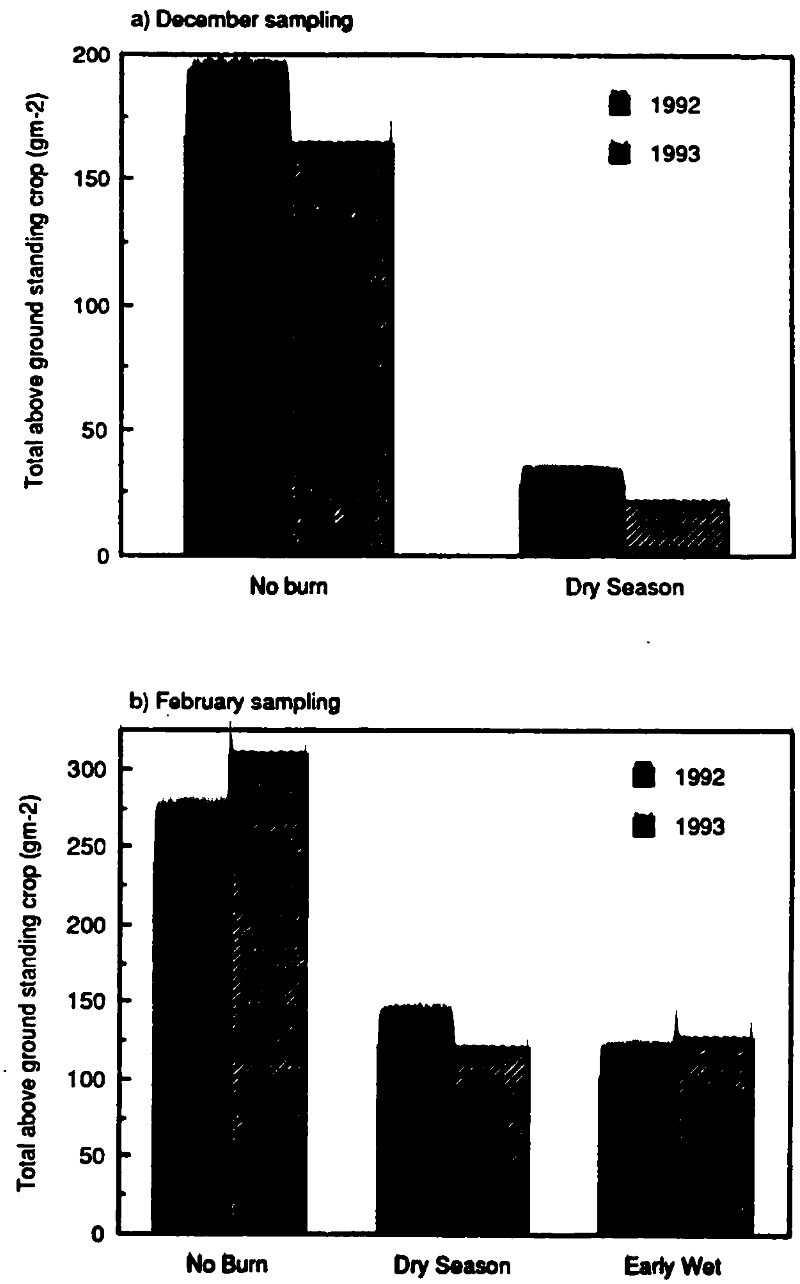

Figure 2.6 Comparison of the first year effects of the 1992 and 1993 burn treatments on total standing crop for the sampling periods a) December and b) February.

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CHAPTER 3 EFFECTS OF SEASON OF BURNING ON VEGETATION QUALITY

3.0 INTRODUCTION

About 80% of the surface area of Botswana is natural rangeland suitable for extensive grazing of ruminant animals. These rangelands support an increasing number of livestock and a comparatively large population of wildlife, both of which are important to the majority of the people of Botswana. About 95% of the livestock feed is provided by natural rangelands and provision of mineral supplements are minimal (Tacheba and Mphinyane 1993). In common with other semi-arid pastoral countries, the problem of effective use of rangelands and its vulnerability to misuse is well recognized in Botswana. It is for these reasons that range management and improvement are and will remain important areas of research in Botswana.

The primary objective of the management of conservation areas, like Makgadikgadi Pans National Park in north-central Botswana, is to maintain their wilderness quality through minimal human interference. As a result, the management of wildlife areas has followed a basic policy of non-interference. However, because of the rapid growth of human population in settlements around the parks, the encroachment of livestock into wildlife areas, and increasing conflicts between livestock production and wildlife management, this policy is bound to change.

Management of herbivore-grassland systems to attain specific goals requires an understanding of the quality of forage available. Assessment of the nutrient status of forages provides information for decision making pertaining to stocking rates, habitat suitability for particular herbivore species, season of burning and nutrient limitation to the herbivore (Shackleton and Mentis 1992). Information on nutritive value of the grazing animals' diet is essential for efficient livestock and game production (Holechek, Vavra and Pieper 1982). Nutrient status is usually measured through estimation of digestibility, crude protein and minerals. Digestibility is an important measure of forage value since it has a marked effect on the absolute amount of forage ingested. Holechek et al. (1982) found in vitro digestibility more closely correlated with cattle performance than crude protein. However, crude protein is a possible limiting factor to the growth of herbivores (Bransby 1981).

The composition of natural grasslands in Botswana varies considerably throughout the country mainly due to the highly variable rainfall which can fluctuate from less than half to twice the annual mean (Prachett et al. 1977). This has an effect on seasonal variation in the nutritive value of grasses. As a result of the variation, animal performance is affected, especially when their movements to areas of higher quality vegetation are curtailed by human settlements around the parks. Tropical savanna grasses generally have higher protein content at the beginning of the growing season than at the end when they become tall, coarse and unpalatable (van Rensburg 1971). Afaloyan and Fafunsho (1978) showed that the percentage of grass species utilized by game followed the seasonal changes in their protein content, utilization being highest when the crude protein content was high. Seasonal fluctuations also occur in dietary protein. Dietary protein levels are highest during the growing season and lowest during the dry season (Kinyamario and Macharia 1992). Low dietary protein limits animal production. Sinclair (1975) estimated that a typical wildebeest in the Serengeti required about 5-6% dietary protein for maintenance. Agricultural Research Council (1965) and Owen-Smith (1982) stated that ruminants needed a minimum of 5% crude protein in their food to maintain body weight. Looking at liveweight gains of beef cattle on rangelands in eastern Botswana, Prachett et al. (1977) stated that liveweight changes were largely influenced by low crude protein and digestibility both being limiting during the dry season. Of all the minerals, phosphorus is the most limiting in southern Africa (Blair-Rains et al. 1967, Skarpe 1980, Shackleton and Mentis 1992). McNaughton (1988) found mineral contents of forage to be an important determinant of animal spatial distribution.

Evaluation of herbage quality is important for the attainment of high animal productivity. It must, however, be realised that productivity of grazing animals does not only depend on herbage quality but also on carrying capacity and grazing pressure. The nutritive value of a forage refers to its chemical composition, digestibility and the nature of digested products. The amount of forage consumed by the animal is very important as it affects total nutrient intake, which has an effect on the animal's response. Chemical composition and digestibility vary according to species, site, season and other factors (van Soest 1982). Chemical content of plants may differ because of their inherent ability to extract certain nutrients from the soil and concentrate them in the tissues. Moreover, chemical content of the same species varies with state of maturity, soil conditions or general climatic conditions.

Knowledge of adequacies or shortages of nutrients that exist may enable a park manager to seek alternatives during critical periods. This is extremely important during the recurring droughts in Makgadikgadi Pans National Park where at intervals thousands of zebras and wildebeests have died due to insufficient forage (both in terms of quality and quantity) and lack of water in their grazing areas. Livestock encroachment into the park has contributed to the overgrazing along the river, which is a dry season concentration area for wildlife. Because of the limited supply of water in the park, animals could not move away from the Boteti River in the southwest of the park to other areas with sufficient forage and hence they died en masse along the river.

One of the traditional tools used for the management of rangelands is prescribed burning. Prescribed burning, when used as a vegetation manipulation tool in range management by the park managers, usually creates a secondary succession to meet specific objectives. One of the reasons often given by park managers for the use of prescribed burning is to stimulate range grasses to produce seeds or to stimulate out of season growth during long dry season to improve herbage quality (Crowder and Chheda 1982). This process also aids in the distribution of the animals for better game viewing. In developing countries, like Botswana, tourism is an important source of revenue.

The effect of fire on vegetation depends on the weather conditions during burning, as well as quantity and type of fuel available for combustion (Trollope 1982). Several researchers have studied the effect of fire on forage quality (Child et al. 1987, Tainton and Mentis 1984, Tainton et al. 1977, West 1965) and all agree that, at least in the short term, fire improves forage quality. However, the effects of burning on herbage quality seldom lasts into the second growing season after the fire (Child et al. 1987). Tainton and Mentis (1984) stated that fire enhances the concentration of nutrients in grasses but this enhancement is maintained for different lengths of time according to vegetation type and nutrient investigated. Shackleton and Mentis (1992) found that protein on burned plots was approximately three times higher than that of the control plots in the first sample after a fire.

Fresh green shoots of new growth on burned grasslands are eagerly sought by the grazing animals (Rowe-Rowe 1982, Child et al. 1987, Novellie 1987). Shackleton and Mentis (1992) also found burning stimulated large increases in crude protein, dry matter digestibility, phosphorus and potassium. West (1965) reported that after burning the average crude protein content of herbage was 19% for common grass species growing on three soil types at the Matopos Research Station in Zimbabwe. However, Tainton et al. (1977) reported that in the moist Tall Grassveld of Natal the initial protein content of new leaves of grass burned during the dry season and shortly after spring rains was approximately 2.6% greater than grass mown at the same times.

Dry matter digestibility, on the other hand, decreases with plant maturation following a fire (Hardy and Mentis 1986, O'Reagain and Mentis 1989). This has a bearing on the amount of food that an animal can ingest during the dry period, thus affecting animal survival. During the dry months, Kinyamario and Macharia (1992) observed that crude protein levels dropped concomitantly with that of standing crop biomass, such that grazing animals may suffer not only from poor quality forage but also from lower amounts of forage. They further stated that crude protein and dry matter digestibility varied from month to month and between different plant categories, both variations being highest during the growing season.

In light of the foregoing information, it is important to develop an effective and inexpensive means of providing higher quality forage during the dry season. This study was conducted to test the hypothesis that burning does not have an effect on the nutritional quality of key forage species in the grassland vegetation of the Makgadikgadi Pans National Park. A second hypothesis tested was that there was no difference in nutritional quality of grasses in Dry season and Early wet season burn treatments.

3.1 STUDY AREA

3.1.1 Location

The Makgadikgadi Pans National Park (MPNP), formerly Makgadikgadi Pans Game Reserve (MPGR), lies between 20° 10.0'S, 24° 15.0'E and 20° 50.0'S, 25° 05.0'E in north-central Botswana (Appendix 1). The park, which is about 4900 km^2, was established in 1970 to preserve the western part of the Makgadikgadi Pans ecosystem and the adjacent open plains as well as the bush country between Nxai Pan to the north and the Boteti River to the southwest (von Richter 1976). In 1992 the park was increased in size by incorporation of some areas of the northern statelands. The park forms part of the ancient Makgadikgadi lake-bed (Hutton 1974).

3.1.2 Geology and Soils

The Makgadikgadi Pans is an enormous flat area covered with salt-bearing fine white sand and clay (Hutton 1974). The Makgadikgadi pans complex occupies a basin that is the lowest point in a drainage system extending from Botswana into Namibia, Angola and Zimbabwe (Baillieul 1978). It is the desiccated remnants of a huge lake into which the Letlhakane, Okwa and Mmono Rivers used to flow from the south; the Nata, Semowane, Mosetse and Lephashe Rivers from the east; and into which the Boteti River used to drain via the Okavango Delta from southeast Angola to the west. The origins of the basin and pans are closely tied to complex climatic and tectonic changes that occurred in the Kalahari region during the late tertiary period, about three million years ago, and in quaternary time (Cooke 1979). Grove (1969) estimated that lake Makgadikgadi covered 34000 km^2 at its maximum extent, with a volume of about 500-1000 km^3. Climatic changes have caused the lake to fluctuate in size. As the climate became drier, the rivers ceased to flow and the water in the lake began to recede, leaving the old beach as evidence of its previous extent (Hutton 1974). In some places, vegetation has encroached on the pan while in others wind action has prevented vegetation growth.

The western part of the Makgadikgadi basin consists of lacustrine, fluvial and aeolian landforms (Blair-Rains et al. 1967, Blair-Rains and McKay 1968, Cooke and Verstappen 1984). Quaternary deposits of aeolian, fluvial and lacustrine origin, forming part of the of the Pliocene, about two million years ago, and recent Kalahari beds, are underlain by rocks of the Karoo system (Field 1978, Jones 1980, Jones and Key 1987).

The sedimentary material overlying this basin includes sands of the Kalahari type, pan sediments, calcrete and silcrite. Sands of the Kalahari type have been carried by wind and water into the basin at varying times during the tertiary and subsequent periods, though some material may have been derived from the underlying rocks of the Stromberg series (Blair-Rains et al. 1967, Cooke and Verstappen 1984).

In addition to the soils derived from sandy parent material, riverine or lucastrine alluvial materials, there are areas of lithosols derived from basalt and vertisols either of lithomorphic origin or occurring in depressions. These soils are found in the north-east of the park (Blair-Rains et al. 1967). Soils are developed on the deep sheet of Kalahari type sand. These soils are structureless, mildly acid to neutral in reaction and of low fertility. They are usually porous and free draining although relatively impermeable soils occur in topographic depressions.

Tectonic and climatic changes have affected the sedimentation in the drainage basin (Blair-Rains and McKay 1968, Cooke and Verstappen 1984). As a result of sub-aerial exposure, some of the sedimentary materials, have become silcified and calcified. Within the basin of an extensive earlier lake, and around the present Makgadikgadi depression, outcrops of calcrete and silcrete are common. Such soils are generally poorly developed and have a poor nutrient status. The sands are prone to erosion by wind, especially where vegetation is sparse (Dutch Consulting Engineers 1980).

3.1.3 Climate

The climate of the Makgadikgadi area is sub-tropical with distinct winter and summer seasons (Blair-Rains and McKay 1968). Temperatures are low during the winter months, minimum of about 5 °C in June, and frosts may occur. In summer temperatures can be extremely high during the day for example there may be maximum temperatures of about 35 °C in October. Extreme temperatures recorded were -4.4 °C in August and 43.3 °C in November (Blair-Rains, Child and McKay 1967).

During the wet season, wind direction is variable especially in the mornings and afternoons. However, winds tend to be northeasterly. During the winter, winds are generally easterly. The relative humidity (RH) is highest during the late half of the wet season (January-April), up to about 76% in March, and low for the rest of the year. From August to October, relative humidity is particularly low, going down to 19-22% (Blair-Rains and McKay 1968).

Southern Africa is periodically visited by severe and sometimes prolonged droughts (Schulze 1972). The degree of surface aridity in Southern Africa is not only a function of precipitation, but also of evaporation. Potential evaporation exceeds the total rainfall and this creates water deficit for plant growth. Herbage grows on soil moisture, and soil moisture essentially reflects the difference between precipitation and evapotranspiration.

Precipitation over the region follows an annual cycle and is entirely a summer phenomenon (Tyson 1986). More than 80% of the annual rainfall in this region occurs between October and March. However, there are great variations from both the monthly and yearly rainfall averages (Blair-Rains and McKay 1968). The total rainfall for any one year may vary from half to nearly double the average, and monthly variations are even more extreme than yearly fluctuations. Years of less than average rainfall are more frequent than years of above average rainfall (Appendix 2). The mean annual rainfall for the Makgadikgadi area is 450 mm (Pike 1971, Field 1978, van Zon 1984) with a variation of about 35% (Bhalotra 1985) and a standard deviation of 200 mm and the intensity is highly variable (Mbano 1984). The general rainfall pattern can be divided into two periods. The months of October to December constitute the early wet period whilst January to April constitute the late wet period. Most of the rain in Makgadikgadi falls during the late wet period. The study area lies between two rainfall recording stations located in Maun (about 160 km west of the study area) and Gweta (50 km east of the study area). The longest recorded rainfall is that of Maun (1922 to 1990) (Appendix 2).

Total seasonal rainfall for the period preceding and during the study was highly variable. Annual precipitation was generally below normal except for the 1990/91 and the 1993/94 season when the total rainfall exceeded the 450 mm mean annual rainfall. The rainfall for the 1991/1992 season was extremely low, only 270 mm, which is below the mean annual rainfall of 450 mm. Effective precipitation for plant growth was considerably higher in January 1994 (275 mm) compared with that of the same period in 1993 (67 mm).

3.1.4 Topography

The Makgadikgadi Pans form part of the depression which extends further north to Mababe. Makgadikgadi Pans consists of the Sua Pan and the western Ntwetwe Pan and is the main focus of drainage in the area. The Makgadikgadi area is generally flat or gently undulating at a general elevation of about 914 m above sea level (Blair-Rains and McKay 1968, Cooke 1979, Verstappen 1981, Cooke and Verstappen 1984). The comparative flatness is broken by isolated sand ridges, and in some places by linear or crescent shaped dunes.

3.1.5 Vegetation

The vegetative cover of Botswana consists of an herb layer composed of a mixture of grasses and forbs with an upper layer of scattered trees and shrubs. The density of trees or shrubs varies from location to location but it is closely associated with the annual rainfall and local drainage conditions (Animal Production Research Unit 1980). The vegetation is classified into the following three main types: i) Tree savanna in which the taller woody species are mainly trees, ii) Shrub savanna in which there are no or very few trees and many scattered shrubs and, iii) Grassland savanna in which there are very few or no trees or shrubs and the vegetative cover is a mixture of grasses, sedges and herbs.

The vegetation of the Makgadikgadi has been documented by Blair-Rains and McKay (1968), Child (1968), Weare and Yalala (1971) and Mbano (1984). The area is described as predominantly delta grassland savanna. However, various vegetation types can be identified within the park. The southwestern part of the park is riverine vegetation dominated by *Acacia* spp. with little or no herbaceous understory because of overgrazing by livestock from nearby settlements. The western part of the park is scattered wooded savanna (park woodland) also dominated by *Acacia* spp. and with a lot of brush encroachment. The herbaceous layer is dominated by *Stipagrostis uniplumis*

(Licht) de Wint., *Eragrostis* and *Aristida* spp.

Open grassland savanna occurs in the central part of the park and to the east and southeast where bare pans become common. Extensive grassland occurs on the slightly higher ground away from the sparse vegetation of the pan fringes. The pans are surrounded by extensive short grassland in which the principal species are *Aristida meridionalis* Henr., *Heteropogon contortus* (L.) Beauv., *Odyssea paucinervis* Stapf., *Digitaria* spp., *Cynodon dactylon* (L) Pers. and *Cenchrus ciliaris* (L). East of the pans these grasslands occur in narrow belts, in some cases not more than 1 km wide and give way abruptly to tree savanna (Dutch Consulting Engineers 1980). Trees and shrubs are absent, although there may be scattered or fringing groups of *Hyphaene* sp. and *Acacia* spp., and on raised hummocks stands of *Albizia* sp. and *Terminalia* spp.. Among the grasses are *Cenchrus ciliaris*, *Panicum* sp., *Schmidtia pappophoroides* Stend., *Cymbopogon* sp., *Eragrostis* sp., *Aristida* sp. and *Odyssea paucinervis*. The grassland zone of Makgadikgadi is dominated by the following grass species; *Schmidtia pappophoroides*, *Eragrostis rigidor* Pilger., *Stipagrostis uniplumis*, *Odyssea paucinervis* and *Cenchrus ciliaris*. The upper layer is dominated by scattered groups of *Hyphaene* sp. and shrub to tree savanna dominated by *Albizia spp.* and several *Acacia* spp.

3.1.6 Wildlife

A principal feature of the Makgadikgadi ecosystem is the migration of Burchell's zebra (*Equus burchelli* Gray) and blue wildebeest (*Connochaetes taurinus* Burchell) populations. During the wet season, usually in November to April, animals graze the short grass plains along the western edge of Ntwetwe pan (Dutch Consulting Engineers 1980). As this region dries out, the animals migrate westwards to the Boteti River where they spend the entire dry season usually from May to October, moving out to the plains again as soon as it rains. In the wet season when surface water is widely available, animals tend to be dispersed in smaller groups but during the dry season animals concentrate in large groups within reach of the permanent water source, the Boteti River.

Approximately 80% of the total animal biomass in the Makgadikgadi Pans National Park is composed of the more migratory herbivores: zebra and wildebeest (Kgathi and Kalikawe 1993). Other species found in the area are hartebeest (*Alcelaphus buselaphus* G. Cuvier.), gemsbok (*Oryx gazella* L.), eland (*Taurotragus oryx*), springbok (*Antidorcas marsupialis*), hippopotamus (*Hippopotamus amphibius* L.), giraffe (*Giraffa camelopardalis* L.), kudu (*Tragelaphus strepsiceros* Pallas) and impala (*Aepyceros melampus* Lichtenstein). Elephant (*Loxodonta africana* Blumenbach), roan (*Hippotragus equinus* Harris) and buffalo (*Syncerus caffer* Sparrman) are occasionally seen during years of above average rainfall. Many other smaller mammals occur in the area including many rodents.

The main predators found within Makgadikgadi are lion (*Panthera leo* L.), leopard (*Panthera pardus* L.) and hyaena (*Hyaena brunnea* Thunberg). Movement of the predators is usually tied to the movement of the prey. Developments on the periphery of the park, such as human settlements and livestock grazing on all sides except the north, have affected the impending free migration of wildlife. These have led to perpetual conflicts between wildlife conservation and livestock production sector, because of predator depredation on livestock.

Another factor of importance to the livestock sector is the transmission of certain diseases between wildlife and livestock. There have been past outbreaks of Foot and Mouth disease in northern Botswana. African buffalo are known carriers of the virus that causes the disease even though the disease is not apparent in them. The main concern is the mixing of cattle and buffalo. Another disease that is likely to be transmitted when cattle and wildebeests are in contact is malignant catarrh.

3.2 METHODS

3.2.1 Experimental design

The study was conducted using a randomized complete block design with four blocks (sites). Each of the four sites was divided into six equal-sized plots (100m by 100m). The least representative plot (that is, plot with heavy termite mounds or rodent burrows etc.) was rejected leaving five plots per site. One plot at each site was randomly selected as a Control plot (No burn treatment) leaving four plots per site for the burning treatments. The remaining four plots at each site were then randomly selected as either 1992 or 1993 burning plots (2 plots per year) and further distinguished as Dry season (September) or Early wet season (November) burning plots for the two years, respectively.

3.2.2 General Procedures for Burning

Prescribed burning was conducted in the Makgadikgadi Pans National Park in September and November of 1992 and 1993, respectively, following the guidelines of Bailey (1988). Firebreaks, about five metres wide, were constructed around each site to prevent wild fires from entering the study sites before or after the prescribed burns were implemented. The firebreaks also ensured maximum fire control during the prescribed burns. At each burning time one 100m x 100m plot was burned at each of the four sites. Prior to burning, in five randomly located 1m x 1m quadrats, fuel load was harvested by clipping in both the Burn and No Burn treatment plots. During the Early wet season (November) burns all clipped materials were sorted into live and dead components. Only the dead material was considered to constitute the fuel. If there was any precipitation prior to conducting the burns, sufficient drying time was allowed before burning.

On the day of the burn, prior to ignition, the relative humidity (%RH), wind speed (km h^{-1}) and direction were obtained at the site. Most of the burning was conducted in the afternoon when the relative humidity was at its lowest and wind speed (less than 20 km h^{-1}) was considered optimal for burning. The first task was to widen firebreaks prior to the actual burning of the study plots. At times the burning of the firebreaks proved to be a formidable task because of the poor distribution of the fuel. All of the burning was started near the firebreak on the leeside (downwind). All sites were burned using strip head-fires.

In areas with complete burns and for the control plots, five clusters per treatment were randomly located and marked with 0.5m stakes. Clusters were used for both destructive (productivity determination) and non-destructive sampling (species composition and ground cover). Field sampling was carried out starting in December 1992 for two treatments (Control and Dry season burns), in February for three treatments (Control, Dry and Early wet season burns) and in July for all three treatments. More burns were instituted in September and November of 1993. Sampling was continued in December 1993 and concluded in February 1994. Only the February 1994 sampling period yielded results for all the treatments and for the two years of study.

3.2.3 Sampling for vegetation quality analysis

Herbaceous material was hand-harvested to a stubble height of 2 cm above the ground using sheep shears. All the harvested material was sorted into live and dead components where necessary. The separated material was air-dried for five to seven days. The air-dried material was then sorted into the three main species namely:

a) *Schmidtia pappophoroides* Stend.

b) *Odyssea paucinervis* Stapf.

c) *Stipagrostis uniplumis* (Licht) de Wint.

Five grams of each species from the live and dead components was sub-sampled for nutritional quality analysis. Sub-samples were taken to the Ministry of Agriculture, Plants Analytical Laboratory at Sebele, Botswana, where nutritional quality analysis was conducted using the standardized techniques. The three species were analysed for crude protein (CP) content, in vitro dry matter digestibility (IVDMD), dry matter content (DM), and ash content. Other elements analyzed included potassium, calcium, phosphorus, magnesium, iron, manganese, copper and zinc.

Analysis of samples pooled from the five clusters for each treatment from each site were conducted on each of the three species. Live and dead components for each species were analyzed separately for each harvest date. On occasions there were insufficient amounts of particular species or complete absence and therefore not all the minerals could be quantified at any sampling period.

The following describes the standard techniques that were used for the various tests: Dry matter digestibility was determined using the two-stage in vitro technique described by Tilley and Terry (1963), incubating with fresh rumen fluid for 48 hours and with HCl-pepsin for a further 48 hours. The rumen fluid was taken from fistulated steers. Nitrogen content (N) was determined on extracts from Kjeldahl digestion using titration. Crude protein was calculated as 6.25 x N content (Bransby 1981). This is the standard figure used for routine analyses by the Ministry of Agriculture in Botswana (Animal Production Research Unit 1980).

To obtain percent dry matter, samples were oven-dried at 100 °C overnight. Ash was obtained from samples ignited at 550 °C overnight (Animal Production Research Unit 1980). To obtain zinc, copper, iron and manganese, dry ash was dissolved in concentrated hydrochloric acid and then determined by atomic absorption spectrophotometry. Calcium, magnesium and phosphorus were also determined on extracts from Kjeldahl digestion. Calcium and magnesium were determined by the atomic absorption spectrophotometry after wet digestion with selenized sulphuric acid (H_2SO_4-Se). Phosphorus was determined colorimetrically by spectrophotometer (phosphomolybdic method) after wet digestion with selenized sulphuric acid. Potassium was determined by flame emission spectrophotometry after wet digestion with selenized sulphuric acid.

3.2.4 Data Analysis

Data were analyzed using the GLM procedure of SAS to compute analyses of variance (SAS 1985) with sources of variation of blocks, treatment, species, status (live or dead) and two factor interactions among treatment, species and status. Anova table for crude protein content is in Appendix 3B.

Because of missing combinations, many least-squares means could not be computed. Therefore, for consistency of presentation only the simple means and their standard errors are given. Standard errors of the simple means were computed using the square root of error mean square divided by the number of observations. Significant means were separated by the Student-

Newman-Keul Multiple Range test ($p<0.05$).

3.3 RESULTS

The effects of the season of burning on the nutritional quality of the vegetation are presented in Tables 3.1 and 3.2 for the 1992 and 1993 treatments, respectively. In general, IVDMD and crude protein content showed a close relationship with the age of the burn, being high in the newest burn for all three species. In 1993 burn treatments, IVDMD and crude protein content were high in December following the intensive spring flush of the early growing season compared to the No Burn treatment. The variables then declined as the rainy season progressed and the vegetation matured. However, there are some differences between IVDMD and the crude protein content. Crude protein content was highest in the youngest burn and then declined. Maximum values of crude protein content were recorded during the December sampling for both the 1992 and 1993 burn treatments. Crude protein showed a closer relationship with phenology of the grasses, being highest in the youngest grasses and decreasing with maturity of the grasses (Table 3.1, 3.2). IVDMD was highest in the burn treatments and was highest for the 1993 burn treatments compared to the 1992 burn treatments. For the burn treatments, highest levels of IVDMD were recorded in February (mid-growing season) when the grasses were in the early stages of flowering or had flower buds (Figures 3.1-3.3).

IVDMD showed gradual decline with the progression of the dry season, in contrast to the rapid decline of crude protein content for all species (Table 3.1, 3.2). Low values of IVDMD and crude protein content were recorded during the dry season. Most of the variables were low in July and then continued to decline well into the 1993 growing season. There were differences in IVDMD and crude protein between the three species. Both the 1992 and 1993 treatments showed similar trends but the 1993 treatments were significantly higher than the 1992 treatments for both crude protein content and IVDMD. All measured variables were low during the sampling period of February 1994. The 1993 burn treatments were lower than the 1992 burn treatments for the similar period.

The IVDMD never exceeded 52% at Makgadikgadi and most values were below 50%. For the three grasses, *Schmidtia pappophoroides* usually had the highest digestibility for all treatments throughout the study. For the 1992 burn treatments, only the February 1994 sampling period showed significant differences between the Burn and the No Burn treatments (Figure 3.1). The 1993 Burn treatments were significantly higher than the No Burn. *Stipagrostis uniplumis* was intermediate with digestibility values ranging from 30-52% (Figure 3.3). There were significant differences between the 1992 and 1993 burn treatments for this species. Furthermore, for the 1993 burn treatments there were significant differences among all three treatments for the February 1994 sampling period. The Burn treatments were significantly higher than the No Burn. The Dry season burn was significantly higher than the Early wet season burn. *Odyssea paucinervis* was the least digestible. The species showed some significant differences between treatments (Figure 3.2). For the 1993 burn treatments at the February 1994 sampling period, there were significant differences between the No Burn and the Burn treatments. Vegetation from the Burn treatments was more digestible than the No Burn. Similarly, in February 1994, for the 1992 burn treatments, vegetation from the Early wet season burn was more digestible than the Dry season burn and the No Burn.

Crude protein content for the three grasses is presented in Figures 3.4 to 3.6. In general, young regrowth in Burn treatments had a higher crude protein content than the No Burn for all three species for both the 1992 and 1993 burn treatments. Crude protein was highest in the youngest burn and then declined. During the dry season most levels were in the 2-5% range with little variation between the species and treatments. For all the species, crude protein was higher during the early stages of growth in December than during the mid-growing season in February. Crude protein content was lower in the 1992 Burn treatments than the 1993 Burn treatments at the February 1994 sampling period for all three species. The 1993 Burn treatments were significantly higher than the No Burn for all three species.

Moisture content of the herbaceous vegetation was highest in the newly burned plots compared to the No Burn plots (Figure 3.7). During the dry season, July 1993, there were no significant differences among the three treatments. By February 1994, moisture content of the regrowth was significantly higher in the 1993 Burn treatments than in the 1992 Burn and No Burn treatments.

Phosphorus levels in the three grasses ranged from 0.01 to 0.12% (Tables 3.1 and 3.2). Little variation existed between the species. Burning appears to have minimal effect on phosphorus content of the three grass species. Phosphorus levels also tended to decrease with plant maturity.

Calcium tended to have the most irregular variation. There was variation between the treatments as well as species (Table 3.1 and 3.2). However, the highest values tended to be in both the 1992 and 1993 burn treatments. Calcium levels also tended to decrease with plant maturity. The lowest recorded level was 0.3%. For the 1992 burn treatments, Ca:P ratios for all three species ranged from 9:1 to 27:1. For the 1993 burn treatments, the range 5:1 to about 28:1 for all three species.

Treatment effects on the IVDMD and crude protein content of the live and dead components of the vegetation are presented in Figures 3.8 and 3.9, respectively. IVDMD was significantly higher in the live component (46%) of the vegetation at the sampling in February 1993 compared to the dead component (22%) (Figure 3.8b). Likewise crude protein content was significantly higher in the live component (8%) in the youngest burn (Dry season 1993) compared with 3% for the dead component in the 1992 Burn treatments and the No Burn at the December 1993 sampling period (Figure 3.9d). Both variables showed a closer relationship with the phenological stages of the grasses, being highest in the newly burned area and declining into the dry season. There were some significant differences between the 1992 and 1993 burn treatments (Figure 3.8e). The live component of the vegetation in both 1993 burn treatments was significantly more digestible than the No Burn and the 1992 burn treatments. At the December 1992 sampling period, the live component of the burn treatment had at least 30% higher crude protein content than in the No burn (Figure 3.9a). This dropped to about 25% at the sampling period in February 1993. At the sampling period in February 1994, there were differences between the 1992 and 1993 burn treatments (Figure 3.9e). The 1993 burn treatments had a slightly higher crude protein content than the 1992 burn treatments and the No Burn. However, crude protein content for the 1993 burn treatments (Figure 3.9e) were lower than for the similar period for the 1992 treatments (Figure 3.9b). Results for the other minerals are presented in Appendix 4.

3.4 DISCUSSION

Prescribed burning in Makgadikgadi Pans resulted in vegetation higher in digestibility and crude protein content compared to the unburned vegetation. There was little variation in the nutrition content of the vegetation as a result of the season of burn but there was a trend that the Dry season burns were generally higher. However, there were differences in the nutrient content and digestibility of the three grasses studied. Generally, most of the variables maintained the same ranking order throughout the study period. *Schmidtia* ranked first, *Stipagrostis* intermediate and *Odyssea* last. The ranking agrees well with the findings of Field (1978) and Animal Production Research Unit (1980), and the opinion that *Schmidtia* is a good fodder species, while *Stipagrostis* is good when young, but becomes inferior when it matures. *Odyssea* is unpalatable and is a poor forage species. Except for the initial higher values in December and February for crude protein content and IVDMD respectively, both variables were generally lower than that quoted as the minimum requirement for livestock maintenance.

There was a tendency for lower crude protein content during the sampling period of February 1994 compared to the similar period of February 1993. However, crude protein content was highest in the most recent burn compared to the No Burn (Figure 3.9e). It is believed that the above-average rainfall (275mm) in January 1994 compared to 75 mm in January 1993 had a role in lowering this variable. Abundant rainfall may have induced rapid growth of the vegetation resulting in lower crude protein in forage of the 1993 burn treatments while resulting in higher digestibility for all three grass species (Figures 3.1-3.3). The burn treatments were significantly more digestible than the No Burn treatment, with the most recent burn having the most digestible forage (Figure 3.8e). IVDMD in the most recent burn vegetation was about 15% higher than in the No Burn. Although not significant, there was a similar trend for the 1992 burn treatments.The productivity of large herbivores basically depends on the intake of digestible energy and nutrients, that is, not only on the biomass of the fodder available, but also on its nutritive composition and digestibility.

Required levels for crude protein have a range of 4 to 8%, and these do not include the costs of reproduction, lactation and growth (Van Soest 1982). It is generally believed that if the quality of the forage falls below the 6% level, then there is food shortage (Knight 1991). Forage at Makgadikgadi Pans National Park tended to be of lower nutritional content than the recommended values and as such there could have been evidence of shortage in terms of forage quality. However, it is important to note that animals are highly selective when feeding and as such they might be selecting a higher quality diet than that sampled for nutritional quality determination.

Changes in nutritional quality of the herbage in the grasslands may be of sufficient magnitude to affect the herbivore population. The low forage quality in Makgadikgadi Pans National Park during the dry season might help explain the seasonal movement of the wildebeest and zebra within the park. Ben-Sharar and Coe (1992) reported on the movement of wildebeest and zebra in response to variation in the levels of certain minerals. Browse might play an important role for many of the herbivores during the dry season by providing a higher quality diet when grass is of low nutritional quality. More browse is available along the Boteti River on the western side of the park which is a dry season concentration area. The quantity and quality of herbage available in various habitats are very important to the management of wildlife populations (Afolayan 1979). Seasonal rainfall is the primary determinant of the quality and quantity of the vegetation available for the consumption by herbivores, thereby structuring the plant and animal component of the grasslands (Button et al. 1988).

There was a general shortage of phosphorus in all three grass species with values generally below the recommended 0.10%. The deficiency of this mineral was also observed by Blair-Rains and McKay (1968). Wildlife in the area must be adapted to such low levels of phosphorus; and the availability of salt-licks in the area might play an important role. The effect of such shortage in wildlife has not been investigated. However, in cattle, phosphorus plays a major role in animal nutrition and the prevention of botulism and where the mineral is deficient, supplementation might be necessary. Shortage of this mineral might be one reason why cattle ranching operations failed at Bushman Pits within the Makgadikgadi/Nxai Pan ecosystem, giving way to wildlife conservation in the area.

Ca:P ratios at Makgadikgadi Pans were much variable. It appears burning has little effect on Ca:P ratios. Generally a ratio of 2:1 is considered optimal for the herbivores (Stoddart et al. 1975). However, it appears that herbivores in the area are adapted and can survive on vegetation having such wide ratios. The significance of such ratios is questionable because adequate supplies of calcium and phosphorus are enough to sustain an animal (Minson 1990).

Forage quality varies greatly due to a number of factors. There is a general decline in nutritional value as plants mature (Figure 3.5). Van Soest (1982) attributes such changes to altered chemical composition involved in increased lignification and decrease in the proportion of leaves to stem. Plants differ seasonally in nutritional quality according to stage of growth (Figure 3.8) (Afolayan and Fafunsho 1978, Mentis and Tainton 1984, Button et al. 1988), and the percentage of grass species utilised follows the seasonal changes in the protein content (Afolayan and Fafunsho 1978). Vesey-FitzGerald (1971) stated that the stage of growth is more an important characteristic of palatability than the species. He further stated that grazing retarded maturation and promoted vegetative growth which favoured utilisation. This may be true for a species like *Stipagrostis* which is less palatable when mature. Digestibility was only 44% at three months regrowth following burning and crude protein content was only 6%. There were signs of utilisation of this species when young (personal observations).

3.4.1 Conclusions

1) Nutritional content of the live plant material was generally higher in the burn treatments than the unburned area. Vegetational nutritional content varied little between Dry season and Early wet season burn treatments of the same year.

2) Following burning, nutritional changes in the vegetation are short-lived; usually, they were not maintained into the second growing season.

3) Highest levels of IVDMD were attained during the mid-growing season; crude protein content levels were highest at the onset of growth.

4) IVDMD and crude protein content were generally higher in *Schmidtia pappophoroides* than in *Stipagrostis uniplumis* and *Odyssea paucinervis.*

Table 3.1 In vitro dry matter digestibility (IVDMD) and nutrient content (% of dry matter) for the 1992 burning treatments for *Schmidtia pappophoroides, Stipagrostis uniplumis* and *Odyssea paucinervis*.

	Date Sampled	Dec-92		Feb-93			July-93			Dec-93			Feb-94		
Species	Treatment	No Burn	Dry Season	No Burn	Dry Season	Early Wet	No Burn	Dry Season	Early Wet	No Burn	Dry Season	Early Wet	No Burn	Dry Season	Early Wet
Schmidtia	IVDMD	39	-	52	48	49	41	43	43	40	43	42	24	32	32
	CP	5	8	5	5	8	4	3	3	3	2	3	4	3	3
	Ash	8	-	10	12	11	12	11	11	12	12	12	12	12	7
	Ca	0.4	1.3	0.8	0.8	1.1	0.8	0.9	0.7	0.8	0.9	1.0	0.6	0.5	0.5
	P	0.05	0.10	0.05	0.06	0.06	0.03	0.09	0.03	0.08	0.10	0.06	0.05	0.03	0.03
Odyssea	IVDMD	32	-	38	38	43	42	35	35	34	31	34	21	22	30
	CP	5	10	5	6	7	3	3	4	3	4	3	4	3	3
	Ash	9	-	12	10	11	12	9	13	14	14	13	12	12	12
	Ca	0.3	0.7	0.3	0.5	0.4	0.7	0.6	0.6	0.7	0.7	0.7	0.4	0.2	0.4
	P	0.10	0.10	0.05	0.06	0.06	0.03	0.09	0.03	0.08	0.10	0.06	0.05	0.03	0.03
Stipagrostis	IVDMD	30	-	45	43	-	31	34	31	33	35	32	28	32	31
	CP	5	-	5	6	-	3	5	2	4	4	3	4	4	4
	Ash	7	-	5	8	-	12	8	10	6	6	8	9	8	9
	Ca	0.5	-	0.6	0.8	-	0.4	0.7	0.9	0.6	0.6	0.6	0.7	0.4	0.5
	P	0.05	-	0.01	0.05	-	0.03	0.03	0.01	0.10	0.09	0.03	0.04	0.03	0.04

Table 3.2 In vitro dry matter digestibility (IVDMD) and nutrient content (% of dry matter) for the 1993 burning treatments for *Schmidtia pappophoroides, Stipagrostis uniplumis* and *Odyssea paucinervis.*

	Date Sampled	Dec-93		Feb-94		
Species	Treatment	No Burn	Dry Season	No Burn	Dry Season	Early Wet
Schmidtia	IVDMD	40	51	24	41	41
	CP	3	10	4	5	5
	Ash	12	13	12	12	12
	Ca	0.8	1.3	0.6	0.7	0.7
	P	0.12	0.12	0.05	0.07	0.07
Odyssea	IVDMD	34	35	21	36	36
	CP	3	7	4	5	6
	Ash	14	11	12	10	9
	Ca	0.7	0.5	0.4	0.4	0.3
	P	0.08	0.08	0.05	0.05	0.06
Stipa-grostis	IVDMD	33	-	28	52	45
	CP	4	-	4	6	5
	Ash	6	-	9	10	9
	Ca	0.6	-	0.7	0.9	1.1
	P	0.10	-	0.04	0.09	0.04

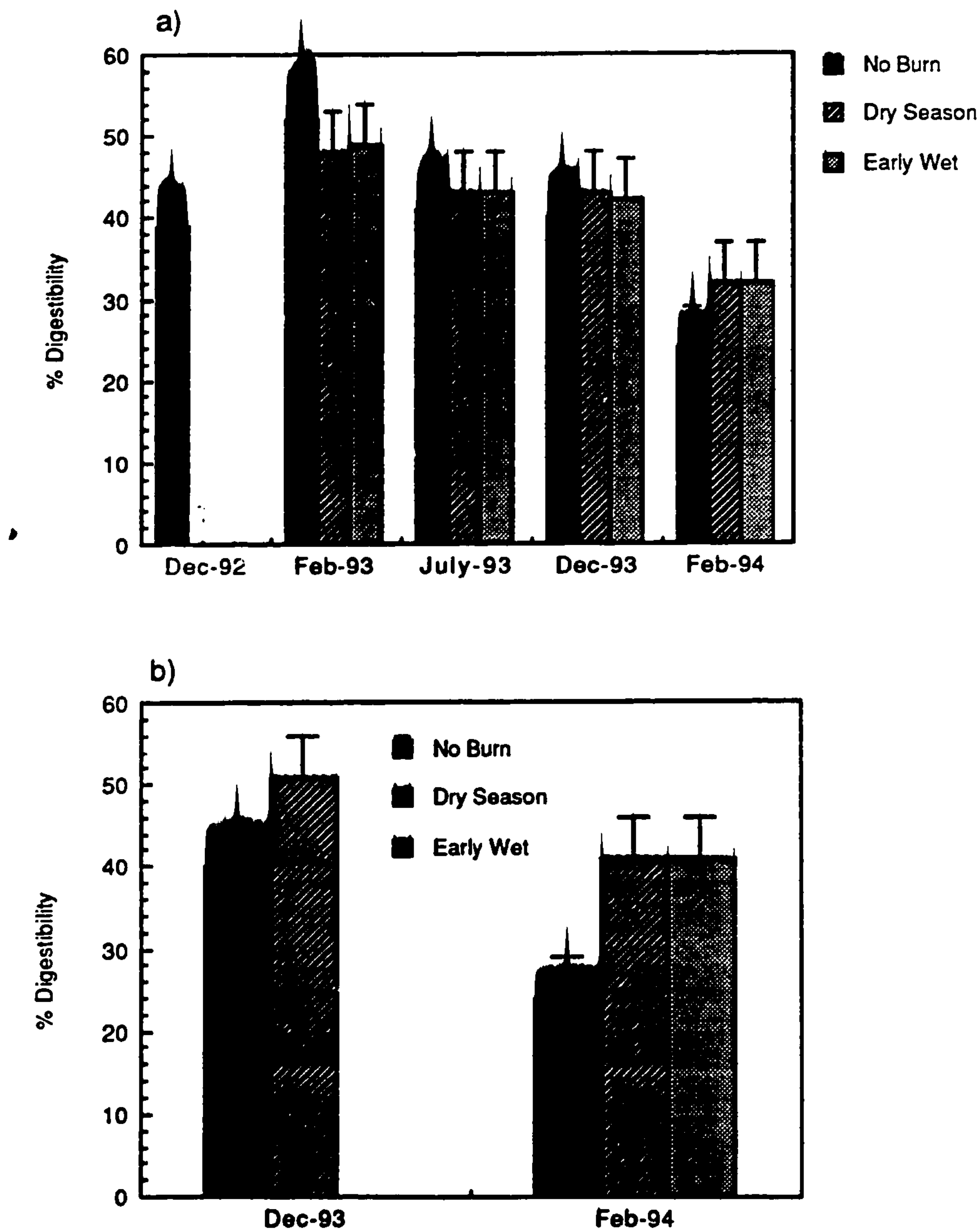

Figure 3.1 In vitro dry matter digestibility (% dry matter) for *Schmidtia pappophoroides* for treatments applied in a) 1992 and b) 1993 (bars are 95% confidence interval).

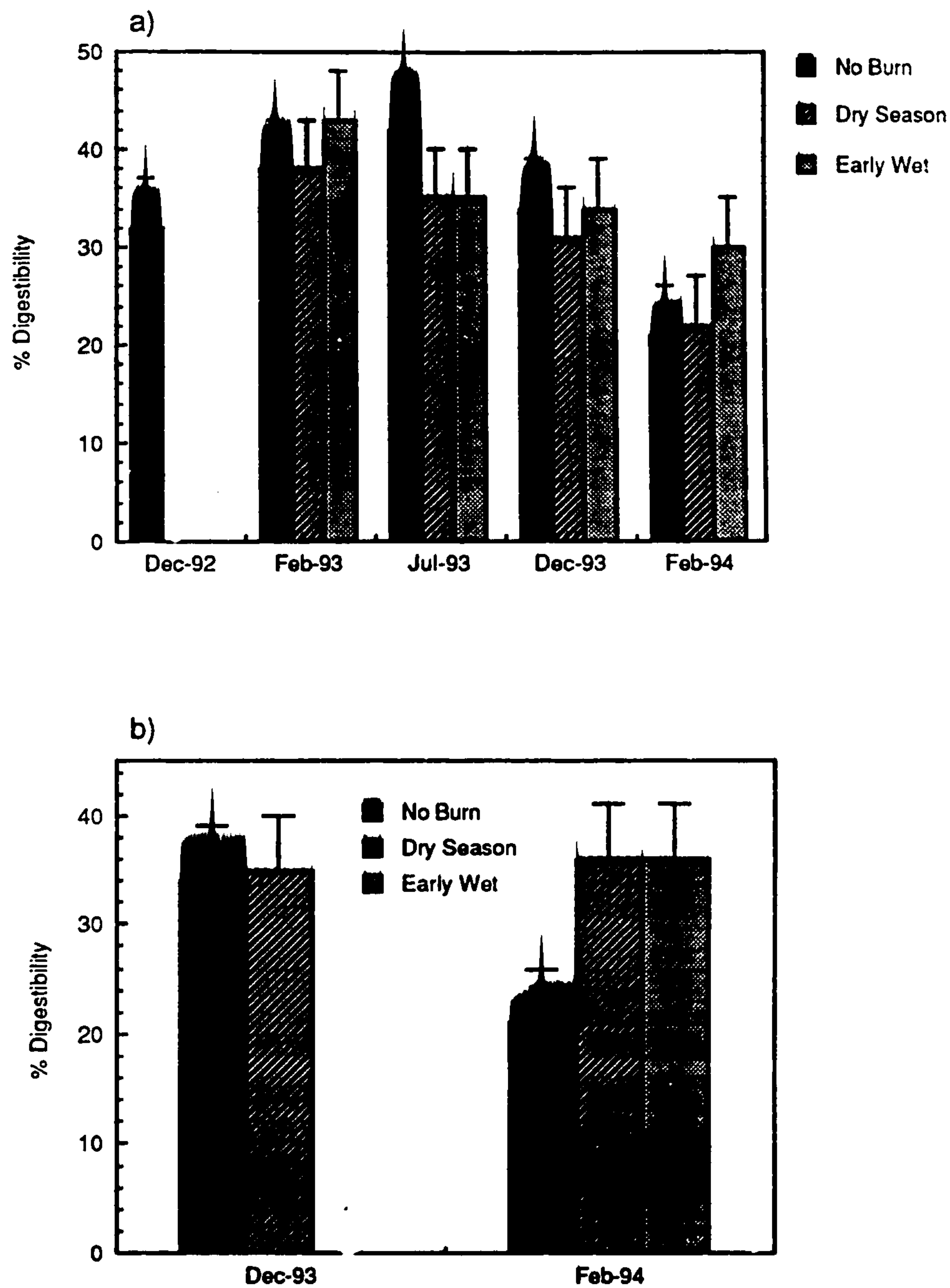

Figure 3.2 In vitro dry matter digestibility (% dry matter) for *Odyssea paucinervis* for treatments applied in a) 1992 and b) 1993 (bars are 95% confidence intervals).

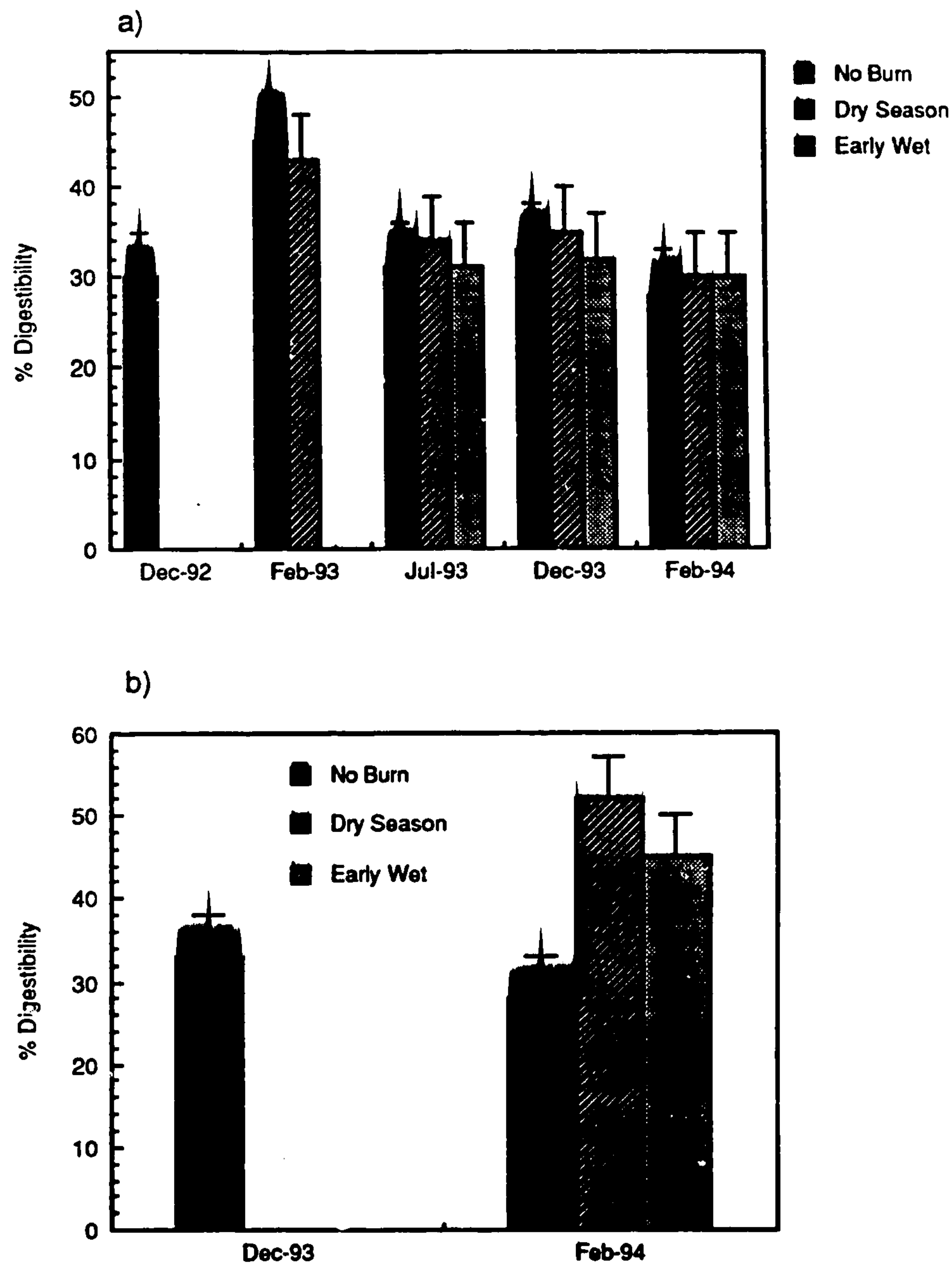

Figure 3.3 In vitro dry matter digestibility (% dry matter) for *Stipagrostis uniplumis* for treatments applied in a) 1992 and b) 1993 (bars are 95% confidence intervals).

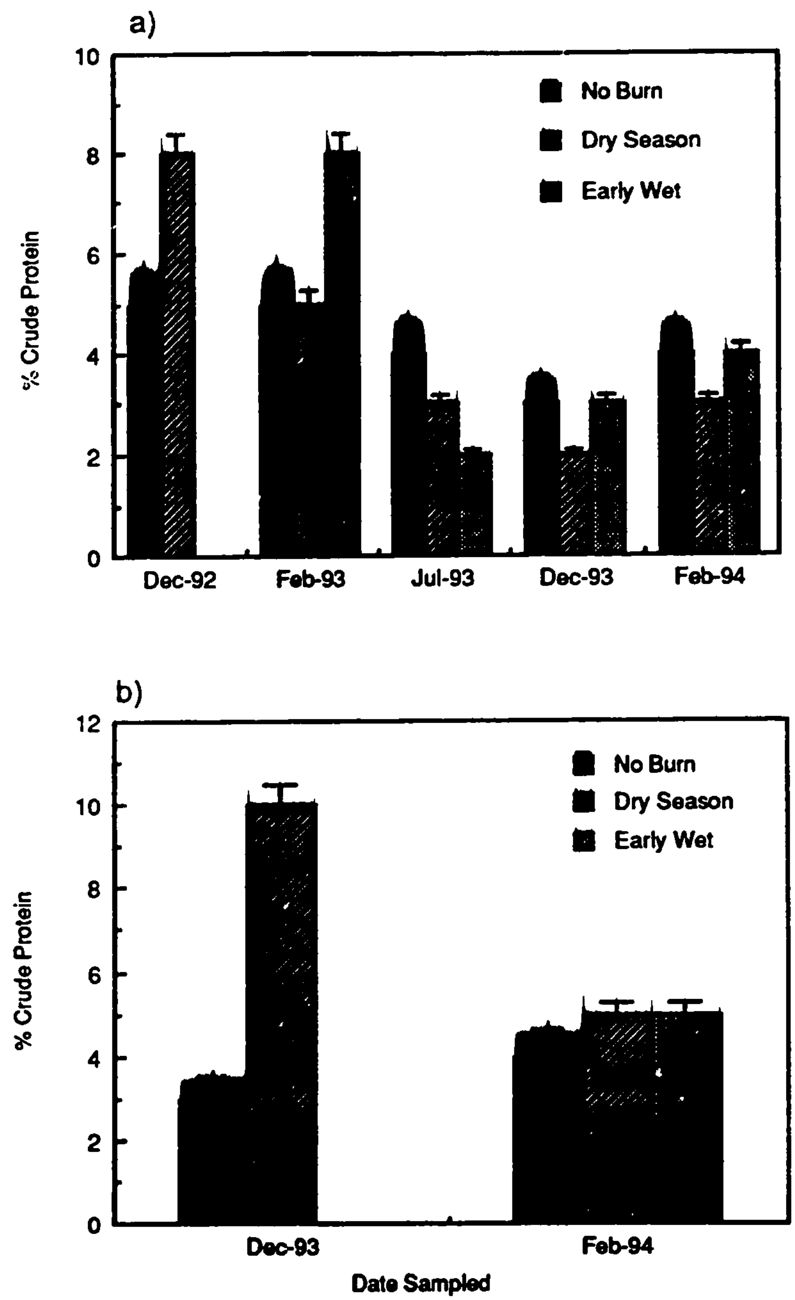

Figure 3.4 Crude protein content (% dry matter) for *Schmidtia pappophoroides* for treatments applied in a) 1992 and b) 1993 (bars are 95% confidence intervals).

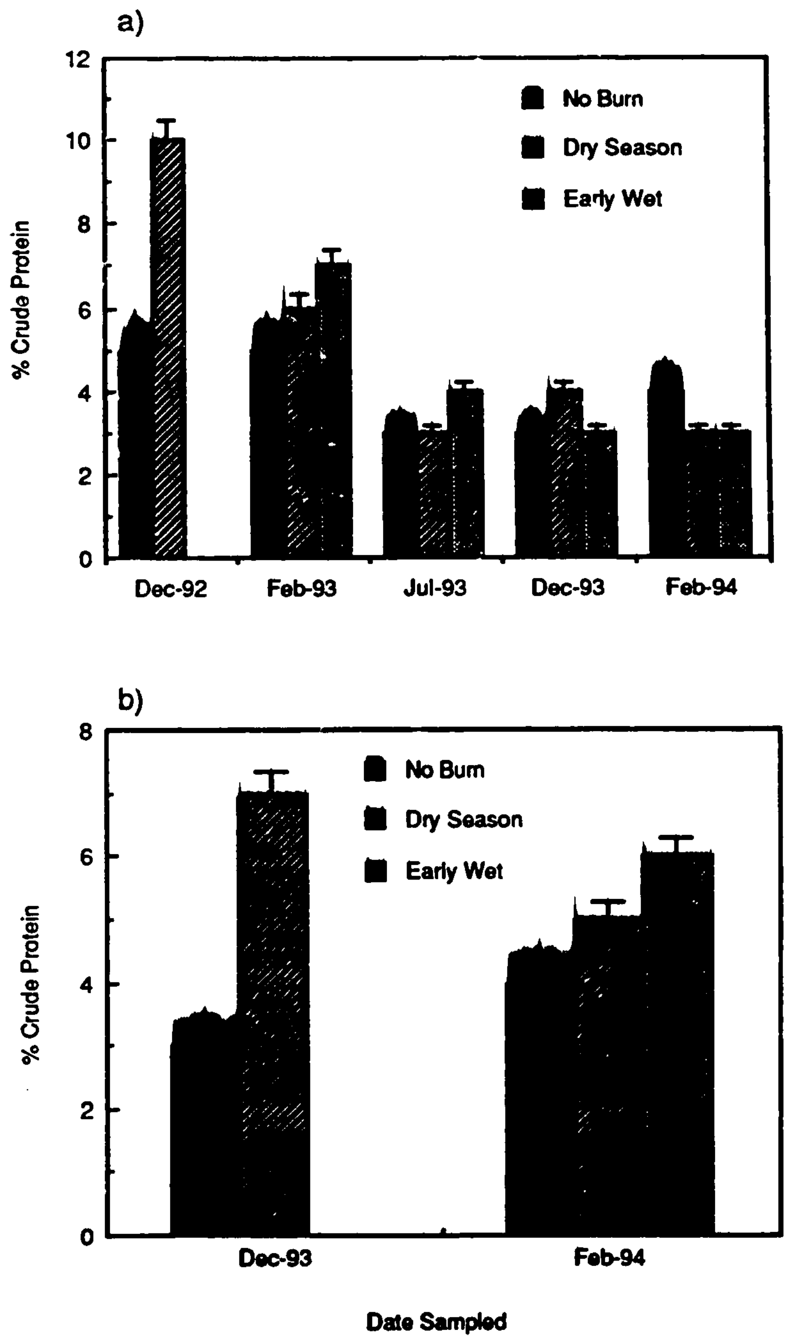

Figure 3.5 Crude protein content (% dry matter) for *Odyssea paucinervis* for treatments applied in a) 1992 and b) 1993 (bars are 95% confidence intervals).

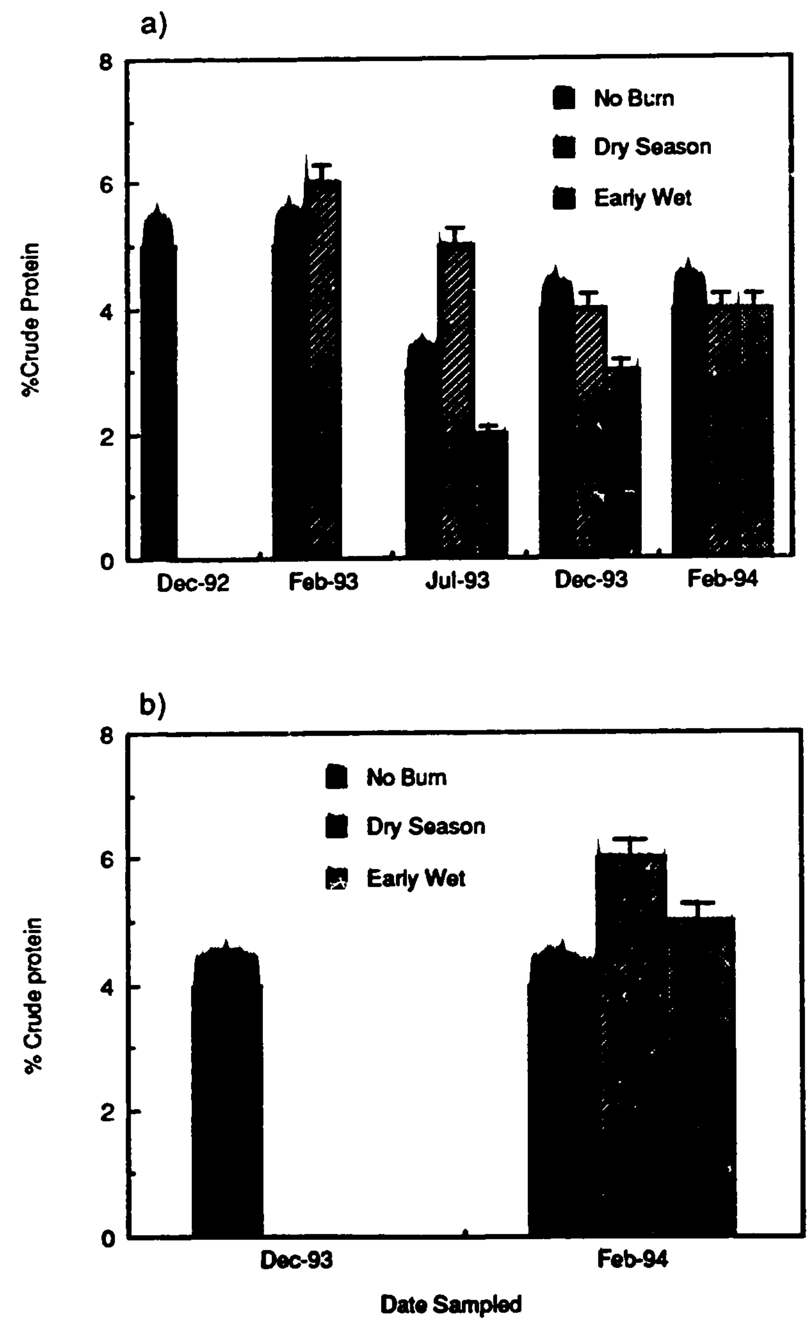

Figure 3.6 Crude protein content (% dry matter) for *Stipagrostis uniplumis* for treatments applied in a) 1992 and b) 1993 (bars are 95% confidence intervals).

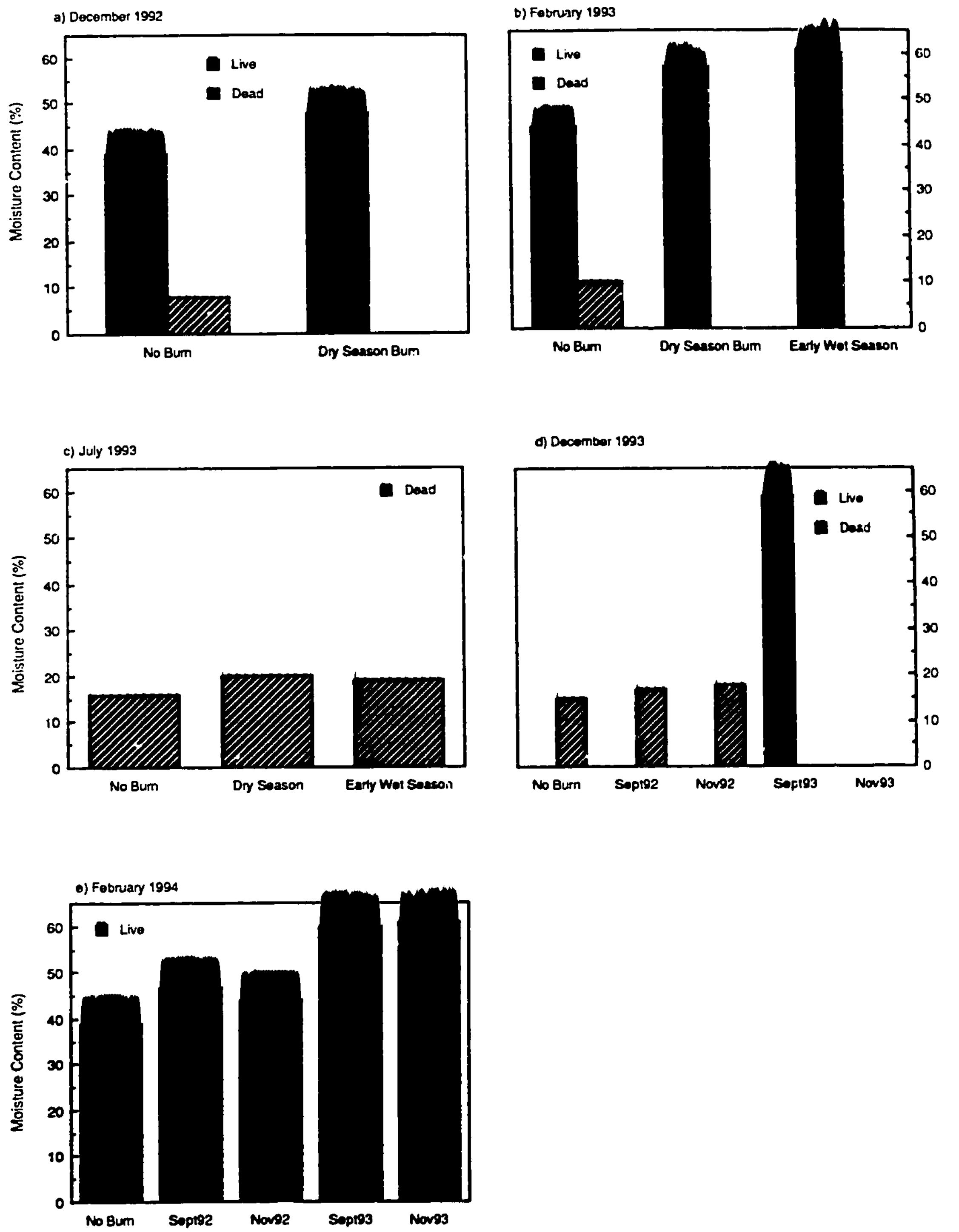

Figure 3.7 Moisture content of the herbaceous vegetation during different sampling dates.

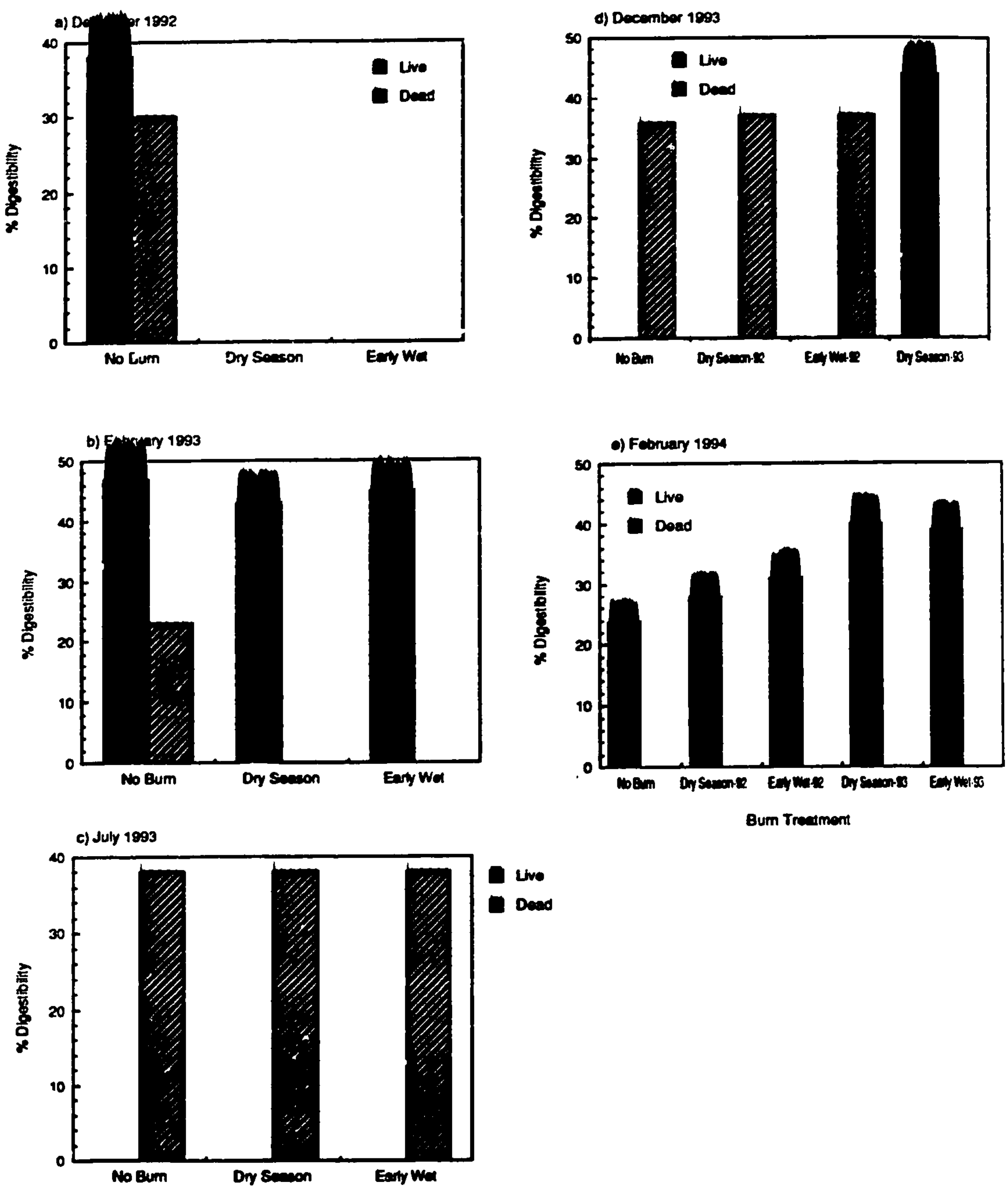

Figure 3.8 In vitro dry matter digestibility (%) for live and dead plant biomass from December 1992 to February 1994.

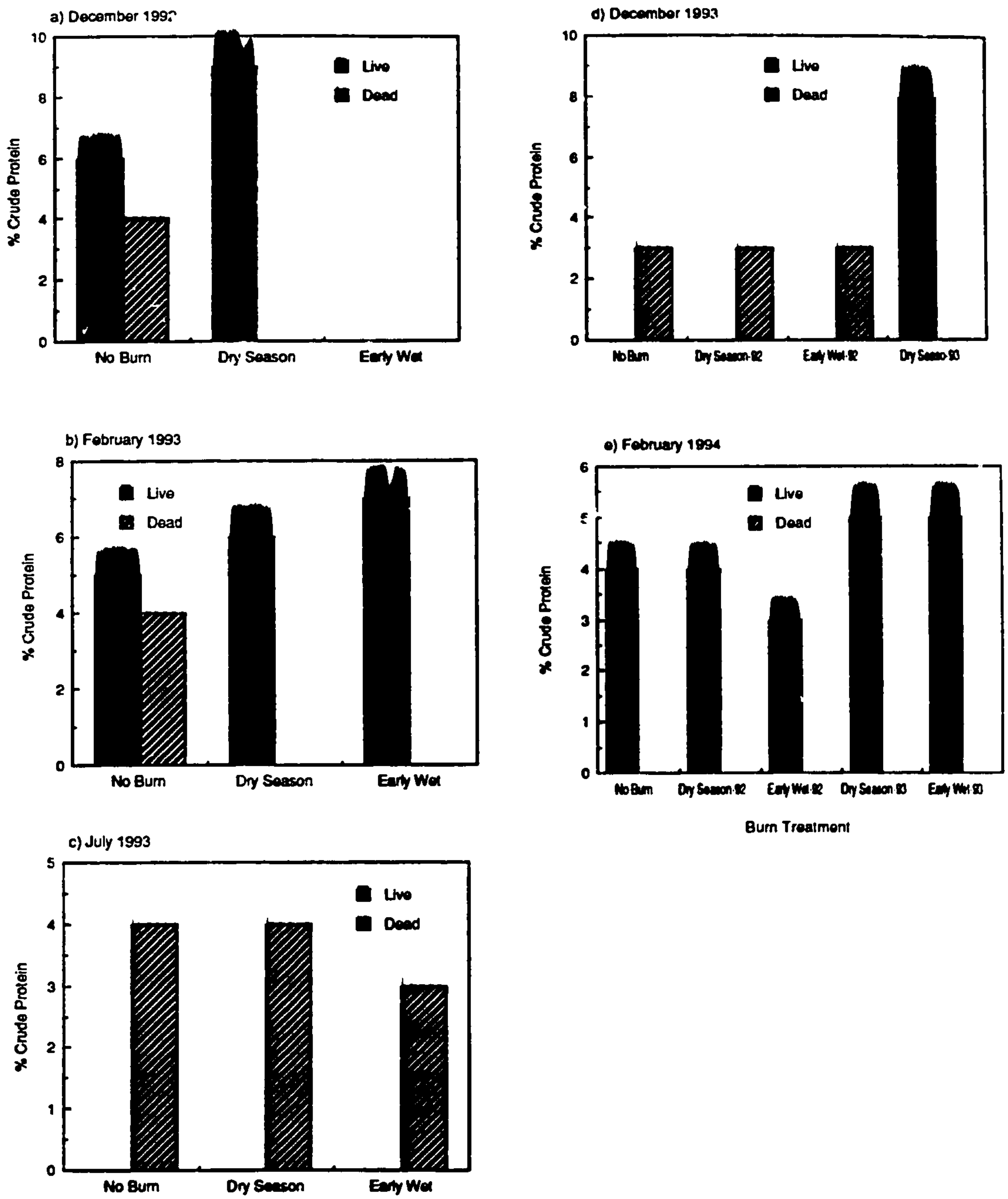

Figure 3.9 Crude protein content (%) for live and dead plant biomass from December 1992 to February 1994.

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CHAPTER 4 EFFECTS OF PRESCRIBED BURNING ON VEGETATIVE COVER AND SPECIES COMPOSITION

4.0 INTRODUCTION

In Botswana, when soil is disturbed, the combination of sandy soils and a dry climate results in a vegetative cover subject to rapid deterioration. About 80% of the country is covered by the Kalahari sands. These 'sandveld' soils are highly susceptible to erosion. Usually, in the sandveld environment, it is impossible to distinguish between the effects of fire on the vegetation and the detrimental effects of heavy grazing immediately after a fire. Brush encroachment caused by over-grazing is also a serious problem and prescribed burning has been considered the only economic way to control it.

A great part of the savanna area of Botswana gets burned every year either by design, mistake or natural causes. The government has, with little effect, banned all uncontrolled burning. Legislation is in place that controls the use of fire in the country. The Herbage Preservation Act (Prevention of Fires) of 1977 prohibits the setting of any uncontrolled fires. Despite this legislation, it is estimated that about 20% of Botswana's rangelands are burned every year (Animal Production Research Unit 1980). Large areas of the rangeland, including the conservation areas, are repeatedly burned. It is, therefore, important to have an understanding of the effects of these repeated fires on the vegetation. It is also important to know how often these fires occur and to what extent a fire management plan could be incorporated into the overall park management plan. Except for a few studies on the use of fire to control brush encroachment on the hardveld of eastern Botswana, no studies on the effects of fire on grassland vegetation have been carried out (Sweet 1982, Sweet and

Tacheba 1985). Studies need to be undertaken to determine whether prevention of fires in the grasslands of the Makgadikgadi ecosystem is deleterious.

Many conservation areas in sub-Saharan Africa use fire as an active management tool according to predetermined goals (van Wyk 1971, Trollope 1982). In Botswana, this has not been the case despite frequent repeated fires over much of the country. The Makgadikgadi Pans National Park is repeatedly subjected to these fires. Fire has played a major role in the development and maintenance of plant communities in Botswana long before human settlements. Because of this age-old influence of fire on the ecosystems, fire, like climate, must be regarded as a natural phenomenon which has contributed towards the establishment of a climax vegetation. Thus fire is often used as an efficient means of removing moribund herbaceous material (Trollope 1982, Mentis and Tainton 1984) and for the control of woody biomass (van Wyk 1971), and thereby an optimum fire management plan is one that simulates the natural incidence of fire. Another reason often given for prescribed burning is to obtain a more desirable species composition, taking into account the various needs of animals. Some animals prefer shorter grasses (Bell 1970), so that there is need for constant removal of the excessive unwanted growth. In some conservation areas, prescribed burning has been conducted to maintain ecological diversity (Hodgkinson et al. 1984).

The Makgadikgadi Pans National Park is surrounded by human settlements where range burning is prohibited and even natural fires that are started outside the borders of the park are controlled. Fires that start within the boundaries of the park are supposed to be controlled to prevent them from spreading. But, as late as 1990, the Department of Wildlife has debated whether or not to control such fires within the conservation areas. Many African national parks are mandated to conserve biodiversity. Implicit in such a goal is the need to conserve habitat diversity. In this particular case, it might be important to preserve the fire-sensitive vegetation types while maintaining productive grasslands in other areas and also allowing succession to continue in others.

The African Convention on the Conservation of Nature and Natural Resources as accepted in 1968 by the Organization of African Unity (O. A. U.), of which Botswana is a signatory, includes the following in the definition of a National Park (i) an area exclusively set aside for the propagation, protection, conservation and management of vegetation and wild animals, as well as for the protection of sites, landscapes or geological formations of particular scientific or aesthetic value, for the benefit and enjoyment of the general public, and (ii) an area in which the killing, hunting and capture of animals and the destruction of plants are prohibited except for scientific and management purposes (von Richter 1976, Nchunga 1983). The policy on national parks in Botswana is that these are areas set aside for the preservation of natural and scenic features of national and international significance for scientific, educational, cultural and recreational purposes. This policy statement is also supported by the Wildlife Conservation Policy of 1986 and the National Conservation Strategy Policy of 1990. The primary objective in the management of the protected areas is to maintain their wilderness quality through minimum human intervention. Fires occurring under natural circumstances, in the absence of humans and initiated by lightning, should be regarded as a natural fire regime. In this regard, the occurrence of fires within the Makgadikgadi ecosystem seems to be natural and hence any control of all fires should be seen as upsetting the natural system.

Much of Africa's savannas are maintained by fire and as a result of the frequency of grass fires in most savannas many vegetative communities consist almost exclusively of fire tolerant plants. The timing and the frequency of grass fires greatly affect the structure and composition of vegetation as well as other environmental conditions. Prescribed fires have been used in other areas of sub-Saharan Africa with positive results, and hence it is inherent that if prescribed burning is to be used in Makgadikgadi, then the fire management plan should closely simulate the natural incidences of fire. If the main objective of management of the protected areas is to be achieved, then management of the vegetation and wildlife within the park should be based on some understanding of the responses and the dynamic effects of fire on the vegetation within the park. In the conservation and management of conservation areas like Makgadikgadi Pans National Park, knowledge of a natural fire regime of the area is of utmost importance.

Factors such as basal cover, plant density and frequency have been recorded to determine changes in the proportion of bare ground, the encroachment of woody species and the botanical composition of the grass and herbaceous layer. The most obvious result of prescribed burning in conservation areas is the increase in fire-tolerant species and the decrease in those sensitive to fire. The reaction of plants to fire, however, varies depending on the phenological stage of the plant and on the conditions of the fire, such as amount and character of fuel available and weather conditions such as speed and direction of wind and relative humidity (Daubenmire 1968). Grasses may be damaged or stimulated by fire. Grass species respond differently to burning and their reaction is strongly influenced by the time and intensity of burn as well as the type of grass cover and local environmental conditions (Kennan 1971, Skovlin 1971, West 1965).

The influence of fire on the structure of plant communities within grasslands largely depends on their successional status (Tainton and Mentis 1984). The role of fire in low rainfall areas, where grassland is climax, is different from that of high rainfall areas where grassland is successional to scrub. In high rainfall areas, the absence of fire permits fire-intolerant woody species to invade the grassland. Consequently, such areas are inevitably subject to occasional high intensity fires which kill woody species. Hence, in high rainfall areas, annual burning assures the retention of a dense grass cover while in the low rainfall areas annual burning may lead to plant death causing a reduction in plant density of the plant community.

Changes in botanical composition of an area are related to the effect of fire on vegetation. Time and frequency of burning are critical factors in plant species response to fire (Trollope 1983). Even fire-resistant species can be reduced in a plant community if the competitive advantage is given to another species due to phenological stage at the time of burning. Phenological stage is, therefore, an important factor in the response of vegetation to prescribed burns. An ecosystem may be taken back to bare soil or to the very beginning of succession. However, in extensive grasslands, fire usually has little effect on the botanical composition beyond the temporary changes in the first year or two (Child et al. 1987).

Fire tends to favour those species that best resist damage (Heady and Heady 1982, Bailey 1988). Adaptations of grasses, forbs and shrubs that permit them to resist or endure burning are similar to those characteristics that provide tolerance to grazing. Furthermore, the combination of burning and grazing are seen as the principal determinants of the species composition of the grasslands. Such adaptations include grass plants structured in a way that they are able to tolerate periodic removal of aerial structures. Some of the grasses survive such drastic defoliation by producing underground rhizomes or stolons at or close to the surface. Such structures possess tiller initials, some of which may develop into tillers in the absence of defoliation. Others have an annual life cycle, an abundant seed crop, a short period for rapid distribution of seed and its burial, and a short period of vigorous growth, followed by rapid maturation of above-ground herbaceous material.

Fires also have indirect effects on vegetation. They change microclimate and soil properties both of which have a bearing on the regrowth potential of the vegetation. As a rule, soil moisture is reduced after a fire (Booysen and Tainton 1984). Soil moisture levels are closely related to vegetation response after a prescribed burn. Nitrogen and sulphur are largely lost in gaseous form whilst phosphorus, potassium, calcium and magnesium may be lost by blowing ash away (Skarpe 1980).

The new growth after a burn is more readily available to large herbivores than where old and mature herbage remains unburned. Grazing animals prefer the new growth on the burned areas (Novellie 1987). It has been speculated that the excessive concentration of grazing animals after a fire may be a greater source of damage than the fire itself (Child et al. 1987). The frequency of grazing can affect the production and the botanical composition by eliminating grasses grazed too frequently or at susceptible stages in growth (Edroma 1981). The overgrazed plants become unable to produce healthy roots and ultimately deteriorate and may die earlier than usual. The more resistant grasses then become dominant.

Botswana inherited the fire-suppression policy without necessarily evaluating the consequences of such a policy. There has been little research on the effects of fire on the grassland vegetation of the Makgadikgadi Pans National Park and hence very little information is available for use in management decisions which might have far reaching consequences. Bearing in mind that the area is subject to repeated burning, the main aim of undertaking the project was to develop an understanding of the effects of fire on the grassland vegetation of the Makgadikgadi Pans National Park.

The project was conducted to test the hypothesis that prescribed burning did not have any effects on changes in vegetative cover and species composition of the grassland vegetation of the Makgadikgadi Pans National Park.

4.1 STUDY AREA

4.1.1 Location

The Makgadikgadi Pans National Park (MPNP), formerly Makgadikgadi Pans Game Reserve (MPGR), lies between 20° 10.0'S, 24° 15.0'E and 20° 50.0'S, 25° 05.0'E in north-central Botswana (Appendix 1). The park, which is about 4900 km^2, was established in 1970 to preserve the western part of the Makgadikgadi Pans ecosystem and the adjacent open plains as well as the bush country between Nxai Pan to the north and the Boteti River to the southwest (von Richter 1976). In 1992 the park was increased in size by incorporation of some areas of the northern statelands. The park forms part of the ancient Makgadikgadi lake-bed (Hutton 1974).

4.1.2 Geology and Soils

The Makgadikgadi Pans is an enormous flat area covered with salt-bearing fine white sand and clay (Hutton 1974). The Makgadikgadi pans complex occupies a basin that is the lowest point in a drainage system extending from Botswana into Namibia, Angola and Zimbabwe (Baillieul 1978). It is the desiccated remnants of a huge lake into which the Letlhakane, Okwa and Mmono Rivers used to flow from the south; the Nata, Semowane, Mosetse and Lephashe Rivers from the east; and into which the Boteti River used to drain via the Okavango Delta from southeast Angola to the west. The origins of the basin and pans are closely tied to complex climatic and tectonic changes that occurred in the Kalahari region during the late tertiary period, about three million years ago, and in quaternary time (Cooke 1979). Grove (1969) estimated that lake Makgadikgadi covered 34000 km^2 at its maximum extent, with a volume of about 500-1000 km^3. Climatic changes have caused the lake to fluctuate in size. As the climate became drier, the rivers ceased to flow and the water in the lake began to recede, leaving the old beach as evidence of its previous extent (Hutton 1974). In some places, vegetation has encroached on the pan while in others wind action has prevented vegetation growth.

The western part of the Makgadikgadi basin consists of lacustrine, fluvial and aeolian landforms (Blair-Rains et al. 1967, Blair-Rains and McKay 1968, Cooke and Verstappen 1984). Quaternary deposits of aeolian, fluvial and lacustrine origin, forming part of the of the Pliocene, about two million years ago, and recent Kalahari beds, are underlain by rocks of the Karoo system (Field 1978, Jones 1980, Jones and Key 1987).

The sedimentary material overlying this basin includes sands of the Kalahari type, pan sediments, calcrete and silcrite. Sands of the Kalahari type have been carried by wind and water into the basin at varying times during the tertiary and subsequent periods, though some material may have been derived from the underlying rocks of the Stromberg series (Blair-Rains et al. 1967, Cooke and Verstappen 1984).

In addition to the soils derived from sandy parent material, riverine or lucastrine alluvial materials, there are areas of lithosols derived from basalt and vertisols either of lithomorphic origin or occurring in depressions. These soils are found in the north-east of the park (Blair-Rains et al. 1967). Soils are developed on the deep sheet of Kalahari type sand. These soils are structureless, mildly acid to neutral in reaction and of low fertility. They are usually porous and free draining although relatively impermeable soils occur in topographic depressions.

Tectonic and climatic changes have affected the sedimentation in the drainage basin (Blair-Rains and McKay 1968, Cooke and Verstappen 1984). As a result of sub-aerial exposure, some of the sedimentary materials, have become silcified and calcified. Within the basin of an extensive earlier lake, and around the present Makgadikgadi depression, outcrops of calcrete and silcrete are common. Such soils are generally poorly developed and have a poor nutrient status. The sands are prone to erosion by wind, especially where vegetation is sparse (Dutch Consulting Engineers 1980).

4.1.3 Climate

The climate of the Makgadikgadi area is sub-tropical with distinct winter and summer seasons (Blair-Rains and McKay 1968). Temperatures are low during the winter months, minimum of about 5 °C in June, and frosts may occur. In summer temperatures can be extremely high during the day for example there may be maximum temperatures of about 35 °C in October. Extreme temperatures recorded were -4.4 °C in August and 43.3 °C in November (Blair-Rains, Child and McKay 1967).

During the wet season, wind direction is variable especially in the mornings and afternoons. However, winds tend to be northeasterly. During the winter, winds are generally easterly. The relative humidity (RH) is highest during the late half of the wet season (January-April), up to about 76% in March, and low for the rest of the year. From August to October, relative humidity is particularly low, going down to 19-22% (Blair-Rains and McKay 1968).

Southern Africa is periodically visited by severe and sometimes prolonged droughts (Schulze 1972). The degree of surface aridity in Southern Africa is not only a function of precipitation, but also of evaporation. Potential evaporation exceeds the total rainfall and this creates water deficit for plant growth. Herbage grows on soil moisture, and soil moisture essentially reflects the difference between precipitation and evapotranspiration.

Precipitation over the region follows an annual cycle and is entirely a summer phenomenon (Tyson 1986). More than 80% of the annual rainfall in this region occurs between October and March. However, there are great variations from both the monthly and yearly rainfall averages (Blair-Rains and McKay 1968). The total rainfall for any one year may vary from half to nearly double the average, and monthly variations are even more extreme than yearly fluctuations. Years of less than average rainfall are more frequent than years of above average rainfall (Appendix 2). The mean annual rainfall for the Makgadikgadi area is 450 mm (Pike 1971, Field 1978, van Zon 1984) with a variation of about 35% (Bhalotra 1985) and a standard deviation of 200 mm and the intensity is highly variable (Mbano 1984). The general rainfall pattern can be divided into two periods. October to December constitute the early wet period whilst January to April constitute the late wet period. Most of the rain in Makgadikgadi falls during the late wet period. The study area lies between two rainfall recording stations located in Maun (about 160 km west of the study area) and Gweta (50 km east of the study area). The longest recorded rainfall is that of Maun (1922 to 1990) (Appendix 2).

Total seasonal rainfall for the period preceding and during the study was highly variable. Annual precipitation was generally below normal except for the 1990/91 and the 1993/94 season when the total rainfall exceeded the 450 mm mean annual rainfall. The rainfall for the 1991/1992 season was extremely low, only 270 mm, which is below the mean annual rainfall of 450 mm. Effective precipitation for plant growth was considerably higher in January 1994 (275 mm) compared with that of the same period in 1993 (67 mm).

4.1.4 Topography

The Makgadikgadi Pans form part of the depression which extends further north to Mababe. Makgadikgadi Pans consists of the Sua Pan and the western Ntwetwe Pan and is the main focus of drainage in the area. The Makgadikgadi area is generally flat or gently undulating at a general elevation of about 914 m above sea level (Blair-Rains and McKay 1968, Cooke 1979, Verstappen 1981, Cooke and Verstappen 1984). The comparative flatness is broken by isolated sand ridges, and in some places by linear or crescent shaped dunes.

4.1.5 Vegetation

The vegetative cover of Botswana consists of an herb layer composed of a mixture of grasses and forbs with an upper layer of scattered trees and shrubs. The density of trees or shrubs varies from location to location but it is closely associated with the annual rainfall and local drainage conditions (Animal Production Research Unit 1980). The vegetation is classified into the following three main types: i) Tree savanna in which the taller woody species are mainly trees, ii) Shrub savanna in which there are no or very few trees and many scattered shrubs and, iii) Grassland savanna in which there are very few or no trees or shrubs and the vegetative cover is a mixture of grasses, sedges and herbs.

The vegetation of the Makgadikgadi has been documented by Blair-

Rains and McKay (1968), Child (1968), Weare and Yalala (1971) and Mbano (1984). The area is described as predominantly delta grassland savanna. However, various vegetation types can be identified within the park. The southwestern part of the park is riverine vegetation dominated by *Acacia* spp. with little or no herbaceous understory because of over-grazing by livestock from nearby settlements. The western part of the park is scattered wooded savanna (park woodland) also dominated by *Acacia* spp. and with a lot of brush encroachment. The herbaceous layer is dominated by *Stipagrostis uniplumis* (Licht) de Wint., *Eragrostis* and *Aristida* spp.

Open grassland savanna occurs in the central part of the park and to the east and southeast where bare pans become common. Extensive grassland occurs on the slightly higher ground away from the sparse vegetation of the pan fringes. The pans are surrounded by extensive short grassland in which the principal species are *Aristida meridionalis* Henr., *Heteropogon contortus* (L.) Beauv., *Odyssea paucinervis* Stapf., *Digitaria* spp., *Cynodon dactylon* (L) Pers. and *Cenchrus ciliaris* (L). East of the pans these grasslands occur in narrow belts, in some cases not more than 1 km wide and give way abruptly to tree savanna (Dutch Consulting Engineers 1980). Trees and shrubs are absent, although there may be scattered or fringing groups of *Hyphaene* sp. and *Acacia* spp., and on raised hummocks stands of *Albizia* sp. and *Terminalia* spp.. Among the grasses are *Cenchrus ciliaris*, *Panicum* sp., *Schmidtia pappophoroides* Stend., *Cymbopogon* sp., *Eragrostis* sp., *Aristida* sp. and *Odyssea paucinervis*. The grassland zone of Makgadikgadi is dominated by the following grass species; *Schmidtia pappophoroides*, *Eragrostis rigidor* Pilger., *Stipagrostis uniplumis*, *Odyssea paucinervis* and *Cenchrus ciliaris*. The upper layer is dominated by scattered groups of *Hyphaene* sp. and shrub to tree savanna dominated by *Albizia spp.* and several *Acacia* spp.

4.1.6 Wildlife

A principal feature of the Makgadikgadi ecosystem is the migration of Burchell's zebra (*Equus burchelli* Gray) and blue wildebeest (*Connochaetes taurinus* Burchell) populations. During the wet season, usually in November to April, animals graze the short grass plains along the western edge of Ntwetwe pan (Dutch Consulting Engineers 1980). As this region dries out, the animals migrate westwards to the Boteti River where they spend the entire dry season usually from May to October, moving out to the plains again as soon as it rains. In the wet season when surface water is widely available, animals tend to be dispersed in smaller groups but during the dry season animals concentrate in large groups within reach of the permanent water source, the Boteti River.

Approximately 80% of the total animal biomass in the Makgadikgadi Pans National Park is composed of the more migratory herbivores: zebra and wildebeest (Kgathi and Kalikawe 1993). Other species found in the area are hartebeest (*Alcelaphus buselaphus* G. Cuvier.), gemsbok (*Oryx gazella* L.), eland (*Taurotragus oryx*), springbok (*Antidorcas marsupialis*), hippopotamus (*Hippopotamus amphibius* L.), giraffe (*Giraffa camelopardalis* L.), kudu (*Tragelaphus strepsiceros* Pallas) and impala (*Aepyceros melampus* Lichtenstein). Elephant (*Loxodonta africana* Blumenbach), roan (*Hippotragus equinus* Harris) and buffalo (*Syncerus caffer* Sparrman) are occasionally seen during years of above average rainfall. Many other smaller mammals occur in the area including many rodents.

The main predators found within Makgadikgadi are lion (*Panthera leo* L.), leopard (*Panthera pardus* L.) and hyaena (*Hyaena brunnea* Thunberg). Movement of the predators is usually tied to the movement of the prey. Developments on the periphery of the park, such as human settlements and livestock grazing on all sides except the north, have affected the impending free migration of wildlife. These have led to perpetual conflicts between wildlife conservation and livestock production sector, because of predator depredation on livestock.

Another factor of importance to the livestock sector is the transmission of certain diseases between wildlife and livestock. There have been past outbreaks of Foot and Mouth disease in northern Botswana. African buffalo are known carriers of the virus that causes the disease even though the disease is not apparent in them. The main concern is the mixing of cattle and buffalo. Another disease that is likely to be transmitted when cattle and wildebeests are in contact is malignant catarrh.

4.2 METHODS

4.2.1 Experimental design

The study was conducted using a randomized complete block design with four blocks (sites). Each of the four sites was divided into six equal-sized plots (100m by 100m). The least representative plot (that is, plot with heavy termite mounds or rodent burrows etc.) was rejected leaving only five plots per site. One plot at each site was randomly selected as a Control plot (No Burn) leaving four plots per site for the burning treatments. The remaining four plots at each site were then randomly selected as either 1992 or 1993 burning plots (2 plots per year) and further distinguished as Dry season (September) or Early wet season (November) burning plots for the two years, respectively.

4.2.2 General Procedures for Burning

Prescribed burning was conducted in the Makgadikgadi Pans National Park in September and November of 1992 and 1993, respectively, following the guidelines of Bailey (1988). Firebreaks, about five metres wide, were constructed around each site to prevent wild fires from entering the study sites before or after the prescribed burns. The firebreaks also ensured maximum fire control during the prescribed burns. At each burning time one 100m x 100m plot was burned at each site. Prior to burning, in five randomly located 1m x 1m quadrats, fuel load was harvested by clipping in both the Burn and No Burn treatment plots. During the November burns all clipped materials were sorted into live and dead components. Only the dead material was considered to constitute the fuel. If there was any precipitation prior to conducting the burns, sufficient drying time was allowed before burning.

On the day of the burn, prior to ignition, the relative humidity (%RH), wind speed (km h^{-1}) and direction were obtained at the site. Most of the burning was conducted in the afternoon when the relative humidity was at its lowest and wind speed (less than 20 km h^{-1}) was considered optimal for burning. The first task was to widen firebreaks prior to the actual burning of the study plots. At times the burning of the firebreaks proved to be a formidable task because of the poor distribution of the fuel. All of the burning was started near the firebreak on the leeside (downwind). All sites were burned using strip head-fires.

In areas with complete burns and for the control plots, five clusters per treatment were randomly located and marked with 0.5m stakes. Clusters were used for both destructive (productivity determination) and non-destructive sampling (species composition and ground cover). Field sampling was carried out starting in December 1992 for two treatments (Control and Dry season burns), in February for three treatments (Control, Dry and Early wet season burns) and in July for all three treatments. More burns were instituted in September and November of 1993. Sampling was continued in December 1993 and concluded in February 1994. Only the February 1994 sampling period yielded results for all the treatments and for the two years of study.

4.2.3 Sampling for vegetative cover and species composition

Species cover (%) was determined during the sampling periods of February 1993, December 1993 and February 1994 for all 1992 burn treatments and during December 1993 and February 1994 for the 1993 burning treatments. Sampling of vegetative cover was conducted in fixed quadrats. Sampling points were randomly determined prior to sampling, permanently marked with painted stakes and monitored throughtout the study. At each sampling period, a 50cm by 20cm quadrat was placed on the marked stake and all the species rooted within the quadrat recorded. At each sampling period, vegetation was developed well enough for most species to be easily identified. All species were estimated individually. Percent foliar cover (vertical projection of the plant's aerial parts) was recorded to the nearest five percent. A total of ten quadrats per cluster were sampled. Species cover per cluster was obtained by averaging the ten quadrats per cluster.

Each permanently marked quadrat also had the following parameters estimated: i) bare ground (%), ii) area covered by visible erosion (%) (i.e. area covered by loose sand etc.), iii) total vegetation cover (%), iv) live vegetation cover (%), and v) dead vegetation (including litter) cover (%).

4.2.4 Data Analysis

The vegetative cover data were analyzed using the GLM procedure of SAS to compute analysis of variance (SAS 1985) with source of variation of blocks, treatment, cluster and two factor interaction of treatment, block and cluster. The cluster within the block by treatment was used as the error term. Preliminary analysis of the data indicated that transformed and untransformed data yielded the same results. Therefore, for presentation purposes only the means from the untransformed data are presented. Anova table for changes in vegetative cover is in Appendix 3C.

Least square means and their standard error of means were computed. Where least square means could not be computed because of missing combinations, the means and their standard errors were computed by dropping the block by treatment interaction and the error term. Significant means were separated by the Student-Newman-Keul Multiple Range test ($p<0.05$).

Treatment means for percent species cover for the dominant species were generated but not subjected to analysis of variance. All grasses with less than 1% cover for all the treatments for any sampling period were lumped under the category 'Other grasses'. All forbs were combined under the category 'Forbs'.

4.3 RESULTS

4.3.1 Changes in vegetative ground cover

In the No Burn, mean bare ground cover (%) ranged from a high of 88% in December 1993 to a low of 75% in February 1994 (Table 4.1). Thus, mean total vegetative cover was low, ranging from 14 to 24%. Live vegetation cover only range from 4 to 24%. The cover of dead vegetation (litter) never exceeded 10%. In February 1993, bare ground was highest and total vegetative cover (live and dead combined) was lowest in the Early wet season burn compared to the No Burn and the Dry season burn treatments (Table 4.1). All three 1992 burn treatments were significantly different from each other with the No Burn having the highest total vegetative cover (23%) and the most recent burn, the Early wet season burn, had the lowest total vegetative cover (14%) (Table. 4.1).

In December 1993, the Dry season burn of 1993 had the highest percent bare ground (95%). At any sampling period the newest burn had the highest percent bare ground. By February 1994, the 1993 burn treatments were significantly higher in bare ground and lower in total vegetative cover than were the 1992 burn treatments and the No Burn. In terms of total vegetative cover and live vegetation component, the Early wet season burn of the 1992 burn treatments was significantly different from the Dry season burn of 1992 and No Burn treatments. By the second growing season the Dry season burn of 1992 had fully recovered to preburn levels whereas the 1992 Early wet season burn live vegetation cover had not.

At the sampling period in December 1993, the newest burn treatment (Dry season 1993) had the highest potential for erosion (Table 4.1). The potential of the area to possible erosion was highest in the 1993 burn treatments compared to the 1992 burn treatments and No Burn at the sampling period in February 1994.

The live and the dead components of the vegetation were variable. For the live vegetative cover, the No Burn and the Dry season burn treatment of 1992 were significantly higher than the 1992 Early wet season burn at the sampling in February 1993 (Table. 4.1). By February 1994, live vegetative cover of the 1992 Dry season treatment was significantly higher than the 1992 Early wet season burn and both were significantly higher than the 1993 burn treatments. The 1992 Dry season burn treatment had recovered rapidly to pre-burn levels compared to the 1992 Early wet season burns which had not recovered fully by the second growing season.

Cover of dead vegetation in the No Burn was significantly different from the Burn treatments during the sampling in February 1993 (Table. 4.1). By the second growing season (February 1994) for the 1992 burn treatments, the No

Burn and the Dry season Burn were significantly greater than the 1992 Early wet season burn. The 1993 burn treatments were significantly lower in dead vegetation than either the 1992 burn treatments or the No Burn treatment. Both 1993 burn treatments had very low dead vegetative component.

4.3.2 Effects of prescribed burning on species composition

The effects of prescribed burning on the composition of the grass sward and forbs for the two years of study are presented in Table 4.2 and Table 4.3 for the 1992 and 1993 burn treatments, respectively. Foliar cover was too low and too variable to demonstrate statistical significance. Generally, the burning treatments appeared to reduce foliar cover of most species the first growing season after burning. Both *Schmidtia* and *Odyssea* recovered very well from the treatments and by the second growing season the average foliar cover was at the pre-burn levels. These species also recovered rapidly after the 1993 burn treatments. By February 1994, *Schmidtia pappophoroides* was the dominant species for all 1992 treatments (Table. 4.2). The 1993 treatments also showed similar trends (Table 4.3).

Odyssea paucinervis, an unpalatable rhizomatous perennial, also seems to be highly adapted to periodic burning. At the sampling period in February 1994, both the Dry and Early Wet season burns for 1992 treatments had recovered to the No Burn level (Table. 4.2). For the 1993 burn treatment, the Dry and Early Wet season burns had about 3% cover each, which was about half the No Burn cover (Table 4.3).

Stipagrostis uniplumis, the third dominant species in the study area after *Schmidtia* and *Odyssea*, was greatly reduced by fire. By February 1994, *Stipagrostis* cover in the 1992 burn treatments was one-third to two-thirds of the coverage in the No Burn (Table 4.2). For the 1993 burn treatments, *Stipagrostis* cover was half of the coverage in the No Burn (Table 4.3). *Stipagrostis uniplumis* coverage was greatly reduced by the Early wet season burns for both 1992 and 1993 burn treatments.

Digitaria milanjiana, another dominant species in the study area, was also greatly affected by fire. By February 1994, *Digitaria* contributed about 7%, 4% and 2% cover for the No Burn, Dry season and the Early Wet season burns of the 1992 treatments (Table 4.2). On the other hand, *Digitaria* contributed about 3% and 6% cover for the Dry season and Early Wet season burns for the 1993 treatments (Table 4.3). The percent cover for *Digitaria* for the Early wet season burn for 1993 was more than double that of the same period for the 1992 treatments despite the fact that the 1993 Early wet season burns had only been growing for three months compared with 15 months regrowth for the 1992 Early wet season burn.

There is a general trend that most of the species were initially affected by burning but by February 1994 most had recovered to pre-burn levels. Most of the species had suppressed growth during the December 1993 sampling. Percent plant species cover for all the species present was lowest at this time. The 1992 treatments showed few differences whilst the 1993 burn treatments also showed good recovery. *Eragrostis* spp., *Urochloa tricophus, Aristida congesta, Tragus racemosus*, Other grasses and the Forbs were favoured by the Dry season burns of 1992 (Table 4.2). Most of the species had recovered by the February 1994 sampling.

The forbs were also dominant by February 1994 for both the 1992 and 1993 burn treatments (Tables 4.2, 4.3). The dry season burn for 1992 had the highest cover by the forbs compared to the No Burn and the Early Wet season burn. Forbs seems to grow rapidly after a fire. Annual forbs like *Tribulus terrestris, Gisekia* spp and *Solanum incanum* increased rapidly after a fire.

4.4 DISCUSSION

4.4.1 Changes in vegetative ground cover

The Makgadikgadi burning study has shown that the total vegetative cover is roughly 25%. The vegetation is highly adapted to fire and recovers to pre-burn levels within 17 months following a dry season. Bare ground and erosion potential were highest in the youngest burn and by the second growing season there was no difference between the three burn treatments. In this study, the percent bare ground decreased from February to July indicating that there was further growth after the February sampling and then decreased going into the long dry season. Bare ground, in this case, may be a function of the arrangement of the individual tufts of grass and the amount of detached dead material to cover the ground. In this study there was very little detached dead material as most of the dead vegetation component was dominated by standing dead thereby contributing very little to the reduction of the bare ground. The proportion of bare ground is a temporary phenomenom varying with seasons and extent of disturbance. It was highest in the newest burn treatment but recovered to pre-burn levels going into the dry season. The erosion potential also seems to vary with the proportion of the bare ground. Late rains in 1993/94 contributed to the high erosion potential for the 1993 Dry season burn as the area remained bare for a longer time than in the 1992/93 season. The main aspect for erosion in the area is by wind from June to August. Therefore, erosion potential is not much of a factor since by November winds are generally low. Skarpe (1986), working in western Botswana, found the proportion of bare ground in the ungrazed reference area to be about 64% whereas in the highly stocked area the proportion of bare ground was roughly 75%.

Prescribed burning in Makgadikgadi resulted in reduced amount of dead vegetation and increased live vegetation component as well as total vegetative foliar cover. Removal of the dead, unutilised material will surely contribute to the regrowth vegetation being readily available to the herbivores. Dry season burning seems to be the most appropriate in terms of the vegetation recovery. The differences between years are indicative of the fact that factors such as rainfall play an important role in vegetation recovery. The 1992/93 season was characterized by below average rainfall spread over a longer period (more rain days) while the 1993/94 season was characterized by above average rainfall with most of it falling in January 1994 as high intensity, short duration thunder showers. The high rate of vegetative foliar cover recovery is indicative of a vegetation adapted to fire.

Rainfall is a major factor in the recovery of the vegetation in the Makgadikgadi area. It is important to have sufficient moisture for the vegetation regrowth. It is speculated that the above normal rainfall in January 1994 provided sufficient moisture to enable substantial plant regrowth. For example, the positive response of the vegetative cover for the Early wet season burns of 1993 can be attributed to the availability of sufficient moisture in January 1994 compared with the same period in 1993 for the 1992 burn treatments.

4.4.2 Effects of prescribed burning on species composition

Results from the Makgadikgadi study indicate that average foliar cover for *Schmidtia* and *Odyssea* had recovered to their pre-burn levels by the second growing season. The two species were also contributing greatly to species foliar cover in the 1993 treatments. One conclusion that can be drawn is that both species are highly adapted to periodic defoliation by burning. Observations on burns applied during the Dry season in both years of the study indicated that *Schmidtia* grew rapidly and was already in flower by December when sampling was done. *Schmidtia* is a stoloniferous grass with swollen basal internodes. It is speculated that this species is promoted by fire by rapidly establishing new plants from seed and/or rooting stolons. *Odyssea* on the other hand re-established from rhizomes. Rhizomatous grasses mostly survive a fire and then regrow vegetatively to dominate the sward. Skarpe (1980), working in western Botswana, also observed greater increases in *Schmidtia* at the expense of *Stipagrostis*. She attributed the decrease in *Stipagrostis* production to the reduction in the number of tufts remaining after a burn than the reduction of vigour of the surviving tufts. The fire tolerance of *Schmidtia* was also mentioned from an experimental burning study in eastern Botswana where the species was considered to be of high forage value (Animal Production Research Unit 1977).

Rainfall also plays a major role in determining the rate of recovery of an area after a prescribed burn. If there is very little moisture available after a burn, then the regrowth will wilt and die-back. In the lower rainfall areas of southern Africa, higher rainfall generally has a significant positive effect on the recovery of grasslands following a prescribed burn. The 1993/94 growing season in the Makgadikgadi was characterized by above normal precipitation in January 1994 (275 mm) and this might have contributed greatly to the regrowth. The forb component is the more sensitive indicator of these environmental gradients. The marked differences in the percent foliar cover of forbs during the December 1993 and February 1994 sampling periods indicates that moisture was a limiting factor after the 1993 Dry season burns as rains were rather late.

Another important factor that might have contributed to lack of noticeable differences in species composition might be the high variability in the foliar cover as well as observer variability. Up to three observers were used for the estimation of percent foliar cover and therefore observer bias might have contributed to the estimation error.

Fire tends to create a more arid environment and hence the rate of plant recovery is affected. The effect of burning on grasses, forbs and shrubs is closely tied to the species present at the time of the burn and the climatic conditions during and after a burn. Wright (1985) indicated that the effects of fire on grasses was largely determined by the season of burn, size of the plant, amount of fuel, growth form of plant, individual species response and above all precipitation. Wright and Bailey (1982) indicated that fire effects on arid environments of southern Alberta led to a reduction in soil moisture content and that soil moisture content continued to be lower under burned grassland throughout the and second growing seasons. Damage to individual plants depends upon temperatures reached in the live tissues, the length of time the critical temperatures are maintained and the physiological state of the plant at the time of burning (Heady and Heady 1982, Child et al. 1987).

Thus the overall effect of the season of burning on species composition is that regardless of the species, there was, in general an initial reduction in species foliar cover. However, for those species fairly adapted to burning, there was recovery to pre-burn levels by the second growing season. Burning during the Early wet season seems to have had no better recovery than burning during the dormant season. In fact certain species seems to have been eliminated by the Early wet season burns. This could be attributed to the high intensity fires of the Early wet season burns or may be heat damage to actively growing tillers and meristems. Many of the tufts and seeds might have been destroyed by the high intensity fires. Also tillers which might had initiated growth and the shoot apices which were in an elevated and vulnerable position could have been destroyed. The exception is *Digitaria*, which was greatly favoured by the 1993

Early wet season burn. Rapid recovery might, however, have been influenced by the above-average rainfall in January 1994.

In a desert rangeland on the Santa Rita Experimental Range in Arizona, Cable (1967) concluded that fire had no lasting effects, beneficial or detrimental, on perennial grass cover following a 15-year burning experiment. Generally the detrimental effects of fire on most of the perennial grasses lasted one to two years. Tainton et al (1978) also found long-term range burning to have little effects on grassland composition when burned in the dormant season and when applied annually, biennially or triennially.

4.4.3 Conclusions

1) Burning temporarily reduced species foliar cover but those grasses adapted to periodic burning were fully recovered by the second growing season.

2) Generally, Dry season burns recovered more rapidly than the Early wet season burns, hence if the objective is to improve species diversity then Dry season burns are appropriate.

3) *Schmidtia* and *Odyssea* appeared to be well adapted to burning but *Stipagrostis* was negatively affected.

4) *Schmidtia*, *Odyssea* and *Stipagrostis* accounted for more that 50% of the total foliar cover at any sampling period.

Table 4.1 Treatment means for vegetative cover (%), bare ground (%) and eroding ground (%) for treatments applied in 1992 and 1993.

		1992			1993	
Date Sampled	Parameter (%)	No Burn S.E	Dry Season S.E	Early Wet S.E	Dry Season S.E	Early Wet S.E
Feb '93	B/ground	78b 1.0	79b 1.0	84a 1.3	-	-
	Eroding	19a 1.2	17a 1.2	21a 1.5		
	Total Veg	23a 0.7	20b 0.7	14c 0.9		
	Live Veg	17a 0.6	17a 0.6	11b 0.9		
	Dead Veg	6a 0.2	2b 0.2	2b 0.2		
Dec '93	B/ground	88bc 0.5	85c 0.5	89b 0.7	95a 0.5	
	Eroding	16bc 0.8	17b 0.8	13c 1.0	29a 0.8	
	Total Veg.	14a 0.4	14a 0.4	12b 0.6	5c 0.4	
	Live Veg.	4ab 0.2	4ab 0.2	4ab 0.3	5a 0.2	
	Dead Veg.	10a 0.4	9ab 0.4	8b 0.5	0c 0.4	
Feb '94	B/ground	75b 1.1	75b 1.1	77b 1.0	87a 1.1	88a 1.1
	Eroding	21b 1.2	17b 1.2	18b 1.3	26a 1.2	25a 1.2
	Total Veg.	24a 1.0	25a 1.0	21b 0.9	13c 1.0	12c 1.0
	Live Veg.	22ab 0.9	23a 0.9	19b 0.9	13c 0.9	11c 0.9
	Dead Veg.	2a 0.2	2a 0.2	1b 0.2	0.02d 0.2	0.4c 0.2

(In each row, means followed by a common letter are not significantly different at $p<0.05$)

Table 4.2 Post-treatment composition of the grass sward for burn treatments applied during the Dry season and Early wet season of 1992 (Data expressed as percentage foliar cover).

	No Burn			Dry Season Burn			Early Wet Season Burn		
Species	Feb-93	Dec-93	Feb-94	Feb-93	Dec-93	Feb-94	Feb-93	Dec-93	Feb-94
Schmidtia	8.7	9.5	13.2	7.6	8.8	13.1	7.7	7.4	14.7
Odyssea	6.0	5.1	7.0	4.2	5.8	6.7	3.6	5.5	7.0
Stipagrostis	3.0	2.3	3.9	1.5	1.9	2.8	0.6	0.6	1.1
Digitaria	3.7	2.7	7.0	1.4	0.6	3.9	2.5	0.8	2.5
Eragrostis lehmaniana	0.0	0.3	0.3	1.5	1.4	2.1	0.0	0.3	0.0
Urochloa	0.5	0.0	0.3	2.3	0.0	0.3	0.0	0.0	0.0
Eragrostis echinochloidea	0.1	0.3	0.1	1.0	0.7	2.1	0.0	0.0	0.0
Aristida	0.1	0.5	1.1	0.2	0.2	0.8	0.1	0.0	0.8
Tragus	2.8	0.0	0.8	3.7	0.0	1.3	0.5	0.0	1.6
Other grasses	1.6	1.0	1.0	0.7	1.4	0.9	0.5	0.3	0.3
Forbs	7.7	1.5	10.3	8.3	1.7	14.8	3.9	0.6	8.0

Table 4.3 Post-treatment composition of the grass sward for burn treatments applied during the Dry season and Early wet season of 1993 burn treatments (Data expressed as percentage foliar cover).

	No Burn		Dry Season Burn		Early Wet Season Burn	
Species	Dec-93	Feb-94	Dec-93	Feb-94	Dec-93	Feb-94
Schmidtia	9.5	13.2	3.2	6.5	N/A	5.7
Odyssea	5.1	7.0	2.0	3.3		2.7
Stipagrostis	2.3	3.9	0.4	1.7		1.7
Digitaria	7.0	1.4	2.0	3.5		6.0
Urochloa	0.0	0.3	0	1.1		1.3
Tragus	0	0.8	0	2.4		2.7
Other grasses	1.0	1.0	0.1	3.6		3.4
Forbs	1.5	10.3	2.4	8.3		9.0

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CHAPTER 5 MANAGEMENT IMPLICATIONS

Prescribed burning has potential in the Makgadikgadi Pans National Park. Even though burning had somewhat mixed impacts on the grassland vegetation, the vegetation is well adapted to periodic burning. Therefore, burning at intervals longer than annually likely is not detrimental to the vegetation. it would be of benefit to the wildlife and also useful for brush control in the western side of the park. Burning temporarily reduces total vegetative cover and bare ground increases to about 80%, with a risk for possible erosion. However, the vegetation recovers to pre-burn levels by the second growing season. The dominant species, *Schmidtia* and *Odyssea*, recover to pre-burn levels whilst *Stipagrostis* is negatively affected by burning and takes longer to recover.

Park management can use burning for improvement of wildlife habitat including the provision of enough high quality forage for the herbivores. This would lessen the movement of wildlife to areas outside the park and thus avoid conflict with livestock owners. Many national parks in Africa have management programs that include fire as an important component (Lemon 1968, van Rensburg 1971). With increased realisation amongst wildlife biologists that vegetation management is the key to most wildlife problems, there has been an increased understanding of the use of fire for management of grasslands and savannas. The current study demonstrated that prescribed burning has potential as a management tool. Burning resulted in vegetation higher in IVDMD and crude protein and also both variables were higher in the live vegetation than in the dead vegetation component. Thus removal of the dead vegetation will allow for unhindered growth and utilization by wildlife of more palatable vegetation. This study has shown that following burning, IVDMD declined gradually going into the dry season and is maintained well into the second growing season. As both major variables were found to be higher in the burned plots than the unburned and maintained for about 12 months, then a well planned burning program will surely benefit the wildlife in the Makgadikgadi Pans. This will result in a more digestible forage being available for a longer period for the herbivores. *S. pappophoroides,* the dominant and most palatable species, is well adapted to burning and recovered by the second growing season and also maintains a higher IVDMD going into the dry season. In order to have a constant supply of high quality forage it will be necessary to burn certain areas at different times.

Forage has been shown to be a possible limiting factor for about 17 months following the burns. Even though productivity is lowered in the first growing season there was a tendency for productivity to recover fully by the second growing season. Therefore, reduced productivity is only temporary. So in order to limit forage shortage at critical times, it will be necessary to leave certain areas unburned. Because rainfall is highly variable and unpredictable, it would be appropriate to burn following years of above average rainfall. In the western side of the park, late dry season burns could be used as they meet other objectives like brush control. The burned area would be less susceptible to erosion especially from the wind. Also, in that aera, there is also a less likelihood for high concentration of animals in the burned area at this time of the year because most the animals are already moving to their wet season dispersal areas. Vogl (1974) stated that the presence or concentration of herbivores particularly after burning can completely alter the vegetational responses to fire. He further stated that the majority of grassland mammals responded favourably to changes created by the judicial use of prescribed burning. Rainfall in the area is both erratic and highly unreliable and as such a fire regime should be adopted that would not be detrimental to the ecosystem.

Burning lowered the dead vegetation cover from about 10% to zero. This removal of the dead, unutilised forage eliminates the barrier effect to the new regrowth. Periodic burning of the grasslands would eliminate the old growth and make available the new palatable regrowth to the herbivores (Child et al. 1987). Rowe-Rowe (1982) stated that antelopes prefer the burned areas because of the higher nutritive value. A proper burning program can be used to attract herbivores to areas of less usage and this can be important for game viewing as tourism is an important component of the park.

The Early wet season burns are desirable for the central grasslands of the park. The regrowth will not be limited by moisture as the burns will be conducted after the first rains. The burned areas would be used by the animals at the start of their movements to the dry season concentration areas since these grasslands are mainly in the central area of the park. Most of the movement to the dry season concentration area on the western side of the park occurs as the water pools dry up around May. Observations from the current study shows that there was very little growth by the end of October and as such burned areas could not be heavily overgrazed by the migrating herds of zebra and wildebeests to their wet season dispersal areas on the eastern side of the park. Early wet season burns would have recovered by the beginning of the dry season and the forage would be readily available to the herbivores.

Water is the most limiting resource in the park. During the dry season, the Boteti River to the southwest, is the only source of water for the animals. However, its flow has of recent been very unpredictable because of the low outflow from the Okavango Delta. During years of the poor outflow there is competition between livestock and wildlife for the limited water pools along the river. As a result, the western part of the park is an important dry season concentration area. The area is also denuded of any grazing by high livestock numbers on the periphery of the park and as such wild animals have to make longer trips between their grazing and watering points. The pans in the east side of the park holds mainly brackish water for shorter periods after the rains but ultimately dry-up going into the dry season forcing animals to migrate to the western side for the park for the entire dry season. The length of time the pans hold water is dependent on the amount of rainfall during the rainy season. Animal movement patterns are governed by the availability of water (Williamson, Williamson and Ngwamotsoko 1988, Kgathi and Kalikawe 1993). Thus the amount of rainfall is an important factor in determining the extent of movement as it affects both the water supply and and the amount of food available. Pennycuick (1975) and Western (1975) also found the movement patterns of the migratory herds in the Serengeti to be strongly influenced by rainfall patterns and rainfall is the most important factor affecting grass accumulation (Odum 1993). The provision of water through boreholes and the provision of high quality forage through burning going into the dry season would thus maintain some animals on the eastern side of the park and thus from the point of view of tourism this is something desirable.

Prescribed burning should, therefore, go hand in hand with the development of watering facilities in the park away from the dry season concentration area on the western side of the park. Provision of water and high quality forage through burning might promote more uniform usage throughout the park. If cattle were kept out, this would enable proper utilization by the wild herbivores as there would be delayed movement to western side of the park. The provision of permanent waterholes in an area naturally free of surface water for most of the year has its own disadvantages. The main problem is that it could encourage the establishment of resident populations of animals from the migratory herds with resultant effects on vegetation around the watering holes.

There has been no formal research into the effects of prescribed burning on the grassland vegetation of the Makgadikgadi Pans National Park. The current study acted as a pioneer and hence attempted to provide some answers for some of the pertinent questions regarding the use of fire. The results from this study indicate that the potential for use of fire in Makgadikgadi Pans is there. In order to reduce the unplanned fires that normally occur during the dry season, a management program that incorporates prescribed burning should be adopted for this conservation area. In addition to reducing fire hazard, prescribed burns will remove the unutilised vegetation.

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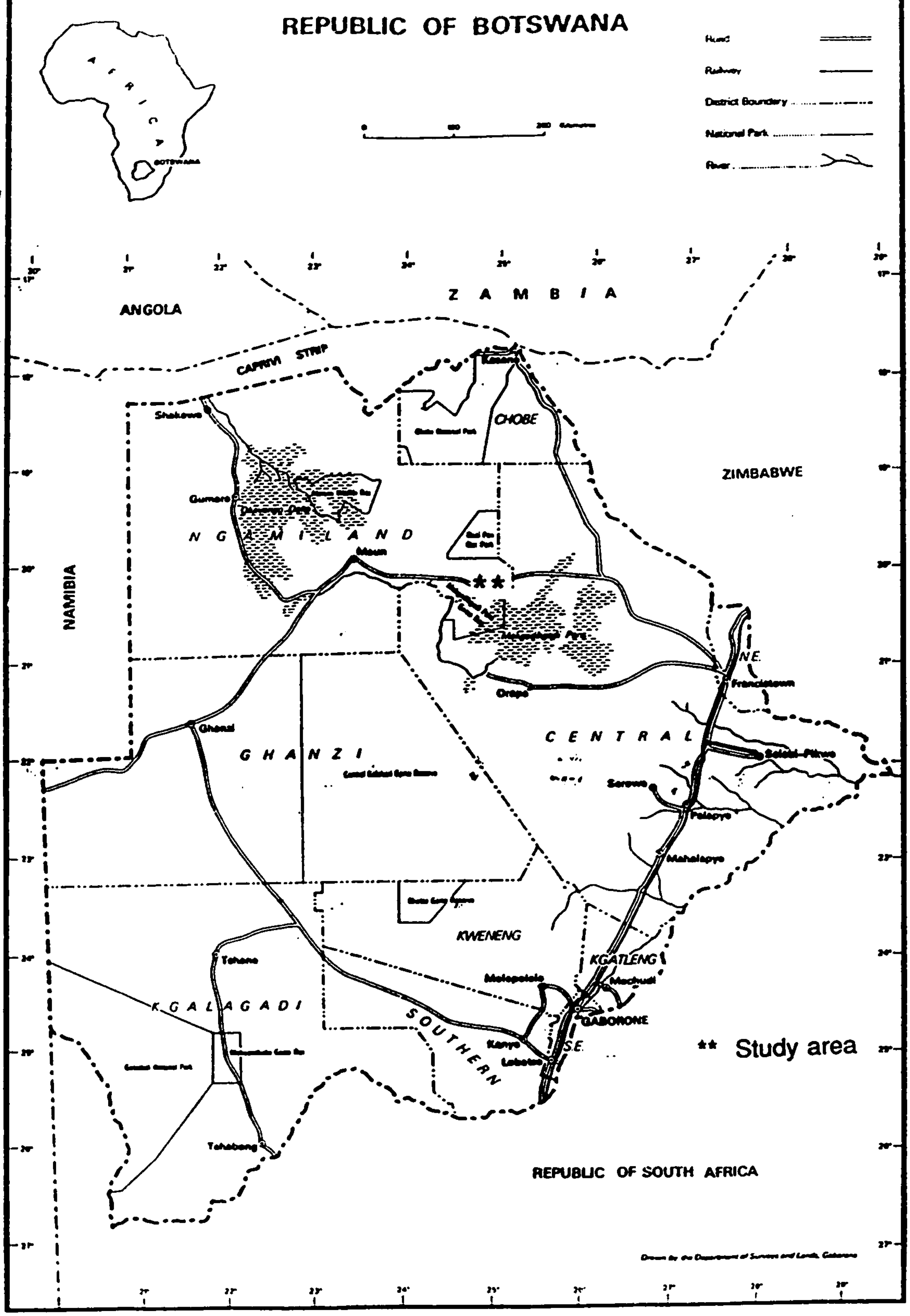
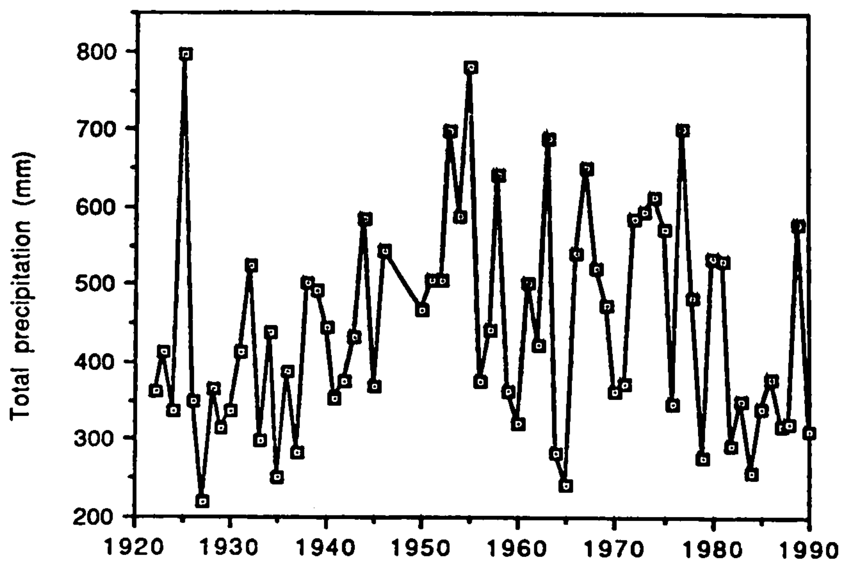
Appendix 1 Map of Botswana showing study area.



Appendix 2 Long term rainfall (1922-1990) recorded at Maun, Botswana (Long term rainfall mean is 450 mm).



Appendix 3 ANOVA tables for a) Productivity, b) Crude protein content and c) Changes in vegetative cover for the Makgadikgadi Pans prescribed burning experiment.

a) Productivity

Source	df	MS	F-value	Pr>F
Block	3	50166.41	7.34	0.0002
Treat	4	323137.3	47.26	0.0001
B*T	11	95877.31	14.02	0.0001
Error	76	9957.31	1.46	0.0412

b) Crude protein content

Source	df	MS	F-value	Pr>F
Block	3	1.45	2.15	0.13
Treat	4	3.56	5.28	0.005
B*T	11	0.56	0.84	0.61
Sp.	2	1.56	2.32	0.13
Tr*Sp	8	1.34	1.99	0.13

c) Vegetative Cover

Source	df	MS	F-value	Pr>F
Block	3	442.29	3.75	0.01
Treat	4	8863.31	75.09	0.0001
B*T	11	548.23	4.64	0.0001
Error	76	260.76	2.21	0.0001

Appendix 4A Nutritional content of the other minerals for the 1992 burning treatments for *Schmidtia pappophoroides*, *Stipagrostis uniplumis* and *Odyssea paucinervis*.

	Date Sampled	Dec-92		Feb-93			July-93			Dec-93			Feb-94		
Species	Treatment	No Burn	Dry Season	No Burn	Dry Season	Early Wet	No Burn	Dry Season	Early Wet	No Burn	Dry Season	Early Wet	No Burn	Dry Season	Early Wet
Schmidtia	K	0.7	1.0	0.8	1.0	1.1	0.3	0.4	0.6	0.2	0.2	0.3	0.6	0.6	0.9
	Mg	0.11	0.14	0.07	0.08	0.11	0.14	0.13	0.17	0.08	0.08	0.10	0.08	0.06	0.06
	Fe	36	295	154	293	267	245	246	134	271	343	308	514	200	174
	Mn	15	14	50	55	110	39	37	36	49	47	45	20	8.3	75
	Cu	1.4	3.0	1.0	1.5	4.0	3.7	5.4	4.3	9.8	9.8	8.3	21.5	16.5	14.3
Odyssea	K	0.5	1.2	0.8	1.0	1.1	0.5	0.5	0.5	0.6	0.6	0.4	0.7	0.9	0.4
	Mg	0.19	0.17	0.09	0.32	0.10	0.12	0.11	0.13	0.10	0.11	0.11	0.08	0.07	0.09
	Fe	36	139	99	211	201	247	219	234	246	244	242	125	146	174
	Mn	11	16	19	47	17	35	22	23	15	20	14	20	75	16
	Cu	1.1	1.8	-	1.5	1.0	10.0	12.2	5.7	9.0	8.0	5.0	26.0	16.0	13.0
Stipagrostis	K	0.7	-	1.0	1.0	-	0.4	0.4	0.5	0.8	0.5	0.3	0.8	0.8	0.8
	Mg	0.36	-	0.04	0.05	-	0.08	0.09	0.07	0.05	0.08	0.05	0.07	0.05	0.05
	Fe	38	-	122	163	-	283	185	214	168	154	145	207	421	629
	Mn	14	-	36	35	-	18	12	13	13	17	17	19	55	-
	Cu	1.6	-	1.0	1.0	-	6.7	3.0	3.0	7.3	7.7	5.0	13.5	14.7	22.5

Appendix 4B Nutritional content of the other minerals for the 1993 burning treatments for *Schmidtia pappophoroides, Stipagrostis uniplumis* and *Odyssea paucinervis.*

	Date Sampled	Dec-93		Feb-94		
Species	Treatment	No Burn	Dry Season	No Burn	Dry Season	Early Wet
Schmidtia	K	0.2	2.1	0.6	1.1	1.0
	Mg	0.08	0.12	0.08	0.11	0.15
	Fe	271	229	515	185	220
	Mn	49	40	20	-	-
	Cu	9.8	10.0	21.5	15.5	13.2
Odyssea	K	0.6	1.2	0.7	1.1	1.0
	Mg	0.10	0.08	0.08	0.14	0.15
	Fe	246	209	254	140	178
	Mn	15	55.5	20	-	-
	Cu	9.0	9.0	26.0	11.2	20.8
Stipa-grostis	K	0.8	-	0.8	1.2	1.7
	Mg	0.05	-	0.07	0.12	0.09
	Fe	168	-	207	60	130
	Mn	13	-	19	-	-
	Cu	7.3	-	13.5	13.0	24.0

END

19-09-95

FIN