NGORONGORO CRATER RANGELANDS: CONDITION, MANAGEMENT AND MONITORING

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DECLARATION

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The work was supervised by Prof. K.P. Kirkman and Prof. W.S.W. Trollope.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others it is duly acknowledged in the text.

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ABSTRACT

The Ngorongoro Crater is a volcanic caldera located within the Ngorongoro Conservation Area in Tanzania. The Crater comprises a flat grassland plain surrounded by steep, bushy walls. It contains extremely high densities of animals and is ecologically the central feature of Ngorongoro Conservation Area. The management of the Ngorongoro Crater has changed significantly in recent times, with cattle being removed and fire excluded about 30 years ago. A detailed vegetation assessment was carried out in the Crater floor by Herlocker & Dirschl in 1972. Since then noticeable changes in vegetation structure and composition, with associated changes in wild herbivore numbers have occurred. The original vegetation survey was repeated in this study as accurately as possible using similar point-based techniques in order to quantify changes and form a baseline for management decision-making and future monitoring. In addition to repeating the vegetation survey, the standing biomass was estimated using a Pasture Disc Meter with associated calibration equations. Data were summarised using multivariate classification and ordination techniques in order to delineate six Homogenous Vegetation Units (HVUs) which can be used for management and management planning purposes, define transects and HVUs in terms of dominant species, describe the main species in relation to their occurrence in different associations and determine the fuel load of the standing crop. A key grass species technique was developed for rapid assessment of the Crater rangeland by the Ngorongoro Conservation Area staff who only need to be familiar with the dominant species. Bush surveys using a point centred quarter technique were conducted along transects in two distinct vegetation types, namely the Lerai Forest and Ngoitokitok *Acacia xanthophloea* forests and the lower caldera scrub vegetation. The data collected from these transects were analysed to determine density and composition of the vegetation in the various height classes and the overall structure of the vegetation communities. A range monitoring system in conjunction with a controlled burning programme has been developed to provide an objective means of managing the rangeland of the Ngorongoro Crater. Data revealed that changes have taken place in the vegetation, with a trend towards dominance by taller grasses and dominance by fewer species. Lack of fire has probably contributed to these changes. Reincorporating fire in the crater is recommended.

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CHAPTER ONE: INTRODUCTION

The Ngorongoro Crater is situated in north central Tanzania (3°10'S 35°35'E) in the Highlands of the Ngorongoro Conservation Area (NCA) (Figure 1.1). It is a world heritage site and biosphere reserve (Fosbrooke 1972), and as such is considered to be of international conservation importance. The NCA is adjacent to the Serengeti National Park and the two are ecologically contiguous. The Ngorongoro Crater is floristically very varied, leading to a diverse range of animal species. The last remaining big population of black rhino in Tanzania is found in the Crater. Some of the densest populations of grazing animals in the world are also present, with associated large populations of predators.

The Ngorongoro Crater was formed as a result of volcanic activity in the African Rift Valley approximately two million years ago. It is the largest inactive, unbroken, unfolded caldera in the world (Fosbrooke 1972). The central plain of the caldera (c.1 750 m above sea level) is flat with colluvial deposits, derived from basalts, tuffs and scoria, covering most of the southern, eastern and northern parts of the plains (Fosbrooke 1972; Herlocker & Dirschl 1972). The flatness of the plains is broken in some areas, including areas of step erosion between the western wall and lake Magadi, and a mound field at the base of the south western wall. Lacustrine deposits surround Lake Magadi. Streams flowing into the Crater from Oldeani Mountain to the west have deposited silt and clay in a coalescent fan pattern on the south-western floor (Pickering 1961 (cited by Herlocker & Dirschl 1972)). The Crater walls comprise relatively steep slopes rising to the surrounding rim of the Crater (c. 2 400 m above sea level).

The climate of the Ngorongoro Crater is influenced by the monsoon rainfall patterns arriving from the East resulting in climatic variation between the eastern and western areas. The difference in altitude between the Crater floor and the rim of the Crater also results in climatic variation with the rim receiving 540-760 mm and the Crater floor, specifically the western section and Lake

Magadi, as little as 300-380 mm annual rainfall respectively (Herlocker & Dirschl 1972).

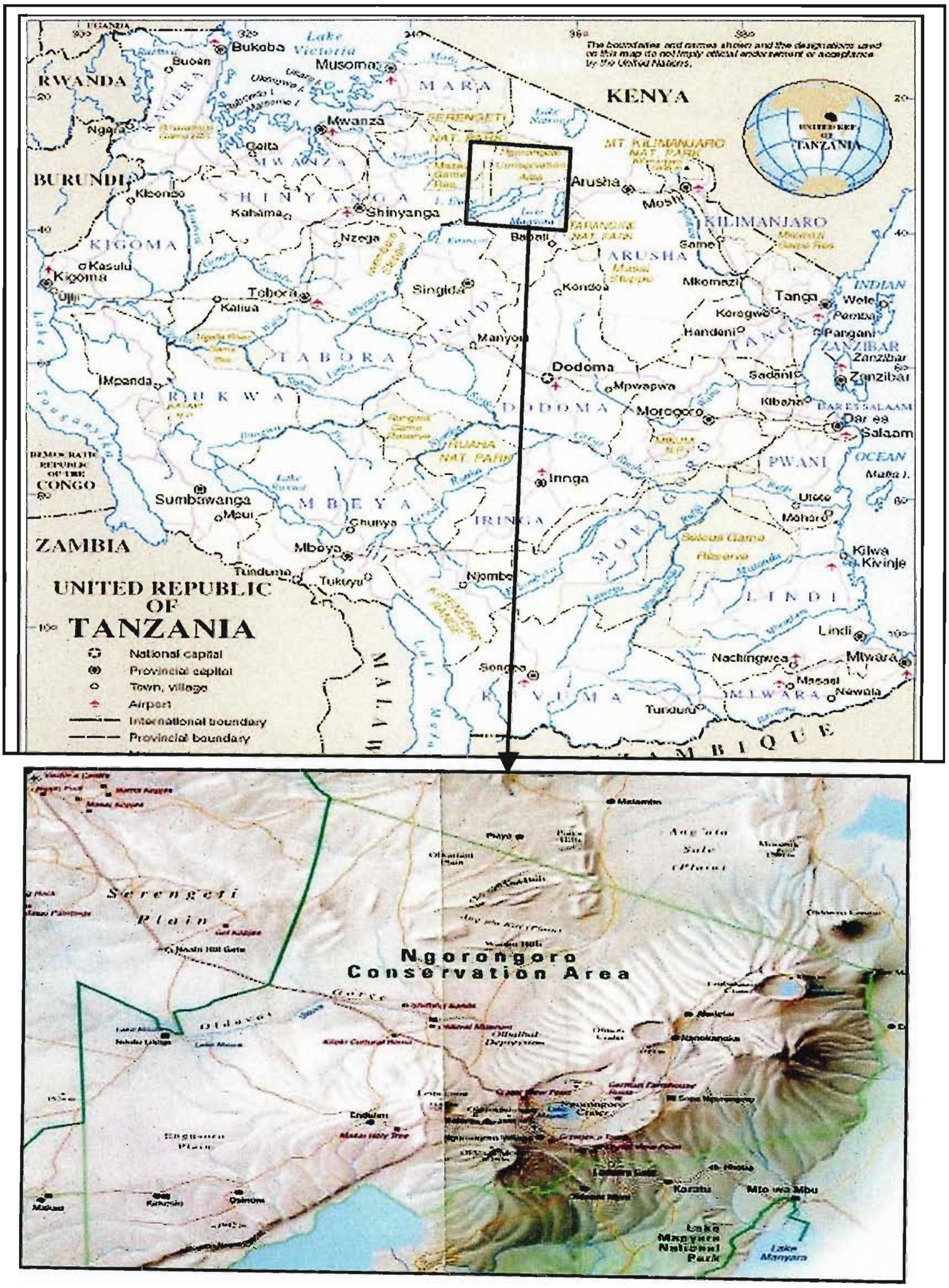

Figure 1.1. Map of Tanzania showing the location of the Ngorongoro Conservation Area.

The northern section of the Crater receives rainfall ranging between 510-630mm per annum. Temperature also varies with altitude and aspect, although the entire area may be regarded as temperate. Wet season diurnal temperatures range from 7.4°C - 14.5°C and dry season diurnal temperatures range from 10.6°C - 19.6°C. There is a distinct seasonal variation in rainfall with a pronounced dry season (June – October) and wet season (November - May) with a peak in April. During the wet season precipitation engulfs the entire Crater, and fog and mist frequently cover the rims (Estes 2002). Likewise during the early dry season, mist hangs heavily almost daily on the south and east rims of the Crater while the rest of the Crater usually lacks cloud cover (Herlocker & Dirschl 1972).

Water flows into the Crater from the northeast through the Oljoronyuki and Munge streams, from a series of springs high on the south wall and at the base of the eastern and western walls, and from seasonal streams with small watersheds such as the Leyanai stream in the north. Drainage is internal and terminates in a soda lake, Lake Magadi, and a series of permanent and seasonal swamps which, with the exception of the swamp to the north of Engitati Hill, are interconnected and affiliated with the lake via surface flow (Herlocker & Dirschl 1972). The most notable hydrological feature in the Crater is the Ngoitokitok spring and associated swamp in the southeast. The existence of the Lerai Forest is attributed to a large spring in the forest itself and also to the Lerai stream originating in the Oldeani Mountains outside the Crater. The silt and clay deposits associated with the stream probably play a role in the forest system.

Prior to 1974, Maasai pastoralists and their livestock were resident on the Crater floor (Estes 2002). They regularly used fire as a means of pasture management for the large number of cattle kept in the Crater. A decision was taken to move the Maasai out of the Crater because of perceptions of conflict in resource utilisation between cattle and wildlife and because of an increased focus on tourism in the Crater. Accurate data on cattle numbers grazing in the Crater prior to 1974 are not available, partly because the cattle grazing practices at the time were semi-nomadic. Estimates of carrying capacity in the Crater for wildlife and cattle are not reliable. Currently the Maasai inhabit the rest of the NCA and number about 60 000 (Runyoro 2001). Maasai pastoralists are allowed to take their livestock into the Crater for water and salt from the soda lake, but cattle are not permitted to spend excessive time grazing in the Crater.

The greater NCA, including the Crater, was proclaimed as a multiple land-use area in 1959. Several different but compatible land-use practices, including conservation, pastoralism and tourism were combined within an integrated comprehensive land-use policy (Fosbrooke 1972; Mascarenhas 1983). The NCA was proclaimed a world heritage site in 1979 by UNESCO due to a combination of outstanding natural features, great diversity of flora and fauna, the pastoralists with their livestock and archaeological richness. These features are of national and international significance (Mascarenhas 1983).

The decision to move the Maasai pastoralists and their cattle out of the Crater in 1974 had several consequences with the most obvious being a sudden decrease in the numbers of grazing animals present and a dramatic decrease in the number of grass fires. The conservation authorities implemented a no-burn policy at this time based on the belief that fire was damaging to the vegetation.

The first detailed vegetation survey of the Ngorongoro Crater (Herlocker & Dirschl 1972) was completed shortly before the Maasai were moved out of the Crater. They classified the vegetation broadly as short and medium grasslands and herbaceous swamp on the Crater floor, with woodland dominating the Crater walls and two areas of the Crater floor (Lerai Forest and Ngoitokitok Forest which are both dominated by *Acacia xanthophloea*). Moist evergreen forest occurred on the eastern wall and in some canyons on the southern and north-eastern walls. Bush or scrub communities ringed the outer edge of the Crater floor and also cover parts of the adjacent floor in the eastern and northern areas.

The 1972 survey creates a convenient reference point for assessing vegetation change over the past three decades and for evaluating current management practices and impacts. Subjectively, there have been major vegetation changes in the Crater during this time. The grassy vegetation of the Crater floor, especially the southern and part of the western areas is much denser and taller now than in the past (Herlocker 2004 pers. comm.), probably as a result of an increased abundance of the tall, stoloniferous *Chloris gayana*. The scrub vegetation (Figure 1.2) appears to have moved further down towards the Crater floor in the north, east and south. Both of these changes could probably be attributed to a lack of grass fires over the last three decades.

Figure 1.2. The change in the scrub vegetation as indicated by photographs taken from a similar point in the 1960's (top) by Herlocker & Dirschl and 2004 (bottom). The bottom photo shows encroachment of scrub lower down to the grassland.

Fosbrooke published an article in the Swara Magazine in which he included a photo of the old cattle trail ascending diagonally up the Crater wall behind the

Lerai ranger post close to the exit road. The photos clearly showed how the vegetation below the trail was much more open and grassy than above the trail. This probably indicates the effect of grass fires burning up fom the Crater floor where they were stopped by the cattle trail. However, now there is little difference in the vegetation on either side of the trail, which coincides with the significant reduction of grass fires (Figure 1.3).

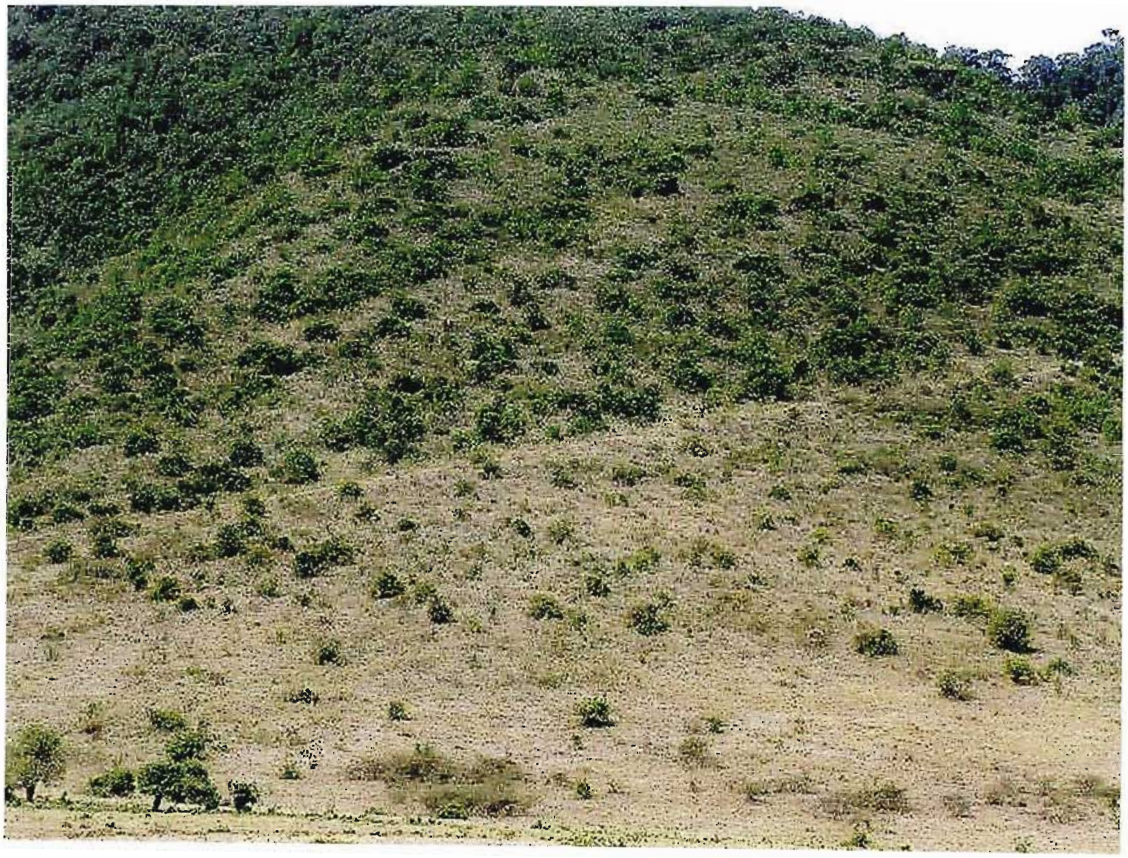

Figure 1.3. Vegetation below the cattle trail (seen as a diagonal line across the photo from the lower left to the upper right) used to be maintained as grassland by regular fires. Encroachment of scrub vegetation below the cattle trail in the absence of fire is clear.

The Lerai Forest has changed dramatically since the 1960's (Goddard 1968; Herlocker 2004 pers. comm.) largely through the loss of the mature *Acacia xanthophloea* trees that dominate the forest. The demise of these trees has not been accompanied by recruitment and replacement of young *Acacia* trees. There are a number of possible reasons for this die-off that have been proposed by various scientists:

- The exceptional rains of 1964 and the El Nino floods of 1997/98 raised the water table of Lake Magadi, temporarily flooding the Lerai Forest and increasing the soil salinity to the detriment of the trees (Roux 2002; Mills 2003).
- The exceptional rains of 1964 actually caused the flooding of the Lerai Forest (Figure 1.4) also resulting in death of mature trees (Fosbrooke 1972).
- Damage to the stems of the mature trees by elephants. This damage results in the onset of fungal induced decomposition with subsequent weakening of the stem (Estes 2002).
- The community is a cohort of even-aged trees that have come to the end of their lifespan (Estes 2002).
- A decrease in the amount of water entering the forest from the Lerai stream (Venter 2002).

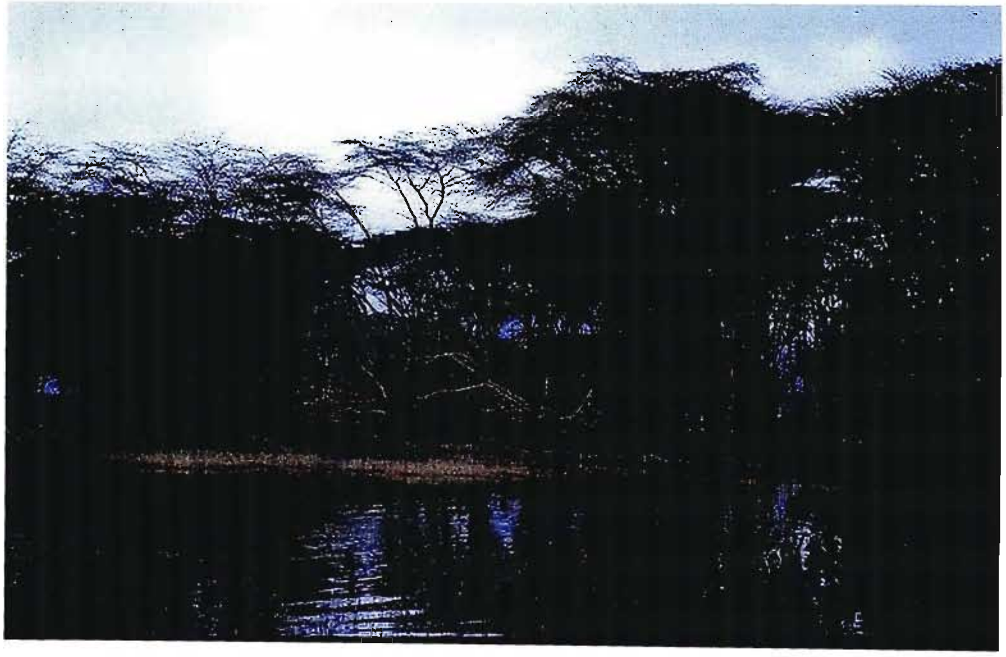

Figure 1.4. Flooding of the Lerai Forest after heavy rains in the 1960's. (Photo, courtesy of DJ Herlocker).

Faidherbia albida (formerly *Acacia albida*) used to be the next most dominant tree species in the Lerai Forest. Currently this species has almost completely disappeared. The next most dominant tree species currently is the *Rauvolfia caffra* and the strangler fig (*Ficus thonningii*). The Lerai Forest has shown recruitment closer to the Crater wall where no trees were evident in the past (Figure 1.5).

Figure 1.5. The change in the Lerai forest in the Ngorongoro as indicated by photographs taken in 1960's (top) by Herlocker & Dirschl and 2004 (bottom) from the same point.

The vegetation of the Mandusi and Gorigor swamps has changed since the 1960's (Figure 1.6). The dominant species in the Mandusi swamp were *Aeschynomene schimperi*, *Leersia hexandra*, *Panicum repens* and *Diplachne fusca*, which was found in standing water (Herlocker & Dirschl 1972). The *Aeschynomene schimperi* was stimulated by fire when the Mandusi swamp was burnt in 1974 and it attracted the black rhino to spend much of their time foraging in this swamp during the dry season (Goddard 1968). Significant changes in the vegetation composition of the Mandusi swamp are obvious from visual appraisal (Herlocker 2004 pers. comm.), with a significant decline in *Aeschynomene schimperi*. These changes are probably due to increased utilization by elephants and the lack of fire. Black rhino currently do not spend much time foraging in the Mandusi Swamp during the dry season.

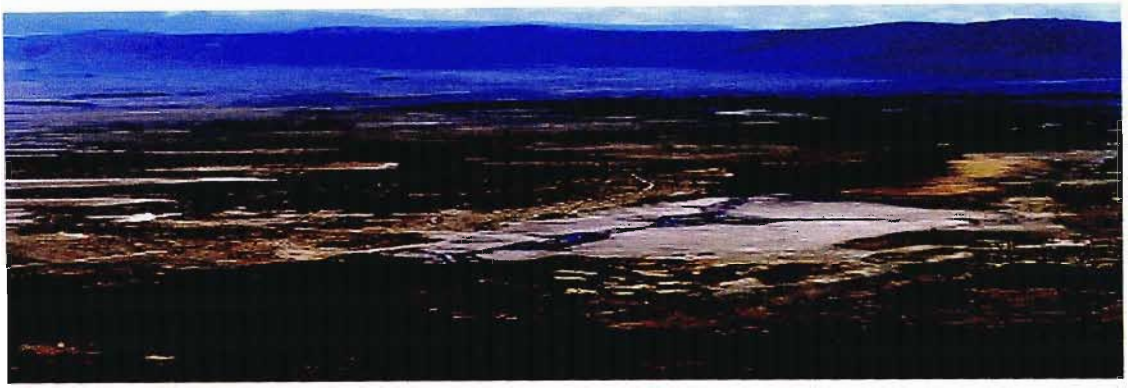

Figure 1.6. The change in the vegetation of the Gorigor swamp area as indicated by photographs taken in 1960's by Herlocker & Dirschl (top) and 2004 (bottom) from the same point.

Since the Ngorongoro Crater is an open, unfenced system where free movement of animals is relatively unrestricted, active management is not as intensive as in many other protected areas of similar size. Game counts are conducted biannually in the Crater – once in the wet season and once in the dry season. All animals are counted from the road network by total count in the wet season and by the transect method in the dry season.

A controlled burning program proposed by Trollope & Trollope (1995) was initially accepted with trepidation. Although fire was used in September 2003 in an attempt to control the problem weeds *Gutenbergia cordifolia* and *Bidens schimperi*, the first serious attempt at a controlled burn was conducted in early September 2004 (Figure 1.7). The decision to burn the area was based on the initial data collection for this study. The use of fire as a management tool in the Crater has been identified as an important step towards pro-active management.

Figure 1.7. Wildebeest feeding on the newly grown shoots of *Cynodon dactylon* on the burnt area in September 2004 in the Ngorongoro Crater.

From a conservation perspective the black rhino (*Diceros bicornis michaeli*) is the most important wildlife species in Ngorongoro and in Tanzania. Historically the Crater had a stable population of black rhino, which was part of a bigger population found in the Serengeti ecosystem and the rest of East Africa (Goddard 1968). Poaching during the 1970's and 1980's decimated the Crater rhino population, along with the rest of the East African population. The Crater black rhino population was reduced from 108 animals in 1966 to 10 animals in 1993. For the last decade security for the black rhino has been good but ecological and human induced problems are holding the population back, and the population increase is considered to be below potential. The Ngorongoro Crater currently has nineteen black rhino with a very favourable age structure and sex ratio and if suitable habitat and conditions are re-created there is no reason why the population should not increase and approach the previous numbers.

Elephant numbers have increased over the years (Estes 2002). This increase is probably because of suitable breeding conditions, good security in the Crater and the closure of migratory routes outside of the NCA, which limits elephant movement out of the Crater. Increased elephant numbers have affected the black rhino in a number of ways including habitat modification, direct nutritional competition and disturbance of rhino calves when they are left alone. The increase in elephant numbers has probably accelerated the compositional change in the Lerai Forest and the swamps.

Forty years ago there were no buffalo in the Crater floor (NCA Annual Report 1975) whilst currently there are more than 4000 in the Crater (Estes 2002). Buffalo are the preferred host of the brown ear tick *Rhipicephalus appendiculatus*. It is the most common tick in the Crater and it can occur in massive numbers at certain times. Besides being a vector for *Theileriosis* and *Babesiosis* they also affect the condition and lower the resistance of animals to other diseases.

The increase in buffalo numbers has been accompanied by a concurrent decrease in wildebeest numbers (Estes 2002) (Figure 1.8).

Research undertaken in 1995 on the long-term trends of wild herbivore species in the Ngorongoro Crater indicated a significant decline in wildebeest and increase in buffalo populations from 1963 and 1974. Runyoro *et al.* (1995) and Mohelman *et al.* (1997) in their analyses of Ngorongoro Crater animal counts, compared data from before and after 1974, when the Maasai and their cattle were removed from the Crater. It was observed that wildebeest numbers increased until approximately 1974 but then declined after the pastoralists were removed in the Crater. The Maasai pastoralists and their cattle occupied permanent bomas on the Crater floor until the beginning of the dry season 1974. They used to burn the rangelands of the Crater as a means of improving pasture condition and to control ticks.

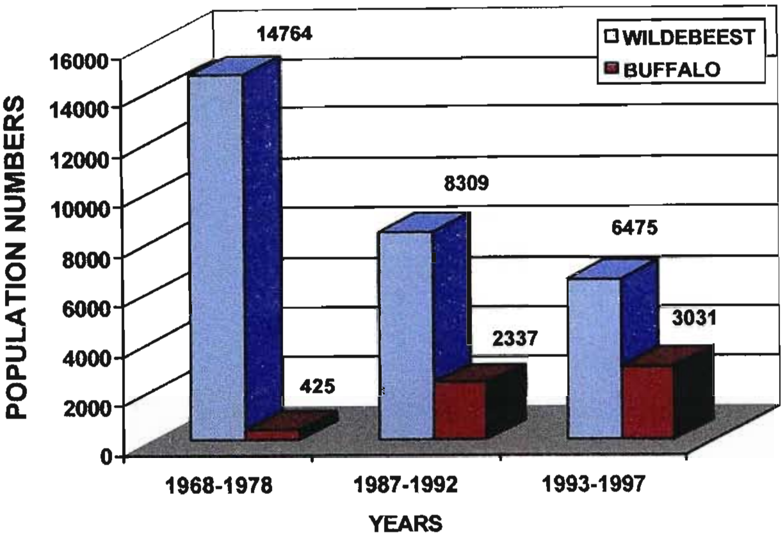

Figure 1.8. Estimated average populations of wildebeest and buffalo in the Ngorongoro Crater during different periods from 1968 to 1997 (Estes 2002).

Concurrent with the decline in the wildebeest population, all other grazers such as Thomson's gazelle, eland, and kongoni have shown significant decreases in numbers post 1974 (Runyoro *et al.* 1995). The mixed grazers, such as black rhinoceros and Grant's gazelles, have also declined in number, probably due to decline in abundance of preferred forbs in the grasslands and scrub areas due to a lack of fire (Runyoro *et al.* 1995).

The total number of spotted hyena in the Crater between 1964 and 1968 was found to be 430 animals (Kruuk 1972). The current population size of spotted hyena clans, population demography and total population size has been monitored by Honer and Watcher in the Crater since 1996. Their analyses on the effects of a swelling disease caused by *Streptococcus equi* subsp. *ruminatorum* indicate that the outbreak between September 2002 and February 2003 was concurrent with an increase in hyena mortality. The total population size of spotted hyena is currently at 355 individuals (Honer & Watcher 2005). During 1970-72, the resident lion population size was estimated to be 65 (Elliott & McTaggart Cowan, 1978). It was observed that from 1975 to 1995 the lion population was relatively stable and numbers have fluctuated around 85 (Pusey & Packer 1987). Recently the number has decreased to 50 individuals (Kisui 2001). The decline in predator population numbers in the Crater suggests that there are factors other than predation which are keeping down the population of wildebeest and other grazers.

During 1995, 1998 and 2001 it was found that extensive areas of grassland in the Crater were in a moribund or tall and unpalatable condition and had a fuel load exceeding 4 000 kg ha^{-1} (Trollope & Trollope 1995, Trollope & Trollope 2001). In 1998 it was also found that buffalos favoured areas where the standing crop of grass exceeded 4 000 kg ha^{-1} in contrast to wildebeest, which were found where there was less than 3 000 kg ha^{-1} (Trollope *et al.* 1999). From this evidence Trollope & Trollope (2001) concluded that the observed changes in the buffalo and wildebeest populations have most probably been a result of the general prohibition of fire in the Crater implemented since the early 1970's. It is argued that this has resulted in the grass sward being able to grow out taller, particularly in the northern sections that receive a higher annual rainfall (510-630 mm). This in turn has resulted in the condition of the grass sward becoming more favourable for buffalo that prefer grazing tall grass, and less favourable for wildebeest that prefer shorter grass (Trollope & Trollope 2001). These conditions in the grass sward have also resulted in a significant increase in tick populations in the Crater (Figure 1.9) that, in combination with stress caused by drought, caused a significant mortality of wildlife in 2001 (Horak 2001).

Trollope & Trollope (1995) and Trollope & Trollope (2001) recommended that a controlled burning program be introduced in the Crater as a means of controlling the development of high tick loads in the grasslands that are in a moribund or tall and unpalatable condition. It was suggested that burning could also have the added advantage of significantly improving the nutritional status of the grass sward by stimulating the regrowth of highly palatable grass material. Fire could also reduce the spread of the two common annual weed species (*Gutenbergia cordifolia* and *Bidens schimperi*). It was suggested that the Crater area should be considered for burning only if it is dominated by Decreaser or Increaser I grass species and if it is in a moribund or tall and unpalatable condition as indicated by a grass fuel load of >4000 kg ha^{-1}.

Figure 1.9. Brown ear ticks (*Rhipicephalus appendiculatus*) accumulating on the *Chloris gayana* grass in the Ngorongoro Crater.

In this case therefore, considering the variable mean annual rainfall of 510-630 mm in the Crater, it was recommended that not more than 10% of the Crater area should be burnt at one time. Also considering that the total area of the Crater is 25 000 ha, the maximum area to be burnt was thus recommended to not exceed approximately 2 500 ha in one year. The accumulated grass fuel load resulting from the prevailing rainfall and intensity of grazing should be used to determine the actual burning frequency. Lastly, it was recommended that the minimum area to be burnt at any one time should not be less than 500 ha in order to prevent excessive accumulation of animals on the burnt areas.

In order to prevent fire from escaping to the highlands due to high fuel loads, especially on the areas around Mandusi swamp, Oldoinyo Olkaria and Engitati, it was recommended that a system of fire breaks be introduced to subdivide these areas into manageable units whereas on the other areas, the existing tourist roads provide an adequate system of fire breaks from which to apply controlled burning.

Monitoring of the rangelands of the Crater based on functional characteristics such as botanical composition, the standing crop of grass and a basal cover of the grass sward was recommended in order to adapt management recommendations over time.

Large areas of the Crater floor have been infested with unpalatable indigenous and exotic forbs in recent years (Estes 2002). The density of stands of two indigenous species, *Bidens schimperi* and *Gutenbergia cordifolia* (Figure 1.10), have reduced the available forage for herbivores in large areas (Henderson 2003). Investigations conducted by Mills (2003) into the edaphic conditions prevailing in areas dominated by *Bidens schimperi* and the immediately non-infested adjacent areas provided some scientific insight into this phenomenon. Soil surveys showed that the nutrient status of the forb-infested areas was significantly higher than that in the grassland dominated areas i.e. the former were more fertile than the latter. This type of phenomenon has been recorded in South Africa where the fertilization of natural grasslands with nitrogen and phosphatic fertilizers resulted in a significant and marked increase in annual forbs in high rainfall areas (Booysen 1981). Relating these results to the current situation in the Ngorongoro Crater, it seems that these annual forb species germinate prolifically on an opportunistic basis, particularly in areas where the soils are more fertile, during the wet conditions that commonly follow extreme events such as the drought that occurred in the Crater in 2000.

It is obvious that there have been extensive changes in the vegetation subsequent to the study by Herlocker & Dirschl (1972). These changes have not been objectively quantified, but there are perceptions that the habitat for certain animals, particularly black rhino, has declined in quality and extent. The vegetation changes have been accompanied by significant changes in animal numbers and ratios between different species. These phenomena are poorly understood, although there is a general consensus that the exclusion of fire over the last three decades has caused or at least accelerated some of the vegetation changes (Trollope & Trollope 1995). There is also no current scientific basis for developing range management strategies or monitoring programs. As a consequence of an increasing requirement for a sound scientific knowledge base for developing scientific management strategies with associated monitoring systems, a project was initiated to resurvey the sites recorded by Herlocker & Dirschl (1972).

Figure 1.10. Young *Gutenbergia cordifolia* weeds in the Ngorongoro Crater.

The main objective of the study is to assess vegetation change of the Crater by describing the current composition of the grassland, scrub and forest areas and relating this to the earlier survey conducted by (Herlocker & Dirschl 1972). Additional objectives are to use this information to develop rangeland monitoring techniques for the Crater to assist management decision making processes, and to use this information in relation to philosophies and management strategies from other African savanna systems, particularly the Serengeti and Kruger National Parks, to develop management strategies for managing the grasslands of the Ngorongoro Crater. Lastly this information obtained from the study will be used for re-mapping the vegetation in the

Crater and drawing up a consolidated map outlining homogenous vegetation units which can be used for management purposes, particularly planning of controlled burning if considered necessary. Pienaar (1983) highlights the need for developing a research programme aimed at studying ecosystem functioning and relationships in order to provide the management foundations for the preservation of optimum conditions in the ecosystem.

The Ngorongoro Crater should not be considered as a self-sustained ecological unit, but as an integral part of the Crater highlands catchment area (Estes & Small 1981). There is a need to understand the underlying factors influencing the movements of animals into and out of the Crater and the impact of increased human activity on this movement by, for example, affecting passage through traditionally used corridors into adjacent wildlife dispersal areas. Over the past 40 years, the pastoralist population in the NCA has increased from 8 000 to 60 000 (Runyoro 2001) by means of rapid population growth as well as immigration, proportionally increasing in the Crater highlands catchment area raising concerns that the Crater will become increasingly isolated with the associated risk of losing habitats, increased fragmentation of habitats and declining biodiversity. These concerns need to be urgently addressed and this can only be achieved by adopting a more pro-active management philosophy in line with other wildlife conservation areas such as the Kruger and Serengeti National Parks (both of which are well studied systems with active management plans). The techniques developed by this study to monitor rangeland condition provide management with a valuable tool for understanding the rate and scale of change taking place in the ecosystem. With such understanding it will be possible to develop strategic and adaptive management strategies that will enable the NCA to preserve and continue to justify its world heritage status.

CHAPTER TWO: APPROACHES TO CONSERVATION IN THE SERENGETI AND KRUGER NATIONAL PARKS AS COMPARED TO THE NGORONGORO CONSERVATION AREA.

2.1. Management Philosophies and Strategies

The Management of Conservation Areas has always been a complex issue and will become increasingly complex as human population pressure increases. The level of management intervention varies considerably between Conservation Areas. Size is often a factor determining the levels of management input, with smaller areas commonly managed more intensively.

Any conservation area should be considered in terms of its physical and biological features, as well as the political and administrative institutions involved with controlling it (Sinclair 1983). These characteristics determine the management goals of a conservation area and shape the management philosophies employed to achieve the goals. Management philosophies range from a "hands-off" non-interventionist approach to high input "hands-on" intervention or manipulation approach. A common theme across both approaches is protection, and even where systems intervention is low, the system is usually still protected.

Reasons for non-intervention management include:

- The belief that natural systems should be left alone;
- The lack of knowledge as to what the implications of intervention are; and
- The views that change in a system is natural, and managers should not follow a reaction approach in trying to restore stability.

Reasons for intervention management include a realisation that very few conservation areas can be regarded as totally natural systems where human influence has not impacted on the system significantly in recent years. The Ngorongoro Conservation Area (NCA) provides an example of a conservation area where there has been significant human impact.

Pienaar (1983) puts forward a case for active management of conservation areas where these cannot be considered to be self-regulating ecological units. This implies areas with boundaries and areas where human intervention has impacted the functioning of the system.

Intervention management, in the context of the interactions between vegetation (grassland) and grazing herbivores can comprise one or more of the following:

- Moderating animal numbers
    - Culling
    - Translocation
    - Vegetation manipulation
    - Habitat modification
    - Inclusion or exclusion of animals by fencing
- Influencing animal type and ratios between types
    - Culling
    - Translocation
    - Vegetation manipulation
    - Habitat modification
- Controlling animal movement
    - Vegetation manipulation
    - Habitat modification
    - Inclusion or exclusion of animals by fencing
    - Manipulation of water provision

Common themes across the interventions above include vegetation manipulation and habitat modification.

One of the most important management options available to conservation managers is the manipulation of vegetation and habitat by the use of fire (Sinclair *et al.* 1995). Fire is generally considered to have been a natural component of savanna and grassland ecosystems, particularly in Africa. Africa is able to sustain fires because of the seasonal wet and dry cycles (short cycle) and cycles of drought interspersed with floods (long cycles) (Pyne *et al.* 2004). Commonly listed causes of fire include lightning and anthropogenic influence. Considering that man has been part of African savannas for millennia, it can be safely assumed that much of the current vegetation in Africa developed in response to man's influences, including the regular use of fire (Goldammer & De Ronde 2004). As such any significant change in the fire regime can have a large influence on vegetation composition, structure, quality and animal habitat. These changes can include an increase or decrease in fire frequency, total exclusion of fire, or changes in seasonal burning time.

In the process of developing a management philosophy for the Ngorongoro Crater, focused on vegetation/herbivore dynamics and management, it was considered useful to compare and contrast similarities and differences in the management of the neighbouring Serengeti National Park (Tanzania) and the Kruger National Park in South Africa. A wealth of well-documented research has been conducted in both these parks, and management philosophies have evolved significantly over the years. This information, together with data and experience from the current study, will contribute to a management philosophy for managing the vegetation of the Ngorongoro Crater.

2.2. Kruger National Park

The Kruger National Park was founded in the early part of the 20th century and comprises about 20 000 km^2 of African savanna. Mean annual rainfall in the Park is 530 mm, falling mainly in the summer months of October to April often in the form of thunderstorms. Mean annual rainfall varies from 730 mm in the southwest to 400 mm in the northeast (Mabunda *et al.* 2003).

The area that now makes up the Kruger National Park has been subject to increasing human impacts and pressures. Known historical sequences begin with the San, who lived in the area for many thousands of years (late stone-age). Being nomadic, with a very low population density, impacts on the environment were probably negligible. From AD 200 to 1836 (Iron Age), farmers, metalworkers, and traders settled and moved around in the area. There is evidence of extensive hunting, using fire as a means of capturing animals, and the active trade in skins and ivory during this period. The colonial period (1836 – 1902), was characterised by increased human impacts in the form of hunting. Population increases exacerbated the impacts, and sport hunting was introduced for the first time. Hunting was essentially uncontrolled, leading to the game populations being decimated and ratios between species being drastically altered. In 1902, protection of game in the area was formalised. In 1926 a National Park was created. A policy of providing artificial water points was initiated in 1933. This heralded the start of a change in management philosophy from a protectionist approach to one of intervention. Controlled burning of grass was outlawed in 1946, and the provision of artificial watering points continued. Fencing of all borders commenced and was completed by 1980, creating an island and preventing any seasonal migration of animals outside the borders of the park. Aerial censuses were initiated and culling programmes started where it was thought that animal numbers were approaching ecological limits. Several research programmes were initiated, and management changed accordingly in the light of the findings. As an example, following range burning experiments, the Kruger National Park was divided into about 400 burning blocks and a rotational fire management programme was initiated. Changes in management philosophy by 1992 led to a "natural" fire approach where controlled burning and other anthropogenic fires were stopped, with the expectation that lightning fires would be sufficient (Mabunda *et al.* 2003). This approach has again changed in recent years to a more integrated approach where controlled burning has been re-introduced in the form of a "patch-mosaic burning programme".

System fluctuations in the Kruger National Park are relatively severe, with the area being characterised by droughts and floods. The realisation that outside stakeholders are important in the decision making processes, coupled to general changing perceptions of ecosystems, has led to further changes in management philosophies including elephant control, fire management and water provision (Mabunda *et al.* 2003).

In essence, the management approaches in the Kruger National Park have fluctuated widely from protectionism in the early days, through management by intervention in a relatively rigid framework, to a more integrated, adaptive management approach to managing heterogeneity.

There is a strong realisation that heterogeneity, both in space as well as in time, is the mainstay of biodiversity. This has led to heterogeneity being the ultimate focus of ecological management in the Kruger National Park (Rogers 2003).

The heterogeneity paradigm emphasizes that the ecological system functions across a full hierarchy of processes with physical and biological components, processes and scale in a dynamic space - time mosaic (Pickett & Rogers 1997). Historically savanna management has been influenced to a large extent by a stable state concept mainly focused on commercial agriculture (Peel *et al.* 1999). The perverseness of spatial heterogeneity and flux in an ecosystem means that incorporating this concept into management is becoming a major challenge for savanna conservation and protected areas. It is explained that the theory of patch dynamics provides the scale perspectives needed in relation to multiple level perspectives of biodiversity (Pickett & Rogers 1997).

A useful adaptive management concept under the heterogeneity paradigm consists of a broad understanding of the learning process in adaptive management which includes knowledge generation, transformation and achievable goals of ecosystem heterogeneity and flux (Rogers 1998). It is argued that ecosystems are complex, non-linear, dynamic and self-organizing permeated with uncertainty and discontinuities (Rogers 1998).

The philosophy of science explained by Picket *et al.* (1994) provides an insight into the spectrum of science and process used to improve knowledge and thereby indicating the important but limited role of experiments. It has been suggested that the understanding about the process of scientific investigation and experimentation, in its proper context, can give the protected area managers knowledge for incorporating science into adaptive management. It is explained that the success of the Kruger National Park in the context of conservation of the fauna and flora comes from the knowledge that has been generated by various research programmes conducted in the Park such as the Kruger National Park Rivers Research Programme (KNPRRP) (Breen 2000). It is further argued that treating policy or management actions as an experiment gives limited views of the process involved in improving our understanding. It is suggested that it is better to consider policy as a flexible conceptual construct and relate this to observable situations of natural or managed components of the ecosystem. Wildlife managers are sometimes forced to make important decisions with limited data on the possible ecological effects. In the Kruger National Park for example, four big concrete dams were constructed in the Letaba River in 1970's following severe over-utilization of the water outside the KNP and the drying up of this once perennial river. With the significant knowledge base that was built up during the era of the KNPRRP (1980's and 1990's), as well as improved water legislation, two of these dams have recently been demolished along with others throughout the KNP because of their impact on aquatic system diversity (Venter 2002). It has been suggested that scientists, protected area managers and policy makers should collectively translate broad policy statements into conceptual constructs that are scientifically useful and compatible with management potential. It is further argued that good management needs to go hand in hand with a monitoring or assessment programme (Noss 1990).

Monitoring programs to support the measurement of biological diversity and threat status are globally recognised as important elements of any protected area management (Noss 1990). The proposed actions or activity plans help identify exactly which of the target's ecological characteristics need to be monitored, encourage the identification of measurable ecological indicators and help protected area managers answer logical questions concerning where and when an indicator should be monitored given its likely natural fluctuation and susceptibility to change. In most cases programs are not designated to monitor the short term effect of specific management actions, rather they aim at assessing the general state of limited ecosystem components. It is useful to specify the scientific and management questions which monitoring is intended to address in a certain ecosystems and validate the relationship between the indicators and components of heterogeneity that they represent. It is argued that indicators should be identified for all levels of organisation of the ecosystem. Good indicators have the sensitivity to provide an early warning of ecosystem change (Noss 1990).

It has been suggested that the role of biotic factors in creating spatial patterns and the implication of community and ecosystem dynamics is less well understood than the role of abiotic factors for instance topography and precipitation (Augustine & Frank 2001). Large herbivores are an important dictating element of the savanna that do not respond to spatial heterogeneity in plant communities but affect spatial heterogeneity in the landscape. The direct effect of herbivory on ecosystems has been well studied in conservation areas such as the Serengeti (McNaughton 1988). It is argued that determining the patterns and causes of spatial and temporal heterogeneity in ecosystem function including the process associated with energy and nutrient cycling is important in understanding the ecosystem ecology.

Fire, climatic variability, soils and large herbivores interact to shape the vegetation and drive the spatial and temporal heterogeneity in Africa savannas. Managers in the Kruger National Park have used fire for decades. Because fires depend on fuel and weather that vary over space and time they cannot be considered in isolation (Mills *et al.* 1995). The most important sources of variability include soil fertility, rainfall, levels of herbivory and variability in the conditions under which fire burns. Soil fertility influences the regrowth of grasses and trees and rainfall influences the biomass of the grasses that provides the fuel for fire. The numbers of grazing mammals in the

Kruger National Park fluctuate in response to rainfall (Mills *et al.* 1995). Many studies in the Kruger National Park have shown that the exclusion of fire from savannas leads to an increase in woody biomass and this has been interpreted as evidence that fire is essential for the persistence of savannas. Grass-tree coexistence may be made possible by separation of rooting niches, with trees having sole access and being superior competitors for water in the surface soil (Walters & Green 1997). It is suggested that an understanding of the role of fire has been built on research, observation at a broader scale and modelling in the Kruger National Park. Fire research was initiated after fire burnt 25 percent of the Kruger National Park in 1953 (Van Wyk 1971). Many decades of fire research and experiments in Kruger National Park has led the managers to understand the role of fire.

The Kruger National Park ecosystem has over time experienced a wide range of elephant densities, from complete extinction, through low densities to the current high levels (approximately 12 500) which are causing significant habitat changes. During the 1970's and 1980's elephant numbers were kept between 6500 and 8500 through an extensive culling programme. Some of these changes can ultimately result in a major simplification of habitats through the loss of species. At high densities the sustained impact of elephant browsing can result in woodland being converted to grassland (Cumming *et al.* 1997).

Large carnivores can exert a significant influence through the predation of species at the top of the food web. By regulating or limiting prey populations they modify the spatial heterogeneity exerting a particular impact on the patch dynamics (Sinclair *et al.* 1985). They influence each other's population through competition. Large carnivores may also respond to temporal heterogeneity (Scheel & Packer 1985). They exhibit population fluctuation and this is reflected in the population densities of the prey species (Mills & Shenk 1992). In this case they are an important component of ecosystem dynamics and of the flux of nature paradigm. By their nature large carnivores are an important consideration in strategic planning of protected areas and have often occupied a centre place in management decisions at the Kruger

National Park (Smuts 1978). Their role as predators and competitors contributes to determination of heterogeneity although this is mediated through changing ecological conditions induced by both nature and humans.

Many protected areas are established in heterogeneous areas where surrounding social, economic, political and environmental factors have influenced their origin. It is an often unappreciated fact that most of earth's biodiversity is found outside of the protected areas (Pigram & Sundell 1997). In view of this, conservationists advocate that moving the principles and practices beyond the boundaries of the protected areas can help to influence people to support conservation (Murphee 1996). The Kruger National Park has extended its practices beyond its boundaries by building partnerships with neighbouring communities for the future of the park. Campbell & Olson (1991) pointed out that over many years, understanding the state of the landscape in Kruger National Park and the interrelationships with social-cultural, environmental, economic and political factors has become a foundation for an integrated analytical approach. It is further pointed out that the main land use practices outside the Kruger National Park are small-scale cultivation, commercial farming and grazing while the main farming activities include cattle and game farming, private conservation and high value tropical crops along the major rivers. Increased collaboration with stakeholders of the neighbouring wildlife dispersal areas can lead to extending the area of biodiversity protection outwards through the establishment of successful joint ventures. As a result of these initiatives the fence between Kruger National Park and some of its neighbours was removed in 1994. Currently this has taken an international dimension with the proclamation of a trans-frontier conservation area linking Kruger National Park with protected areas in Zimbabwe and Mozambique. It is further explained that the aim of this integration is to encourage conservation and preservation of biological biodiversity within and beyond the Kruger National Park boundaries and increase local community participation in sustainable management and conservation of that diversity.

Scientific management and conservation in the Kruger National Park commenced in the 1940's and has continued to the present. Managers have applied scientific principles with a variety of complementary approaches from the level of vision and objectives through program management, relationships with outside agencies and institution and use of frameworks and models as facilitatory tools for the future of the park. These scientific management approaches have provided new tools for the sustainable management of the resources in the Park for present and future generations. At present the management philosophy in the Kruger National Park is Strategic Adaptive Management, allowing for adaptations to management practices as new knowledge is generated and circumstances change.

2.3. Serengeti National Park

The name Serengeti comes from the Maasai word "Siringeti" referring to an endless plain. Nearly two thirds of the park is bush or woodland. The plains were formed 3 - 4 million years ago when ash blown from a volcano in the Ngorongoro Highlands covered the rolling landscape. This layer of ash preserved traces of early man and established the rich soil which supports the southern grass plains. From this early beginning, man and wildlife have shared this magical place. The Serengeti was first inhabited by hunter-gatherers and more recently pastoralists. Agriculturalists mostly avoided the Serengeti as the woodlands were full of tsetse flies, inflicting them and their livestock with sleeping sickness, and the plains were controlled by Maasai. The Europeans who arrived by the late 1800's found a land virtually untouched, and exploited it for its exceptional hunting opportunities, particularly lion, leopard and buffalo (Persall 1957).

The climate of the Serengeti National Park is very mild showing a relatively constant mean monthly maximum temperature of 27-28^{0}C at Seronera with minimum temperatures of 16^{0}C during the hot months of October to March to 13^{0}C during May to August. The Park has a bimodal rainfall distribution with the "long rains" from March to May and the "short rains" in November and December. However, the rains can combine into one long period particularly in the north or the "short rains" can fail to occur particularly in the southeast. There is a rainfall gradient from approximately 500 mm in the dry south-eastern grassland plains to 1 200 mm in the north-western region on the border with Kenya (Sinclair 1995).

In recognition of the need to preserve this special area, the central Serengeti was declared a Game Reserve in 1929. In 1951, the Reserve became Tanganyika's first National Park, which included the Ngorongoro Crater. In 1959 the Park was officially gazetted as a National Park under the act of parliament CAP 412. Part of the Serengeti plains and the highlands were removed and added to Ngorongoro Conservation Area, while extensions to the north and south were included to provide more protection for the wildebeest migration. Covering 14 763 km^2, Serengeti is the largest national park in Tanzania. The park is the centre of the Serengeti ecosystem, an expansive area of 25 000 to 30 000 km^2, which is defined by the annual wildebeest migration (Sinclair 1995). The Serengeti National Park was designated as a World Heritage Site by UNESCO in 1972 and as a Biosphere Reserve in 1981 (Sinclair 1995). The greater Serengeti comprises the Serengeti National Park with its buffer zones – the Ngorongoro Conservation Area, four Game Reserves, one Game Controlled Area and Kenya's Maasai Mara National Reserve, an ecosystem that protects the largest single movement of wildlife on earth.

Management approaches in the Serengeti have been influenced by research findings which guided the design of conservation and management plans for the park. These approaches are reflected in Serengeti's pre-eminent position in world conservation. As in the Kruger National Park the conservation of both spatial and temporal heterogeneity has been one of the major management themes of the Serengeti. It is explained that heterogeneity allows the migration of herbivores in the whole ecosystem. Serengeti, being unique as an ecosystem, was one of the first conservation areas to be proposed as a World Heritage Site and with its high profile provides a unique location for applied research and conservation biology. This suggests that the attitude that parks and reserves should be left to look after themselves without research and monitoring must change. This is because the conservation of biological diversity is facing an ever increasing number of challenges and therefore requires special attention, including management by intervention.

The Serengeti ecosystem supports an abundant population of large herbivores. The migratory herds move to the Serengeti plains at the onset of the rains and they roam on the range receiving continuous rainfall. They leave the plains abruptly as the rains stop and as the grass dries out (Inglis 1976). The resident herds concentrate on the top of the catena during the wet season and may reach high densities due to the concentration of several species of herbivores (Bell 1970). The grasslands are of typical short structure (McNaughton 1984) and are utilised within a grazing season that is determined by the growing season. In the dry season the herbivores engage in a rotational passage grazing system. They move rapidly through tall and medium grasslands returning to them when there is a recurrence of rain or when the residual soil water is sufficient to generate new grass growth (McNaughton 1985). It is observed that the resident herd moves more frequently during the dry season than during the wet season following sporadic dry season showers (McNaughton 1985).

It has been argued by Belsky (1985) that the pattern and the structure of the vegetation are largely determined by environmental and edaphic factors and to a lesser extent by mammals. Rainfall, geology, soil characteristics including moisture, alkalinity and sodicity, are the dominant influencing factors shaping the African landscape. Large mammals, however, have a strong influence on species composition, nutrient cycling and micro-site structure. It was suggested by De Wit (1978) that the presence of a calcareous hardpan and high soil nutrient levels prevent trees from establishing themselves on the Serengeti plains - even after prolonged protection from large herbivores. It was noted, however, that species composition and height does change with protection (McNaughton 1983).

Buffalo and wildebeest account for over 60 percent of the biomass of the grazing ungulates in Serengeti (Norton-Griffiths 1973). It is argued that, if their number were to be reduced it will affect the impact of grazing on the grasslands, and will result in a situation where the grassland will be underutilized. Wildebeest numbers are regulated by food in the dry season (Sinclair *et al.* 1985). At this time they eat either dry, dormant grass or the short regrowth that appears after the short rains in north Serengeti. Growth of the grass is influenced by rainfall and very little by grazing. On the plains in the southern Serengeti, wildebeest graze the swards in the wet season, when growth is occurring, and the potential for a reciprocal interaction between herbivory population and plant communities exist. The plains are true grasslands, trees being excluded because of the shallow alkaline soils (Belsky 1985). The structure of the grassland is strongly influenced by grazing, particularly on the eastern plains (McNaughton 1983). It has been suggested that the increasing grazing pressure might be resulting in overgrazing. Holling (1973) concluded that grazing enhances primary production even though it reduces the standing crop of herbage at any particular time.

Fire determines both structure and change in savanna tree populations. The Serengeti experiences grass fires rather than canopy fires and they occur regularly. Most of the fires in the park are started by people (Buechner & Dawkins 1961). The pastoralists and agriculturalists around the park burn their rangelands annually, and these wild fires sweep into the park. Cattle raiders light fires within the park to obscure their tracks as do poachers and honey hunters. Park wardens light fires to make it easier to apprehend the poachers and finally wildlife biologists light fires as part of long-term experiments. Fire research conducted in the Serengeti has shown that, similar to the Kruger National Park, rainfall has a major influence on the timing, frequency and extent of grass fires. Fires start in July once the long rains are over and the grass is beginning to dry out. It is argued that there is a strong correlation between the frequency of fire and the mean annual rainfall. The production of grass and therefore of fuel is greater in the higher rainfall areas where fires are more frequent and more extensive.

Elephants determine both structure and composition dynamics of Africa savanna. They are described as a keystone species in the Serengeti National

Park through their significant effect and interaction with fire on occurrence of woodland vegetation (Owen 1971). Between 1970's and 1986 (Figure 2.1) their numbers decreased significantly due to poaching (Dublin, 1995) but currently their numbers have increased to approximately 2 360 animals (TAWIRI 2003).

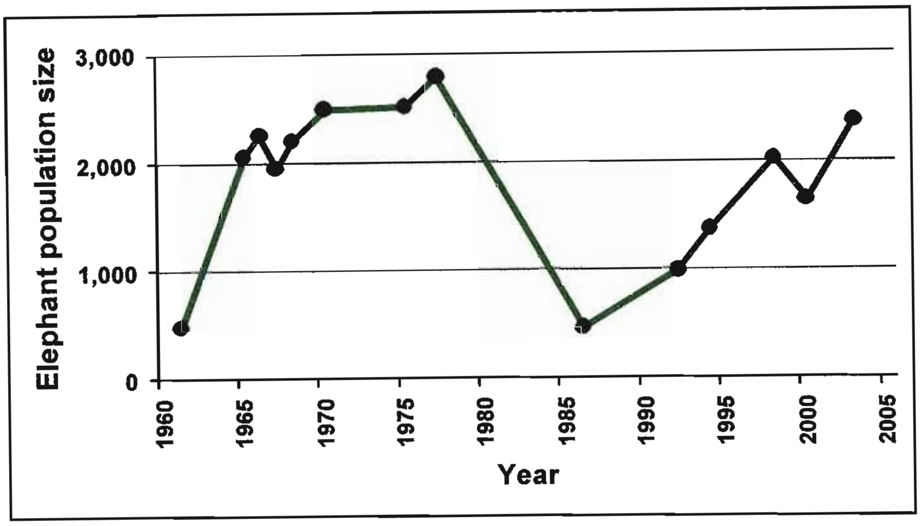

Figure 2.1. Long-term elephant population trend in the Serengeti (TAWIRI 2003).

During the end of 20th century the Serengeti–Mara area was described as open grassland with lightly wooded patches much as it is today (Dublin 1995). Due to the great rinderpest pandemic of 1890, human and animal populations are thought to have been reduced to low numbers in the Serengeti–Mara area. Fires were infrequent due to the low human population and elephant numbers were low having suffered from intensive hunting during the previous decades. Over the next 30 to 50 years these prevailing conditions of low fire frequencies and low elephant numbers caused the establishment of dense woodlands and thickets. This woody vegetation provided an ideal habitat for infestation by the tsetse fly which further inhibited significant human settlement within the Serengeti ecosystem. Due to this situation, in the early 1940's, the area had become densely wooded and the Serengeti National Park and the Maasai - Mara National Reserve were characterised by dense woody vegetation and remained in this condition for over 20 years. During the late 1950's and 1960's these woodlands began to decline due to the increase in frequency of burning as result of the concurrent increase in the human population which was recovering from effect of the rinderpest pandemic. The small populations of ungulates were unable to reduce the density of grass especially on the areas with high rainfall. This resulted in increased burning by Maasai pastoralists to create better grazing for their livestock. The high intensity of fires and frequency of burning helped to clear the area of bush and attract ungulates to the highly nutritious grazing created by the fires. Due to rinderpest control campaign that commenced in the 1970's buffalo have increased from 20 000 to their 1982 number of 70 000 animals, wildebeest from 200 000 in the 1960's to 850 000 in the 1970's to their present number of about 1.3 million in the early1990's (TAWIRI 2003). Thomson's gazelle number about 440 000 and zebra approximately 200 000 (Sinclair 1995).

Although the Serengeti ecosystem is characterised by seasonal migration, it also supports a large number of resident ungulates. Serengeti predators such as lions are territorial, except during the migration period. It is argued that lions prefer to prey on wildebeest and zebra during the migration season, whilst warthog and buffalo species are preferred when the migrants have left (Scheel 1993). Prey movement in Serengeti is influenced by rainfall. In line with prey movement, predation on prey species changes between season and across different habitats. While predation of buffalo occurs on the woodland, the predation on gazelles occurs on the plains and it varies with the size of gazelle population groups.

2.4. Ngorongoro Conservation Area

The Ngorongoro Conservation Area (NCA) is a multiple land use area that is unique in East Africa. It has practised integrated conservation and human development for the past 48 years. Its plains form part of the Serengeti ecosystem providing grazing and calving grounds for migrating wildebeest and zebra. NCA has demonstrated two distinct approaches to multiple land use management since its establishment in 1959. From the period of 1959 to 1974, human habitation was combined with natural resources conservation.

The needs for protection of both vegetation and animals led the NCA to prohibit human habitation in some areas. The management of the area has followed this policy since 1968 when the first conservation plan was developed. In line with this plan human activities were banned in the Ngorongoro Crater and in the Northern Highland Forest Reserve (NHFR). The implementation of this policy came into effect fully in 1974 when resident Maasai and their cattle were removed from the Crater. Since 1974 the Ngorongoro Crater has been managed as a core zone and the remainder of the NCA managed as a buffer zone to both the Crater and the adjacent Serengeti National Park. The human population in the NCA has increased from about 8,000 between the 1960's and 1970's to the current number of 60,000 (Runyoro 2001). The human population increase in the NCA is associated with a negative impact on the resources in the area. Human activities such as cultivation, grazing in the NHFR, (although a restricted zone) and uncontrolled fires in the Forest Reserve have resulted in forest degradation. Cultivation and human settlement has resulted in the migratory routes of wildlife being blocked. Within the Crater the apparent decline in herbivores such as the wildebeest suggests that a more active programme of pasture management, particularly burning, is required to reverse the apparent deterioration in sward quality and composition.

The future management direction of NCA will present complex and unpredictable challenges due to the fact that a non-interventionist approach has been followed, despite significant human impacts, and many changes have occurred in spite of the passive non-interventionist management style. Changes have also occurred in the animal population with some species such as buffalo increasing in the recent years compared to their numbers in 1970's, while other species such as wildebeest have shown a tremendous decrease (Runyoro *et al.* 1995). The black rhino number has remained stagnant for many years with a current population of 19 individuals compared to 108 individuals in 1960's although security has been intensified in and outside of the Crater. The Lerai forest, which used to be a dense and vital habitat for black rhino, is close to disappearing (Herlocker 2004 pers. comm.). Water flow and direction has been altered in the Crater by digging trenches to safeguard roads and as a result the important swampy vegetation and associated bird species have disappeared. Grassland species composition has changed since the last study conducted in the 1970's. Some grass species have become tall and unpalatable and as a result only a part of the Crater area is utilized for grazing (Trollope & Trollope 1995). The scrub vegetation has grown much higher and is no longer accessible for browsing animals such as the black rhino (Brown 2004). Most of these shrubs are only utilized by elephants. The Crater has been described as an area with a tick load higher than any other protected area in the world (Trollope & Trollope 2001). The important wildlife migratory routes have become increasingly blocked by human settlements and cultivation outside the Crater. Due to this the Crater is becoming isolated from other neighbouring ecosystems such as the Serengeti, Maasai Mara and Lake Manyara National Park.

2.5. Development of a management philosophy for managing the vegetation of Ngorongoro Crater.

All three areas have a history of experiencing significant changes due to human influence in the past few centuries. The Serengeti National Park, being an open, unfenced system with no restriction on animal movement, does not have a strong requirement for active intervention. To date, research has provided an excellent understanding of the system dynamics and this information could be used in formulating management actions, should these be required. There is an increasing focus on a fire management programme for the Serengeti, in recognition of the role of humans in setting fires, and the potential impacts of uncontrolled fires.

The Kruger National Park is an example of a conservation area where the management philosophies and approaches have changed over time in response to new information. The KNP is an isolated, fenced system where animal migration and movement routes have been blocked, and interventions have accordingly been focused on controlling animal numbers, water provision, fencing and fire.

The greater NCA is an open system, connected to the Serengeti National Park. However, human impacts within the system are probably greater than in the above two systems. The Crater is unique in that, although it is part of an open system, it is becoming increasingly isolated in terms of animal movement due to increased human settlement with associated habitat fragmentation and has been significantly impacted by past management decisions. This necessitates a unique approach to developing a management philosophy. Table 2.1 below summarises different management styles and interventions which have been practised in other Conservation areas in Africa such as the Kruger and Serengeti National Parks.

Table 2.1. A Summary of the different management styles of the Kruger and Serengeti National Parks and the Ngorongoro Conservation Area.

Management Activity	**Kruger National Park (KNP)**	**Serengeti National Park (SENAPA)**	**Ngorongoro Conservation Area (NCA)**
	Strategic adaptive	Scientifically driven	Non-interventionist
Culling	Culling programmes have been undertaken when it was considered that animal numbers within given populations were approaching ecological limits	The conservation of both spatial and temporal heterogeneity has been one of the major management themes for the park. However, the culling of animals has never been practised in the park since its establishment in 1959.	The carrying capacity of the Ngorongoro Conservation Area has not been determined since being established in 1959. As in the Serengeti NP, the culling of animals has never been practised.
Water provision	A policy of proving artificial water points was initiated in 1933. This was the beginning of management philosophy from total protection to one of intervention.	There are no artificial water points for wildlife in the park. Animals depend on seasonal rainfall and on Grumeti river especially during migration period.	There are dams providing water for both domestic animals and wildlife outside of the main Crater. In the Crater animals depend on permanent rivers, springs and seasonal swamps.

Table 2.1 Continued...

Management Activity	**Kruger National Park (KNP)**	**Serengeti National Park (SENAPA)**	**Ngorongoro Conservation Area (NCA)**
	Strategic adaptive	Scientifically driven	Non-interventionist
Fencing	Fencing of all borders commenced 1946 and was completed by 1980. This created an island and preventing any seasonal migration of animals.	There is no physical boundary or fence allowing animals to migrate between the Serengeti and the Maasai Mara. Protecting this annual migration is one of the park's primary management objectives.	As in Serengeti National Park, there is no physical boundary or fences in the Ngorongoro Conservation Area. Animals move freely in the Ngorongoro Serengeti-Mara ecosystem. However, the Crater is becoming increasingly isolated from the rest of the NCA due to human encroachment.
Burning	Fire management in the Kruger National Park has followed several trends. Occasional and limited burning was applied between 1926 and 1948 to provide green grazing. Between 1948 and 1956, prescribed burning was established to control fires. In 1957 a formal system of burning blocks once every three years was introduced. In 1992 this policy was again changed to one of allowing natural (lightning-ignited) fires to burn freely whilst prescribed burning ceased and all other fires of human origin were suppressed. This policy has again changed to a more integrated approach where controlled burning has been re-introduced in the form of a "patch-mosaic burning programme".	Management in the Serengeti has been influenced by various research findings including fire research and monitoring of fires. From these findings controlled early burning in the Serengeti National Park is conducted after the end of wet season May/June whilst late burning to cause hot fires are conducted in the driest period of September and October. The results of the Serengeti Fire Policy provide a compelling argument in favour of the use of controlled burning to optimise rangeland productivity and promote biodiversity.	The management of the area has followed a non-interventionist policy since establishment. Prior to 1974 the Maasai lived in the Crater floor and they used fire to improve pasture for their livestock. Since 1974 the Ngorongoro Crater has been managed as core zone and the use of fire banned. The deterioration in the quality of the grazing in the Crater floor has called into question the no-burn policy and, as practised in SENAPA, the use of controlled burning is now being advocated.

CHAPTER THREE: VEGETATION CHANGES IN THE NGORONGORO CRATER BETWEEN 1972 AND 2004

3.1. Introduction

In order for an adaptive management philosophy to be successful in a wildlife conservation area, management decision making processes need to be based on a sound understanding of the functioning of the ecological system. In particular, an understanding of change and the drivers of change are critical if any management interventions are planned. In the Ngorongoro Crater, vegetation and animal dynamics are perceived to have changed significantly in the last few decades. However, apart from animal census data that shows changes in animal numbers and ratios between animal species, there is currently no quantitative data on vegetation dynamics. Herlocker & Dirschl (1972) carried out a vegetation survey of the Ngorongoro Conservation Area (NCA) with a more detailed focus on the Ngorongoro Crater, being the central and most important wildlife area in the NCA.

The methodology used by Herlocker & Dirschl (1972) can be summarized as follows:

- Recognition of five primary physiognomic classes: grassland; herbaceous swamp; bush; woodland and forest.
- Subdivision into secondary classes according to height or density of the upper stratum.
- Subdivision into species types according to dominant plants of the main strata.
- Mapping units were delineated on aerial photos using a stereoscope.
- Ground-truthing of mapping units and further subdivision were carried out where appropriate.
- Bush communities were sampled by the PCQ (Point Centred Quarter) method using transects of 50 points.

- The nearest tree and shrub was recorded in each quadrant at each point.
- Density was then determined and the dominant species were listed.
- A representative number of the final mapping units were sampled to determine structure and species composition.

Maps, field notes and photographs were available from Herlocker & Dirschl's survey of the grasslands in the Crater, and it was decided to repeat their grassland survey as a first step in accumulating information on system change.

3.2. Methods

The 39 grassland transects surveyed by Herlocker & Dirschl (1972) were repeated as accurately as possible in this study (2004) in order to draw comparisons between the two studies. The original field map depicting the original transects was obtained from Herlocker so that the co-ordinates of each transect could be determined. Herlocker visited Ngorongoro Crater to assist and participate in the initial phase of planning and data collection to ensure accurate location of transects and compatibility between techniques.

Transects were located in the field by recording the beginning and end UTM co-ordinates obtained from the topographical map on a Global Positioning System (GPS), which was then used to locate the transects in the field (Appendix 5 and 6). Each transect comprised 100 points to ensure compatibility with the original survey. This number was chosen after evaluation (see Appendix 7). Since the length of the transects varied, the distance between points that was required to ensure that each transect had 100 points was determined beforehand. Herlocker also used 100 points for most transects during the 1972 grassland survey in the Crater.

A thin metal rod approximately 1.5 m in length was used to identify the point position. Since the rod was placed at fixed intervals dictated by a predetermined inter-point distance, the selection was not influenced by bias.

At each point the nearest rooted grass species was recorded as well as the distance between this plant and the rod. The point-to-tuft distances were used to delineate and describe the Homogeneous Vegetation Units (Chapter 4) and were not used for the comparison with the 1972 study. If the nearest grass species was an annual, then the nearest perennial species was also recorded. Adjacent to this point, a reading was taken with a disc pasture meter (DPM) to record the standing crop of grass. The end result was 100 records each of nearest grass species, point to tuft distances and DPM readings per transect.

Direct comparisons with the data from the 1972 study were complicated by the non-availability of the original raw data. The only data available were in the form of summarised field notes where the abundance (%) of three dominant species was recorded. In the case of a few transects only two dominant species were recorded. As a consequence, several analytical approaches were adopted in an attempt to answer the following questions:

1. Has a change in species composition taken place between 1972 and 2004?
2. How much change has taken place?
3. What is the direction of change?
4. What is the extent of the change (in terms of proportional area of the crater)?

Species were ranked in order of abundance, the single dominant species and the dominant three species in each transect were tabulated for the current and initial surveys respectively. These data were analysed using the gamma rank correlation coefficient (Siegel & Castellan 1988) using the GENSTAT statistical package (GENSTAT Version 7.1) to examine the relations between the dominance of species in the transects from the two surveys. The gamma rank correlation coefficient is commonly used to detect agreement between variables measured on an ordinal scale. It is considered suitable for data sets where there are tied values. A gamma coefficient of 1 indicates that the rank order of the species has remained unchanged, while a coefficient of –1 indicates complete dissimilarity between the samples. A value of zero indicates that the samples are unrelated. Individual transects were not tested using the gamma rank coefficient because of the low number of species (three per transect) available for the comparison.

The data were then examined with multivariate analysis techniques using the CANOCO 4 package (Ter Braak & Smilauer 1998). The data were initially subjected to a Detrended Correspondence Analysis (DCA) to determine the lengths of the gradients and species turnover, and assess whether a Principal Components Analysis might be appropriate. The relatively high turnover of species indicated that a Correspondence Analysis (CA) would be more appropriate. After attempting the CA analysis a pronounced arch effect was noted, necessitating the use of a DCA.

3.3. Results

In order to make a direct comparison between the study of Herlocker & Dirschl (1972) and this study the three most abundant species in each transect were tabulated for both surveys (Table 3.1). The full names of the species encountered in each sampled transect are presented in Appendix 1. A total of 39 transects were surveyed in the same vegetation types surveyed during the 1972 study. The vegetation types referred to here are those 19 grassland vegetation types delineated by Herlocker & Dirschl (1972) occurring on the Crater floor. Only two species were available for comparison in vegetation type 2 transect 2, vegetation type 3 transect 7 and in vegetation type 4 transect 1 while in vegetation type 24 transect 2 one species was available for comparison from 1972 study (Table 3.1).

Table 3.1. Species composition (%) of the Ngorongoro Crater in 2004 and 1972 (Herlocker and Dirschl). (VT = Vegetation Types & T = Transect).

No.	Transects	Species (2004 study)	% Dominance	Species (1972 study)	% Dominance
1	VT1T1	*Andropogon greenwayi*	30	*Pennisetum mezianum*	39
		Chloris pycnothrix	30	*Andropogon greenwayi*	39
		Cynodon dactylon	22	*Digitaria abyssinica*	34
2	VT2T1	*Cynodon dactylon*	42	*Digitaria abyssinica*	39
		Digitaria abyssinica	27	*Digitaria macroblefara*	27
		Brachiaria umbratilis	22	*Cynodon dactylon*	13
3	VT2T2	*Cynodon dactylon*	71	*Digitaria abyssinica*	44
		Digitaria abyssinica	25	*Cynodon dactylon*	22
		Brachiaria umbratilis	3		
4	VT2T3	*Cynodon dactylon*	62	*Digitaria abyssinica*	32
		Digitaria abyssinica	31	*Cynodon dactylon*	30
		Chloris pycnothrix	4	*Digitaria macroblefara*	14
5	VT2T4	*Chloris gayana*	35	*Digitaria abyssinica*	46
		Cynodon dactylon	23	*Digitaria macroblefara*	11
		Andropogon greenwayi	17	*Pennisetum mezianum*	10
6	VT2T5	*Cynodon dactylon*	59	*Digitaria abyssinica*	34
		Digitaria abyssinica	37	*Cynodon dactylon*	29
		Chloris gayana	3	*Digitaria macroblefara*	16
7	VT2T6	*Panicum coloratum*	34	*Digitaria abyssinica*	32
		Digitaria abyssinica	25	*Cynodon dactylon*	17
		Cynodon dactylon	23	*Panicum coloratum*	17
8	VT2T7	*Cynodon dactylon*	30	*Digitaria abyssinica*	59
		Andropogon greenwayi	18	*Digitaria macroblefara*	28
		Digitaria abyssinica	16		
9	VT3T1	*Themeda triandra*	50	*Digitaria abyssinica*	27
		Pennisetum schimperi	29	*Pennisetum schimperi*	27
		Hyparrhenia hirta	11	*Chloris gayana*	27
10	VT3T2	*Andropogon greenwayi*	74	*Andropogon greenwayi*	38
		Digitaria abyssinica	11	*Digitaria abyssinica*	20
		Cynodon dactylon	8	*Themeda triandra*	20
11	VT3T3	*Digitaria abyssinica*	35	*Digitaria abyssinica*	38
		Andropogon greenwayi	23	*Eragrostis tenuifolia*	21
		Cynodon dactylon	21	*Cynodon dactylon*	12
12	VT3T4	*Cynodon dactylon*	29	*Digitaria abyssinica*	34
		Chloris gayana	28	*Cynodon dactylon*	29
		Andropogon greenwayi	17	*Digitaria macroblefara*	16
13	VT3T5	*Andropogon greenwayi*	26	*Digitaria abyssinica*	29
		Cynodon dactylon	23	*Andropogon greenwayi*	28
		Digitaria abyssinica	19	*Sporobolus fimbriatus*	19
14	VT3T6	*Chloris gayana*	34	*Digitaria abyssinica*	30
		Andropogon greenwayi	22	*Andropogon greenwayi*	28
		Cynodon dactylon	19	*Sporobolus fimbriatus*	16
15	VT3T7	*Cynodon dactylon*	33	*Andropogon greenwayi*	39
		Themeda triandra	19	*Digitaria abyssinica*	32
		Digitaria abyssinica	18		
16	VT3T8	*Andropogon greenwayi*	61	*Andropogon greenwayi*	43
		Sporobolus fimbriatus	21	*Digitaria abyssinica*	22
		Themeda triandra	9	*Sporobolus fimbriatus*	18
17	VT4T1	*Andropogon greenwayi*	73	*Themeda triandra*	63
		Themeda triandra	15	*Sporobolus fimbriatus*	11
		Sporobolus fimbriatus	10		
18	VT6T1	*Cynodon dactylon*	24	*Themeda triandra*	42
		Setaria sphacelata	14	*Sporobolus fimbriatus*	21
		Chloris gayana	13	*Setaria sphacelata*	12
19	VT7T1	*Themeda triandra*	33	*Themeda triandra*	55
		Hyparrhenia sp	19	*Sporobolus fimbriatus*	30
		Chloris gayana	16	*Hyparrhenia sp*	10

Table 3.1 Continued…

No.	Transects	Species (2004 study)	% Dominance	Species (1972 study)	% Dominance
20	VT8T1	*Setaria sphacelata*	50	*Themeda triandra*	36
		Themeda triandra	19	*Andropogon greenwayi*	20
		Digitaria abyssinica	8	*Cynodon dactylon*	10
21	VT10T1	*Cynodon dactylon*	51	*Cynodon dactylon*	31
		Digitaria abyssinica	43	*Digitaria abyssinica*	27
		Sporobolus fimbriatus	6	*Pennisetum stramenium*	10
22	VT10T2	*Cynodon dactylon*	43	*Cynodon dactylon*	31
		Digitaria abyssinica	35	*Digitaria abyssinica*	20
		Sporobolus fimbriatus	9	*Digitaria macroblefara*	21
23	VT10T3	*Cynodon dactylon*	50	*Digitaria abyssinica*	33
		Digitaria abyssinica	34	*Sporobolus fimbriatus*	20
		Chloris gayana	11	*Digitaria macroblefara*	8
24	VT12T1	*Chloris gayana*	49	*Cynodon dactylon*	18
		Cynodon dactylon	43	*Chloris gayana*	18
		Sporobolus spicatus	5	*Digitaria homblei*	17
25	VT13T1	*Cynodon dactylon*	52	*Sporobolus spicatus*	24
		Sporobolus spicatus	22	*Sporobolus homblei*	13
		Sporobolus ioclados	16	*Chloris gayana*	13
26	VT14T1	*Cynodon dactylon*	56	*Digitaria abyssinica*	54
		Chloris gayana	16	*Cynodon dactylon*	16
		Brachiaria umbratilis	9	*Sporobolus fimbriatus*	13
27	VT15T1	*Chloris gayana*	60	*Chloris gayana*	42
		Cynodon dactylon	25	*Cynodon dactylon*	15
		Sporobolus spicatus	6.	*Andropogon greenwayi*	12
28	VT15T2	*Themeda triandra*	18	*Themeda triandra*	28
		Hyparrhenia sp	15	*Cymbopogon afronadus*	12
		Andropogon greenwayi	14		
29	VT15T3	*Chloris gayana*	48	*Themeda triandra*	28
		Cynodon dactylon	36	*Cymbopogon afronadus*	12
		Pennisetum clandestinum	12		
30	VT15T4	*Chloris gayana*	35	*Andropogon greenwayi*	31
		Digitaria abyssinica	24	*Digitaria abyssinica*	21
		Cynodon dactylon	11	*Themeda triandra*	21
31	VT19T1	*Digitaria abyssinica*	47	*Sporobolus ioclados*	36
		Cynodon dactylon	45	*Digitaria abyssinica*	16
		Sporobolus ioclados	7	*Digitaria macroblefara*	16
32	VT20T1	*Cynodon dactylon*	49	*Digitaria abyssinica*	22
		Digitaria abyssinica	19	*Sporobolus homblei*	16
		Sporobolus ioclados	14		
33	VT21T1	*Cynodon dactylon*	47	*Sporobolus homblei*	43
		Cynodon nlemfuensis	32	*Digitaria abyssinica*	22
		Digitaria abyssinica	21	*Cynodon dactylon*	10
34	VT23T1	*Chloris gayana*	43	*Sporobolus ioclados*	47
		Sporobolus spicatus	18	*Sporobolus spicatus*	40
		Cynodon dactylon	15	*Sporobolus homblei*	27
35	VT24T1	*Sporobolus ioclados*	30	*Sporobolus ioclados*	37
		Odyssea jaegeri	22	*Cynodon dactylon*	14
		Cynodon dactylon	20	*Cyperus sp*	14
36	VT24T2	*Cynodon dactylon*	62	*Sporobolus spicatus*	66
		Digitaria abyssinica	28		
		Sporobolus spicatus	3		
37	VT30T1	*Sporobolus ioclados*	35	*Sporobolus homblei*	36
		Cynodon dactylon	22	*Digitaria abyssinica*	20
		Digitaria abyssinica	19	*Sporobolus ioclados*	10
38	VT30T2	*Cynodon dactylon*	48	*Andropogon greenwayi*	30
		Digitaria abyssinica	43	*Sporobolus homblei*	16
		Chloris gayana	4	*Digitaria abyssinica*	12
39	VT31T1	*Cynodon dactylon*	28	*Digitaria abyssinica*	
		Chloris gayana	24	*Cynodon dactylon*	
		Sporobolus spicatus	19	*Sporobolus homblei*	

Note that Herlocker & Dirschl's data were available as three (and in some cases only two) dominant species. The data from the 2004 study were abbreviated accordingly.

The data were summarised in terms of the most abundant (dominant) single species (Table 3.2) and the most abundant or dominant three species (Table 3.3) encountered during the 1972 and 2004 surveys (i.e. the number of transects in a species dominated or occurred in one of the top three positions). Visually, the dominance of species has changed.

Table 3.2. Summary of the most abundant species, indicated by the number of transects in which a species dominated in 1972 and 2004 and ranked in order of dominance. The ecological categories Decrease (D), Increaser I (I), and Increaser II (II) have been included. (Full species names are listed in Appendix 1.)

Transect dominance			Rank order of dominance					
Species	**1972**	**2004**	**Species**	**1972**	**Ecological category**	**Species**	**2004**	**Ecological category**
And gre	7	5	Dig aby	1	II	Cyn dac	1	II
Chl gay	1	7	And gre	2	D	Chl gay	2	I
Chl pyc	0	1	The tri	3	D	And gre	3	D
Cyn dac	3	17	Cyn dac	4	II	Dig aby	4	II
Dig aby	14	3	Spo spi	4	II	Spo ioc	5	II
Pan col	0	1	Spo hom	6	II	The tri	5	D
Pen mez	1	0	Spo ioc	6	II	Chl pyc	7	II
Set sph	0	1	Chl gay	8	I	Pan col	7	II
Spo hom	2	0	Pen mez	8	I	Set sph	7	D
Spo ioc	2	2	Chl pyc	10	II	Pen mez	10	I
Spo spi	3	0	Pan col	10	II	Spo spi	10	II
The tri	6	2	Set sph	10	D	Spo hom		II

The gamma rank correlation coefficient for the dominant species (Table 3.2) was 0.2206 (variance = 0.02928), indicating substantial change in species dominance. There was also substantial change in the three most abundant species considered as a group, with a gamma rank correlation coefficient of –0.0490 (variance = 0.00731) (Table 3.3). Both these correlation coefficients tend towards zero rather than one, reinforcing the observations made above that there has been substantial change in the species composition of the grasslands of the crater floor over time.

Table 3.3. Summary of the most abundant three species, indicated by the number of transects in which a species was present in the top three positions of abundance in 1972 and 2004 and ranked in order of dominance. The ecological categories Decrease (D), Increaser I (I), and Increaser II (II) have been included. (Full species names are listed in Appendix 1).

Transect dominance			Rank order of dominance					
Species	1972	2004	Species	1972	Ecological category	Species	2004	Ecological category
And gre	12	10	Dig aby	1	II	Cyn dac	1	II
Bra umb	0	3	Cyn dac	2	II	Dig aby	2	II
Chl gay	4	15	And gre	3	D	Chl gay	3	I
Chl pyc	0	3	Dig mac	4	II	And gre	4	D
Cym afr	3	0	The tri	5	D	The tri	5	D
Cyn dac	15	32	Spo fim	6	II	Spo spi	6	II
Cyp sp	1	0	Spo hom	7	II	Spo ioc	7	II
Dig aby	26	20	Chl gay	8	I	Bra umb	8	II
Dig mac	9	0	Spo ioc	8	II	Chl pyc	8	II
Era ten	1	0	Cym afr	10	II	Spo fim	8	II
Hyp hir	0	1	Pen mez	10	I	Set sph	11	D
Hyp sp	1	1	Spo spi	10	II	Hyp hir	12	I
Ody jae	0	1	Set sph	13	D	Hyp sp	12	I
Pan col	1	0	Cyp sp	14	II	Ody jae	12	II
Pan sp	0	1	Era ten	14	II	Pan sp	12	II
Pen cla	0	1	Hyp sp	14	I	Pen cla	12	II
Pen mez	3	1	Pan col	14	II	Pen mez	12	I
Pen sch	1	1	Pen sch	14	I	Pen sch	12	I
Pen str	1	0	Pen str	14	I	Cym afr	19	II
Set sph	2	2	Bra umb	20	II	Cyp sp	19	II
Spo fim	7	3	Chl pyc	20	II	Dig mac	19	II
Spo hom	6	0	Hyp hir	20	I	Era ten	19	II
Spo ioc	4	5	Ody jae	20	II	Pan col	19	II
Spo spi	3	6	Pan sp	20	II	Pen str	19	I
The tri	8	7	Pen cla	20	II			

In order to gain further insight into the species composition changes between 1972 and 2004, an ordination was carried out to highlight changes. The DCA technique was chosen for reasons outlined above. A species termed "other" was added to the existing species listed above, with the "other" category making up the proportional score to 100. The "other" species was made passive in the analysis and rare species were downweighted. Samples were grouped into the original (O) and final (F) surveys (Figure 3.1). The first three axes accounted for 73.5% of the variance.

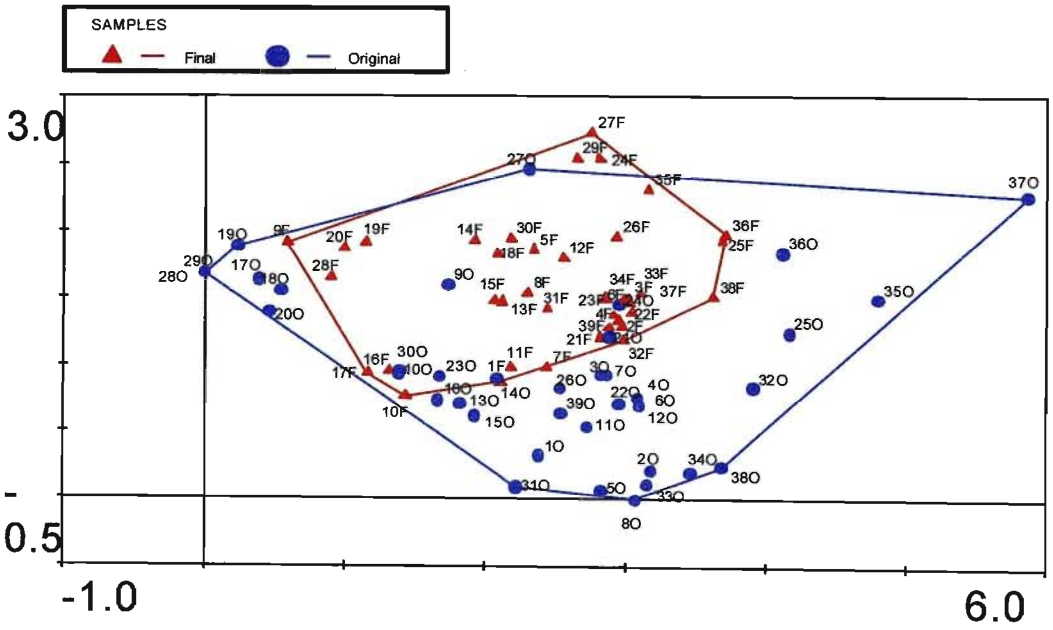

Figure 3.1. Detrended correspondence analysis plot indicating the position of original survey plots in relation to the final survey. "O" indicates original survey plots and "F" indicates final survey plots.

Comparing the position of the survey plots from the two sampling times in relation to the corresponding species from the DCA (Figure 3.2 and 3.3) reveals interesting trends.

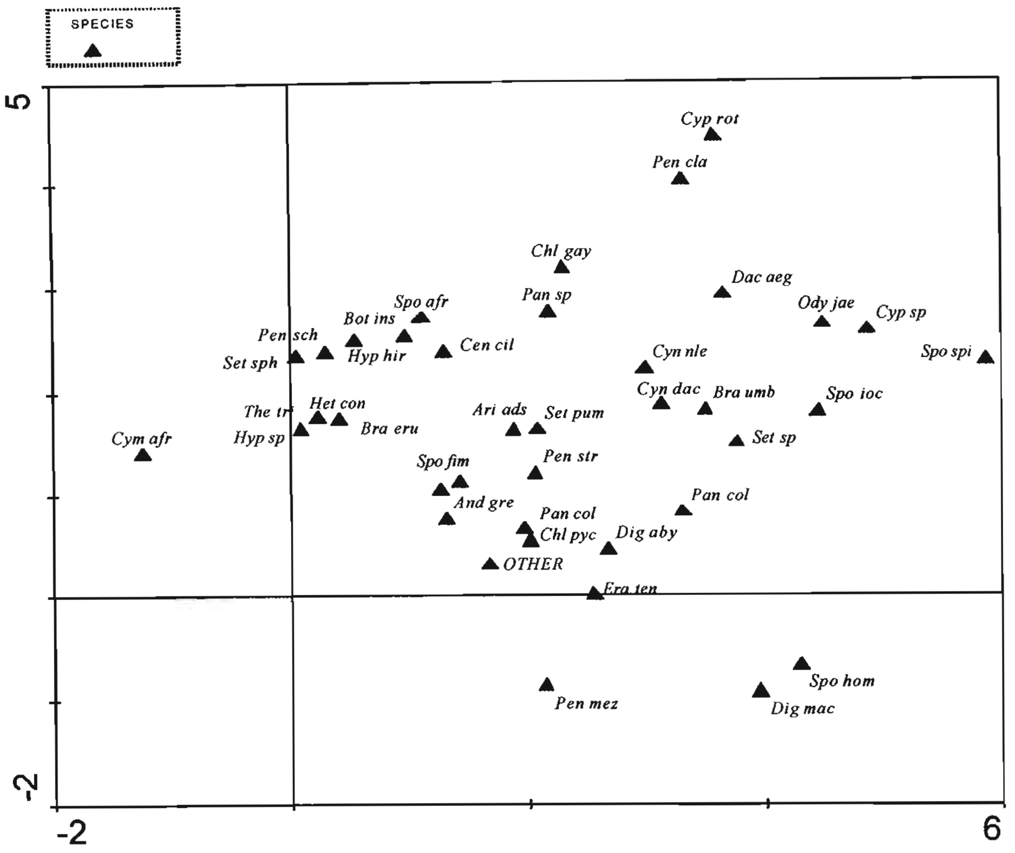

Figure 3.2. Detrended correspondence analysis plot indicating the position of all species (2004). (Full species names listed in appendix 1).

The number of species encountered during the final survey has decreased relative to the first survey, indicated by the more compressed position of the final survey transects in ordination space (Figure 3.1). This indicates a convergence towards a smaller group of dominant species.

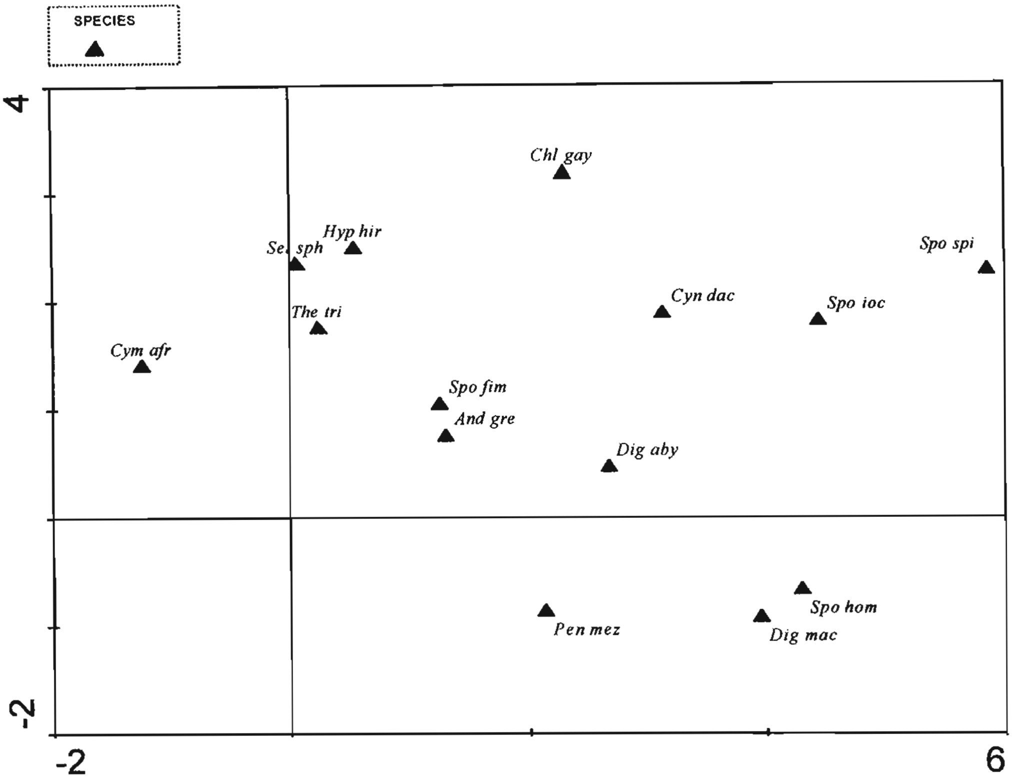

Figure 3.3. Detrended correspondence analysis plot indicating the position of the common species (2004). (Full species names listed in appendix 1).

The indications from table 3.2 are that *Chloris gayana* and *Cynodon dactylon* have become more dominant in recent years in relation to the original survey (Figures 3.2 and 3.3).

Within the 19 individual grassland vegetation types (classified by Herlocker & Dirschl (1972), significant changes were noted. Vegetation type 1 comprised a relatively small zone within vegetation type 2 where the dominant species in 1972 were *Pennisetum mezianum*, *Andropogon greenwayi* and *Digitaria abyssinica.* The dominance of *Pennisetum mezianum* differentiated this vegetation type from the surrounding vegetation. In 2004 significant changes were evident, with *Andropogon greenwayi* (30%), *Chloris pycnothrix* (30%) and *Cynodon dactylon* dominant. *Pennisetum mezianum* declined in abundance from 39% in 1972 to 14% in 2004.

Vegetation type 2 was the largest of the vegetation types delineated by Herlocker & Dirschl (1972), and covered much of the flat areas in the centre of the Crater floor away from the lake and wetland areas. Significant changes were noted in all transects within the vegetation type with a tendency for *Cynodon dactylon* and *Chloris gayana* to increase in abundance, with the exception of transect 6, where *Panicum coloratum* increased in abundance to a position of dominance (Table 3.1 and Figure 3.4).

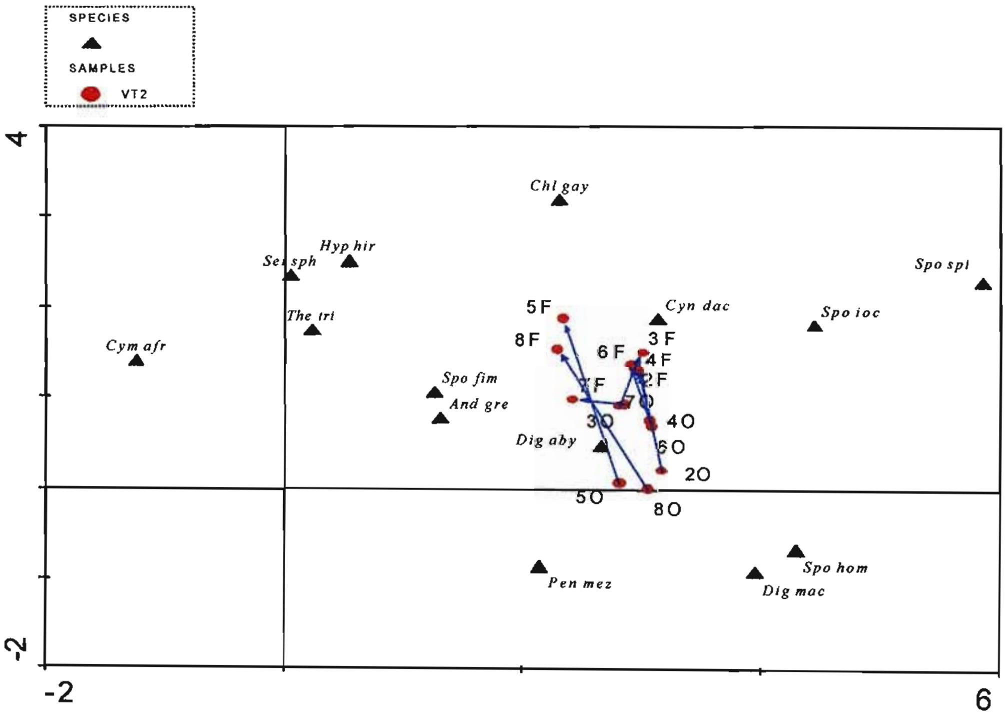

Figure 3.4. Detrended Correspondence Analysis plot indicating the change in species composition of vegetation type 2 (VT2). (Full species names are listed in appendix 1).

The samples labelled 2O, 3O, 4O, 5O, 6O, 7O and 8O indicate the first to seventh original (1972) transects of vegetation type 2 respectively. The samples labelled F indicate the corresponding 2004 transects.

Vegetation type 3 comprises a broad strip between the northern and eastern Crater walls and the flatter areas covered by vegetation type 2. Species composition change within this vegetation type has been less consistent than the changes noted in vegetation type 2 (Table 3.1 and Figure 3.5). There is a noticeable trend towards an increase in *Cynodon dactylon* and *Chloris gayana* and a decrease in abundance of *Digitaria abyssinica*. The species composition of transect 1 showed an increase in *Themeda triandra* and *Hyparrhenia hirta* at the expense of *Digitaria abyssinica*.

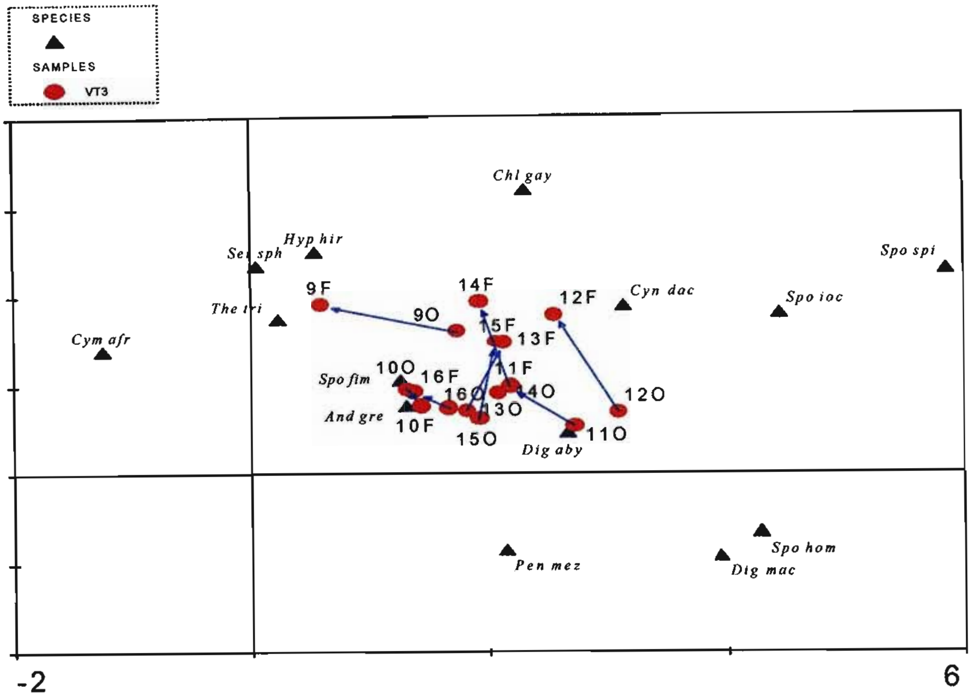

Figure 3.5. Detrended Correspondence Analysis plot indicating the change in species composition of vegetation type 3 (VT3). (Full species names are listed in appendix 1).

The samples labelled 9O, 10O, 11O, 12O, 13O, 14O, 15O and 16O indicate the first to eighth original (1972) transects of vegetation type 3 respectively. The samples labelled F indicate the corresponding 2004 transects.

Vegetation type 4 comprises a belt along the eastern side of the Crater floor between vegetation type 3 and the scrub vegetation on the lower slopes of the Crater walls. Changes in the species composition of this vegetation type included a decline in the proportion of *Themeda triandra* and an increase in *Andropogon greenwayi* (Table 3.1). Some scrub vegetation was present in 1972 with the presence of *Lippia* species being noted at a cover of between

21 and 60%. *Lippia* species are still present, however, it is impossible to objectively quantify any changes in cover. Within vegetation type 4, a belt dominated by *Erythrina abyssinica* was classed as vegetation type 5. The grass layer was deemed to be no different from vegetation type 4. The majority of the *Erythrina abyssinica* trees have disappeared, with elephant damage being the most probable cause. Virtually all of the remaining trees show signs of bark stripping and ring barking by elephants, while all the remaining small trees show signs of elephant damage which will probably preclude their further development. The scrub component, dominated by *Lippia* species, is extremely dense.

Vegetation type 6 comprises a belt of grassland in the southern part of the Crater between the Gorigor swamp and the Crater wall. In 1972 it was dominated by *Themeda triandra*, *Sporobolus fimbriatus* and *Setaria sphacelata*. Currently, *Cynodon dactylon* and *Chloris gayana* have increased in dominance at the expense of the *Themeda triandra* and *Sporobolus fimbriatus* (Table 3.1).

Vegetation type 7 comprises a belt of scrub dominated vegetation in the southern part of the Crater close to the Crater wall. *Themeda triandra* has declined in abundance, and *Chloris gayana* has increased in abundance since 1972 (Table 3.1).

Vegetation type 8 comprises patches of *Acacia xanthophloea* close to the Ngoitokitok Springs. The grass layer was dominated by *Themeda triandra*, *Andropogon greenwayi* and *Cynodon dactylon* in 1972. The current composition is made up of *Setaria sphacelata*, *Themeda triandra* and a small proportion of *Digitaria abyssinica*. (Table 3.1)

Vegetation type 10 consists of a belt of grassland in the south western part of the Crater between the Lerai Forest and adjacent wetlands and the Crater wall. It appears that there is an increase in the dominance of *Cynodon dactylon* (Figure 3.6 and Table 3.1). The ecotype of *Cynodon dactylon* growing in this vegetation type is taller than that growing on many of the other parts of the Crater, and can easily be confused with *Cynodon nlemfuensis* in the vegetative stage. Additional transects sampled in this vegetation type indicate that much of what may have been identified as *Cynodon dactylon* in 1972 may have in fact been *Cynodon nlemfuensis*, or else the proportion of *Cynodon nlemfuensis* has increased. The *Cynodon nlemfuensis* is a taller, more robust grass than *Cynodon dactylon* and readily produces aerial tillers from vertically growing stolons at certain times of the year. The Cynodon species were close together in ordination space (Figure 3.2).

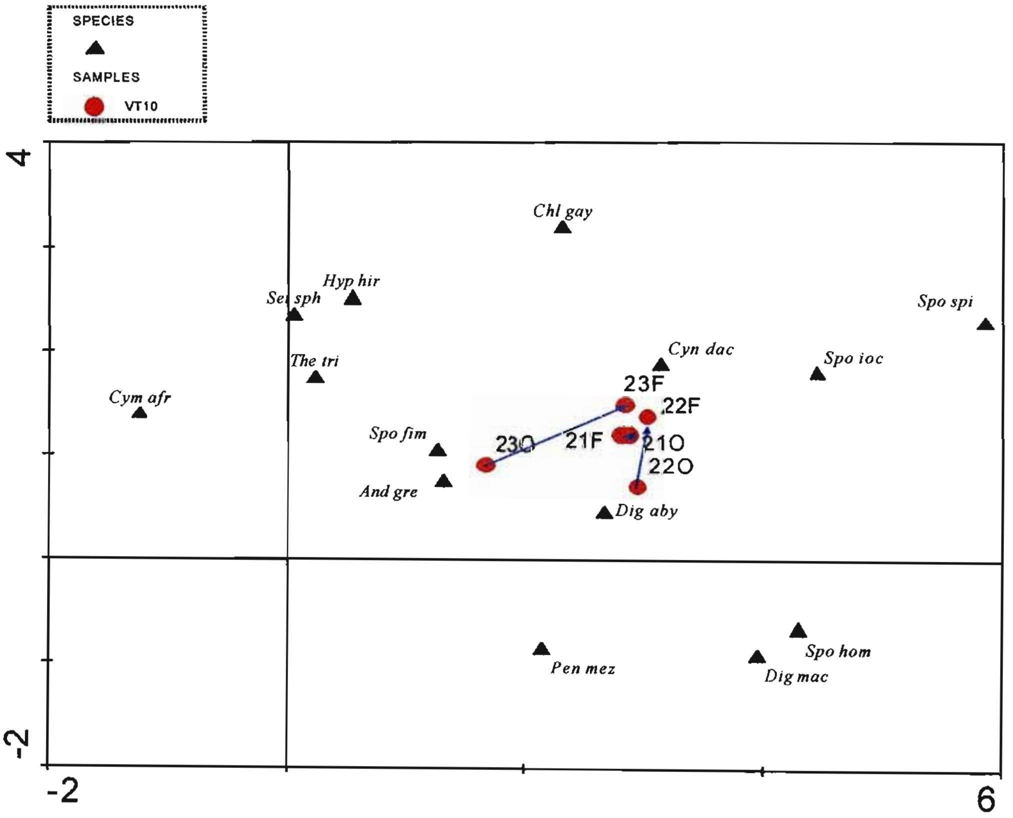

Figure 3.6. Detrended Correspondence Analysis plot indicating the change in species composition of vegetation type 10 (VT10). (Full species names are listed in appendix 1).

The samples labelled 21O, 22O, and 23O indicate the three original (1972) transects of vegetation type 10 respectively. The samples labelled F indicate the corresponding 2004 transects.

Vegetation type 12 comprises a relatively small area of grassland east of the Lerai Forest and south of Lake Magadi. The abundance of *Chloris gayana* and *Cynodon dactylon* has increased relative to 1972 (Table 3.1).

Vegetation type 13 comprises a narrow belt of more alkaline and sodic soils running through vegetation type 12. The abundance of *Cynodon dactylon* has increased since 1972 (Table 3.1).

Vegetation type 14 is situated immediately east of vegetation type 12. The abundance of *Chloris gayana* and *Cynodon dactylon* has increased in a similar manner to that of vegetation type 12 and 13 (Table 3.1).

Vegetation type 15 is located on and around Engitati Hill. There has been a marked shift in composition in most of the transects to a dominance of *Chloris gayana* and a decline in abundance of *Themeda triandra* (Figure 3.7 and Table 3.1).

Vegetation type 19 covers a crescent shaped belt characterised by step erosion. It is also known as the most arid side of the Crater floor, with estimated mean annual rainfall of about 350mm. In 1972 it was dominated by *Sporobolus ioclados, Digitaria abyssinica* and *Digitaria macroblefara*. The current species composition is made up of *Digitaria abyssinica*, *Cynodon dactylon* and *Sporobolus iocIados*. Both *Digitaria abyssinica* and *Cynodon dactylon* have increased markedly in proportional abundance.

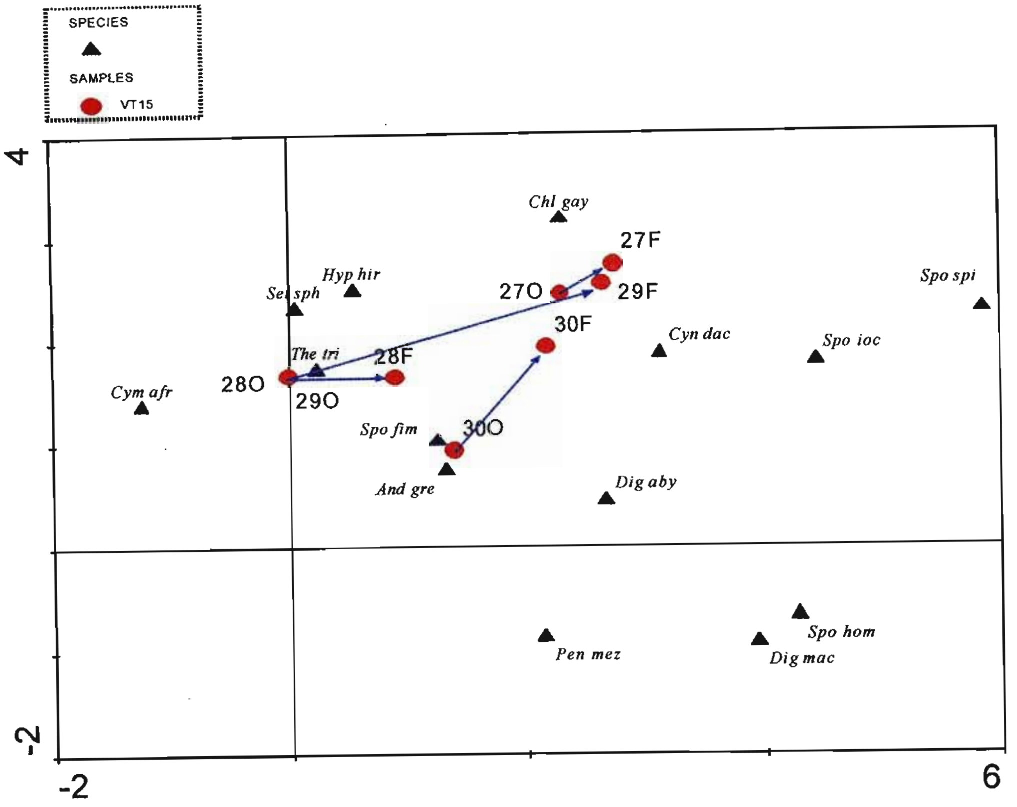

Figure 3.7. Detrended Correspondence Analysis plot indicating the change in species composition of vegetation type 15 (VT15). (Full species names are listed in appendix 1).

The samples labelled 27O, 28O, 29O and 30O indicate the four original (1972) transects of vegetation type 15 respectively. The samples labelled F indicate the corresponding 2004 transects.

Vegetation type 20 consists of a thin strip of grassland between vegetation type 19 and the Crater western wall. Species composition has changed significantly since 1972, with *Sporobolus homblei* declining from 16% to 0. *Cynodon dactylon* has increased substantially in abundance, to 49%.

Vegetation type 22 comprises the grasslands surrounding the lahar mounds in the south-western corner of the Crater floor. *Sporobolus homblei* declined from 43% to 0 between the two surveys, while *Cynodon dactylon* and *Cynodon nlemfuensis* both increased substantially (Table 3.1).

Vegetation type 23 comprises grassland immediately west of Lake Magadi. In 1972 the vegetation was dominated by *Sporobolus ioclados*, *Sporobolus spicatus* and *Sporobolus homblei*. All three species are known to be tolerant of saline conditions. Currently, *Chloris gayana*, *Sporobolus spicatus* and *Cynodon dactylon* are the most abundant species (Table 3.1).

Vegetation type 24 lies immediately to the south east of Lake Magadi. There has been a shift in species composition (Figure 3.8), with increases recorded in abundance of *Cynodon dactylon*, *Digitaria abyssinica* and *Odyssea jaegeri*. *Sporobolus spicatus* declined substantially (Table 3.1).

Vegetation type 27 surrounds Lake Magadi in a thin belt dominated by *Odyssea jaegeri*, with some *Sporobolus ioclados* in places. Because the area of the lake fluctuates significantly seasonally and in longer cycles corresponding to longer term rainfall cycles, the vegetation type was not resurveyed, but remains dominated largely by *Odyssea jaegeri*.

Vegetation type 30 is situated north-west of Lake Magadi. Clearly, species composition change has taken place in both transects, in different directions, but showing convergence towards Cynodon dactylon. In both instances, *Cynodon dactylon* has increased in abundance (Figure 3.9 and Table 3.1).

Vegetation type 31 comprises a large flat are in the centre of the Crater to the north-east of Lake Magadi. Proportional compositions were not found in the records of the 1972 survey, but the three dominant species were recorded as *Digitaria abyssinica*, *Cynodon dactylon* and *Sporobolus homblei*. Dominant species in 2004 were *Cynodon dactylon*, *Chloris gayana* and *Sporobolus spicatus*.

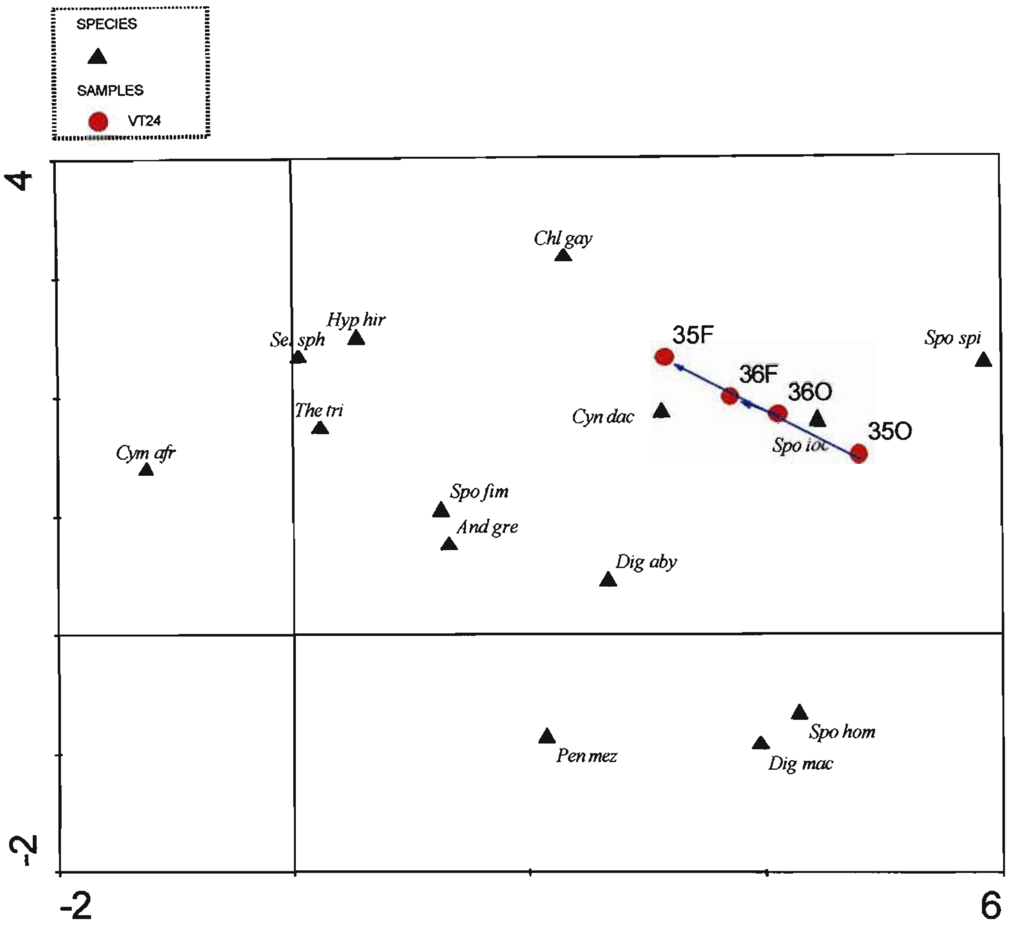

Figure 3.8. Detrended Correspondence Analysis plot indicating the change in species composition of vegetation type 24 (VT24). (Full species names are listed in appendix 1).

The samples labelled 35O and 36O indicate the two original (1972) transects of vegetation type 24 respectively. The samples labelled F indicate the corresponding 2004 transects.

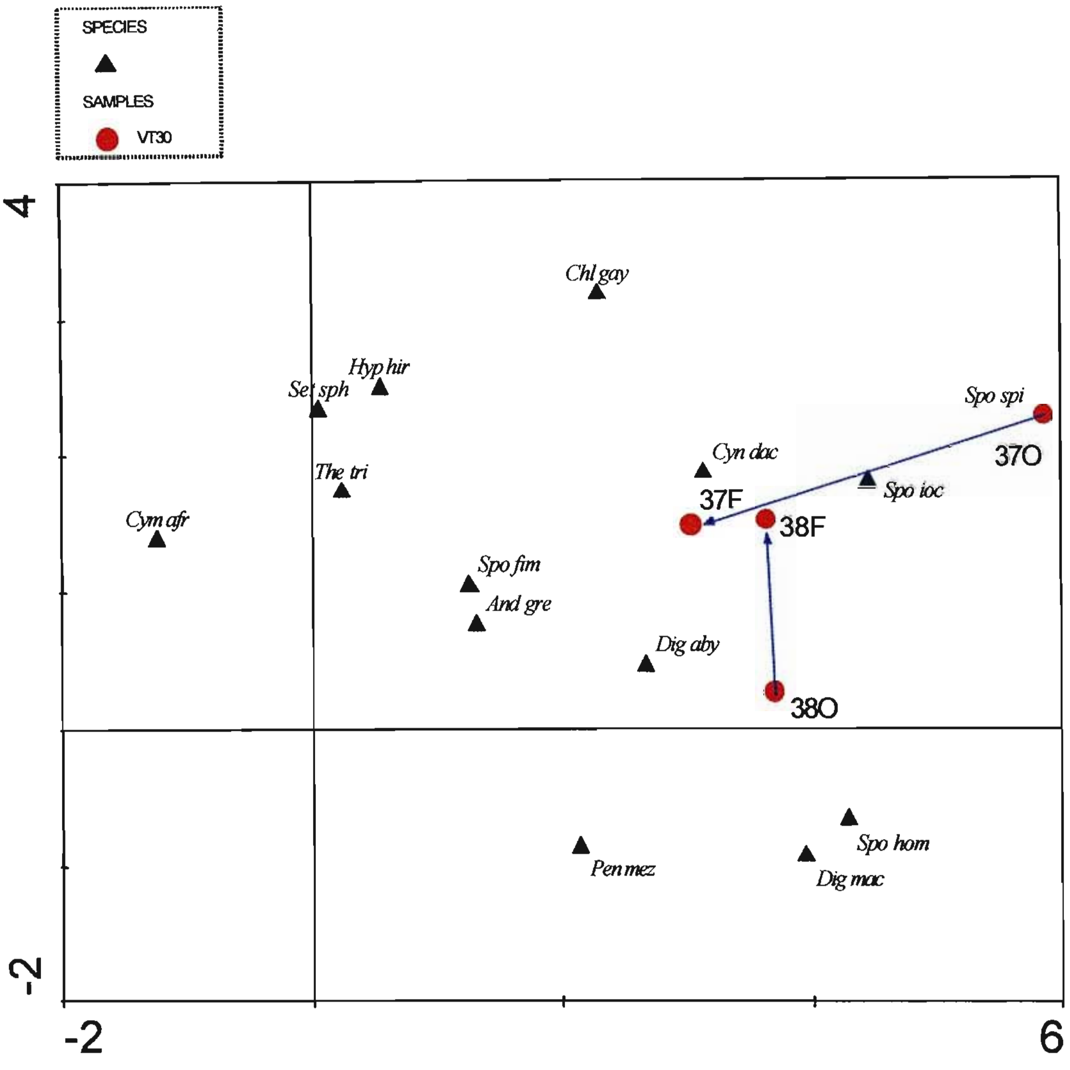

Figure 3.9. Detrended Correspondence Analysis plot indicating the change in species composition of vegetation type 30 (VT30). (Full species names are listed in appendix 1).

The samples labelled 37O and 38O indicate the two original (1972) transects of vegetation type 30 respectively. The samples labelled F indicate the corresponding 2004 transects.

3.4. Discussion

The results of the vegetation survey conducted in 2004 on the same sites surveyed by Herlocker and Dirschl in 1972 show that *Sporobolus homblei* and *Digitaria macroblephara,* which once dominated large areas of the Crater floor, have completely disappeared (Table 3.1). The disappearance of the latter species is especially significant because it was one of the most abundant grass species in the 1960's. It is a productive species and its disappearance may have impacted grazing capacity, although it is difficult to speculate on the influence of one species on the overall productivity and grazing capacity of the system. *Sporobolus homblei* in the 1960's and 1970's was abundant over smaller areas to the south and west of Lake Magadi on the drier, more saline sites. It is a short grass species, but may have been quite productive during wetter periods. It has now replaced by *Sporobolus ioclados* (Table 3.1). Apart from not being recorded during this study these species have not been observed anywhere in the Crater in recent years. It is not known whether changes in management may facilitate these species to return.

Cynodon dactylon, *Chloris gayana* and in most cases *Sporobolus ioclados* and *Andropogon greenwayi* have significantly increased in abundance, especially in areas where *Digitaria macroblephara* was once so important (Table 3.1). Likewise *Cynodon dactylon* and *Andropogon greenwayi* are abundant especially in areas where the grazing is moderate to heavy.

Digitaria abyssinica (formerly *Digitaria scalarum*), which was once a major dominant species on the Crater floor, has shown slight to very strong decreases in abundance over large areas. This species is currently more abundant on the areas which have been burnt recently and where moderate to heavy grazing has occurred. Trollope and Trollope (1995) in their report on the fire ecology of the Ngorongoro Conservation Area, classified *Andropogon greenwayi* as a decreaser species that occurs in areas with moderate grazing intensity, *Chloris gayana* as an increaser I species that occurs in areas of low utilisation intensity and *Cynodon dactylon*, *Digitaria abyssinica* and

Sporobolus ioclados as increaser II species which occur in areas with high intensity of grazing. Therefore, where *Digitaria macroblephara* has disappeared (but was once abundant) and *Chloris gayana* has increased in abundance, grazing intensity has probably markedly decreased. A significant reduction in abundance of *Digitaria abyssinica* (where it was once a dominant or sub-dominant) indicates a reduction in grazing intensity from a previously high level. A significant increase in *Andropogon greenwayi* (especially where *Digitaria abyssinica* has strongly decreased) probably indicates a reduction in grazing intensity from high to moderate levels. An abundance of *Cynodon dactylon* and *Sporobolus ioclados* would probably indicate high intensity grazing. However, there are extensive areas of the Crater where *Cynodon dactylon* and *Cynodon nlemfuensis* are tall, dense and have substantial moribund material. Under these conditions, both species tend to elevate their stolons and develop aerial tillers from the elevated stolons. *Cynodon dactylon* appears to be well adapted to high intensity grazing where it flourishes in prostate, short growth form and in areas of lower grazing intensity where is able to elevate its stolons and compete effectively with some of the taller grasses. These characteristics ensure adaptation to a range of conditions, both in terms of grazing intensity and fluctuating climatic conditions which may favour taller or short grasses.

It is obvious that there has been substantial change in the vegetation composition between 1972 and 2004. These changes correspond to two obvious management changes that were implemented around the time of the 1972 survey. Firstly, Maasai cattle were removed from the Crater and secondly the previously frequent fires were prohibited. Unfortunately, there are no accurate records of the numbers of Maasai cattle resident in the Crater prior to 1972. Wild animal numbers and the ratios between animal species changed substantially between 1972 and 2004. While the changes in vegetation species composition are complex, there seems to have been a marked change towards taller grasses such as *Chloris gayana* at the expense of shorter grasses such as *Digitaria abyssinica*. Grasses known to flourish under frequent fire conditions, such as *Themeda triandra*, have declined. *Cynodon dactylon* has increased substantially in most areas of the Crater, and occurs in all vegetation types from dry, short grasslands to tall, moist grasslands. It appears to be well adapted to all conditions encountered, and there may be several ecotypes of *Cynodon dactylon* in the Crater. At least some of these changes could be attributed to the management changes, of which the most important is probably the prohibition of fire. The increase of buffalo numbers and the concurrent decrease in wildebeest numbers is likely to be a consequence of the increasing grass sward height associated with the increasing abundance of *Chloris gayana* and other taller grasses.

Herlocker & Dirschl (1972) recorded the crown cover of woody plants in the regions close to the Crater walls, particularly along the southern and eastern walls. However, they recorded cover by estimating the canopy cover and assigning it to classes 0-20%, 21-60% and 61-100%. It was not possible to objectively repeat their observations for comparison purposes. When Herlocker visited the Crater in 2004 for the first time since 1972, he was surprised to see that the cover of woody plants in the grasslands close to the Crater walls has increased substantially in recent years as compared to the 1970's, and that the extent of the areas encroached by woody plants has increased. This is also likely to be as consequence of reduced fire frequency.

There are no records of significant climate change, or any other major changes that may have influenced grass species composition changes to the extent outlined above.

In conclusion, it has been shown that the changes in grassland composition and animal numbers can be at least partially attributed to the removal of cattle and prohibition of fire several decades ago. This raises the question of using fire as a means of management intervention. The indications are, for the grassland on the Crater floor, fire may contribute to increasing species diversity and reversing the trend of increasing dominance by *Cynodon dactylon* and *Chloris gayana*.

CHAPTER FOUR: DESCRIPTION OF GRASSLAND HOMOGENOUS VEGETATION UNITS

4.1. Introduction

The main objective of the surveys carried out by Herlocker & Dirschl (1972) was to describe and map the vegetation of the Ngorongoro Conservation Area (NCA). They followed an approach of delineating mapping units from aerial photographs. These mapping units reflected mainly topographic positions and gross physiognomic differences between adjacent vegetation units. Further subdivisions were made on the basis of differences in tone, texture or appearance as viewed through a stereoscope. The resulting map is an accurate reflection of the vegetation of the area. In particular, greater effort was put into surveying the Ngorongoro Crater than the rest of the NCA. This has resulted in a detailed map of the Crater vegetation with 20 vegetation types delineated in the grasslands.

From chapter 3, it is clear that significant changes in the species composition have occurred over large areas of the Crater floor. In addition, for coarse management purposes, such as planning controlled burns, taking account of 20 vegetation types in an area the size of the Crater is considered too fine a scale for practical purposes. Data from the re-survey of the grasslands of the Crater carried out in 2004 were used to objectively define Homogenous Vegetation Units (HVU's) comprising one or more of the original vegetation types with the intention that the HVU's would be at a scale suitable for management purposes.

4.2. Methods

Consequently, in order to develop a scientific base for management decision-making, data from the 2004 survey (outlined in chapter 3) were summarised and analysed using multivariate classification and ordination techniques. TWINSPAN (Hill *et al.* 1975) was used to delineate the Homogenous

Vegetation Units (HVU's), while Correspondence Analysis (Ter Braak & Smilauer 1998) was used to describe the transects and HVU's in terms of dominant species and describe the main species in relation to their occurrence with different associations of species. The HVU's comprised groups of transects from the vegetation types described by Herlocker & Dirschl (1972). Additional transects were surveyed in areas considered to be underrepresented, and extensive visual ground truthing was carried out to verify the species composition of the various vegetation types delineated by Herlocker & Dirschl (1972). It was decided to conduct the analyses using the repeated surveys of the original transects.

A vegetation map was developed using the boundaries (based on topographic features) defined by Herlocker & Dirschl (1972). Using a digitised base map, the HVU's were delineated using ARCVIEW 3.2.

4.3. Results

The grassland species composition data (Appendix 2) has been summarised to indicate species frequencies (occurrence in transects) and means (Table 4.1). *Cynodon dactylon*, *Digitaria abyssinica*, *Chloris gayana* and *Andropogon greenwayi* respectively dominate the grassland in terms of frequency, with *Cynodon dactylon* occurring in 38 of the 39 transects. *Sporobolus fimbriatus*, *Themeda triandra*, *Sporobolus spicatus* and *Sporobolus ioclados* occurred with a frequency of between 10 and 20. Many species occurred in a more localised pattern. Eight species occurred in only one transect. *Pennisetum schimperi* occurred in only one transect, but comprised 29 % of that transect. Several grass species were locally dominant, but not widely distributed. In general, most transects were dominated by relatively few species, making the division into HVU's relatively straightforward.

The TWINSPAN classification procedure grouped the 39 transects into six HVUs at the third level (Figure 4.1). The separation of transects according to species composition conveniently created units that are similar enough in composition and structure to facilitate management of the units independently.

Table 4.1. Summary of the abundance of species across 39 grass transects, ranked according to frequency.

Species	**Frequency**	**% Frequency**	**Maximum**	**Mean**	**Local mean**
Cynodon dactylon	38	97.4	71	31	32
Digitaria abyssinica	34	87.2	47	17	19
Chloris gayana	29	74.4	60	13	17
Andropogon greenwayi	22	56.4	74	11	19
Sporobolus fimbriatus	16	41.0	21	3	7
Themeda triandra	16	41.0	50	6	14
Sporobolus spicatus	13	33.3	22	3	8
Sporobolus ioclados	13	33.3	35	4	11
Pennisetum mezianum	9	23.1	14	1	4
Chloris pycnothrix	9	23.1	30	1	6
Cynodon nlemfuensis	8	20.5	32	1	6
Hyparrhenia hirta	7	17.9	11	1	6
Panicum coloratum	7	17.9	34	1	8
Eragrostis tenuifolia	5	12.8	4	0	2
Brachiaria umbratilis	5	12.8	22	1	8
Aristida adscensionis	4	10.3	3	0	2
Cenchrus ciliaris	4	10.3	9	1	6
Bothriochloa insculpta	3	7.7	3	0	2
Hyparrhenia sp	3	7.7	19	1	13
Odyssea jaegeri	3	7.7	22	1	9
Setaria sphacelata	3	7.7	50	2	23
Sporobolus africana	2	5.1	2	0	2
Pennisetum stramenium	2	5.1	6	0	4
Cymbopogon afronadus	2	5.1	9	0	5
Pennisetum clandestinum	2	5.1	12	0	7
Dactylotenium aegypticum	1	2.6	1	0	1
Diplachne fusca	1	2.6	1	0	1
Setaria pumila	1	2.6	1	0	1
Panicum repens	1	2.6	3	0	3
Cyperus rotundrus	1	2.6	4	0	4
Brachiaria erucifomis	1	2.6	5	0	5
Heteropogon contortus	1	2.6	6	0	6
Pennisetum schimperi	1	2.6	29	1	29

The abundance of each species in the six HVU's (Table 4.2) gives an indication of the important species within and between HVU's. The sward height and point to tuft distance measures for each unit are related to the species composition of the HVU's. Differences in sward height and point to tuft distance were examined using Analysis of Variance (ANOVA) using the GENSTAT statistical package. HVU 1 and HVU 5 were taller than the remainder of the HVU's. The point to tuft distances were skewed and were consequently transformed using a log transformation before analysis to fulfil the requirements for ANOVA. The point to tuft distances were quite variable within transects and were not significantly different between HVU's. The untransformed point to tuft distances are presented in Table 4.2 for convenience and easy comparison with other studies.

Two species, namely *Chloris gayana* and *Cynodon dactylon* dominated HVU 1 (Table 4.2) which collectively comprises 80% of the proportional composition. *Chloris gayana* is a particularly tall species in the local environment, and the sward height of this HVU as measured by the DPM (15.4 cm) reflects this. Both species are stoloniferous. *Cynodon dactylon, Digitaria abyssinica, Sporobolus ioclados, Chloris gayana* and *S. spicatus* dominate HVU 2 (Table 4.2). The shorter sward reflects the strong dominance by *C. dactylon*, with the remaining four species being less abundant. *Cynodon dactylon* and *Digitaria abyssinica* (collectively 84%) dominate HVU 3, which is consequently one of the shortest units in terms of sward height (Table 4.2). *Cynodon dactylon, Digitaria abyssinica, Sporobolus fimbriatus* and *Andropogon greenwayi* are dominant in HVU 4 (Table 4.2). HVU 5 is dominated by *Setaria sphacelata* and *Themeda triandra* (collectively 52%) with *Chloris gayana*, *Cynodon dactylon* and *Digitaria abyssinica* making up the balance, and is similar in sward height to HVU 1 (Table 4.2). *Andropogon greenwayi*, dominates HVU 6, with *Chloris gayana*, *Cynodon dactylon* and *Themeda triandra* being sub-dominant (Table 4.2). *Andropogon greenwayi* is a short species, and counter-balances the taller sub-dominants.

The relatively short point to tuft distances and non-significant differences between HVU's is probably a reflection of several factors. Many of the dominant grasses are stoloniferous, and many of the tufted grasses are grazed short continually and form short, dense grazing lawns.

The four dominant species from Table 4.1, normally *Cynodon dactylon, Digitaria abyssinica*, *Chloris gayana* and *Andropogon greenwayi* are all prominent in the TWINSPAN analysis.

Table 4.2. Mean abundance of grass species in the six TWINSPAN community types and indicator score for species in each group. (Shaded rows indicate significance (P<0.05) and dark shaded figures indicate abundance >10%).

	Mean abundance (%)						Indicator value (% of perfect indication)#							
	TWINSPAN Group												p-value	
Species	1	2	3	4	5	6	1	2	3	4	5	6		
Andropogon greenwayi		3.9		[illegible]	7.5	[illegible]	0	3	0	19	2	68	0.001	**
Aristida adscensionis		3.0	1.0		1.0	2.0	0	3	2	0	4	4	1.000	
Bothriochloa insculpta					2.0		0	0	0	0	60	0	0.003	**
Brachiaria erucifomis					5.0		0	0	0	0	20	0	0.193	
Brachiaria umbratilis		2.0	[illegible]	4.0			0	0	37	1	0	0	0.035	*
Cenchrus ciliaris		3.0			9.0		0	3	0	0	34	0	0.042	*
Chloris gayana	[illegible]	[illegible]	9.7	[illegible]	[illegible]	[illegible]	53	11	2	6	12	6	0.001	**
Chloris pycnothrix		3.0	2.0	30.0		11.0	0	2	13	8	0	3	0.788	
Cymbopogon afronadus					5.0		0	0	0	0	40	0	0.017	*
Cynodon dactylon	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19	19	31	18	6	6	0.001	**
Cynodon nlemfuensis	2.0	1.0		12.3	1.5		3	1	0	34	4	0	0.200	
Cyperus rotundrus	4.0						33	0	0	0	0	0	0.082	
Dactylotenium aegypticum				1.0				0	14	0	0	0	0.760	
Digitaria abyssinica	3.0	21.7	27.7	24.2	11.0	9.5	0	25	31	20	8	8	0.019	*
Diplachne fusca			1.0				0	0	14	0	0	0	0.732	
Eragrostis tenuifolia			3.0			1.5	0	0	32	0	0	7	0.062	
Heteropogon contortus					6.0		0	0	0	0	20	0	0.193	
Hyparrhenia hirta					7.6	1.0	0	0	0	0	96	1	0.001	**
Hyparrhenia sp					10.5	19.0	0	0	0	0	24	6	0.102	
Odyssea jaegeri		9.3					0	30	0	0	0	0	0.106	
Panicum coloratum			2.3	24.0	2.0	1.0	0	0	5	23	1	0	0.349	
Panicum repens				3.0			0	0	0	14	0	0	0.729	
Pennisetum clandestinum	7.0						67	0	0	0	0	0	0.006	**
Pennisetum mezianum		1.0	2.5	7.3	1.0		0	0	4	44	3	0	0.035	*
Pennisetum schimperi					29.0		0	0	0	0	20	0	0.181	
Pennisetum stramenium						3.5	0	0	0	0	0	29	0.196	
Setaria pumila			1.0				0	0	14	0	0	0	0.732	
Setaria sphacelata					32.0	4.0	0	0	0	0	38	1	0.035	*
Sporobolus Africana					2.0	1.0	0	0	0	0	15	4	0.420	
Sporobolus fimbriatus	1.0	4.0	3.0	[illegible]	7.0	9.3	1	2	3	2	7	42	0.026	*
Sporobolus iocIados	2.0	[illegible]			4.0		6	86	0	0	1	0	0.001	**
Sporobolus spicatus	5.5	[illegible]	2.5		1.0		18	53	2	0	0	0	0.010	*
Themeda triandra		1.0		4.3	[illegible]	[illegible]	0	0	0	2	57	38	0.006	**

Means for sward							ANOVA			
Structural variables	1	2	3	4	5	6	df	F-ratio	p-value	
Disc height (cm)^1	15.4a	7.3b	7.1b	9.5b	14.6a	9.4b	5	7.1	0.0001	***
Standard deviation	1.98	2.20	3.08	4.17	1.17	3.68				
Point-plant distance (cm)	1.73	2.02	1.42	1.39	1.64	1.17			NS	
Standard deviation	0.17	1.38	0.14	0.14	0.50	0.07				

Means with no letters in common are significantly different (LSD: p=0.05)

average abundance of species in a group of sites over the average abundance of that species in all sites

However, several less dominant species, such as *Themeda triandra*, *Hyparrhenia hirta*, *Chloris pycnothrix* and *Sporobolus fimbriatus*, among others, are prominent in the process of allocating transects to vegetation units (Figure 4.1). This implies that absence or lack of dominance of species is also important in determining HVU's.

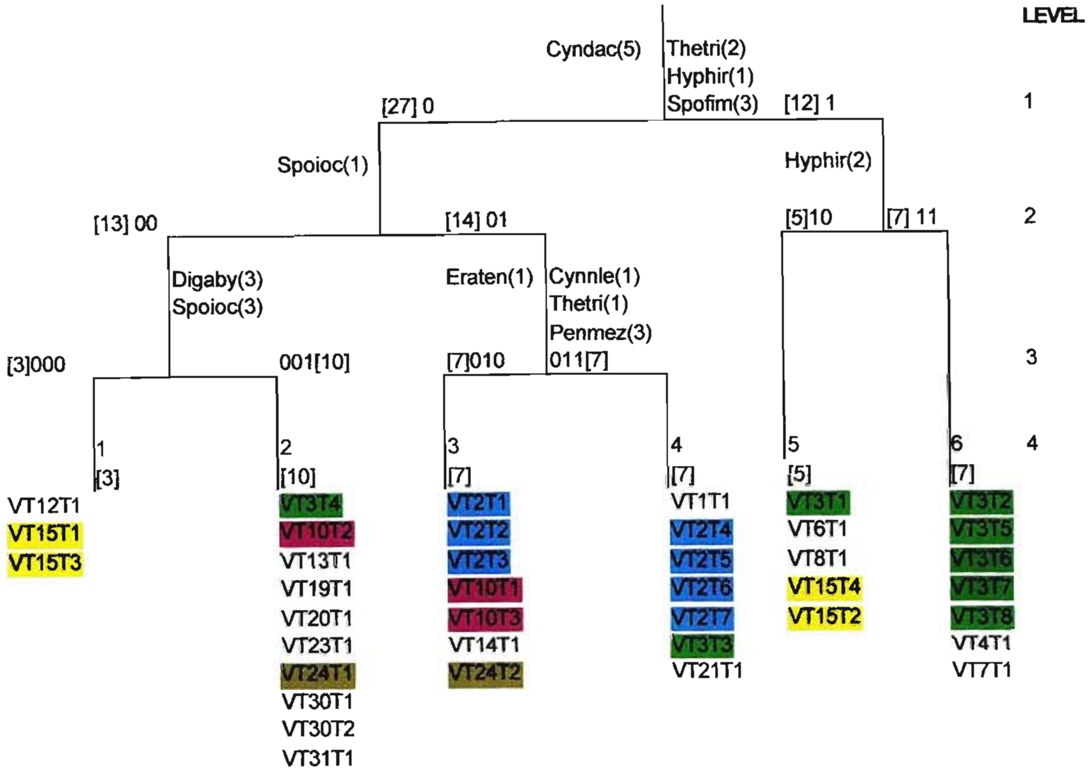

Figure 4.1. Dendrogram of the Two-Way Indicator Species Analysis (TWINSPAN) of 39 grass sampling transects (relative abundance). (The grass species names correspond to those outlined in Appendix 1 and the colours indicate the distribution of transects from the original vegetation types into the HVU's. Unshaded transects represent vegetation types (VT) covered by single transects (T)). Numbers in square brackets indicate transects.

Examination of the current grouping of Herlocker & Dirschl's vegetation types (Figure 4.1) reinforces the changes that have taken place, where many of the transects of the original vegetation types have been separated by the classification analysis. Although different criteria were used in the original study to delineate vegetation units, the substantial differences do reinforce the fact that changes have taken place.

Further insight was gained into the relations between species and their associations with other species from the CA. Rare species were down weighted and the species *Pennisetum schimperi* was made passive, because it occurred only in one transect and dominated the composition of that transect. The first four axes of the CA accounted for 59% of the variation in species data. The position of transects on the first two axes of the ordination diagram are not shown, due to the cluttered appearance of the plot. The position of the six HVU's defined by the TWINSPAN procedure is shown in Figure 4.2. Transects in HVU's 1, 2 and 3 are relatively tightly grouped on the ordination plot along both axes, while transects in HVUs 4, 5 and 6 are more spread out on the ordination plot. This corresponds to the discussion above, where HVUs 1, 2 and 3 are dominated by relatively few species, while the remainder of the HVUs comprise a more diverse range of dominant species. Clearly, the boundaries between the HVU's are somewhat blurred. This is confirmed by field experience, where the cosmopolitan nature of certain species, like *Cynodon dactylon*, creates an element of similarity across the Crater floor, particularly in the flatter areas away from the Crater walls.

The plot of species on the first two axes of the CA ordination plot (Figure 4.3) reveals that HVUs 1, 2 and 3, the most tightly grouped, are dominated by relatively few species in close proximity on the first two axes. HVU's 4, 5 and 6 all comprise a wider range of species. Superimposing the sward height on the ordination plot (Figure 4.4) reveals a consistent trend across the HVU's, with HVU 2 and 3 being relatively short, 4 and 6 intermediate and 1 and 5 being tall. Superimposing point to tuft distance on the ordination plot (Figure 4.5) reveals that the areas with a reasonably diverse species composition and a relatively high proportion of *Themeda triandra* tended to have the lowest point to tuft distance, although it must be remembered that there was a high variation in the point to tuft distances and they were not significantly different between HVU's when tested using ANOVA.

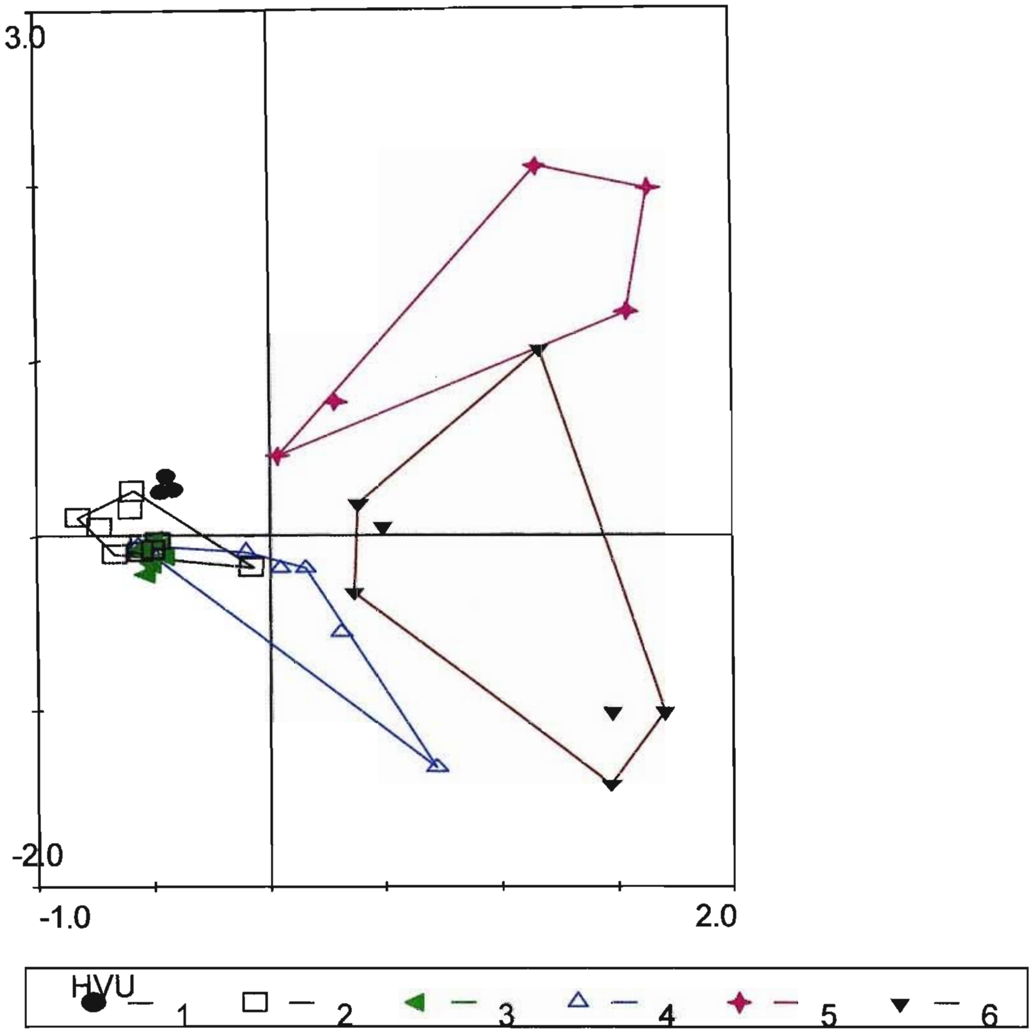

Figure 4.2 Plot of transects along the first two axes of a correspondence analysis (CA) of the grass composition data. (Envelopes enclose transects belonging to six vegetation communities defined by TWINSPAN. Numbers in the legend correspond to the six Homogenous Vegetation Units in the Ngorongoro Crater described in the text).

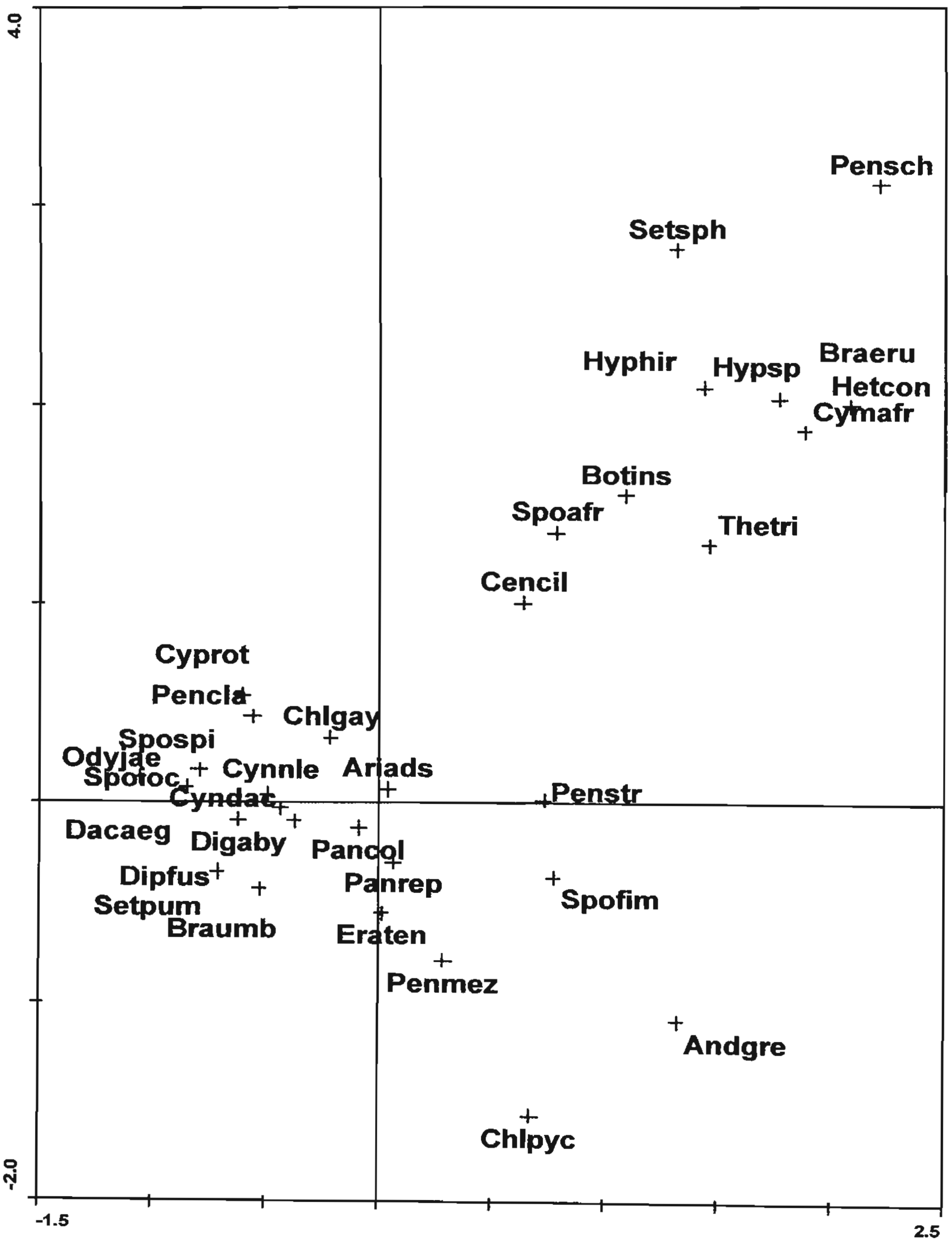

Figure 4.3. Plot of species along the first two axes of a correspondence analysis (CA) of the grass composition data. (See Appendix 1 for full species names).

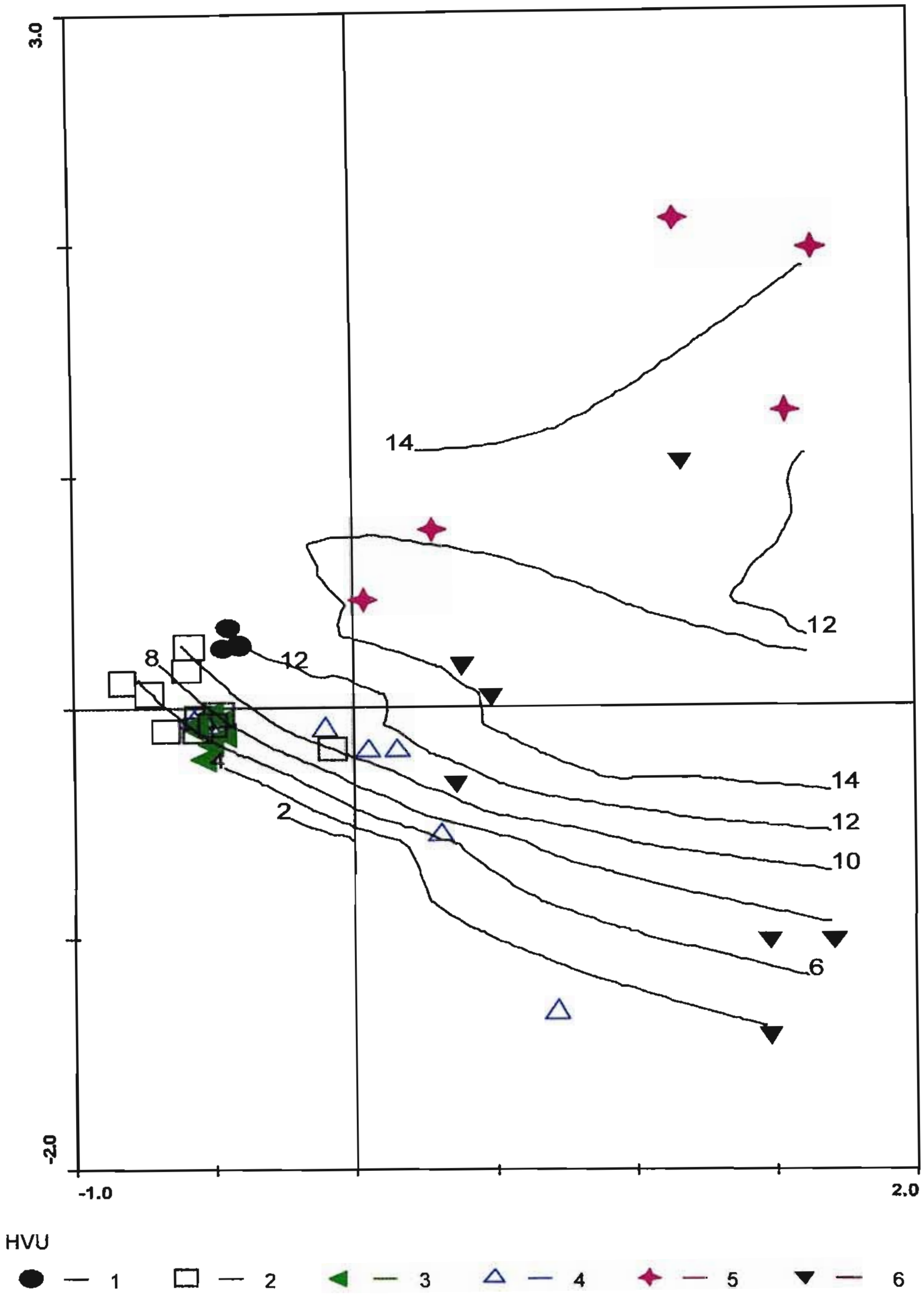

Figure 4.4. Plot of transects and trend of mean pasture disc meter along the first two axes of a correspondence analysis of grass relative abundance data. Numbers in the legend correspond to the six Homogenous Vegetation Units in the Ngorongoro Crater described in the text. Contour lines reflect average disc pasture metre height (cm).

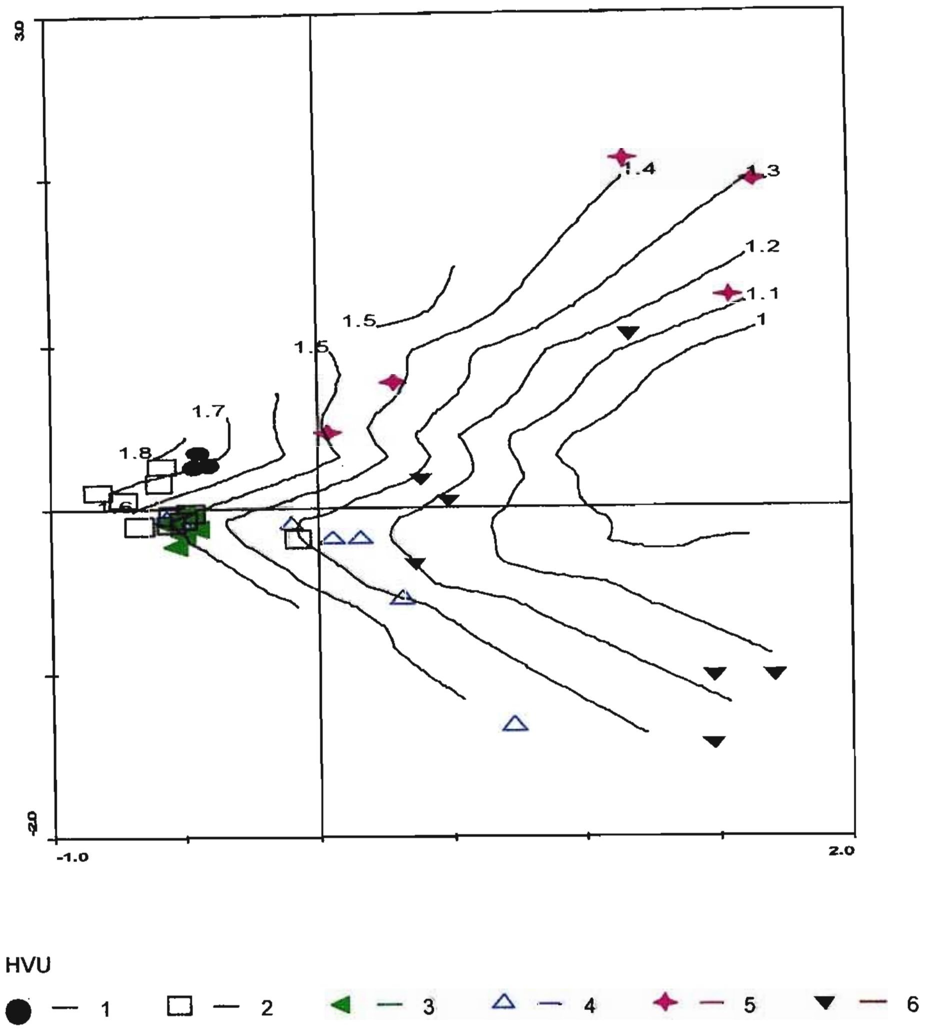

Figure 4.5. Plot of transects and trend in mean point-plant distance along the first two axes of a correspondence analysis of grass relative abundance data. Numbers in the legend correspond to the six Homogenous Vegetation Units in the Ngorongoro Crater described in the text. Contour lines represent mean point to tuft distance (cm).

4.4. Vegetation Map

The HVU's are made up of patches of vegetation dispersed throughout the Crater. From a management perspective, this can be useful when planning management interventions such as controlled burning. Controlled burning can either be carried out on a block burn basis where large areas are burnt at once, or in a mosaic fashion where smaller, unconnected areas are burnt. The block burn approach is usually easier, while the mosaic approach may allow achieving a wider range of objectives for controlled burning. Both approaches need to be carefully planned, and a vegetation map is a useful tool for planning and enhancing decision making processes.

A vegetation map was developed using the original map developed by Herlocker & Dirschl (1972) as a base, with the new consolidated homogenous vegetation units indicated (Appendix 8). Comparisons between the 1972 and 2004 surveys have revealed a significant change in vegetation composition represented by a convergence of species composition to a system dominated by fewer species. It makes sense then to represent fewer units on the vegetation map. This also allows the map to be easily used for management planning purposes. The map will also provide a baseline for monitoring of the ecological trends of the Crater and follow-up studies in future.

CHAPTER FIVE: DEVELOPMENT OF BASELINE MONITORING SYSTEM IN SCRUB DOMINATED VEGETATION ADJACENT TO THE WALLS OF THE NGORONGORO CRATER

5.1. Introduction

In the Ngorongoro Crater, the transitional area between the grasslands dominating the Crater floor and the forest and woodland on the Crater walls comprises scrub vegetation dominated by shrubs such as *Lippia javanica* and *Lippia ukambensis* and a range of others shrubs ranging in height from very short to about two metres tall. This scrub vegetation forms ideal habitat for black rhino, one of the most important animal species and one of the only obligate browsing animal species in the Crater. The black rhino do not readily browse on the dominant *Lippia javanica* (Brown 2004), which tends to grow tall and compete very effectively against other shrub and forbs species that are more favoured by black rhino. No baseline data relating to shrub density in the scrub areas is available that could be used for comparative purposes. Recent research (Brown 2004) has identified those species favoured by black rhino.

There is a strong perception among conservation staff, backed up by photographic evidence, that the extent of the scrub vegetation has increased, and the density of a few dominant shrubs such as *Lippia* spp. has increased at the expense of other, shorter species of shrubs as well as the grass layer. Observations after a recent fire in an area of scrub vegetation indicate that black rhinos favour recently burnt areas and have been observed feeding in those areas for extended periods (Brown 2004). A variety of shrubs and forbs previously suppressed by the tall, dense *Lippia* spp. have been noted to be flourishing in recently burnt scrub vegetation.

In the absence of previous baseline data in the scrub vegetation, it was considered essential to collect and record baseline data on vegetation structure, composition and density that can be used for immediate decision-making for fire management as well as serving as a starting point for longer term monitoring.

There are two patches of *Acacia xanthophloea* dominated forest on the Crater floor. These forests, particularly the Lerai Forest, are deteriorating in that many of the mature trees are dying and regeneration appears to be slower than the rate of decline (Roux 2002). It was also considered important to establish some baseline data relating to vegetation composition and structure in these forests.

5.2. Methods

Bush surveys were conducted using the Point Centred Quarter technique in two distinct vegetation types, Lerai and Ngoitokitok *Acacia xanthophloea* Forests and the scrub vegetation that characterizes the lower slopes of the caldera adjacent to the grasslands (Whalley & Hardy 2000; Trollope & Webber 2002). Three transects were surveyed in the *Acacia xanthophloea* Forest vegetation and seven transects in the scrub vegetation.

Transects were sited around the caldera in the scrub so that distinct scrub communities were surveyed. Each transect comprised 50 points at intervals of 20 m. This interval was standard and chosen such that more widely spaced large trees could be accounted for. At each point, four quadrants were established and the following data was recorded, based on a modification of the PCQ technique developed by Trollope & Trollope (1999).

- In quadrants one and two, the nearest plant to the point that was <2 m in height within 20 m;
- In quadrants three and four, the nearest plant to the point that was >2 m in height within 20 m;
- In quadrant four, the tallest plant within 20 m;

The height of each plant was recorded.

The different height categories were selected to sample the full spectrum of the vegetation without overlap between quadrants from adjacent points. Without deliberately singling out species above 2 m in height, such specimens would tend to be recorded at a lower sampling intensity. Two metres was chosen because it represents an approximate limit of browse availability for black rhino. The 'tallest' category was introduced to record those large low density species that would tend to be missed if not placed in a specific category. Similar procedures were used by Trollope & Hines (2000) when assessing rangeland condition in the East Caprivi region of Namibia and Trollope & Trollope (1999) when assessing rangeland condition and fire ecology of the savanna vegetation on the Lewa Wildlife Conservancy in Kenya.

The data from these transects were analysed to determine the density and composition of the vegetation in the various height classes and the overall structure of the vegetation communities.

5.3. Results

The community structures for all ten sites surveyed in the bush and forest communities are presented in Figures 5.1 to 5.10 (note that the scale on the Y axis varies between figures) and the structure has been presented as number of plants ha^{-1} in half metre height categories in Tables 5.1 to 5.10 respectively. All sites superficially show similar structure in that the greatest density of plants is found below 2 m. The location of the transects is presented in Appendix 4.

Solanum incanum, a small woody shrub, was the most dominant species in seven transects with densities ranging from 4 050 plants ha^{-1} to 262 plants ha^{-1} and was the second most dominant species in another transect. Members of the Malvaceae such as *Abutilon longicuspe*, *Hibiscus aponeurus*, and to a lesser extent *Hibiscus flavifolius* and *Sida ovata* also dominated transects with species densities ranging from 2 326 plants ha^{-1} to 60 plants ha^{-1}. Members of the Verbenaceae were also dominant and were represented by *Lippia* *javanica*, *L. ukambensis* and to a lesser extent *Lantana trifolia*. Other species that were found to dominate the scrub vegetation were *Ocimum suave* and to a lesser extent *Achyranthes aspera* and *Thyathula polycephala*.

While *Lippia javanica* and *L. ukambensis* still dominated the height categories above 2 m on the transects sited in the typical caldera scrub vegetation, this was not the case for the transects in the typical woodland communities at Ngoitokitok and Lerai. At these sites *Acacia xanthophloea* dominated although this dominance by older trees was not accompanied by appreciable recruitment as indicated by the low density of plants below 2 m in height at Ngoitokitok (34 plants ha^{-1}) (Table 5.1) and at one transect at Lerai (109 plants ha^{-1}) (Table 5.4). The second transect at Lerai revealed increased recruitment (502 plants ha^{-1}) (Table 5.5) and probably reflects the patchy nature of the recruitment with a significant population of younger trees occurring in that vicinity of Lerai closer to the caldera slope. In comparison with other *Acacia* dominated vegetation, better recruitment was evident for *Acacia lahai* where communities were sampled at East Rhumbe and near Oljoronyuki sites (Table 5.8-5.10). While *A. lahai* dominated in the categories greater than two meters, this was accompanied by rather high densities of plants below 2 m of (846, 237 and 450 plants ha^{-1}) for the three sites respectively. At Gie spring 1 (Table 5.2) *Lippia javanica* and *L. ukambensis* dominated in the categories less than 2m of (1 590 and 1 119 plants ha^{-1}) respectively while *Solanum incanum*, *Abutilon longicuspe* and *Lippia ukambensis* dominated in the categories less than 2m in the Gie spring 2 (Table 5.3) with (262, 268 and 233 plants ha^{-1}) respectively. Density between sites varied from 1 142 plants ha^{-1} at the site at Ngoitokitok (Table 5.1) to 15 708 plants ha^{-1} at the site near Oljoronyuki (Table 5.10). This variation and the variation in the dominance of species in the various height categories indicates that the scrub and woodland communities are heterogenous and may have been influenced by a variety of environmental factors. Species such as *Vernonia auriculifera*, *Croton macrostachyus*, and *Clausena anisata* were frequent in the height categories above 2 m in numerous localities, while other species were localised. In the Lerai woodland community, *Ficus thonningii* was recorded while *Faidherbia albida*, (previously *Acacia albida*) of low density throughout the community, was not.

Table 5.1. The plant species and associated density (plants ha^{-1}) at the Ngoitokitok (1) site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	Frequency	Density (plants ha^{-1})	Frequency	Density (plants ha^{-1})	Frequency	Density (plants ha^{-1})	Total
Abutilon longicuspe	3	26	–	–	–	–	**26**
Acacia lahai	1	9	1	3	2	3	**15**
Acacia xanthophloea	4	34	32	80	40	61	**175**
Achyranthes aspera	33	282	–	–	–	–	**282**
Caparis tomentosa	3	26	2	5	–	–	**31**
Clausena anisata	11	94	26	65	–	–	**159**
Croton macrostachys	–	–	1	3	–	–	**3**
Gewia bicola	5	43	1	3	–	–	**46**
Grewia similes	–	–	1	3	–	–	**3**
Hibiscus aponeurus	2	17	–	–	–	–	**17**
Hibiscus flavifolius	7	60	–	–	–	–	**60**
Lippia javanica	9	77	10	25	1	2	**104**
Lippia ukambensis	4	34	4	10	–	–	**44**
Melhania ovata	2	17	–	–	–	–	**17**
Ocimum suave	7	60	–	–	–	–	**60**
Solanum incanum	3	26	–	–	–	–	**26**
Vangueria acutiloba	3	26	8	20	5	8	**54**
Vernonia auriculiphera	1	9	2	5	2	3	**17**
Vernonia lasiopus	1	9	–	–	–	–	**9**
Total	**99**	**845**	**88**	**221**	**50**	**76**	

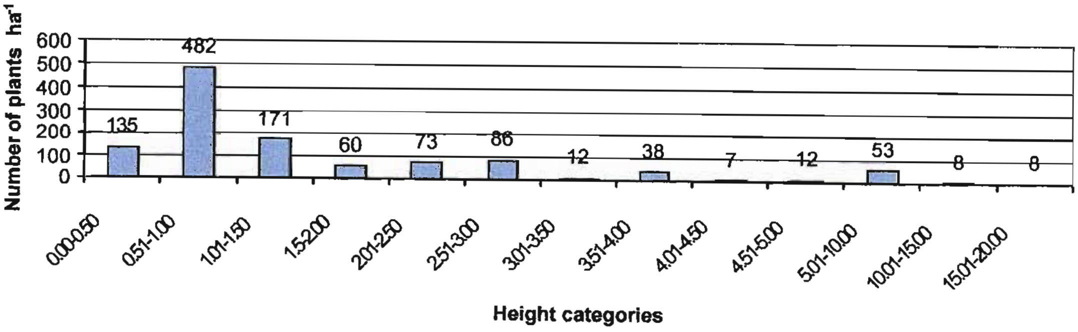

Figure 5.1. The community height structure of all woody plants at Ngoitokitok site in the Ngorongoro Crater.

Table 5.2. The plant species and associated density (plants ha^{-1}) at the Gie Spring (1) site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Total**
Abutilon longicuspe	6	353	3	11	–	–	**364**
Abutilon mauritianum	1	59	–	–	–	–	**59**
Clausena anisata	3	177	1	4	1	4	**185**
Croton macrostachyus	–	–	5	18	12	49	**67**
Hibiscus aponeurus	16	942	–	–	–	–	**942**
Lantana trifolia	1	59	1	4	–	–	**65**
Lippia javanica	27	1590	33	120	12	49	**1759**
Lippia ukambensis	19	1119	35	127	12	49	**1259**
Maerua senegalensis	–	–	2	7	3	12	**19**
Ocimum suave	16	942	1	4	–	–	**946**
Pavoria petens	1	59	–	–	–	–	**59**
Solanum incanum	8	471	–	–	–	–	**471**
Vangueria acutiloba	–	–	4	15	2	8	**23**
Vernonia auriculifera	2	118	15	54	8	33	**205**
Total	**100**	**5890**	**100**	**363**	**50**	**204**	

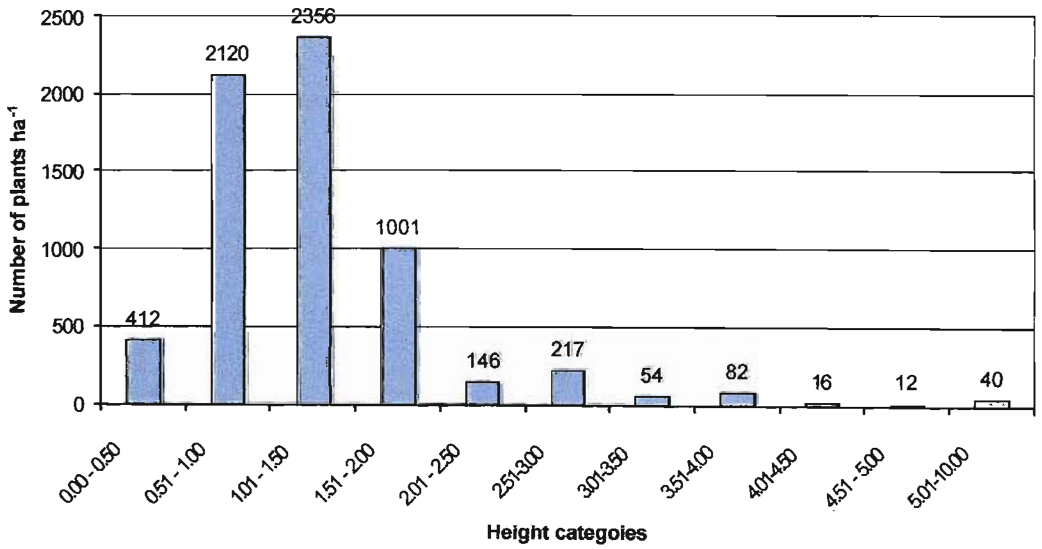

Figure 5.2. The community height structure of all woody plants at Gie Spring (1) in the Ngorongoro Crater.

Table 5.3. The plant species and associated density (plants ha^{-1}) at the Gie Spring (2) site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	**Frequency**	**Density (plants $^{ha-1}$)**	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Total**
Abutilon grandiflora	9	131	2	8	–	–	**139**
Abutilon longicuspe	17	248	6	24	–	–	**272**
Albizia petersiana	2	29	–	–	–	–	**29**
Achyranthes aspera	3	44	–	–	–	–	**44**
Bersama abyssinica	–	–	–	–	1	3	**3**
Buddleja polystacha	–	–	3	12	3	10	**22**
Caparis tomentosa	5	73	4	16	–	–	**89**
Celtis africana	–	–	2	8	6	21	**29**
Clausena anisata	8	117	14	55	7	24	**196**
Croton macrostachys	–	–	1	4	8	28	**32**
Ekebegia capensis	–	–	2	8	2	7	**15**
Erythrococca fischeri	–	–	1	4	–	–	**4**
Ficus thoningii	–	–	–	–	1	3	**3**
Hibiscus aponeurus	3	44	–	–	–	–	**44**
Lippia javanica	1	15	5	20	–	–	**35**
Lippia ukambensis	16	233	40	157	4	14	**404**
Ocimum suave	10	146	–	–	–	–	**146**
Pavonia patens	4	58	–	–	–	–	**58**
Solanum incanum	18	262	2	8	–	–	**270**
Trichilia emetica	1	15	1	4	–	–	**19**
Vangueria acutiloba	1	15	10	39	15	52	**106**
Vernonia auriculifera	–	–	6	24	1	3	**27**
Zanthoxylum chalybelium	2	29	1	4	2	7	**40**
Total	**100**	**1457**	**100**	**393**	**50**	**173**	

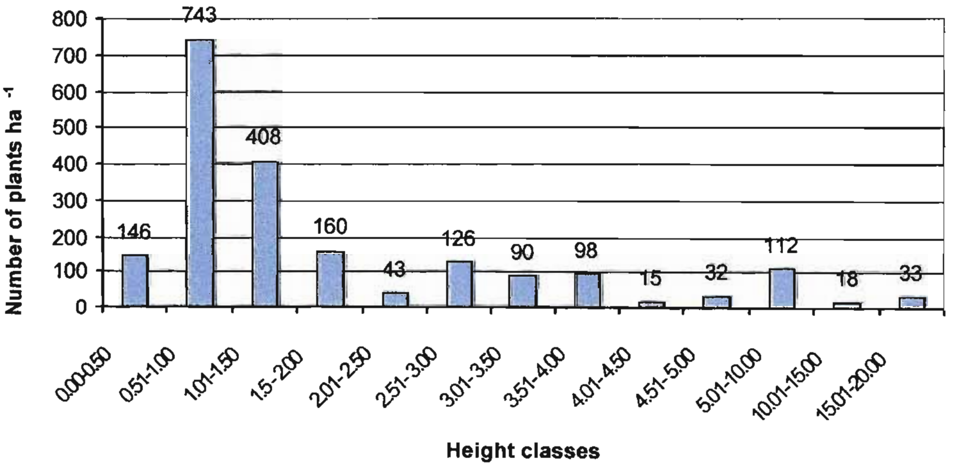

Figure 5.3. The community height structure of all woody plants at Gie Spring (2) in the Ngorongoro Crater.

Table 5.4. The plant species and associated density (plants ha^{-1}) at Lerai Forest (1) site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	Frequency	Density (plants ha^{-1})	Frequency	Density (plants ha^{-1})	Frequency	Density (plants $^{ha-1}$)	Total
Abutilon grandiflorum	2	36	–	–	–	–	36
Abutilon longicuspe	7	127	–	–	–	–	127
Acacia xanthophloea	6	109	80	77	49	71	257
Achyranthes aspera	3	55	–	–	–	–	55
Caparis tomentosa	1	18	–	–	–	–	18
Croton macrostachys	–	–	–	–	1	1	1
Grewia bicolour	1	18	–	–	–	–	18
Hibiscus aponeurus	10	182	–	–	–	–	182
Hibiscus flavifolius	9	164	–	–	–	–	164
Pavonia patens	22	400	–	–	–	–	400
Solanum incanum	37	673	–	–	–	–	673
Vangueria acutiloba	2	36	3	3	–	–	39
Total Density	**100**	**1820**	**83**	**80**	**50**	**72**	

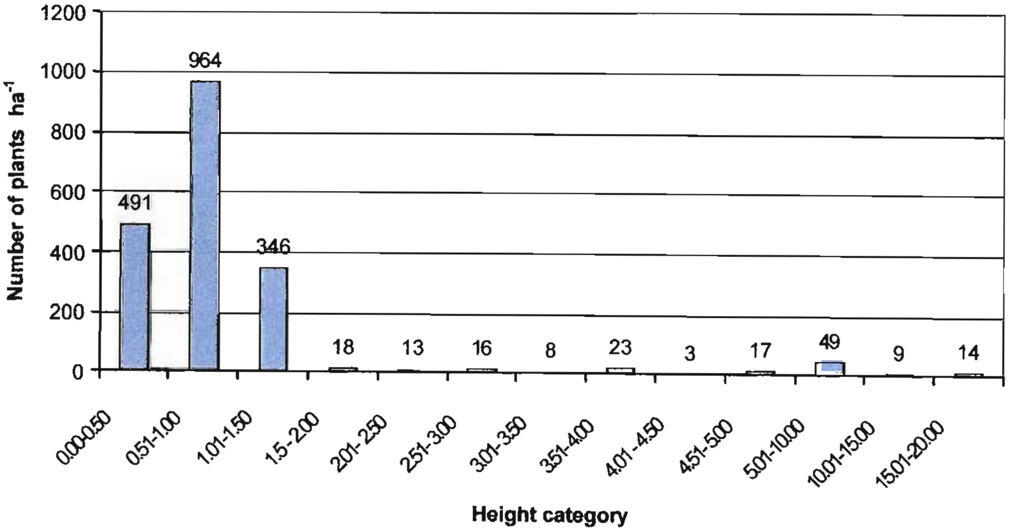

Figure 5.4. The community height structure of all woody plants at Lerai Forest (1) in the Ngorongoro Crater.

Table 5.5. The plant species and associated density (plants ha^{-1}) at Lerai Forest (2) site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Total**
Abutilon grandflorum	17	1068	–	–	–	–	**1068**
Abutilon longicuspe	1	63	–	–	–	–	**63**
Abutilon mauritianum	1	63	–	–	–	–	**63**
Acacia xanthophloea	8	502	64	128	45	59	**689**
Achyranthes aspera	14	879	–	–	–	–	**879**
Caparis tomentosa	3	188	5	10	–	–	**198**
Erythroccoca fischeri	–	–	3	6	–	–	**6**
Ficus thoningii	–	–	3	6	2	3	**9**
Grewia bicola	1	63	1	2	2	3	**68**
Hibiscus aponeurus	6	377	–	–	–	–	**377**
Pavonia patens	16	1005	–	–	–	–	**1005**
Solanum incanum	33	2073	1	2	1	1	**2006**
Vangueria acutiloba	–	–	1	2	–	–	**2**
Total	**100**	**6281**	**78**	**156**	**50**	**65**	

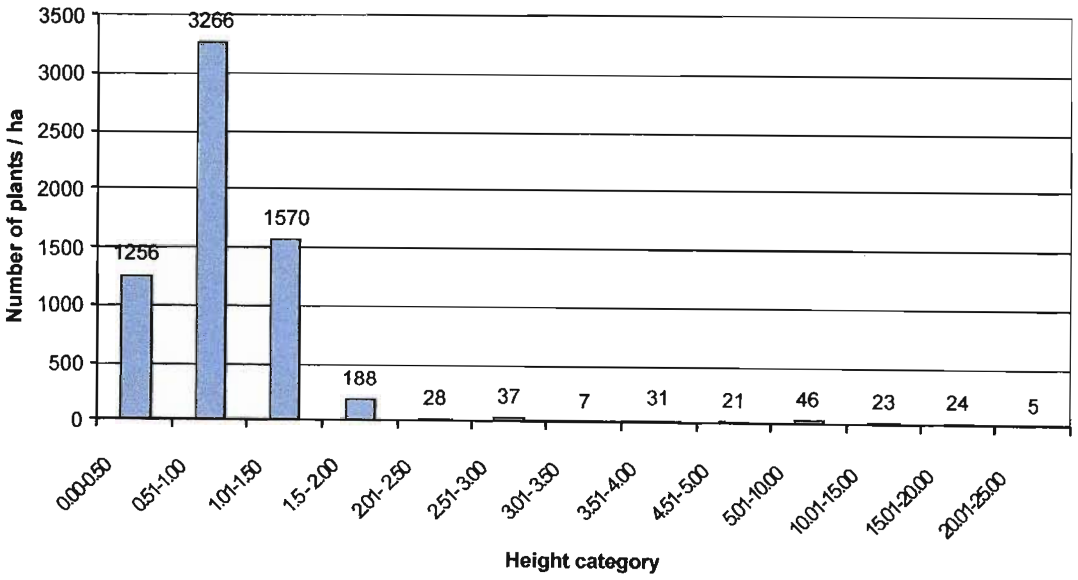

Figure 5.5. The community height structure of all woody plants at Lerai Forest (2) in the Ngorongoro Crater.

Table 5.6. The plant species and associated density (plants ha^{-1}) at East Munge (1) site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Total**
Abutilon longicuspe	–	–	17	110	–	–	**110**
Acacia lahai	7	470	3	19	8	29	**518**
Buddleja polystachya	–	–	–	–	1	4	**4**
Cassia didymobotria	–	–	3	19	1	4	**23**
Croton macrostachys	–	–	2	13	12	44	**57**
Euclea divinorum	–	–	–	–	2	7	**9**
Hibiscus aponeurus	3	201	1	6	–	–	**207**
Indigofera arecta	1	67	1	6	–	–	**73**
Lantana trifolia	1	67	1	6	–	–	**73**
Lippia javanica	5	336	16	104	2	7	**447**
Lippia ukambensis	9	604	36	233	12	44	**881**
Ocimum suave	11	738	5	32	–	–	**770**
Sida ovata	22	1477	–	–	–	–	**1477**
Solanum incanum	38	2551	1	6	–	–	**2557**
Vernonia auriculifera	3	201	14	91	12	44	**336**
Total density	**100**	**6713**	**100**	**647**	**50**	**182**	

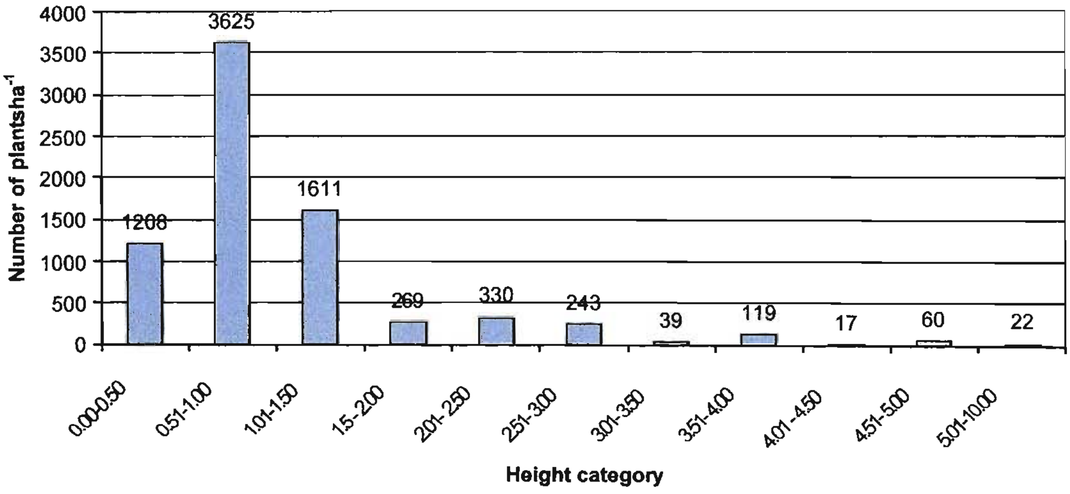

Figure 5.6. The community height structure of all woody plants at East Munge (1) in the Ngorongoro Crater.

Table 5.7. The plant species and associated density (plants ha^{-1}) at East Munge (2) site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Total**
Abutilon longicuspe	2	143	11	86	1	6	**235**
Acacia lahai	–	–	–	–	1	6	**6**
Buddleja polystachya	–	–	–	–	1	6	**6**
Cassia didymobytria	–	–	1	8	–	–	**8**
Croton macrostachys	1	71	4	31	16	89	**191**
Euclea divinosum	–	–	1	8	2	11	**19**
Hibiscus aponeurus	5	357	–	–	–	–	**357**
Lantana trifolia	–	–	2	16	–	–	**16**
Lippia javanica	1	71	18	140	5	28	**239**
Lippia ukambensis	7	500	46	358	14	78	**936**
Ocimum suavum	3	214	10	78	–	–	**292**
Sida ovata	50	3573	–	–	–	–	**3573**
Solanum incanum	31	2215	–	–	–	–	**2215**
Vernonia auriculifera	–	–	7	54	10	56	**110**
Total	**100**	**7145**	**100**	**778**	**50**	**278**	

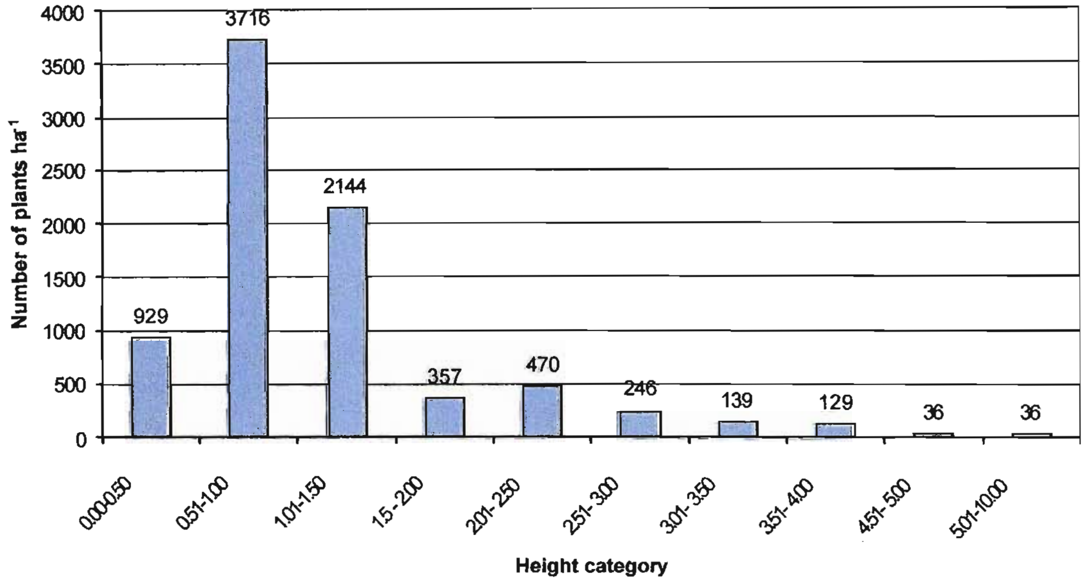

Figure 5.7. The community height structure of all woody plants at East Munge (2) with *Erythrina* belt in the Ngorongoro Crater.

Table 5.8. The plant species and associated density (plants ha^{-1}) at East Rhumbe (1) site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants $^{ha-1}$)**	**Total**
Acacia lahai	8	846	38	191	37	184	**1221**
Achyranthes aspera	8	846	–	–	–	–	**846**
Buddleja polistacha	1	106	–	–	–	–	**106**
Hibiscus aponeurus	22	2326	–	–	–	–	**2326**
Indigofera arecta	1	106	–	–	–	–	**106**
Lantana trifoium	11	1163	13	65	3	15	**1243**
Lippia javanica	15	1586	35	176	8	40	**1802**
Lippia ukambensis	1	106	12	60	2	10	**176**
Ocimum suave	5	529	1	5	–	–	**234**
Solanum incanum	27	2855	1	5	–	–	**1860**
Vernonia auriculifera	1	106	–	–	–	–	**106**
Total	**100**	**10573**	**100**	**502**	**50**	**248**	

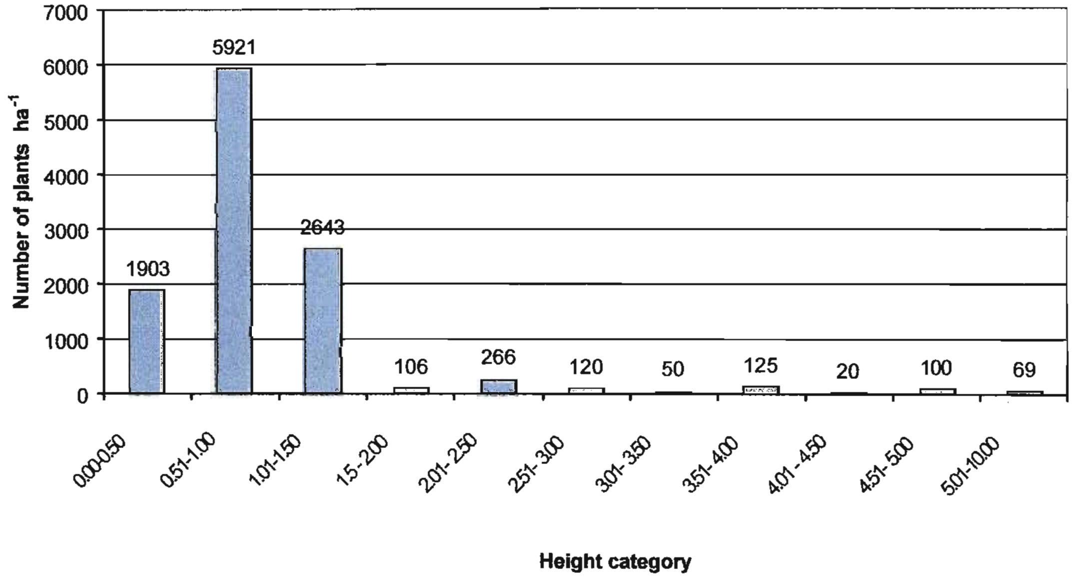

Figure 5.8. The community height structure of all woody plants at East Rhumbe (1) in the Ngorongoro Crater.

Table 5.9. The plant species and associated density (plants ha^{-1}) at East Rhumbe (2) site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Frequency**	**Density (plants ha^{-1})**	**Total**
Abutilon longicuspe	15	1187	5	24	–	–	**1211**
Acacia lahai	3	237	49	240	34	281	**758**
Achyranthes aspera	13	1029	2	10	–	–	**1039**
Cyathula polycephala	5	396	–	–	–	–	**396**
Hibiscus aponeurus	6	475	–	–	–	–	**475**
Lantana trifolia	6	475	5	24	–	–	**495**
Lippia javanica	3	237	11	54	3	25	**316**
Lippia ukambensis	4	317	26	127	13	107	**551**
Ocimum suave	9	712	2	10	–	–	**722**
Pavonia patens	2	158	–	–	–	–	**158**
Solanum incanum	33	2612	–	–	–	–	**2612**
Vernonia auriculifera	1	79	–	–	–	–	**79**
Total	**100**	**7914**	**100**	**490**	**50**	**413**	

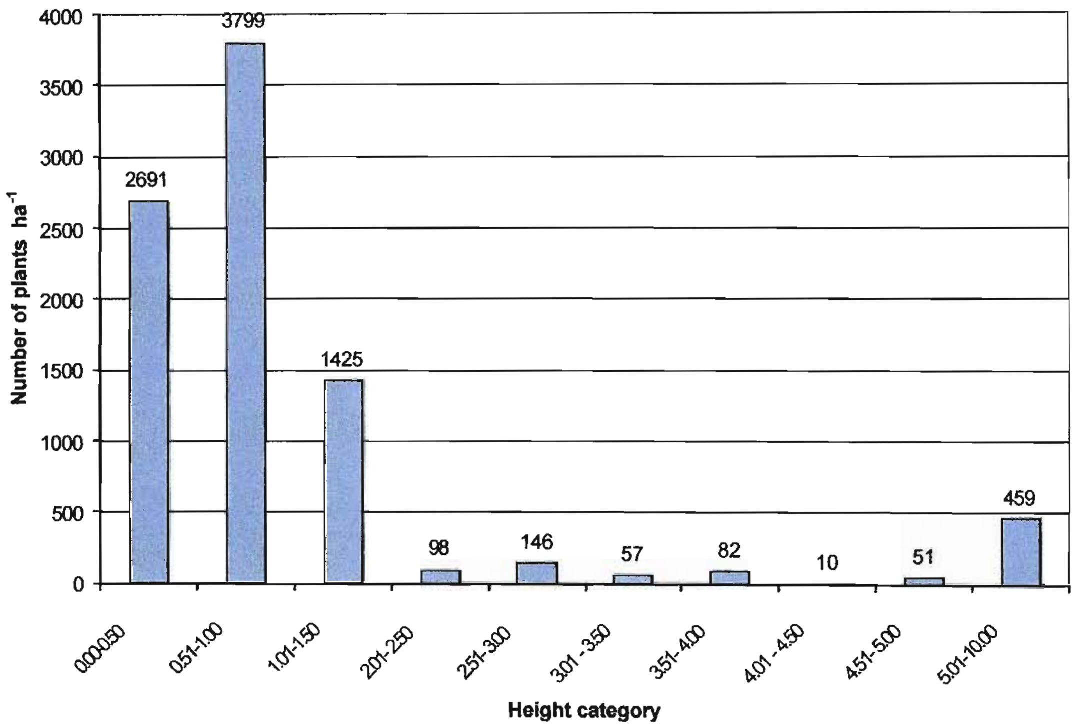

Figure 5.9. The community height structure of all woody plants at East Rhumbe (2) in the Ngorongoro Crater.

Table 5.10. The plant species and associated density (plants ha^{-1}) at Oljoronyuki site in the Ngorongoro Crater as determined by the point centred quarter method.

	<2m		>2m		Tallest		
Species	Frequency	Density (plants ha^{-1})	Frequency	Density (plants ha^{-1})	Frequency	Density (plants ha^{-1})	Total
Abutilon longicuspe	15	2250	12	57	1	5	**2312**
Acacia lahai	3	450	27	127	29	138	**715**
Achyranthes aspera	7	1050	2	9	–	–	**1059**
Cyathula polycephala	8	1200	–	–	–	–	**1200**
Hibiscus aponeurus	5	750	–	–	–	–	**750**
Indigofera arecta	2	300	–	–	–	–	**300**
Lantana trifolia	12	1800	10	47	–	–	**1847**
Lippia javanica	6	900	10	47	2	9	**956**
Lippia ukambensis	5	750	36	170	18	85	**1005**
Ocicimum suave	9	1350	2	9	–	–	**1350**
Pavonia Patens	1	150	–	–	–	–	**150**
Solanum incanum	27	4050	1	5	–	–	**4055**
Total	**100**	**15000**	**100**	**471**	**50**	**237**	

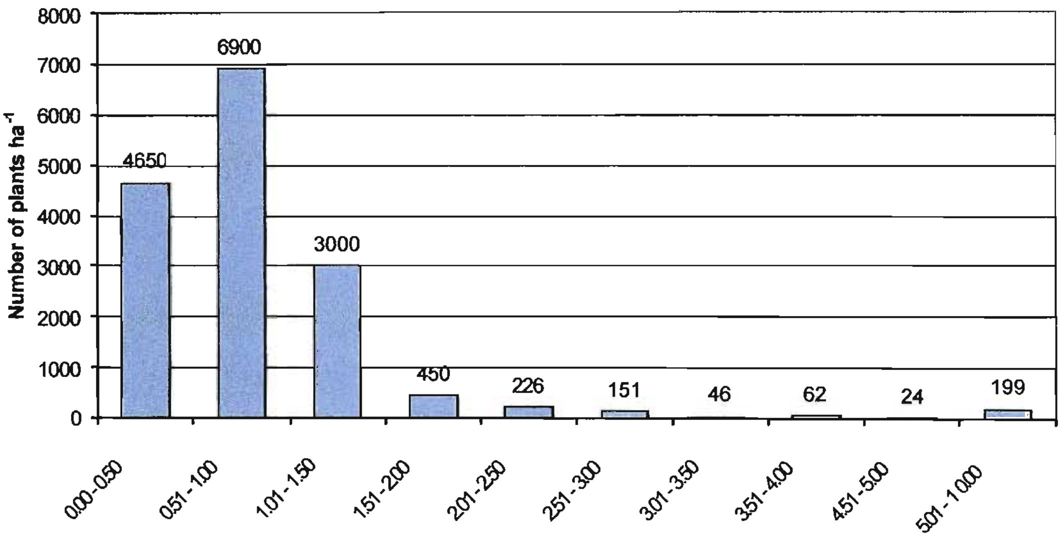

Figure 5.10. The community height structure of all woody plants at Oljoronyuki in the Ngorongoro Crater.

5.4. Discussion

While the PCQ technique and other distance based sampling techniques have been criticised for yielding inaccurate density figures (e.g. Cottram & Curtis 1956; Mark & Esler 1970), the absolute density is less important than the changes in density over time. As a monitoring technique the PCQ technique is acceptable, particularly considering that the distance from point to plant is the actual measure of importance. Changes in distance can be measured accurately. It is convenient to convert these distances into densities, but the potential inaccuracies should be remembered.

The structural data revealed interesting trends in that the greatest density was usually found between 0.51 and 1.00 m in all transects and plants over two metres in height were rare, even in the *Acacia xanthophloea* forests.

While there is a reasonable diversity of species in the scrub areas, it was noticeable that in the areas with the greatest density of shrubs, a few species dominated. In many cases these included *Lippia javanica*, *Lippia ukambensis* or *Solanum incanum*. Black Rhino do eat *Lippia ukambensis*, but do not favour *Lippia javanica* or *Solanum incanum* (Brown 2004). Where densities were lower, a greater diversity of shrubs occurred.

Although these surveys were intended to develop baseline data for future monitoring, the observations above may be useful in the decision making process for deciding on whether to burn or not.

Once decisions have been made on the desired state of the scrub vegetation, then the above data can be used to assist decisions on whether to burn or not and on the type of fire that would be most appropriate. The following pointers should be useful:

1. If encroachment of scrub vegetation into grasslands is evident, then consider regular fire to maintain original boundaries, unless there is a specific requirement for increasing scrub vegetation, for example increasing habitat for black rhinos. Regular hot fires would be effective in controlling or reversing encroachment and maintaining the grass layer.

2. If scrub vegetation is dominated by one or a few species (e.g. *Lippia javanica*) that are not favoured by black rhino, then occasional hot fires may facilitate a more diverse species composition and structure.

3. If the grass layer shows signs of becoming moribund or tall, unpalatable and declining in cover and grazing value but the shrub layer is considered to be in an acceptable condition, then occasional cool fires may contribute to maintaining the grass layer without having a large impact on the composition and structure of the shrub layer.

4. If the grass layer shows signs of becoming moribund or tall, unpalatable and declining in cover and the shrub layer is dense and dominated by single species such as *Lippea javanica*, then regular hot fires may be indicated until the vegetation structure and composition has improved according to the stated objectives prior to the intervention.

It is recommended that the disc pasture meter be used in the grasslands within the shrubby areas in conjunction with the information in chapter six to determine the conditions for the required fire.

It is critical to monitor the impacts of fire by repeating the surveys at regular intervals.

CHAPTER SIX: DEVELOPMENT OF TOOLS FOR IMPLEMENTING A RANGE MANAGEMENT MONITORING PROGRAMME

6.1. Introduction

Management interventions should ideally be based on a sound scientifically based decision-making process. Information required for management decision making usually originates from scientific baseline studies, or from ongoing monitoring programmes. Ideally, information from both sources should be available and should be used. In the Ngorongoro Crater, one of the major decisions that have to be made regarding management intervention relates to fire and fire management. The decision making process is complex. Firstly, a decision has to be made whether fire could and should be used as a management tool.

Most of Africa south of the Sahara shows a cyclical climate pattern, with pronounced wet and dry seasons (short-term cycle). Longer-term climatic cycles are evident as periods of abnormally high or low rainfall, often lasting several years. These long and short-term cycles create ideal conditions for fire, and fire has consequently played a major role in shaping the vegetation that exists today. Before human occupation, fires are likely to have been caused by lightning (and other natural causes in some cases) and are likely to have burnt large areas with an intense fire. Humans have used fire intensively in Africa for many purposes, such as improving grazing quality, hunting, clearing land for cropping and many other reasons. In the Ngorongoro Crater, local Maasai used to live in the Crater and apparently burnt the grasslands on the Crater on a regular basis to improve quality of grazing and to control ticks. They probably based their decision to burn on a few simple criteria, such as grass height.

Importantly, when considering any decision making process related to management intervention, not making a decision in fact constitutes a decision to not carry out the intervention in question. If application of controlled burning as a management intervention is considered, the first step in the decision making process is to decide whether to burn or not to burn. There are only two options. Not making any decision is in fact an active decision to not burn.

The initial decision regarding the use or prohibition of fire requires a good set of scientific baseline data, with long-term records and impressions. The survey conducted by Herlocker & Dirschl (1972) and the follow-up survey reported in chapter 3 form an ideal baseline dataset for the grasslands of the Crater floor. The surveys conducted in the scrub vegetation on and adjacent to the lower slopes of the Crater walls (reported in chapter 5) form a baseline for decision-making regarding fire.

If a decision has been made to use fire as a management tool, then decisions regarding the implementation on a burning programme should be made on data collected with the intention of quantifying the current situation relating to the necessity of fire in a particular area or at a particular time. This data is best collected as part of ongoing monitoring programmes and not as an *ad hoc* process. In practice, few ongoing monitoring programmes are successful. Monitoring programmes are commonly designed to collect and provide complex data, and the data collection process is consequently time consuming. In conservation areas, staff often place data collection far down on priority lists because of the time consuming nature of data collection, and because of perceptions (often valid) that data collected are not used but merely filed and forgotten.

Data required to implement fire management programmes include data on rainfall, animal numbers (including trends), vegetation biomass, species composition and ecological status of the vegetation.

The Disc Pasture Meter (DPM) (Figure 6.1) is used to determine the above ground dry mass of grass vegetation per unit area (Bransby & Tainton 1977). It involves recording the settling height of an aluminium disc dropped onto the grass sward and relating this, using a calibration curve, to the standing crop of grass holding up the disc, expressed in kg ha^{-1} (Trollope & Potgieter 1986). The information derived from the estimation of the standing crop is used for determining areas to be considered for burning based on the degree to which the grass sward has become moribund, overgrown and unpalatable, based on the assumption that a standing crop of grass greater than 4 000 kg ha^{-1} will tend to become moribund and unpalatable. Pasture in this state needs to be burnt to restore its palatability, nutritive value and vigour (Trollope & Hines 2000).

Figure 6.1. The Disc Pasture Meter developed by Bransby & Tainton (1977) was used to estimate the standing crop of herbaceous plant material in the Ngorongoro Crater.

A critical aspect of developing rangeland management strategies is the incorporation of species composition and biomass data into the decision making process. To facilitate this, a simplified key species technique was developed following the procedure developed by Trollope (1990) for the Kruger National Park using forage and fuel scores developed for the Ngorongoro Crater by Trollope & Trollope (1995). The forage and fuel scores were developed by assessing the opinions of a range of local experts regarding the forage and fuel characteristics of the local grasses. These scores were carefully re-assessed in the current study and judged to be suitable. These scores are also influenced by the status of the grass in terms of being an increaser or decreaser. These terms are defined as follows (Hardy *et al.* 1999).

- Decreaser species (D) - Grass and herbaceous species which decrease when the rangeland is under or over utilized.
- Increaser I species - Grass and herbaceous species which increase when the rangeland is under utilised.
- Increaser II species - Grass and herbaceous species which increase when the rangeland is over utilized.

6.2. Methods

In order to arrive at a pasture disc meter calibration equation that adequately represents the variety of grassland communities in the Crater floor, the calibration procedure was conducted in three different grassland communities viz. a *Chloris gayana* dominated community, a *Cynodon dactylon* dominated community, and *Sporobolus ioclados* and *S. spicatus* communities. These communities represent a range from very dense and tall to very short grassland. The data from each of these three communities were pooled to arrive at the equation used for this study.

Relatively homogenous representatives of the three communities described above were selected for sampling. At each site, 20 (1x1 m) quadrats were clipped (Figure 6.2). Before clipping, five readings were taken with the DPM – four in each quarter and one in the centre of the quadrat (Figure 6.1). The quadrats were placed five meters apart in a straight line transect. All grass material was clipped to ground level and collected.

Figure 6.2. A quadrat clipped in the process of calibrating the Disc Pasture Meter in the Ngorongoro Crater.

The grass and litter material clipped in each 1x1 m quadrat was collected and weighed (bulk sample wet mass). A sub-sample was taken and weighed to determine the sub-sample wet mass. This sub-sample was then dried for at least 48 hours in an oven at 60°C. The dry mass of each sub-sample was obtained. The dry matter percentage of each sub-sample was used to determine the bulk sample dry mass, which was converted to kg ha^{-1}, and related to the mean of the five DPM readings taken in each quadrat. The procedure is illustrated in Table 6.1. The resulting calibration will be used in management decision making in future.

Table 6.1. An example of the process of arriving at an estimate of dry mass of grass in kg ha^{-1} from the sub-samples from each quadrat

Sample (g m^{-2})	Wet sub-sample (g)	Dry sub-sample (g)	% Dry matter	Dry sample (g m^{-2})	Dry mass (kg ha^{-1})
500	50	25	50	250	2500

For developing the key species technique, a forward stepwise multiple regression procedure was used to determine the relative impact of key species on the forage and fuel scores for each transect. The different grass species were designated the independent variable (X) and the forage score the dependent variable (Y). The forage and fuel scores developed by Trollope & Trollope (1995) are shown in Table 6.2.

Table 6.2. Classification of grass species in the Ngorongoro Conservation Area into Decreaser and Increaser species and their respective forage and fuel factors estimated on a scale of 0-10 (Trollope & Trollope 1995)

NO	GRASS SPECIES	CATEGORY	FORAGE FACTOR	FUEL FACTOR
1	*Andropogon greenwayi*	D	6	6
2	*Cenchrus ciliaris*	D	7	8
3	*Bothriochloa insculpta*	D	3	4
4	*Heteropogon contortus*	D	6	7
5	*Panicum maximum*	D	10	8
6	*Setaria pumila*	D	10	10
7	*Setaria sphacelata*	D	10	10
8	*Themeda triandra*	D	10	10
9	*Chloris gayana*	I	5	8
10	*Cymbopogon afronadus*	I	2	6
11	*Diplachne fusca*	I	2	2
12	*Eleusine jaegeri*	I	2	8
13	*Hyparrhenia hirta*	I	1	8
14	*Hyparrhenia sp*	I	1	8
15	*Pennisetum mezianum*	I	3	10
16	*Pennisetum schimperi*	I	3	9
17	*Pennisetum stramenium*	I	2	10
18	*Aristida adscensionis*	II	1	1
19	*Brachiaria umbratilis*	II	1	1
20	*Brachiaria erucifomis*	II	1	1
21	*Chloris pycnothrix*	II	1	2
22	*Cynodon dactylon*	II	5	6
23	*Cynodon nlemfuensis*	II	6	7
24	*Dactyloctenium aegyptium*	II	2	3
25	*Digitaria abyssinica*	II	3	3
26	*Enneapogon elegans*	II	1	1
27	*Eragrostis tenuifolia*	II	2	6
28	*Cyperus rotundrus*	II	1	1
29	*Panicum repens*	II	5	5
30	*Panicum coloratum*	II	5	5
31	*Pennisetum clandestinum*	II	5	6
32	*Psilolemma jaegeri*	II	1	1
33	*Odyssea jaegeri*	II	1	1
34	*Sporobolus fimbriatus*	II	5	5
35	*Sporobolus ioclados*	II	1	1
36	*Sporobolus Africana*	II	2	3
37	*Sporobolus spicatus*	II	1	1

6.3. Results

6.3.1. Calibration of disc pasture meter

A linear relation was obtained between disc settling height and standing crop of grass (Figure 6.3 and Table 6.3). This regression relation is similar to calibrations developed by Trollope and Potgieter (1986) when estimating fuel loads with the pasture disc meter in the Kruger National Park in South Africa and Trollope and Hines (2000) when assessing range condition in the east Caprivi region of Namibia.

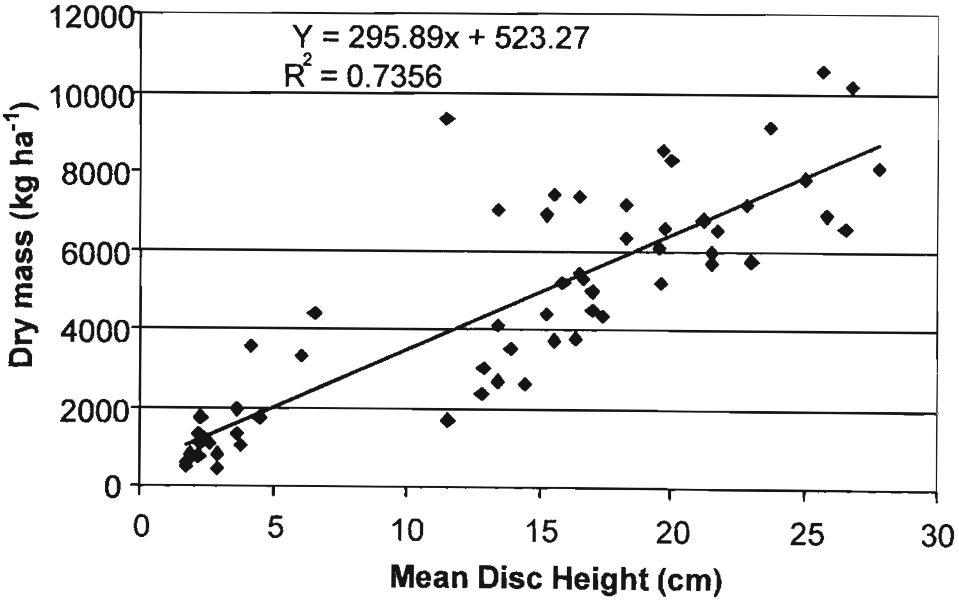

Figure 6.3. Relation between the mean sward height (cm) measured by the Disc Pasture Meter and dry matter of the standing crop of grass (kg ha^{-1}).

The calibration equation was as follows: $y = 295.89x + 523.27$

Where: y = mean *Standing Crop of Grass* or mean *Grass Fuel Load* (kg ha^{-1});

x = mean Disc Height (cm); ($R^2 = 0.74$; $P < 0.001$).

Table 6.3. The relation between the mean disc height (X) and the standing crop of grass (Y) estimated with a Disc Pasture Meter.

X	Y	X	Y	X	Y
cm	kg ha^{-1}	cm	kg ha^{-1}	cm	kg ha^{-1}
1	523	11	3778	21	6737
2	819	12	4074	22	7033
3	1115	13	4370	23	7329
4	1411	14	4666	24	7625
5	1707	15	4962	25	7921
6	2003	16	5258	26	8216
7	2299	17	5553	27	8512
8	2595	18	5849	28	8808
9	2890	19	6145	29	9104
10	3186	20	6441	30	9400

6.3.2. Key Grass Species: Fuel and Forage Factors

The stepwise multiple regression procedure used for identifying key species for both forage and fuel values identified the six key species for fuel and forage values (Table 6.4). The P values for the six forage and fuel score key species indicated significance at least at the 95% level. The relations between the forage and fuel scores predicted by the key species and the forage and fuel scores determined using all species are shown in Figures 6.4 and 6.5 respectively. A key species data sheet for conducting surveys in the field is attached as Appendix 3.

Table 6.4. Key forage and fuel value species identified for the Ngorongoro Crater using a forward stepwise multiple regression procedure.

Species	**Forage regression co-efficient**	**P values**	**Fuel regression co-efficient**	**P values**
Cynodon dactylon	+1.21	<0.05	+1.28	<0.05
Chloris gayana	+1.48	<0.01	+3.66	<0.01
Andropogon greenwayi	+2.41	<0.01	+1.47	<0.05
Themeda triandra	+6.70	<0.01	+8.29	<0.01
Sporobolus ioclados	-4.55	<0.01	-5.82	<0.01
Setaria sphacelata	+6.31	<0.01	+4.87	<0.01

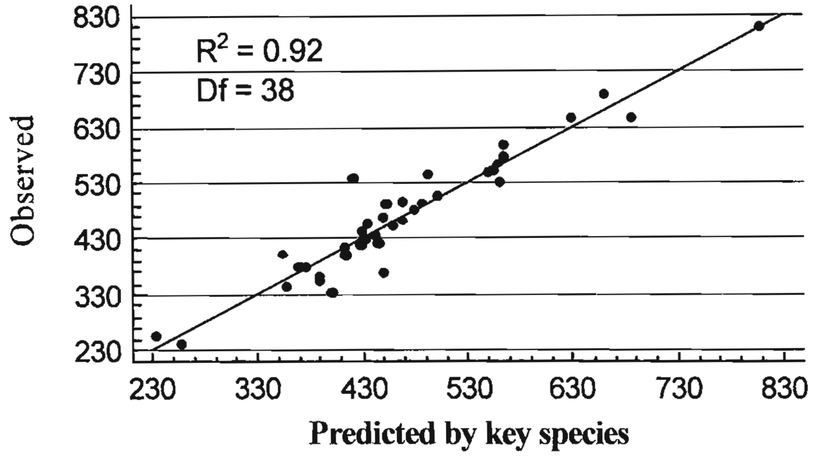

Figure 6.4. The relation between forage scores predicted by the six key species and the forage scores determined from all species in the Ngorongoro Crater (equation presented in Table 6.4).

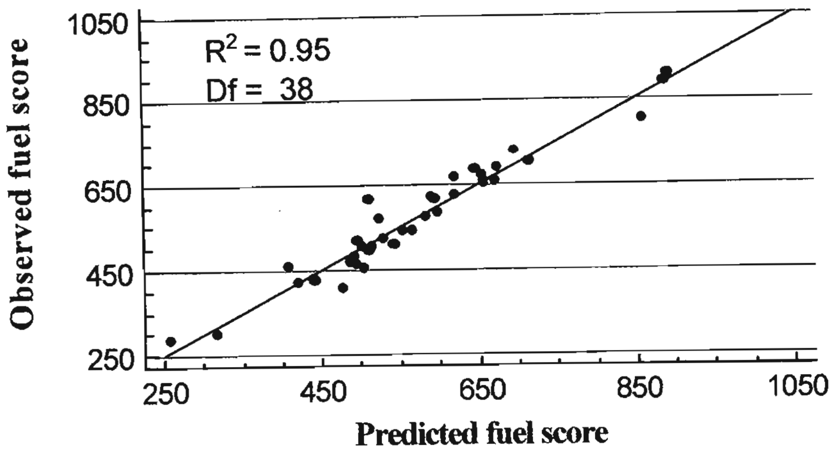

Figure 6.5. The relation between fuel scores predicted by the six key species and the fuel scores determined from all species in the Ngorongoro Crater (equation presented in Table 6.4).

6.4. Discussion

The techniques developed and described above should make it possible and easy for conservation staff to implement an effective monitoring programme with the minimum of effort. No special skills are required to use the disc pasture meter. A general lack of expertise in grass identification skills often limits monitoring programmes. The key species technique allows relatively inexperienced staff to become involved in the monitoring programme, as only six species need to be identified and recorded.

The forage scores and fuel scores obtained from the key species technique can now be used in conjunction with the disc pasture meter readings to make decisions on whether or not to burn particular areas. This approach is preferable to having either rigid burning programmes, or *ad hoc* decision making. In addition, the data obtained can easily be summarised and stored as single values for each transect or area, which simplifies long-term monitoring. The techniques are complimentary, in that the disc meter can be used to measure fuel load at a particular time. This measurement is partly a function of species composition, but also reflects current environmental conditions such as seasonal rainfall. The key species technique (including the ecological classification of species into increaser and decreaser categories), on the other hand, is a reflection of the composition of the vegetation and does not take account of short term climatic fluctuations that might influence decisions regarding fire management. Either measure in isolation would reflect an incomplete picture of the system and may result in poor management decisions.

Trollope & Potgieter (1985) report that in the Kruger National Park, fires will not spread readily when the fuel load is below 2 000 kg ha^{-1}, and will not burn with intensity great enough to control bush encroachment when the fuel load is below 4 000 kg ha^{-1}.

Practically, the key species technique can be used in conjunction with the fuel load data in the following way (Figure 6.6):

The process outlined in Figure 6.6 follows a logical pattern based on fire behaviour and ecological and production characteristics of the vegetation. The first decision involves fuel load. Where the fuel load is less than 1 500 kg ha^{-1}, the vegetation is unlikely to carry a fire (De Ronde *et al.* 2004), and there is not much reason to burn. Where the fuel load is greater than 4 000 kg ha^{-1}, the vegetation will carry an intense fire (Everson 1999). Also, when a fuel load of 4 000 kg ha^{-1} has accumulated, it is likely to continue accumulating in future seasons and pose a potential fire hazard (Everson 1999). For these reasons fire may be considered when the fuel load exceeds 4 000 kg ha^{-1} without considering other factors.

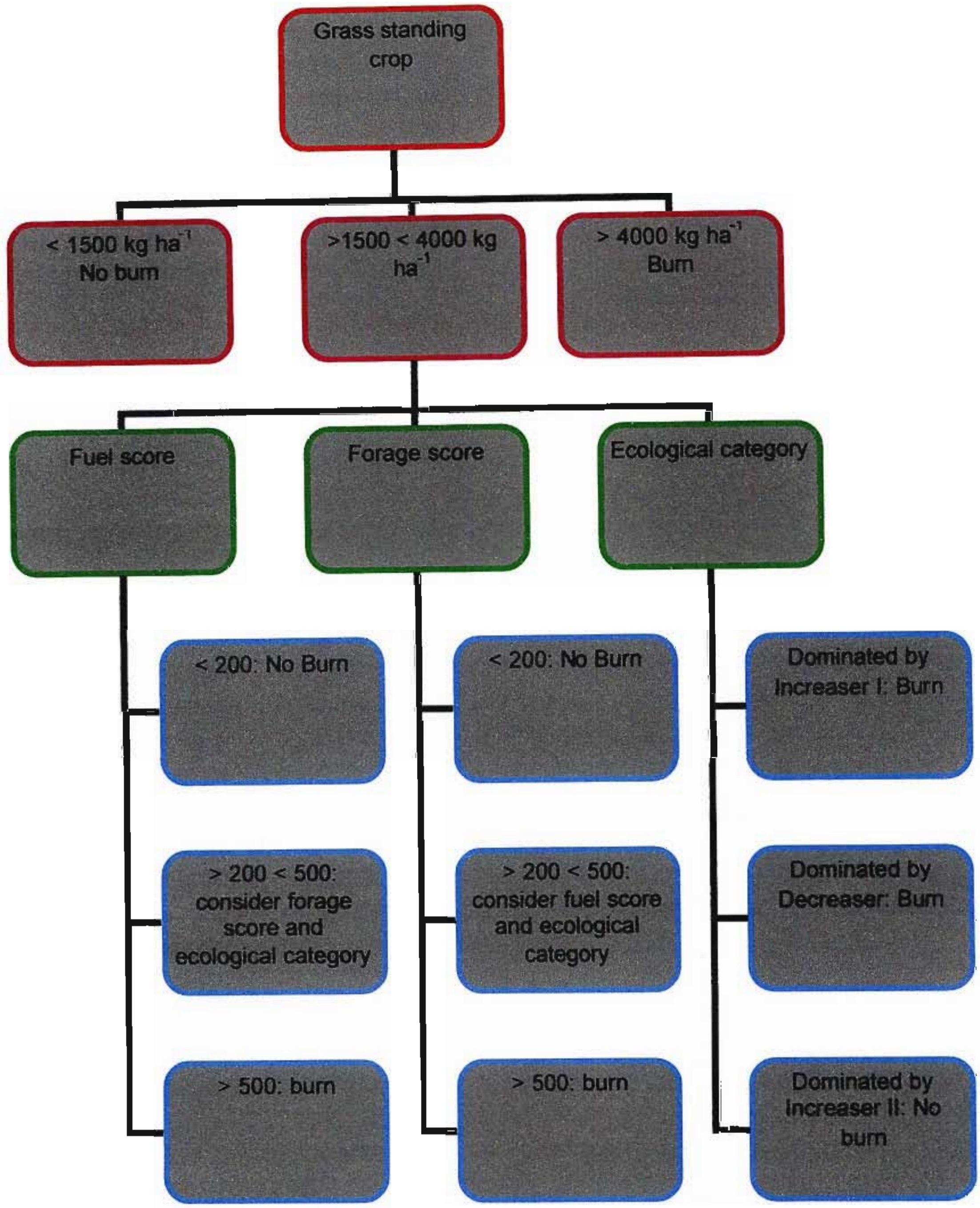

Figure 6.6. Controlled burning decision making process based on forage standing crop, forage scores and fuel scores.

Where the fuel load lies between 1 500 and 4 000 kg ha^{-1}, then a decision must be made based on other factors. A logical approach is to then assess the fuel score, which gives an indication of the contribution of the grass species composition to the long-term potential fuel load. If the score is low (below 200) then fire should be avoided. If the score is high (above 500), then fire should be considered. If the score lies between the two extremes, then forage factors and ecological category should be considered.

Where the forage score is low (below 200) then fire should not be considered, as the forage potential of the vegetation is low, and fire will negatively impact the ability of the vegetation to carry grazing animals. Where the forage score is high (above 500) then fire should be considered, as the grasses present are likely to be productive, fire climax grasses. Where the forage scores are intermediate, then the ecological category and the fuel factor should be considered.

Where the vegetation is dominated by Increaser I species, then fire should be considered depending on forage and fuel scores, particularly in areas where there is a tendency for shrub and bush encroachment and where the management objectives are focused on maintaining grassland. Where the vegetation is dominated by Decreaser species, then fire should also be considered, as many of the Decreaser species are well adapted to regular fires. Again, forage and fuel scores should be considered. Where these scores tend to be low, then the fire frequency should be decreased. Where the vegetation is dominated by Increaser II species, then fire should be avoided unless the fuel load is close to 4 000 kg ha^{-1}. Increaser II species indicate intensive grazing and often indicate over utilisation. Burning such areas will attract grazing animals and may increase the grazing intensity.

Where necessary, additional data manipulation can extend the data collected and make a useful contribution to developing a broader understanding of the system. For example, analysis of sequential disc meter readings can be used to evaluate the patchiness of grazing patterns, which can also be useful in burning decision-making.

The key species data, if collected over time from the same area, can reveal trends in species composition changes, even if all species are not recorded.

CHAPTER SEVEN: DISCUSSION AND CONCLUSIONS

7.1. Discussion

The Ngorongoro Conservation Area Authority has generally followed a non-interventionist approach to management of the NCA, with the main management interventions focused on aspects such as protection of rare animal species and eradication of alien plant species. Most interventions have generally been reactive rather than proactive. This contrasts with management philosophies adopted in other large conservation areas with fixed boundaries such as the Kruger National Park, where an interventionist approach has been followed for many years, backed up by strong scientific research and monitoring programmes. (The recent incorporation of the Kruger National Park into a trans-frontier park has extended the boundaries and may result some changes in the management approach in future). In the Serengeti National Park, which can be regarded as a relatively open system, management interventions are generally rare and have generally focused on protection of endangered species and, more recently, fire management. When interventions are considered in the Serengeti, there is a strong scientific base from which to make management decisions.

The NCA is in a unique position because, although geographically contiguous with the Serengeti National Park, increased human activities and pressures limit wild animal movement in parts of the NCA, including the Crater. The NCA can thus be positioned on a scale somewhere between the Kruger National Park and the Serengeti National Park in terms of the necessity for interventions. In the areas adjacent to the Serengeti National Park, the annual migration is generally not affected by human or other factors and consequently does not require major interventions at present. However, in other areas that are becoming increasingly isolated, such as the Crater, the necessity for management intervention will probably increase in future. Management of the rangeland, both in and around the Crater is seen as a priority and is probably the primary management focus area where interventions should be considered. In particular, when considering the changes that have taken place such as the removal of cattle from the Crater and the prohibition of fire, with consequent changes in grazing animal numbers and ratios, a focus on proactive rangeland management is indicated.

The results of the vegetation survey conducted in 2004 on the same sites surveyed by Herlocker and Dirschl in (1972) show that *Sporobolus homblei* and *Digitaria macroblephara,* which once dominated large areas of the Crater floor, have completely disappeared. The disappearance of the latter species is especially significant because it was one of the most abundant grass species in the 1960's. *Sporobolus homblei* in 1960's and 1970's was abundant over smaller areas to the south and west of Lake Magadi on the drier, more saline sites. It has now largely been replaced by *Sporobolus ioclados.* Apart from not being recorded during this study these species have not been observed anywhere in the Crater in recent years. The implications of the disappearance of these two species is difficult to quantify in terms of grazing capacity, but the loss of any species should be viewed with concern.

Cynodon dactylon, *Chloris gayana* and in some areas *Sporobolus ioclados* and *Andropogon greenwayi* have significantly increased in abundance, especially in areas where *Digitaria macroblephara* was once so important. Likewise *Cynodon dactylon* and *Andropogon greenwayi* are abundant especially in areas where the grazing is moderate to heavy.

Digitaria abyssinica (formerly *Digitaria scalarum*), which was once a major dominant species on the Crater floor, has shown slight to very strong decreases in abundance. This species is currently more abundant in the areas which have been burnt recently and where moderate to heavy grazing has occurred. Trollope and Trollope (1995) in their report on the fire ecology of the Ngorongoro Conservation Area, classified *Andropogon greenwayi* as a decreaser that occurs in areas with moderate grazing intensity, *Chloris gayana* as an increaser I species that occurs in areas of low utilisation intensity and *Cynodon dactylon*, *Digitaria abyssinica* and *Sporobolus ioclados* as increaser II species which occur in areas with high intensity of grazing. Therefore, in areas where *Digitaria macroblephara* has disappeared (but was once abundant) and *Chloris gayana* has increased in abundance, grazing intensity has probably decreased. A significant reduction in abundance of *Digitaria abyssinica* (where it was once a dominant or sub-dominant) indicates a reduction in grazing intensity from a previously high level. A significant increase in *Andropogon greenwayi* (especially where *Digitaria abyssinica* has strongly decreased) probably indicates a reduction in grazing intensity from high to moderate levels. An abundance of *Cynodon dactylon* and *Sporobolus ioclados* would probably indicate high intensity grazing, particularly in areas where the grassland takes on the appearance of grazing lawns. However, there are extensive areas of the Crater where *Cynodon dactylon* and *Cynodon nlemfuensis* are tall, dense and have substantial dead material. These areas are indicated by high fuel loads as determined by the Disc Pasture Meter e.g. areas with >4 000 kg ha^{-1} on the north west of the Crater and areas around Mandusi swamp.

Generally the grassy vegetation over much of the Crater floor, especially the southern and part of the western areas is much taller now than it was a few decades ago (Herlocker pers. comm. 2004). It also seems to be less utilised by animals. Apparently the dominant grass, *Chloris gayana*, is relatively unpalatable to wildlife, at least in its mature stage. Where this vegetation has been recently burnt *Chloris gayana* is not as structurally dominant as on the adjacent unburned areas and there appears to be greater utilisation of the sward by wildlife. In many areas where the grass layer is tall, dominance by one or two grass species, such as *Chloris gayana*, *Cynodon dactylon* or *Cynodon nlemfuensis*, is evident. This results in relatively homogenous areas, both in terms of species composition and structure. The presence of forbs is visually reduced, and where they are present, their growth appears stunted with consequent low productivity. This negatively impacts the availability of forbs for black rhino and controlled burning is seen as a means of promoting vegetation heterogeneity, in terms of species composition and structure.

The shrubby vegetation, comprising *Lippia javanica*, *Lippia ukambensis*, *Indigofera* spp, *Ocimum suave* and *Solanum incanum* has moved down onto parts of the periphery of the Crater floor in the north and east, for example in the *Andropogon greenwayi* and *Digitaria abyssinica* grassland dominated areas. This probably reflects the reduction in grass fires over the past few decades. Evidence of this expansion is mainly anecdotal and based on photographs. A set of baseline data has been collected to use as a reference point for future monitoring and for management decision-making purposes.

The rise in elephant numbers in the Crater has led to increased destruction of both old and young *Acacia xanthophloea* trees. Kabigumila (1988) cautioned that if elephant movement corridors continue to be blocked and elephants are unable to move out of the Crater, the increased numbers of elephants would have an adverse effect on the Lerai Forest. It was also argued that elephants in the Maasai Mara (Kenya) consume woody species of all sorts and their use of shrubs and trees increases significantly when dry conditions prevail. Similar situations can be observed in the Crater, during the dry season elephants face a reduced availability of browse forage. During this period they cause significant destruction of the young *Acacia xanthophloea* trees and saplings. Also at this time of the year when forage availability declines in the Lerai Forest they concentrate their time in the *Croton macrostachyus* and *Abutilon longicuspe* thickets in the scrub vegetation where they disturb and compete with the black rhinos in the Crater. As the forest is dying, a new growth of *Acacia xanthophloea* is developing higher up on the slope towards the Crater wall. This new growth probably started after burning was stopped, as young *Acacias* in this area that has a good sward of grass, would have been destroyed when the Maasai were conducting regular burns in the Crater. Unfortunately this "new forest" is in a drier area and it is unlikely to create the thick undergrowth of bushes and shrubs so favoured by black rhino and it may further reduce the amount water flowing in to the "old forest".

Acacia xanthophloea or fever tree is a water loving tree but flooding of the roots for long periods can be lethal. The El Nino phenomenon of 1997/98 may have resulted in the flooding of the roots of the trees in the lower parts of the forest for a prolonged period. The road around the lower part of the forest with its built up base probably affected the flow of water out of the forest and exacerbated the situation. Also deviation of water flowing into the Crater for human utilization, especially by tourist lodges and NCAA staff may have reduced the amount of water which comes from the Lerai spring and hence reduced the water supply into the forest. Clearly, the Lerai Forest is deteriorating rapidly, due mainly to human induced factors. Again, this information is anecdotal and based on photographs. Apart from the decline of the fever trees, there is also an apparent change in the composition of the important shrubs such as *Pluchea monocephala.* This low growing spiky shrub is a preferred food of black rhino and used to grow in the Lerai forest and on the adjacent plains.

Data reflecting the vegetation composition and structure were collected to serve as a base for future monitoring and management decision making. Some form of management intervention is required. However, this should be based on sound scientific information, which does not exist. It is recommended that research into the deterioration of the forest be given a high priority.

The vegetation of the Mandusi and Gorigor swamps seems to have considerably decreased in height. Herlocker & Dirschl (1972) observed dense vegetation of reeds and sedges that stood 3-5 m high. Now one can look straight across both swamps. Goddard (1968) observed many rhinos spending most of the dry season time foraging and wallowing in this swamp. Currently no rhino are observed in the swamps, instead elephants are now seen there, pulling out and consuming the reeds.

Fire is regarded as a major factor of primary ecological importance in the Serengeti National Park and the greater Serengeti ecosystem due to its essential characteristics of modifying vegetation. Sinclair (2004) pointed out that during the period between the 1950's and 1980's the management of fire was concerned with the loss of trees in the woodlands and a number of attempts were made to rationalise the management of fire in the Serengeti National Park. Stronach (1989) formulated a fire management programme that recommended a series of procedures for controlling fires that originated from outside the Park. These fires were regarded as being undesirable because they were perceived to result in short-term and long-term modifications of the habitat that were regarded as being of an artificial nature. Uncontrolled fires seriously inhibit the regeneration of trees and in the wake of the widespread destruction of mature trees by elephants it was recommended that the promotion of the regeneration of trees should receive high priority in the fire control program. In the woodlands and grasslands the aim of fire management was to enable the survival in some areas of those elements of the ecosystem that tend to be eliminated by frequent burning. Uncontrolled wildfires also destroy fire sensitive vegetation communities and their associated animal life, particularly forest and thicket. These plant communities had decreased significantly and the aim of controlling fires was to stop their decline and to promote their recovery where possible (Sinclair 2004). Therefore the main objective of fire management was to minimise the effects of anthropogenic induced wildfires, particularly limiting the size of fires and during the fire season, the control of wildfires was given priority over all other management activities.

Management intervention in Kruger National Park emerged between 1946 and 1990. Managers in the Kruger Park have consistently used fire as a management tool. The use of fire in the Kruger Park was characterised by prescribed burning for an extended period of 36 years between 1956 and 1992. In the late 1980's, a number of concerns were raised about the putative effect of this fire policy (Biggs & Potgieter 1999). These concerns led to a debate on the role of lightning ignitions in producing variable fire regimes based on point ignitions. Originally it was suggested that lightning should be allowed to play a more important role in the fire regime of the Kruger Park, but not necessarily that it should dominate or replace the prescribed burning. A policy of natural fire was subsequently adopted when a majority of managers supported the notion of wilderness ecosystem management. This policy called for all lightning-ignited fires to burn freely, whereas all other fires were prevented, suppressed or contained where possible (Biggs & Potgieter 1999). Fire research in the Kruger Park was initiated after fires burnt 25% of the Kruger Park in 1953. Experiments were established to test the effect of season and frequency of fire on a series of plots. The important task of the first researchers was to conduct these experiments making them the pioneers of the modern era of scientific management. These experiments have been maintained for half of century and have allowed researchers to formally manipulate fire treatments in order to gain a greater understanding of the role and impact of fire, rather than just using observation. Some of the principles established in these trials can be applied in other areas.

Ngorongoro, Serengeti and Maasai Mara share the same greater Serengeti ecosystem. The annual migration of wildebeest always starts from Maasai Mara heading out towards Ngorongoro via the eastern corridor of the Serengeti National Park and returns to the Maasai Mara via the western corridor. In the past the wildebeest migration used to extend into the Crater floor but this has ceased in recent years and now the most westerly reach of the migration terminates on the Ngorongoro plains close to Serengeti National Park and Olduvai Gorge. This phenomenon is likely to be due to a combination of two main factors – blockage of routes caused by human activities and the presence of good pasture on the Serengeti side especially in the woodlands, where regular fires provide a more palatable grass sward compared to that of the Crater. In the Serengeti and Maasai Mara management by intervention including the use of fire on the woodland and grassland areas has been practised for many decades. Similarly in Kruger National Park the use of fire as a management tool has been practised for half a century and has revealed positive results in terms of maintaining and improving heterogeneity of rangeland. The fire policies that have been adopted for ecosystem management in the Kruger and Serengeti contrast with the Ngorongoro Crater where the use of fire as a management tool for rangeland improvement has not been practised for the past 40 years. The Homogenous Vegetation Units identified during this study can be used as sites where controlled burning can be applied and monitored. The boundaries of these HVU's have been delineated in order to be able to distinguish one HVU from another to facilitate the monitoring work.

The grassland of the Crater has become taller, attracting buffalo and coincidentally providing an ideal habitat for ticks which affect many species including the black rhino. In contrast, wildebeest and gazelle numbers have decreased. As selective concentrate grazers these species seek short grass with higher nutritive value. Cattle, being bulk feeders, are attracted to a coarser grass sward but at the risk of exposure to ticks and tick borne diseases. The Maasai pastoralists who occupy the grasslands on the high rainfall areas surrounding the Crater burn their rangelands more or less on a biennial basis in order to reduce the number of ticks being harboured and to provide better quality grazing. This practice of range burning appears to be successful as the incidence of ticks is very low in the rangelands utilized by domestic livestock outside the Crater. While a reliable record of cattle numbers in the Crater prior to 1974 is not available, it seems that the buffalo, with their similar grazing habits, have replaced cattle in terms of grazing ecology, leaving fire as the major factor that has changed over the intervening decades.

If fire is to be re-introduced as a management tool in the Crater, it has to be based on scientific data leading to an informed decision making process. Scientific data have been collected during the course of this study with the aim of supporting a fire management programme for rangeland improvement. This data includes a vegetation map and the development of a range condition assessment technique based on key grass species.

Following the survey, which was conducted in the Crater during this study, six HVU's have been identified for management purposes. Some are dominated by just a few species while others have a more diverse composition. Point to tuft distances were not important, as the distances were generally small and variation between HVU's was small relative to variation within units. A vegetation map showing these HVU's has been produced which can be used for management planning and monitoring future trends. Baseline vegetation data has been collected that will be used for future comparisons to quantify vegetation change and response to management, animal utilisation or environmental factors.

Six key grass species have been identified that will facilitate quick and easy range condition assessment by conservation staff. Bush surveys have revealed species composition, structure and density providing baseline data for ongoing monitoring. The exact recording of the location of these sites will enable future researchers to repeat the surveys in the same manner such that changes in the bush communities, as induced by factors such as fire, can be determined. The Disc Pasture Meter has been calibrated and can be used for management decision-making purposes in the grasslands and the grass component of the scrub and bush areas when implementing a controlled burning programme.

While burning has been prohibited in the Crater for several decades, some accidental fires have occurred, usually caused by honey gatherers e.g. in 1995 a fire burnt a large area of the Crater from Rhumbe hills to Lemala road. This fire, although it occurred accidentally, had some positive outcomes. It caused sprouting of the shrubs of the scrub vegetation as well as stimulating new forbs within the grasslands, hence attracting many browsers including black rhinos to spend most of their time especially during the dry season on the burnt area. This is clearly indicated by the high number of plants encountered at the Rhumbe site (15 708 plants ha^{-1}), compared to (1 142 plants ha^{-1}) found at the nearby Ngoitokitok site where fire has been absent for the past 40 years. The dominance of plants below 1.5 m in the scrub areas may indicate that fire could create a structure with less potential for thickening up. It seems clear that fire has the potential to influence the extent and density of the shrubby vegetation.

Fire is a useful tool for the pastoralist. If grasses are consistently grazed they are at a disadvantage in their competition with the woody shrubs, which can rapidly become dominant and encroach throughout the grassland. It is currently desirable to keep the Crater floor 'clean' and open to attract grazing animals relative to browsers. Where there is sufficient fuel load (>4 000 kg ha^{-1}) late burning is preferable (end of dry season September/October) because it will have a greater impact and clear the encroaching scrub vegetation. On the other hand if the fire is desired to 'thicken up' the cover as on the Crater wall, an 'early' burn is desirable, that is as soon after the rains as possible (end of wet season June/July). Controlled burning will help stimulate forbs growing on the Crater plains, which are essential for rhino food such as *Vircia hirsuta*, *Pluchea monocephala*, *Medicago leciniata*, *Amphicorpa africana* and *Teramnus repense*. Rhinos can be observed on the Crater plains during wet season rooting these herbs out and leaving the grass untouched.

The Mandusi swamp, into which the Munge River flows before it reaches Lake Magadi, used to provide an ideal cover for the rhino and lions of the adjacent plains. It also attracts elephants, which come down from Leyanai forest for a drink and wallow in the mud. Fire has been kept out of this swamp for several decades. Goddard (1968) recorded many rhinos spending much of the dry season feeding on *Aeschynomene schimperi* within the swamp. In the light of this situation it is considered advisable that fire should again be occasionally applied in this swamp so as to stimulate the vegetation to regain its former productive status.

It is recommended that a fire management programme is implemented in the Crater, based on the guidelines outlined in the previous chapters. At the same time, formal, ongoing monitoring of the impacts of fire is essential.

7.2. Conclusion

Management by intervention such as the use of fire as a management tool has been restricted in the Crater for many decades. Nature has been left to operate itself for long time and as a result the grassland has become coarse and less palatable to grazing animals. The rangeland of the Crater needs a regular and applied programme of monitored controlled burns to restore its palatability and nutritional status. This study has provided NCAA management with the necessary techniques to establish baseline rangeland data and to monitor the impact of interventions, including the use of controlled burns, aimed at improving the palatability of the rangeland forage resource. The Kruger and Serengeti National Parks have provided good examples where a ground based monitoring program of the grass sward has been successfully implemented and has revealed positive results in terms of rangelands improvements. In addition such data have been used in these two parks to a great advantage for implementing a controlled burning program and for obtaining a better understanding of the effects of fire and its interacting effects with the fauna on the ecosystem. Based on these results the NCAA managers can make informed observations regarding the current situation of the rangelands of the Crater and use this information to determine which intervention strategies to employ to achieve the required ecological balance.

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APPENDICES

APPENDIX 1: THE ABBREVIATIONS AND FULL NAMES OF THE GRASS SPECIES IN THIS STUDY

Abbreviation	**Species**	**Abbreviation**	**Species**
And gre	*Adropogon greenwayi*	*Hyp hir*	*Hyparrhenia hirta*
Ari ads	*Aristida adscensionis*	*Hyp sp*	*Hyparrhenia sp*
Bot ins	*Bothriochloa insculpta*	*Ody jae*	*Odyssea jaegeri*
Bra eru	*Brachiaria erucifomis*	*Pan col*	*Panicum coloratum*
Bra umb	*Brachiaria umbratilis*	*Pan rep*	*Panicum repens*
Cen cil	*Cenchrus ciliaris*	*Pen cla*	*Pennisetum clandestinum*
Chl gay	*Chloris gayana*	*Pen mez*	*Pennisetum mezianum*
Chl pyc	*Chloris pycnothrix*	*Pen sch*	*Pennisetum schimperi*
Cym afr	*Cymbopogon afronardus*	*Pen str*	*Pennisetum stramenium*
Cyn dac	*Cynodon dactylon*	*Set pum*	*Setaria pumila*
Cyn nle	*Cynodon nlemfuensis*	*Set sph*	*Setaria sphacelata*
Cyp rot	*Cyperus rotundus*	*Spo afr*	*Sporobolus africana*
Dac aeg	*Dactyloctenium aegyptium*	*Spo fim*	*Sporobolus fimbriatus*
Dig aby	*Digitaria abyssinica*	*Spo ioc*	*Sporobolus ioclados*
Dip fus	*Diplachne fusca*	*Spo spi*	*Sporobolus spicatus*
Era ten	*Eragrostis tenuifolia*	*The tri*	*Themeda triandra*
Het con	*Heteropogon contortus*		

APPENDIX 2: THE CONTRIBUTION OF ALL GRASS SPECIES IN EVERY TRANSECT

	SPECIES																
TRANSECT	Andgre	Ariads	Botins	Braeru	Braumb	Cencil	Chlgay	Chlpyc	Cymafr	Cyndac	Cynnle	Cyprot	Dacaeg	Digaby	Dipfus	Eraten	Hetcor
VT1T1	30				4			30		22							
VT2T1					22			1		42				27	1	4	
VT2T2					3			1		71				25			
VT2T3								4		62				31			
VT2T4	17						35			23	4			11			
VT2T5	1						3			59				37			
VT2T6	3						1			23				25			
VT2T7	18						14			30	1			16			
VT3T1			1				3			5				1			
VT3T2	74							11						11			
VT3T3	23						2			21				35			
VT3T4	17						28			29	1			17			
VT3T5	26	2					18			23				19			
VT3T6	22						34			19				5			
VT3T7	13						7			33				18			
VT3T8	61									5				1		2	
VT4T1	73									1						1	
VT6T1	1						13			24	1			11			
VT7T1	7						16			7				3			
VT8T1							5			6				8			
VT10T1										51				43			
VT10T2					2	1	4			43				35			
VT10T3							11			50				34			
VT12T1							49			43	2						
VT13T1	1						6			52				2			
VT14T1					9		16	3		56			1	6		4	
VT15T1							60			25		4					
VT15T2	14	1	2	5		9	2		9	7	2						6
VT15T3							48			36				3			
VT15T4			3			9	35		1	11				24			
VT19T1	1									45				47			
VT20T1	1					5	1			49				19			
VT21T1										47	32			21			
VT23T1							43			15	1			13			
VT24T1							12	2		20				6			
VT24T2		1					2	1		62				28		1	
VT30T1	5						1	4		22				19			
VT30T2	1	3					4			48				43			
VT31T1	1						24			28				16			
Grand Total	410	7	6	5	40	24	497	57	10	1215	44	4	1	660	1	12	6

Appendix 2 Cont.

Hypsp	Odyjae	Pancol	Panrep	Pencla	Penmez	Pensch	Penstr	Setpum	Setsph	Spoafr	Spofim	Spoioc	Spospi	Thetri	GrandTotal
					14										100
					2			1							100
															100
					3										100
			3		6									1	100
															100
		34			8									6	100
		14			1									6	100
						29								50	100
														4	100
											19				100
											2	1	5		100
											7			5	100
		1									5			13	100
							6				3			19	100
							1				21			9	100
											10			15	100
		2			1				14	2	6	4	1	12	100
19									4	1	10			33	100
6					1				50					19	100
											6				100
											3	9	3		100
		4									1				100
												1	5		100
					1							16	22		100
		1									2		2		100
				2								3	6		100
15														18	100
				12							1				100
											8			5	100
												7			100
											7	14	4		100
															100
												10	18		100
	22											30	8		100
		2											3		100
	4											35	10		100
												1			100
	2											9	19	1	100
40	28	58	3	14	37	29	7	1	68	3	111	140	106	216	3900

APPENDIX 3: A TEMPLATE FOR THE ASSESSMENT AND MONITORING OF THE RANGE CONDITION IN THE NGORONGORO CRATER USING KEY GRASS SPECIES

Veld Type:.........................;

Sample Site: .... **Date: ......**

CATEGORY	SPECIES	FREQUENCY %	FORAGE FACTOR	FORAGE SCORE	FUEL FACTOR	FUEL SCORE
DECREASER SPECIES	Andropogon greenwayi		6		6	
	Setaria sphacelata		10		10	
	Themeda triandra		10		10	
DECREASER TOTAL						
INCREASER I SPECIES	*Chloris gayana*		5		8	
INCREASER I TOTAL						
INCREASER II SPECIES	*Cynodon dactylon*		5		6	
	Sporobolus ioclados		1		1	
INCREASER II TOTAL			TOTAL		TOTAL	
TOTAL						

FORAGE/FUEL POTENTIAL

FORAGE/FUEL SCORE	POTENTIAL	Tick	
		Forage	Fuel
> 500	VERY HIGH		
400 – 500	HIGH		
300 – 400	MEDIUM		
200 – 300	LOW		
< 200	VERY LOW		

POTENTIAL SOIL EROSION

FACTOR	POTENTIAL EROSION		
TUFT DISTANCE	LOW	MOD	HIGH
	<3 cm	3-5 cm	>5 cm
Distance =(cm)			
GRASS STD CROP	LOW	HIGH	
	<1500 kgha^{-1}	≥4000 kgha^{-1}	
Kgha^{-1} =			
OVERALL SOIL EROSION POTENTIAL			

TREND

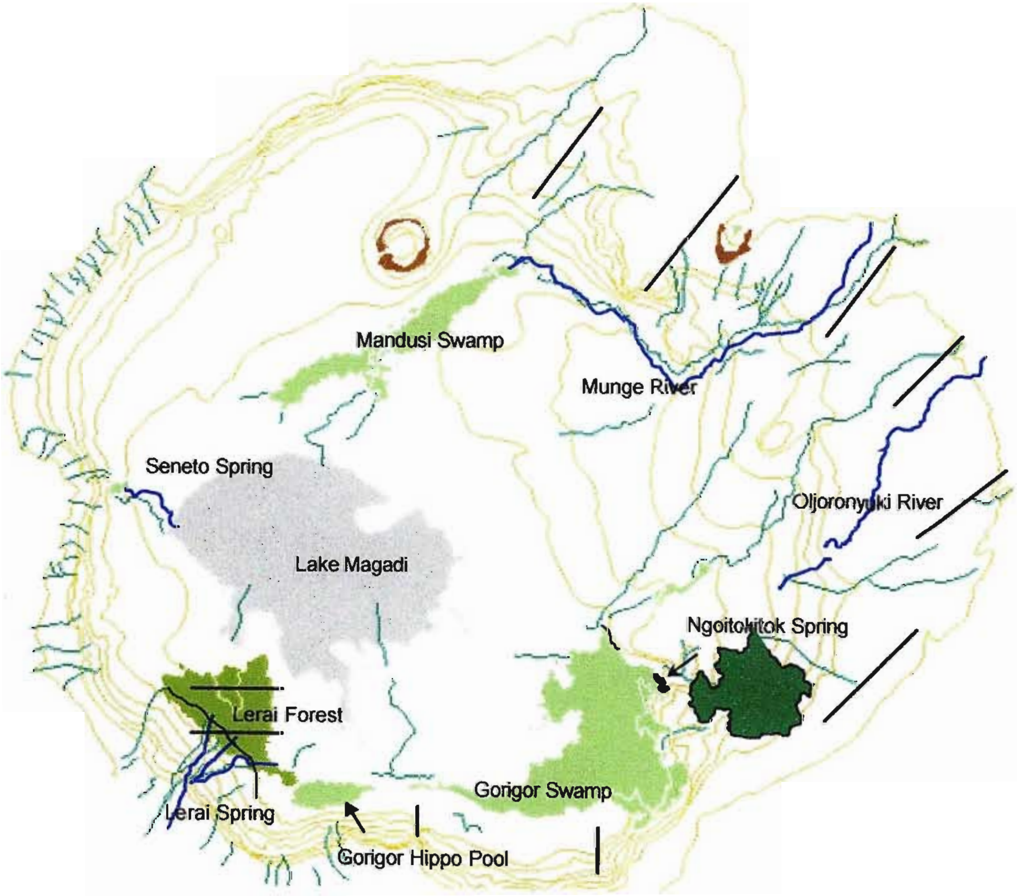
CATEGORY	%	UTILISATION	Tick
DECREASER SPECIES		MODERATE	
		UNDER	
INCREASER I SPECIES		SELECTIVE	
INCREASER II SPECIES		OVER	

CONTROLLED BURNING

BOTANICAL COMPOSITION	%	BURN	
		YES	NO
DECREASER SPECIES			
INCREASER I SPECIES			
INCREASER II SPECIES			
FUEL LOAD – kgha^{-1}			
OVERALL DECISION TO BURN			

APPENDIX 4: THE UTM CO-ORDINATES OF THE SITES SURVEYED IN THE SCRUB AND WOODLAND VEGETATION IN THE NGORONGORO CRATER.

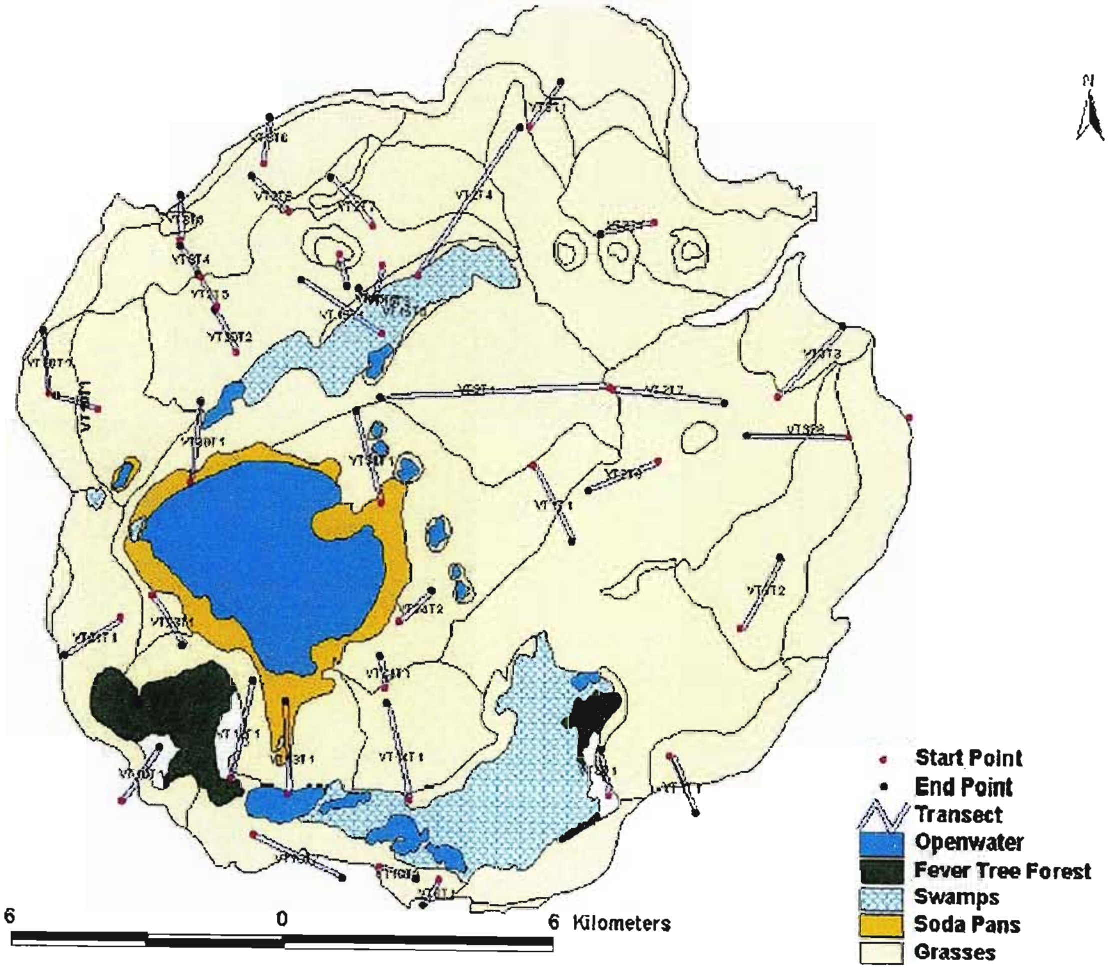
Site	UTM co-ordinates
Ngoitokitok	36m 0789010 UTM 9642330
Gie Spring 1	36m 0784440 UTM 9640604
Gie Spring 2	36m 0786297 UTM 9639846
Lerai 1	36m 0780175 UTM 9642855
Lerai 2	36m 0777976 UTM 9644460
East Munge 1	36m 0794416 UTM 9653575
East Munge 2	36m 0795153 UTM 9654017
East Rhumbe 1	36m 0795784 UTM 9647688
East Rhumbe 2	36m 0795240 UTM 9646935
Oljoronyuki	36m 0795331 UTM 9651346



APPENDIX 5: GPS COORDINATES FOR THE 2004 GRASSLAND SURVEY CONDUCTED IN THE NGORONGORO CRATER (STARTING AND ENDING POINTS).

VT1T1	36M0787550	9649509	VT10T1	36M0778503	9642809
	36M0788400	9648000		36M0779300	9643850
VT2T1	36M0789225	9651056	VT10T2	36M0781402	9642153
	36M0784150	9650850		36M0783350	9641300
VT2T2	36M0789316	9651041	VT10T3	36M0784207	9641556
	36M0791750	9650750		36M0785000	9641300
VT2T3	36M0790300	9649600	VT12T1	36M0780904	9643231
	36M0788750	9649000		36M0781350	9645200
VT2T4	36M0785000	9653300	VT13T1	36M0782144	9642951
	36M0787250	9656200		36M0782100	9644800
VT2T5	36M0780550	9652650	VT14T1	36M0784850	9642877
	36M0780150	9653300		36M0784300	9644750
VT2T6	36M0782150	9654550	VT15T1	36M0784207	9652105
	36M0781300	9655250		36M0782400	9653200
VT2T7	36M0784000	9654250	VT15T2	36M0783250	9653700
	36M0783050	9655200		36M0783400	9653050
VT3T1	36M0787455	9656219	VT15T3	36M0784000	9652793
	36M0788150	9657100		36M0783650	9653000
VT3T2	36M0792139	9646332	VT15T4	36M0784200	9653500
	36M0793000	9647700		36M0784000	9652800
VT3T3	36M0792946	9650904	VT19T1	35M0777930	9650589
	36M0794350	9652300		36M0777000	9650850
VT3T4	36M0780200	9653250	VT20T1	36M0776850	9650900
	36M0779750	9653850		36M0776700	9652150
VT3T5	36M0779750	9654000	VT21T1	36M0778450	9646450
	36M0779750	9654850		36M0777200	9645700
VT3T6	36M0781600	9655500	VT23T1	36M0779150	9646900
	36M0781700	9656400		36M0779800	9645900
VT3T7	36M0790200	9654350	VT24T1	36M0784286	9645074
	36M0789000	9654100		36M0784150	9645700
VT3T8	36M0794500	9650100	VT24T2	36M0784596	9646394
	36M0792250	9650100		36M0785300	9647000
VT4T1	36M0795850	9650500	VT30T1	36M0779985	9649150
	36M0791150	9642650		36M0780200	9650750
VT6T1	36M0785500	9641294	VT30T2	36M0781000	9651750
	36M0785150	9640750		36M0780500	9652600
VT7T1	37M0790600	9643750	VT31T1	36M0784197	9648754
	36M0791150	9642650		36M0783600	9650550
VT8T1	36M0789250	9643000			
	36M0789050	9643850			

APPENDIX 6: A MAP OF THE CRATER SHOWING THE APPROXIMATE POSITIONS OF THE GRASSLAND TRANSECTS SURVEYED IN THE GRASSLAND AREA DURING 2004.



APPENDIX 7: TESTING FOR SAMPLING INTENSITY.

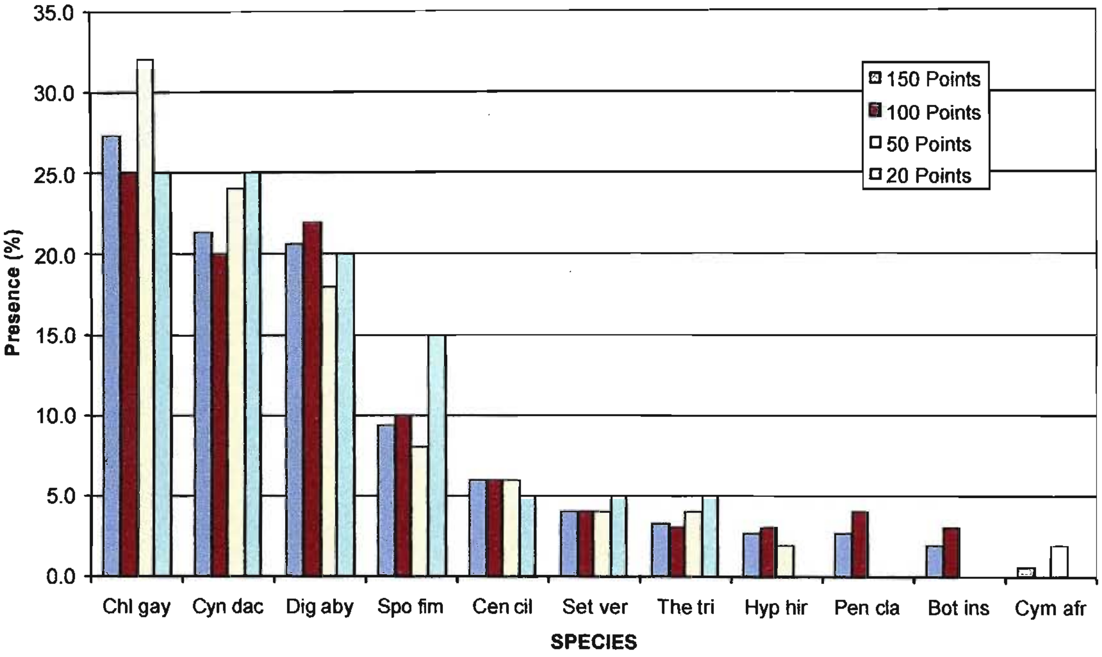
Initially the percentage contribution of grass species with 150 points was determined and the contribution of each species was observed. At this step the first four grass species *Chloris gayana* (27.3%), *Cynodon dactylon* (21.3%), *Digitaria abyssinica* (20.7%) *and Sporobolus fimbriatus* (9.3%) were the most dominant. Secondly fifty points were removed from the original data and the % contribution of grass species with 100 points was determined. In this case, the first four species were still dominant scoring 25, 20, 22 and 10% respectively while one species at the bottom (*Cymbopogon afronadus*) disappeared from the list. The third step was done by removing fifty points from the original data and the percentage contribution of grass species with 50 points was determined. Also at this step the first four grass species were still dominant and they scored 32, 24, 18 and 8% respectively while two species (*Pennisetum clandestinum* and *Bothriochloa insculpta*) disappeared from the list. Step four was done by removing thirty points from the original data and the percentage contribution of grass species with 20 points was determined. At this step the first four species were still dominant but the last four species disappeared from the list. Lastly the sampling intensity of 100 points was chosen based on the fact that dealing with100 points could reveal the same result as 150 points. Also many species could be sampled and large area could be surveyed.

Table showing the sampling intensity for different points in the Crater.

Species	150 %	100 %	50 %	20 %
Chl gay	27.3	25	32	25
Cyn dac	21.3	20	24	25
Dig aby	20.7	22	18	20
Spo fim	9.3	10	8	15
Cen cil	6.0	6	6	5
Set ver	4.0	4	4	5
The tri	3.3	3	4	5
Hyp hir	2.7	3	2	0
Pen cla	2.7	4	0	0
Bot ins	2.0	3	0	0
Cym afr	0.7	0	2	0

Appendix 7 cont.

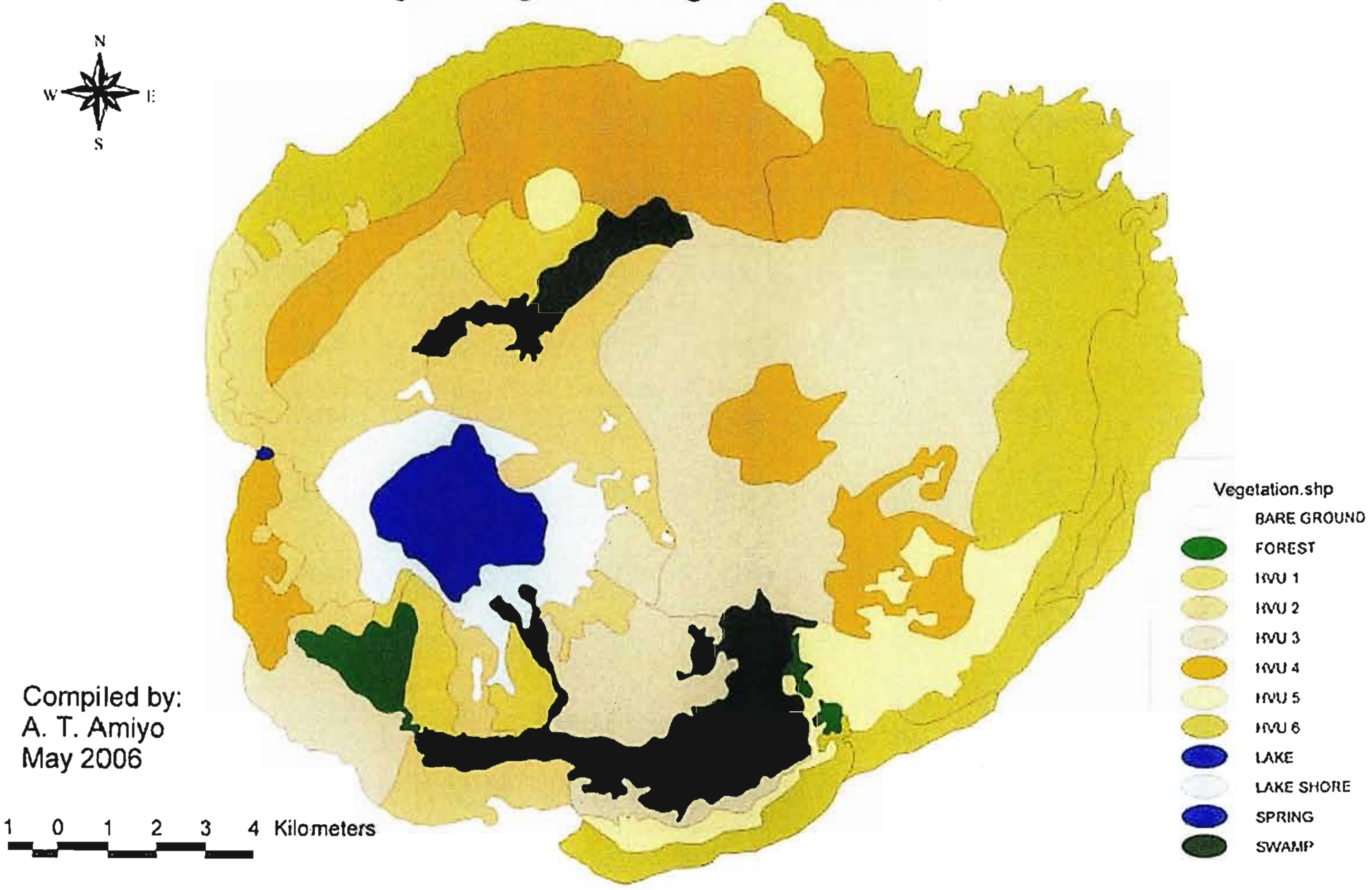
Percentage presence of grass species in vegetation type 13 transect 4



APPENDIX 8: VEGETATION MAP OF NGORONGORO CRATER

See map overleaf.

Ngorongoro Vegetation Map



Compiled by:
A. T. Amiyo
May 2006