# THE ROLE OF FIRE AND MECHANICAL CLEARING IN THE MANAGEMENT OF *CHROMOLAENA ODORATA*.

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# DECLARATION

This thesis is the result of the author's original work except where acknowledged or specifically stated to the contrary in the text. It has not been submitted for any degree or examination at any other university or academic institution.

Signed Wessels..................................

Mathias Fittschen Wessels

Date: 29/3/2007

# Abstract

The effects of fire and mechanical clearing were investigated for their potential in assisting with the eradication of *Chromolaena odorata* (previously *Eupatorium odoratum*). The study was divided into two focus areas, the first focused on mechanical clearing of dense stands of *C. odorata* on three sites and the second focused on the long term influences of a single burn on *C. odorata* plants in the different size categories. For mechanical clearing, two key issues were investigated; namely whether this type of clearing procedure was effective in dense *C. odorata* stands and whether rehabilitation was necessary in these cleared areas. The study was conducted from July 2002 to June 2004. The area was subject to a severe drought throughout the duration of the study. The severe drought had a large influence on the result in both focus areas. A bulldozer was found to be a very effective at clearing dense *C. odorata* stands. Results from the mechanical clearing study showed that there was still a large viable grass seed population in the areas that had been covered by a dense stand of *C. odorata* plants for over three years. Thus, indigenous plants were able to re-colonize the area after removal of *C. odorata* without human intervention, even thought the area was experiencing a severe drought. The density of *C. odorata* seedlings emerging in the cleared areas was far lower than expected. The *C. odorata* density in the permanent plots, for seedlings that germinated in the first season after clearing (September-October 2002), was only 0.25, 0.03 and 0.72 per 5 $m^2$ in the three sites respectively by the end of the study in June 2004. For the *C. odorata* seedlings that germinated in the second season (September-October 2003) the density was, 0.5, 0.56 and 1.06 per 5 $m^2$ in the three sites respectively by the end of the study in June 2004. It was suspected that the drought influenced seed germination. Unfortunately the number of *C. odorata* seedlings was so low, that no significant relationship could be found between grass and *C. odorata* seedling density. By the end of the study the grass fuel mass in all the rehabilitated sites was already over 3000 kg $ha^{-1}$, even though the area was experiencing a severe drought. This grass fuel load, when burnt, will assist land managers in controlling *C. odorata* plants, especially seedlings. Very few other alien invasive plant species emerged in the cleared areas. At the Mhlosinga site, *Senna pendula* made up less than one percent of the herbaceous species composition and only a single *Ricinus communis* plant was recorded. No alien plant species were recorded on the other two sites. Results from the burning trials revealed that plants in all the size categories were affected by fire. Greater fuel masses and fire intensities were required to kill larger *C. odorata* plants relative to smaller ones. Fire was found to be very effective at eliminating small and medium size *C. odorata* plants. Fire applied as a once off treatment had a significant long-term effect on the *C. odorata* population. The following fuel loads were required to achieve 80% mortality in this study: for small plants a fuel load of over 4000 kg ha$^{-1}$, for medium plants a fuel load over 4200 kg ha$^{-1}$ and for large plants a fuel load over 4600 kg ha$^{-1}$. Little difference could be detected between a head or a back burn, as both fire types had their own advantages and disadvantages. Although some of the *C. odorata* plants in the burnt plots had not perished by the time of the first investigation, following the burn (February 2003), by the time of the second investigation (June 2004), many of these plants had eventually succumbed. These results highlighted the fact that plants which are damaged by fire were more likely to persish during an extended droughts period, than plants which were not subjected to fire. Results from the control plots, in the burning trials, for medium and large plants showed dramatic increases in density over time. Tagged individuals from the control plots did reveal that some of the medium and large plants did die during the drought, although the amount was negligible when compared to the number of new plants growing into the new size categories. A large proportion of the small plants in the control plots also survived the drought with many of them even growing into the medium category. The difference between the control plots and the burnt plots was obvious and significant, especially once the fuel mass exceeded 3783 kg ha$^{-1}$. Results from this study show that fire can be used as a very effective tool in assisting land managers to control *C. odorata* in open savanna bushveld.

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# Chapter 1

# Literature review

## 1.1 Alien plants

Alien plant species are plants that have been introduced to areas far from their centre of origin, usually on a different continent or subcontinent. Most alien plants can only survive in their adopted countries through human intervention, especially if the conditions in the adopted countries differ from those they are used to. However, a certain proportion of alien plants are able to survive and propagate in these counties. These alien plants are said to have become "naturalised". If such naturalised plants are also able to spread over considerable distances into new, undisturbed natural areas and replace indigenous vegetation, they are then regarded as alien invasive plants (Klein 2002).

Alien invader plants, particularly woody species, are a major cause of ecosystem collapse worldwide. If these alien plants are left uncontrolled they will impact non-selectively on the environment, replacing species-rich communities with monospecific vegetation (Cronk & Fuller 1995).

Some of these plants have been introduced intentionally for their apparent desirable qualities, for example as crops, forestry species, ornamental plants and for dune binding, and have subsequently 'escaped' from the areas where they were introduced. Many alien plants have also been introduced accidentally for example as contaminants of grain or fodder, or by adhering to animals, humans or vehicles, etc. (Klein 2002).

Undisturbed natural vegetation is resistant to alien invaders (Sagar & Harper 1961). Conversely, land which is mismanaged (i.e. over or under-utilization of the veld, incorrect burning regimes, etc.), will be more prone to invasion by alien plant species. It is often assumed that plant invasion is caused by differences in competitive ability between invading and native flora, but strategies that determine these differences are seldom understood (Byers 2000, Myers & Bazley 2003). There are many theories why some introduced species have become naturalised. The 'absence of a natural predator' hypothesis supports the idea that problem species that were introduced have no natural enemies, and therefore have a competitive advantage over indigenous species in every facet of their life cycles (Huffaker *et al.* 1976). Similarly, Cronk & Fuller (1995) speculated that alien species have a greater reproductive potential, characteristically producing greater quantities of seed than native species that are attacked by herbivores, pathogens and disease. Consequently, alien species have large residual seed banks. Another theory, namely the 'poorly adapted species' hypothesis, suggests that native species are less well adapted to the specific conditions than alien species.

Plant invasion is often thought to be promoted by human-related factors, such as disturbance and eutrophication (D'Antonio 1993; Alpert, Bone & Holzapfel 2000; Thompson *et al.* 2001). This highlights the importance of examining the past management strategies as well as veld condition before the invasion.

Hagar (2004) studied *Lythrum salicaria*, an invasive perennial wetland plant. She mentioned that it was not a good invader of established vegetation, but once it established itself, it was fairly resistant to being outcompeted by the natural vegetation and was better able to suppress the growth of native seedlings than the native vegetation. She also concluded from her studies that *L. salicaria* mostly invaded vegetation that had been disturbed. Here its high growth rate and consequent production of above ground biomass gave it a competitive advantage over the other herbaceous species.

MacDonald & Jarman (1984) identified three causal hypotheses for the alien invasion of the fynbos biome in the Western Cape. The first causal hypothesis is that alien plant invasions only occur in ecosystems disturbed by man. The second one is that the ecosystems in the fynbos biome are inherently susceptible to invasion. The third hypothesis relates to the attributes of the alien invader species themselves.

Considering the first hypothesis, there are examples where alien invaders occur both in obviously disturbed and in apparently undisturbed areas in KwaZulu-Natal (*Lantana camara* and *Chromolaena odorata* stands in Hluhluwe-Umfolozi Game Reserve, personal observations). The second hypothesis, which implies that natural ecosystems are sometimes susceptible to alien plant encroachment, due to a lack of competitive ability amongst the indigenous plants, is supported by the fact that fauna and flora in the areas where alien plants are originally from are able to restrict the growth, abundance and distribution of these alien plant species (Hill 1977; Stirton 1983).

Another major factor that contributes to this susceptibility is the existence of a vacant ecological niche within the community (MacDonald & Richardson 1986). The community is thus rendered vulnerable to encroachment by alien species (Hill 1977). The niche is defined as the position of a species in a community with regards to its spatial, temporal and trophic relationship to other existing species (Oka & Morishima 1982). The ecological niche may have arisen as a result of a disturbance within the existing indigenous vegetation. The disturbance may be natural or man-mediated.

Natural disturbances, such as floods or droughts, disrupt the usual progression of succession, opening up a niche or niches suitable for colonisation by alien plant species. Man-made disturbances are probably more common and take the form of over-utilization and exploitation of the land, resulting in habitats vulnerable to rapid infestations by alien species. In both natural and man-made disturbances an 'ecological vacuum' is created which is rapidly filled by species most suitably adapted to that particular situation (Hill 1977). These species are often alien plant species, because although weeds may have different potential niches, their realized niches are opportunistic (Oka & Morishima 1982). The vacuum may actually result from the removal of an alien weed species, such as observed in KwaZulu-Natal, where there are situations where an area had been infested by *Lantana camara* L., but, on removal, the site has rapidly been colonised by *Chromolaena odorata* (Erasmus 1985). Disturbances, such as fire, typically initiate expansion and increase the density of invasive alien plants in fynbos. But the same may not necessarily be true for grasslands. The frequent fires that occur in grasslands that are in a good condition may actually prevent regeneration of alien plants (for example *C. odorata*).

The third hypothesis proposed for the success of alien species relates to the attributes of the alien invader species themselves. These attributes include: an efficient reproductive system, vigorous growth of seedlings, seed dormancy, the ability to adapt to many different habitats and competitiveness for natural resources and light (Hill 1977; Holzner & Numata 1982; Klingman & Ashton 1982; Stephens 1982).

Neser (1984) also lists the following features and characteristics of aggressive weeds:

i) they show a local or temporary tendency to grow in dense stands;

ii) they have a relatively wide distribution as they are not limited to specialized habitats;

iii) they display variability i.e. the plant's ability to change its growth in response to a change in the environment. Akobundu (1987), for instance, describes five varieties of *Imperata cylindrica*, each of which is distributed over a definite geographical region. Another example is *C. odorata* found in West Africa which has a deep tap root system as opposed to a shallow adventitious root system in Southern Africa (Erasmus 1985);

iv) their seedling numbers are dramatically reduced, in their country of origin, by specialised predators.

## 1.2 Examples of alien invasive species worldwide

The annual grass *Bromus tectorum*, which was apparently first noticed in the United States around the year 1900, is one of the examples of alien invasive species worldwide. It has subsequently become dominant on millions of acres of the western range in the United States. Some of the reasons for it being so successful are because of large seed production, rapid germination and growth of shoots and roots when conditions are favourable, early maturation, and adjustment to drought and other unfavourable conditions such as overgrazing (Hanson 1961). Another example is the grass, *Sporobolus pyramidalis*, which had been introduced accidentally into Australia in the 1960s from Africa via contaminated pasture seed. It is estimated to have infested around 90 000 ha of coastal and sub-coastal areas in Queensland and the northern parts of New South Wales (Bray *et al.* 1998). Another example is the strawberry guava, *Psidium cattleianum*, which is native to the Atlantic coast of Brazil, and which has become naturalised in many tropical regions of the world. It is often introduced into these countries for cultivation of the edible fruit, but quickly escapes cultivation, when the seeds are dispersed by birds and animals (Cronk & Fuller 1995).

## 1.3 Alien plants in South Africa

Unfortunately, South Africa also has its fair share of alien invasive plant species which have been introduced to the sub-continent. One example is *Rubus cuneifolius* (American Bramble), a serious invader of agricultural and forestry land. This species had apparently been imported for its berries which were used for jam-making (Wager 1947), but has subsequently become naturalized, and has encroached on large areas. Another serious alien invader in South Africa is *Hakea sericea*, which was probably imported for growing hedgerows, but has 'escaped' cultivation and become naturalised in large areas of the Western Cape (Neser & Fugler 1983).

Certain species, imported for timber production, have subsequently 'escaped' from the plantation, and encroached adjoining land where they have become serious invaders, for example *Acacia dealbata* in KwaZulu-Natal and *Pinus pinaster* in the Western Cape (Kruger 1983).

Another local example is the grass *Stipa trichotoma* (Nasella Tussock), which originally came from South America, and arrived in South Africa by way of hay imported from Argentina for the horses of the British Army during the Anglo-Boer war in 1899-1902 (Wells 1983). It has subsequently infested approximately 70 000 ha of veld in the Western Cape (Joubert 1984).

*Sesbania punicea* (red sesbania) was introduced into South Africa 150 years ago, and was, until recently, a major weed of wetlands and rivers. Twenty years of biocontrol has almost brought it under control due to the action of three weevil species (Hoffmann & Moran 1998).

Many alien species were also imported as ornamental species, and have now become naturalised and encroached on large areas. Examples of these species include *Eichornia crassipes* (Mort.) (Kluge 1983), *Lantana camara* L. (Stirton 1983) and *Opuntia imbricata* (Haw.) D.C. (Zimmerman 1983). Obviously, in the early stages, the destructive potential of these weeds was not realized. Unfortunately, many were only noticed once they posed a serious ecological threat. Nuclear infestations provide a propagule source from which large areas can become infested, when the correct environmental conditions prevail.

Curators of botanical gardens in the 1900s encouraged the introduction of alien plants, many of which have since become invasive. With the growing awareness of the value of indigenous flora, the trend has increasingly become to focus on the cultivation of indigenous species. Awareness campaigns organised by botanical societies and conservation authorities, have resulted in a strong ‘anti-invasive alien plant’ movement. In future it is likely that most invasive plant species arriving in South Africa will do so by accident (Ferrar & Kruger 1983).

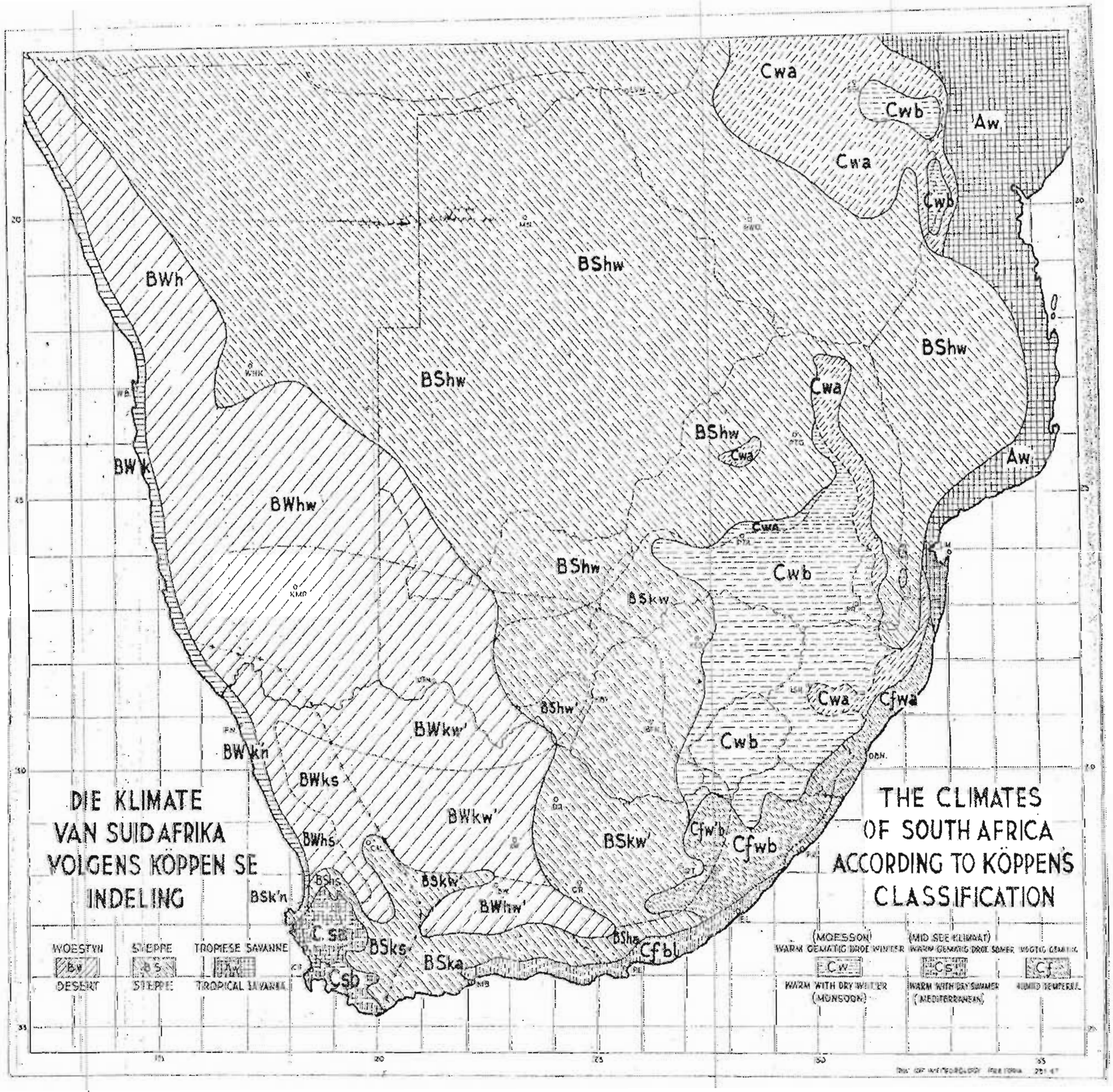
## 1.4 *Chromolaena odorata*

### 1.4.1 Origin

*Chromolaena odorata* (previously *Eupatorium odoratum*) is native to the West Indies and tropical South America, and has spread from these areas to many of the warmer parts of the world (Holm *et al.* 1977). It is currently a major problem in West and Southern Africa, India, Sri Lanka and Southeast Asia and Australia. In Southern Africa it is known to occur in South Africa, Swaziland and Mozambique. It is also a troublesome weed in the areas where it occurred originally (Holm *et al.* 1977). Its distribution is largely determined by the temperature: between 10-37°C (Ambika & Jayachandra 1990) and rainfall: between 750-2000 mm (Kluge 1990).

### 1.4.2 Distribution in South Africa

*Chromolaena odorata* is thought to have arrived in South Africa from the West Indies in seed-contaminated packing material that was off-loaded at the Durban Harbour during the Second World War (1939-1945) (Pickworth 1976). It was thought to have arrived from the West Indies, because the southern African biotype differs from *C. odorata* invasives elsewhere in the world such as Asia, West Africa and Australia (Pickworth 1976). It was first noted growing in the Inanda district and later the Umzinto area where it was known as ‘Armstrong’s weed’ and ‘King’s weed’ respectively, these names refer to the owners of the farms on which it was found (Egberink & Pickworth 1969; Byford-Jones 1979).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Cfw'b
Cfwb
BSkw
BWhs
BSk'n
BSkw
BWhw'
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BSks
BSka
BSha
Cfbl
Csb
DIE KLIMATE VAN SUIDAFRIKA VOLGENS KÖPPEN SE INDELING
THE CLIMATES OF SOUTH AFRICA ACCORDING TO KÖPPENS CLASSIFICATION
WOESTYN
BW
DESERT
STEPPE
BS
STEPPE
TROPIESE SAVANNE
AW
TROPICAL SAVANNA
(MOESSON)
WARM GEMATIG DROË WINTER
Cw
WARM WITH DRY WINTER
(MONSOON)
(MID SEE KLIMAAT)
WARM GEMATIG DROË SOMER
Cs
WARM WITH DRY SUMMER
(MEDITERRANEAN)
VOGTIG GEMATIG
Cf
HUMID TEMPERATE
15
20
25
30
35

Figure 1.1 **The different climates in South Africa according to Köppens classification (Schulze 1947).**

*Chromolaena odorata* can only grow in areas that are frost free and have a mean annual rainfall of above 600mm. In the drier areas (mean annual rainfall 600-700mm), *C. odorata* occurs mainly in the valleys and riverine areas, where the soils have a higher moisture content (Erasmus 1985). The different climates of South Africa compiled by Schulze (1947), according to the classification of Köppen (Figure 1.1) can be used to identify the full range of climates suitable for *C. odorata* distribution. This includes all climates from the marginal zones to those climates which could be considered ideal, (the key to Schulze's classification can be found in Appendix 2).

Two ideal climates for *C. odorata* infestation were identified, namely *A w* (Schulze 1947) and *C f w a* (Schulze 1947) (refer to Figure 1.1). The predominant veld types in these climates are Coastal forest and thornveld (both type 1a typical coast belt forest in Natal and Transkei as well as 1b Zululand palm veld), Zululand thornveld and Lowveld (Acocks 1975).

Two favourable climates for *C. odorata* infestation were identified, namely *C w a* (Schulze 1947) and *C f w b* (Schulze 1947). The predominant veld types in these climates are Coastal forest and thornveld (1a typical coast belt forest in Natal and Transkei), Eastern province thornveld, Lowveld, Ngongoni veld and Zululand thornveld (Acocks 1975). Three marginal climates for *C. odorata* infestation were also identified, although it must be mentioned that the bare minimum requirements in these marginal zones are that they are frost free and that the mean annual rainfall is over 600mm. These climates were *BS h w*, *C w a* and *C f b l* (Schulze 1947) (refer to Figure 1.1). In these three climate types, *C. odorata* is unlikely to become a major problem and should be relatively easy to control with careful management.

### *1.4.2.1 Geographical position of the ideal and favourable climatic zones for C. odorata in South Africa*

*A w* (tropical savanna) is a narrow strip, on the coastline in the north-eastern corner of KwaZulu-Natal, and continues to stretch into Mozambique were it becomes substantially broader. In KwaZulu-Natal it starts roughly north of Richards Bay (Figure 1.1). *C f w a*, which is one of the humid temperate zones, is also a narrow strip that runs along the coastline of KwaZulu-Natal. It starts roughly around Port Edward and stretches all the way North until it joins *A w* (Figure 1.1). *C f w b* another one of the humid temperate zones, is another strip that runs along the eastern coastline although it is slightly broader than *C f w a*. It starts just south of Port St Johns and stretches all the way north to the *C f w a* climate zone (Figure 1.1). *C. odorata* is thought to mainly occur along the eastern section, close to the coast, as it receives higher rainfall than the western interior section. Another one of the humid temperate zones, *C w a* occurs just inland of *C f w a*. This climate zone occurs in a narrow irregular belt up to the lowest escarpment of a series of plateaux that South Africa is made up of. This climate zone also occurs in the lowveld region of Mpumalanga (Figure 1.1).

*Chromolaena odorata* seeds are wind dispersed. Therefore, wind direction is a major influence in seed dispersal patterns (Campbell 1991). The spread of *C. odorata* in Natal, although poorly documented, has been very rapid. By 1950 it had already been recorded at Ginginhlovu, 120 km north of Durban (Hilliard 1977), and by 1961 it was recorded for the first time in Hluhluwe Game Reserve, 280 km north of Durban (MacDonald 1983).

Pickworth (1976) suggested that *C. odorata* had reached its northern-most limit in Natal at Hluhluwe, and that environmental constraints would prevent it from spreading any further. However, by 1995 *C. odorata* had invaded extensive tracts of land: from south of Port St. Johns to north of Louis Trichardt in the Limpopo Province.

In KwaZulu-Natal, *C. odorata* occurs throughout areas with an altitude lower than 800m, with dense infestations mainly occurring in areas that have a relatively high rainfall, as well as in riverine areas and areas that have fertile soils with poorly managed veld. It has become established as far west as Pietermaritzburg and Melmoth (Egberink & Pickworth 1969; Liggitt 1983; Henderson 1989). *C. odorata* also occurs extensively in the low altitude parts of Swaziland, Mpumalanga and Northern Province (Goodall & Erasmus 1996). Over a period of 10 years, starting in 1985 *C. odorata* spread from Ndumo Game Reserve to Venda (averaging around 45 km per year). The highest altitude infestation was recorded at Tzaneen in 1994 at 1250m (Goodall & Erasmus 1996). Two thousand percent increases from 1978 to 1982 had been recorded north of Eshowe, and it is continuing to spread northwards at an alarming rate (Liggitt 1983).

In Southern Africa a key constraint for many species is rainfall, particularly the frequency and intensity of dry seasons and drought (Erasmus 1985). Previous studies have emphasised the vulnerability of riparian zones to invasion. In general the rivers of the moist subtropical coastal belt and the lowveld appear to be the worst affected by invasion of alien plants. Riparian zones are physically dynamic areas with changes in flow, especially floods, altering river beds and exposing bare soil to colonisation by weeds.

From personal observations, large *C. odorata* plants can withstand drought by going into a state of dormancy and by producing very few seed seeds. However, *C. odorata* plants quickly recover as soon as moisture becomes available. Infestations produce large quantities of seeds which invade areas as soon as more favourable conditions return. As a result there is very little spreading of this alien plant during drought periods.

Man-made disturbed areas, such as road verges, rail verges and other utility areas, are very susceptible to invasion by alien invasive plants. Not only is the plant difficult to control in these areas, but there is also no economic incentive to do so. There is definitely a positive correlation between these areas and the occurrence of *C. odorata*. Alien plants such as *C. odorata* do well along road verges because the complete lack of grazing and burning in these areas results in moribund grass, which offers little competition to alien plants. Road sides form vital links from which *C. odorata* plants can quickly spread along until the plant finds suitable habitat adjacent to the road side.

### 1.4.3 Description of *Chromolaena odorata*

In Southern Africa *C. odorata* is commonly known as 'Triffid Weed' or 'Paraffin Bush'. The 'Triffid Weed' is apparently derived from this species' ability to rapidly encroach on large areas, while the name 'paraffin bush' describes the black oil-like smoke given off during burning. *C. odorata* is ranked on the national ranking scale as the sixth worst alien invasive plant in South Africa, and is believed to have, after the aquatic invasive species, the fastest spreading capability (Erasmus 1985).

#### *1.4.3.1 Description*

*Chromolaena odorata* belongs to the family *Asteraceae*, and, along with many other members of this family, bears numerous, small, single, non-fleshy fruits called achenes (Erasmus 1985). *C. odorata* is a perennial shrub; its growth form depends on the habitat in which it is growing.

In open savanna the young plants are upright, slender and single-stemmed while the mature plants are typically upright, bushy shrubs that are up to three metres in height with stem diameters of between two to eight centimetres at the base (Erasmus 1985). In savanna conditions, mature infestation consists of dense stem entangled thickets. In habitats predominated by arborescent and shrubby species, *C. odorata* assumes a scrambling habit with elongated and comparatively thin stems (one to four centimetres at the base) (Erasmus 1985). These plants, searching for sunlight, grow considerably taller than savanna counterparts, and can reach heights of up to seven metres.

*Chromolaena odorata* stems are round, and branch in opposite pairs at the nodes. The lateral branches usually become noticeable only towards the end of the first year's growth. The stems and branches at maturity are brittle and fairly woody. First-year stems are conspicuously green in colour, while the older stems are beige to grey. The light-green leaves are opposite each other at the nodes, alternating at successive nodes and are ovate to triangular in shape. In shady, habitats, the leaves are up to 10 cm wide and 13 cm long have serrated margins and are three-veined (Erasmus 1985). However, the first leaves produced on the seedling lack three veins. When crushed, the leaves give off a strong, pungent, paraffin-like odour, leading to the botanical nomenclature of '*odorata*' or '*odoratum*'.

### *1.4.3.2 Flowers*

Flowering can occur over a wide range of day-length conditions (10 to 14 hours) but the flowers are mainly stimulated by the shortening of the days' lengths (Sajise *et al.* 1974). In KwaZulu-Natal flowering starts with the development of flower-buds in May, which develop further into white to creamy inflorescences from June to August. The colour is variable, as these flowers are pale blue in Nigeria (Ivens 1974). Presumably therefore, shorter day lengths are important in stimulating the plants to flower in Natal (Erasmus 1985). In South-East Asia (Northern Hemisphere) flowering occurs during the months of November and December, during the onset of short-day conditions (Sajise *et al.* 1974). In Nigeria, *C. odorata* flowers during December and January (Ivens 1975).

### *1.4.3.3 Achenes*

Seeds form an important and persistent stage in the life cycle of plants. Since the embryo is usually protected within coverings such as testa and/or pericarp, the seeds can survive adverse environmental conditions. The achenes are narrow, dark brown to black, linear-shaped structures of about 4 mm in length, and closely resemble two common Southern African weeds namely *Tagetes minuta* L. and *Bidens pilosa* L. (Erasmus 1985). Being small and light, the papus-bearing achenes are well adapted to wind dispersal; this facilitates the rapid and widespread dissemination of the reproductive propagules. From various studies it was confirmed that adult *C. odorata* plants produce large quantities of these achenes each season (Weerakoon 1972, Ivens 1974, Todd 1980, Liggitt 1983). However, the number produced is dependent on the locality. In areas not particularly well suited to this weed's growth, it was found that although large numbers of achenes were produced, the percentage of viable achenes was comparatively low (Erasmus 1985). However, because germinable achenes were found to be produced in these marginal areas, the threat of further encroachment remains a reality.

Each flower-head (capitulum), which is borne on a raceme inflorescence, produces varying numbers of achenes that are attached to the receptacle. The number of achenes per capitulum had been incorrectly reported as being 'a hundred or more' (Egberink & Pickworth 1969). In Nigeria 25 to 30 achenes per capitulum are produced (Ivens 1974). The number of capitulas on each plant varied considerably, this in turn caused the number of achenes per plant to also be very variable.

Weerakoon (1972), stated that in Sri Lanka it had been estimated that an annual average of 93 000 achenes are produced per plant. In Nigeria, an average of 125 000 achenes had been estimated (Ivens 1974), while Liggitt (1983) had recorded 110 000 achenes for a fairly small plant in Hluhluwe Game Reserve. Meanwhile, Todd (1980) had found an average of 440 000 seeds per plant in the Kloof region of Natal, and estimated that plants that are 0.3 m high, produce 1000 achenes, while larger plants produce between 28 000 and 1 300 000 achenes. One individual bore approximately 1 600 000 achenes. These findings show that achene production appears to increase with plant size, but is not known whether it is a function of plant size or age.

Soil-burial studies revealed that achenes were viable for at least one year in the soil (Wilson 1995). Seeds buried by soil, had a lower germination percentage (Wilson 1995), although some of these buried seeds may have gone into dormancy (Wilson 1995). Some researchers believe that those seeds that do go into a state of dormancy could remain viable for over three years (Kluge 1990).

Large numbers of achenes from areas infested with *C. odorata*, are usually present in the soil. The majority of these achenes are found on or near the soil surface. Up to 50 % of the recovered achenes can be germinable, and this represents approximately 12 000 seedlings $m^{-2}$ (Erasmus 1985). The remainder are either non-viable or secondarily dormant. Ivens (1974) germinated 4 500 seedlings from one square metre of soil collected under a *C. odorata* thicket.

Comparatively few seedlings appear to reach maturity. Mortality may be due to a variety of factors, including intra- and inter-specific competition and unfavourable environmental conditions (Erasmus 1985). Seedlings which do become established grow vigorously. The growth initially consists of vertical elongation, which is probably due to the strong manifestation of apical dominance, but, towards the end of summer (March), growth is dominated by profuse lateral-branch production, resulting in a dense canopy.

According to Campbell (1991) *C. odorata* achenes do not appear to be able to travel dramatic distances by wind from the source plant, with a vast majority of the seeds falling within a 10 m radius of the plant (Campbell 1991). However, Campbell did state that the number of achene traps he used was not sufficient to justify this statement.

The introduction of *C. odorata* into countries where it is now a serious weed problem, had, without exception, been unintentional. Introduction had been either by way of contaminated seed in Nigeria (Ivens 1974) and Ghana (Hall, Kumar & Enti 1972), or by contaminated clothing in India (Moni & George 1959). In other countries infested with *C. odorata*, no explanations could be given, as to how *C. odorata* entered the country.

On introduction, the spread of *C. odorata* in the respective countries had been rapid. Owing to the fact that *C. odorata* seeds have been reported to be viable for longer than three years (Wilson 1995), the importance of follow-up work in the management of invasions is highlighted. *C. odorata* shades the soil so that nothing grows beneath its canopy. Some *C. odorata* stands are estimated to be between 10 and 30 years of age. It is suspected that a large portion of the indigenous seed bank, below these stands, has perished.

In South Africa, it seems that germination occurs between September and February. The dense mat of seedlings which is sometimes observed in exposed areas following warm, moist conditions has been described as 'sward-like' (Egberink & Pickworth 1969). Under a closed canopy however, very few seedlings have been observed (Rai 1976; Ivens 1975; Wilson 1995).

For maximum germination Erasmus (1985) found that the following conditions enhanced germination:

i) an alternating temperature between 15 and 30 °C;

ii) imbibitions, for at least 12 hours at alternating temperatures of 15/30 °C prior to irradiation, were necessary to sensitize achenes to light;

iii) percentage germination increased with increased exposure to irradiation up to a maximum of six hours; however, neither six nor 12 hours of white light was sufficient to stimulate germination to the same extent as diurnal light;

iv) germination of achenes is enhanced if they are in dark storage at 25 °C for seven months.

### 1.5 Why *Chromolaena odorata* is a problem

*Chromolaena odorata* has a high growth rate and a shallow root system that enables it to effectively out compete grass in mismanaged veld (i.e. where the grass has a low vigour). The *C. odorata* in this disturbed area will quickly form a dense stand so that no grass or any other plants will be able germinate below. This, in turn, will greatly increase the erosion potential and decrease the carrying capacity of the area for both browsers and grazers (Liggit 1983, Erasmus 1985, Blackmore 1993, Wilson 1995, Goodall 2000). Some of the seeds from these mature *C. odorata* plants that grow in the mismanaged veld, will fall into the adjacent undisturbed areas.

Some of these seeds in these undisturbed areas will be able to become established (as a result of the plant's strong competitive ability), thereby assisting the plant to spread into new areas.

By decreasing the carrying capacity of the land, *C. odorata* does have a direct bearing on animal production. In conservation areas this will directly affect hunting and game viewing. This, in turn, determines how much money is put back into land management. The dense thickets obstruct game viewing, and provide ideal habitats for the concealment of snares. The cost of clearing these dense, extensive infestations is prohibitive and often exceeds the value of the land itself.

As the *C. odorata* displaces the grass, the grazing pressure on other undisturbed grassland areas will increase, thereby increasing the grazing pressure on the veld, and possibly causing the rest of the veld to be overgrazed. This will subsequently provide more disturbed habitat for *C. odorata* to spread quickly (Erasmus 1985).

*Chromolaena odorata* stands are persistent. With some stands being over 30 years of age (Wilson 1995), this indicates that once *C. odorata* invades an area and matures into large plants, it will not be out competed and replaced by other plants. Some large *C. odorata* plants can re-coppice after a fire, especially in areas where the veld had a low fuel mass (Goodall 2000), and therefore carry on propagating. *C. odorata* can grow on forest margins; and, during a veld fire will carry the fire from the neighbouring grasslands into the forest interior, killing indigenous trees and shrubs (MacDonald 1983).

In South Africa there are no indigenous herbivores that seem to be having any significant effect on *C. odorata*, and so it has a distinct advantage over the indigenous vegetation. Leaves of *C. odorata* contain high levels of tannins, which in turn prevent browsers from consuming large quantities (Wilson 1995).

*Chromolaena odorata* has the ability to adapt too many different habitats, even in areas that could be described as undesirable for it; for example, areas with sandy soils that receive less than 800mm rain per annum (Goodall 2000). *C. odorata* also has the ability to root from stems which are in contact with the soil and thereby produce daughter plants (personal observation).

Water catchment areas provide another instance where alien invaders are of economic importance, especially in South Africa, where water is a limiting commodity for many industries (Erasmus 1985). Woody alien species, especially *Acacia*, *Eucalyptus* and *Pinus* species, have impacted greatly on hydrological processes in South Africa (Mueller-Dombis 1973 (cited by Goodall 2000)). Versveld, le Maitre and Chapman (1998) have estimated that 7% (3 300 million $m^3$) of South Africa's mean annual water runoff is lost through the transpiration of alien plants in mountain catchments. *C. odorata* is a moisture-loving species that quickly shows signs of stress under dry spells. It uses more moisture than the indigenous vegetation. Rivers and streams will have less water if they have *C. odorata* infestations in their vicinity. An example of this is a fresh-water spring on Kubuyeni Game Reserve (Hluhluwe). The spring ceased flowing once the area had become infested with *C. odorata*. When these plants were removed, the spring started to flow again (K. Boyce pers. comm.[1]).

*Chromolaena odorata* is invading large sections of thicket vegetation in conservation areas where Black Rhino (*Diceros bicornis L.*) browse and shelter, thereby displacing an endangered species in the process.

Nile crocodiles (*Crocodylus niloticus*) make their nests on riverbanks where light and temperature are important in ensuring both embryonic development and balanced sex ratios. *C. odorata* invades these areas and shades out nesting sites. This results in increased egg mortality and female-biased sex ratios (Dr A. Leslie pers. comm.[2]).

*Chromolaena odorata* does not appear to be a direct threat to agriculture, but the weed is a host to several plant diseases which may be transmitted to economically important plants (Campbell 1991). Several pathogenic seed-borne fungi have been identified as coming from the achenes of *C. odorata*, and further research into their pathogenicity is required (Liggitt 1983). In southern Nigeria, *Zonocerus variegates* feeds almost exclusively on weeds, and has increased drastically in numbers, which is probably due to the spread of *C. odorata*. The nymphs of this grasshopper are responsible for considerable damage to crops such as cassava (*Manihot esculenta*), citrus and bananas (*Musa acuminata*) (Liggitt 1983). The potential for damage to fruits in the "banana province" of KwaZulu-Natal, could be devastating.

It is disturbing that the problem has been allowed to reach the present proportions, and intensive measures to reduce the impact of this weed should be implemented without delay. A particular problem is posed when *C. odorata* invades areas of low economic productivity. In such cases, control is impractical due to the high cost of chemical or mechanical control. These areas include a wide variety of grazing lands, protected areas and other non-agricultural land, including indigenous forests, riverine systems, wetlands and water bodies. It is important to devise inexpensive procedures that would limit the extent of future invasion, and provide management strategies for those already established (Ferrar & Kruger 1983). The cost of follow-up action also needs to be considered, because the problem often recurs, and then the time and money spent on the initial action is wasted. Such is the case at Charter's Creek in the Greater St Lucia Wetland Park, where stands of *C. odorata* had been cleared, but no follow-up action was undertaken, causing the cleared areas to quickly revert back to dense monospecific stands of *C. odorata* (Wilson 1995). In South Africa *C. odorata* has been declared a category 1 noxious weed under the provision of the Conservation of Agricultural Resources Act 43 (1983), which imposes the legal requirement to remove and destroy it immediately.

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### 1.6 Why *Chromolaena odorata* has been so successful in invading the tropical savanna and humid temperate zones of KwaZulu-Natal.

Despite repeated warnings of the dangers of *C. odorata* during the 1960s in KwaZulu-Natal, very little in the way of control was carried out by landowners in the early stages of *C. odorata* invasion when the problem may have been contained (MacDonald & Jarman 1984). This can be ascribed to apathy, ignorance and limited resources. In addition, a no-burning policy imposed by the Department of Agriculture and Ezemvelo KZN Wildlife (formerly the Natal Parks Board) over the past few decades has resulted in encroachment by both indigenous and alien invasive woody species, including *C. odorata* (Zachariades & Goodall 2004).

The geographical topography of KwaZulu-Natal can be quickly summarised as follows: the steep Drakensberg Mountain range forms the western border of KwaZulu-Natal. At the foothills of the Drakensberg the land falls in a series of steps down to the coast. These steps fall more steeply in the southern parts of Natal, whereas in the northern parts they are broader and have some steep Mountain ranges on these step escarpments, for example the Ngoye and the Lebombo Mountains series range (Adamson 1938, Acocks 1975). The coastal strip, especially in the south, is very narrow with high rainfall and temperatures, producing almost tropical conditions even though the latitude is well outside the tropics (Adamson 1938, Schulze 1947, Acocks 1975).

These steps and mountain ranges run in a parallel fashion to the coastline, i.e. south-north direction (Adamson 1938).

These steep step escarpments, along with the high rainfall, create many rivers and valleys which often have deep, fertile, alluvial soils close to their banks. In combination with the warm subtropical weather these areas create 'ideal' germinating sites for *C. odorata*. These 'ideal habitats' can be found at regular intervals all the way from the southern to northern parts of KwaZulu-Natal and Zululand. Unfortunately, both commercial and subsistence agriculture are also often practiced right up to, or very close, to these streams and rivers, thereby promoting invasion of *C. odorata* in these disturbed areas.

KwaZulu-Natal's soils are extremely variable, but large patches of very fertile clay soils can be found dispersed throughout most of its lower lying areas. The prevailing winds in KwaZulu-Natal are generally south-westerly and north-easterly, which partially explains the rapid spread of *C. odorata* both north and south from Durban. August is also generally

KwaZulu-Natal's windiest month. This, unfortunately, coincides perfectly with the period when the *C. odorata* seeds are ready to be blown off the parent plants (Erasmus 1985). All these factors contribute to the extensive spreading of *C. odorata* north or south at an alarming rate from parent colonies. Strong winds will also funnel *C. odorata* seeds up mountain valleys into mountain ranges, which are often very inaccessible and where weed control is difficult.

As mentioned already (in section 1.4.2-Distribution in Southern Africa) *C. odorata* potentially is able to invade most of the areas falling into the *C f w a*, the *A w* and the *C w a* climate zones in Natal. These three zones encompass a fairly large proportion of Natal (Figure 1.1). The *A w* and the *C w a* climate zones, are characteristically known for their inconsistent rainfall cycles, with some years receiving way above average rainfall, and other years receiving way below average rainfall (Goodman 1981). It is during these wet years that *C. odorata* is able to expand its habitat, and spread into new areas.

During the drought years, most of the adult plants in the new areas will go into senescence, and lie dormant until good rainfall follows. The problem is that the drought usually only lasts for one or two years, which is not enough time to cause most of the adult plants to die. As soon as the rains return, these plants will quickly regrow and seed new adjacent areas. During these drought periods a lot of the public awareness and outcry that occurs during the wet years goes away, as it seems visually that a lot of the *C. odorata* has died and wilted away, which is obviously not the case. Thus, people are reluctant to fund clearing operations when it seems (incorrectly though) that the *C. odorata* problem will be solved by the drought. This is a pity, because it is during these drought periods that it is essential to clear out *C. odorata*, as the dense stands have wilted to such an extent, that it becomes possible for workers to walk through these areas and quickly gain access to the stumps which they can chop and spray. The cost of clearing these areas drops considerably during dry spells, for example on the Munyawana Game Reserve it usually requires an average of 20 workers to clear one hectare of dense *C. odorata* per day in the wet years, whereas in the dry years the same area can be cleared with only 12 workers (personal observation).

The veld types, which correspondence to the climate zones where *C. odorata* mainly occurs in KwaZulu-Natal, are the Coastal forest and thornveld 1a and 1b, Zululand thornveld, Lowveld and Ngongoni veld (personal observations). Land in these veld types is owned by a number of different parties, both private and state. These areas can be divided up into the following, namely small estates, private farms, tribal lands, conservation areas and timber plantations (both state owned and private). Few of these groups have any active alien invasive plant clearing programmes. Even though the few landowners that do have a clearing programme may be succeeding in controlling the alien infestations on their land, it is going to require a coordinated effort from all parties, both national and regional, to solve the problem. Unfortunately, a large proportion of people in South Africa live below the breadline, especially in the rural areas. Hunger for many is a daily occurrence, which means that often the last thing on people's minds is finances for clearing alien invasives.

Road verges form ideal disturbed habitats for *C. odorata* seedlings to become established. The verges develop into a thick visible band of *C. odorata* growing alongside the highway. From these areas the *C. odorata* quickly spreads into adjacent suitable areas beyond the boundaries controlled by the National roads department clearing programme. This clearing programme has only recently become established, so it is still very much in its infancy. The N2 highway, which runs in a north-south direction, and which is often relatively close to the sea, has a large portion of commercial plantations, for example blue-gum trees (*Eucalyptus* spp.), sugar cane (*Saccharum officinarum* L.), pineapples (*Ananas comosus* L.) and sisal (*Agave sisalana* ) adjacent to it. The soils in these commercial plantations are often disturbed, and when crops are harvested the area is often left open and exposed. These form ideal seedling establishment sites for *C. odorata*. In addition, Blackmore (1993) has found that the seeds of *C. odorata* easily become attached to motor vehicles, especially in combination with mud on the tyres, and this drastically increases the spreading capability of the plant.

In the Hluhluwe area the main commercial crops are pineapples and sisal. To help the soils regain essential organic matter, pineapple farmers often let their lands lie fallow for a year or two. It is during this fallow period that *C. odorata* invades these fields, often completely covering the area. The farmers are often very reluctant to clear the land as there is little economic incentive to do so. When they want to plant the field again, which could be in a year or two, they merely plough the *C. odorata* back into the soil. Unfortunately, by this stage, *C. odorata* has already produced large numbers of seeds which would have blown into adjacent areas.

Many farmers, who plant commercial crops, keep their cultivated lands clear of any weeds that may invade there, but unfortunately the remainder of the farm which is not used for commercial purposes, is often totally neglected. These neglected areas often become invaded with alien weeds, and form important 'islands' in helping these plants to spread into new areas. Large parts of KwaZulu-Natal are covered by commercial *Eucalyptus* plantations, and these large areas form ideal disturbed habitats for *C. odorata* to become established. The trees are spaced apart far enough to allow enough light to penetrate the ground, especially on the edges of the plantation. This partial shading creates an ideal habitat for *C. odorata* to become established, and a large seed bank is produced and blown each year into adjacent (often conservation) areas, for example the coastal timber plantations in Maputuland which border on the Greater St Lucia Wetland Park.

Many of the conservation areas and private game farms are also incorrectly managed, i.e. incorrect stocking rates and use of fire. This results in the veld being often either over-utilized, causing grass to have a very low vigour and soil cover; or under-utilized, which allows the grass to become moribund and also have a low vigour. This allows *C. odorata* to rapidly invade these areas. The cost of clearing these invaded areas in many of these conservation areas will often exceed the cost of the land and thereby does not make it economically worthwhile to start a plan of action to get rid of the alien plants. Another reason that *C. odorata* has been allowed to spread is that many landowners have actually given up trying to combat this weed. Many have employed incorrect clearing strategies at great costs and have failed. Land owners also often don't realise that it requires dedicated follow-up treatment, sometimes every three months in very wet years, and if this is not done, the area will very quickly revert back to a dense stand of *C. odorata*. Ezemvelo KZN Wildlife have attempted to clear *C. odorata* in protected areas within their jurisdiction, for example, in 1997, they spent an estimated US$ 370 000 on a *C. odorata* clearing operation (le Roux N. P. pers. comm.[3]). However, continuous seed pollution from outside the reserve boundaries has necessitated repeated follow ups, and renders these actions unsustainable.

The main reason why *C. odorata* has been allowed to spread to such proportions is as a result of a lack of knowledge and ignorance of the negative effects of this powerful and destructive weed.

## 1.7 Biological control

In the countries where *C. odorata* occurs naturally, it is not considered an invasive species, although it is sometimes a minor problem during establishment of plantations. No control methods other than slashing are required in the Neotropics, which is the reverse of the situation in Africa and Asia (Goodall 2000). The only logical explanation is the cumulative effect of biotic factors, principally host-specific insects, other arthropods and diseases that attack the plant throughout its range in the New World, but are largely absent from Asia and Africa (Cruttwell 1991 (cited by Goodall 2000)).

Biocontrol involves the use of natural enemies, especially insects and fungi from the weed's country of origin, to decrease reproduction and growth to a level where other control methods can be more effectively employed. Research into the control of *C. odorata* began in

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1988 with the aim of introducing a range of insects to attack different parts of the plant, namely its leaves, stems, roots and flowers (Goodall 2000).

Over 258 insect species have been recorded as feeding on, or affecting the growth of *C. odorata* in South America (Campbell 1991). These insects all play a part in suppressing its copious seed production, which, in turn, limits its growth and spread. In 1989 a defoliating moth, *Pareuchaetes pseudoinsulata,* was released with unsuccessful establishment in the wild (Zachariades, Strathie-Korrubel & Kluge 1999). Another defoliating moth, *P. aurata aurata*, was released several times between 1990 and 1993, but it also was unable to establish in the field. Several other species have been imported, cultured and tested, but only *P. insulata* has been authorised for immediate release. No field data are available yet. Several species under quarantine appear promising, namely *Melanagromyza eupatoriella* (stem-tip borer), *Lixus aemulus* (stem borer), *Calycomyza* sp. (leaf miner) and *Longitarsus* sp. (root borer). Research on these insects is currently at different stages and some of these agents should be released in the near future (Goodall 2000).

## 1.8 Methods to control *Chromolaena odorata* infestation

The best method to use in order to control large *C. odorata* plants, is to chop the plants and then spray the cut stumps with a suitable herbicide, or to allow them then to re-grow to knee height and then spray them with a suitable registered herbicide, as a foliar spray. A tree popper can also be an effective method for clearing large *C. odorata* plants, especially in areas that have a low *C. odorata* density and sandy soils.

For treating the cut stump either a 1% solution of '*Access*'® (active ingredient *Picloram*) or a 2% solution of '*Chopper*'® (active ingredient *Imazapyr*) can be used (Grobler *et al.* 1996; Ikuenobe & Ayeni 1998). The herbicide should be applied within half an hour, otherwise the cut wound will seal. The stump height should not be cut higher than 10cm off the ground. Cane knives, motorized brush cutters and even tractor-mounted gyro-mowers can be used to chop large *C. odorata* plants. The tractor mounted gyro-mowers can only be used in areas where the tree density is low enough to allow the tractor to move freely through the area.

For foliar spraying of the coppicing re-growth, the herbicide '*Garlon*'® can be used (active ingredient *Triclopyr*) at 0.375 % concentration (Grobler *et al.* 1996; Ikuenobe & Ayeni 1998). The foliar spraying should be done during the active growing season when the plants are knee high and there is enough leaf cover to absorb the herbicide (Grobler *et al.* 1996; Ikuenobe & Ayeni 1998). To control small and medium plants, the best methods are to hand pull in areas with low densities and to use a foliar spray in areas that have a higher density.

Very little information could be found, both locally and internationally, on the effect of fire on *C. odorata*. Goodall (2000) had found in his burning trials that the mortality of the *C. odorata* was positively correlated to the grass fuel loads, and in areas that had a grass cover of 30 % (which was equal to a fuel mass of around 1000 kg $ha^{-1}$), 80% mortality of the *C. odorata* infestation after the initial burn could be achieved. Goodall also found in his study area that after seven years of annual burning the grass biomass had increased whilst the *C. odorata* infestation had been effectively controlled.

Goodall did his research very close to the coast were the soils were sandy in nature and the high rainfall allowed grass to provide a suitable fuel mass for annual burning. Fire often fails to kill adult *C. odorata* plants in areas which have clayey soils, especially if these areas had received good rainfall prior to burning (Goodall 2000). In these situations he recommended an integrated control method to be adopted (i.e. using mechanical methods, chemicals and fire to control *C. odorata*). In his research Goodall (2000) also found that dense infestations could only be killed by running head fires from adjacent grasslands into thickets.

Follow-up control is essential in a *C. odorata* clearing programme because if this is not done, the area will quickly revert back to its original density. It also allows indigenous vegetation to re-colonize the area, thereby making it less susceptible to invasion by alien plants and stabilizing the exposed soils.

There is very little information available on the rehabilitation of areas that have been densely infested with *C. odorata*. Erasmus (1991) did the following trials in infested coastal forests at St. Lucia. He compared control efficacy of mechanical control, uprooting, uprooting combined with burning, and chemical control integrated with grass planting and fertilization. He recorded the following:

i) fire reduced the intensity of re-infestation, and improved the establishment of sown grasses;

ii) grass establishment was poor in unburnt plots due to a thick mulch layer left after clearing;

iii) the grass, *Setaria megaphylla*, grew best where chemical control was applied (2.5 t $ha^{-1}$);

iv) the grass, *Panicum maximum*, grew best in a manual control treatment (i.e. uprooting), but *Chloris gayana* yields were also significant;

v) natural grass established in plots that were not planted, was highest in the plots treated with herbicide (0.9 t $ha^{-1}$) and lowest in the plots that were burnt (0.4 t $ha^{-1}$);

vi) nitrate and phosphate application increased grass yield, but over sowing or planting grasses was expensive, and was only considered feasible in situations where large amounts of soil were exposed after clearing *C. odorata*;

vii) secondary weeds were often a problem after the removal of dense infestations;

viii) bugweed (*Solanum mauritianum*) and lantana (*Lantana camara*) were the most important alien species responsible for secondary invasion in coastal grasslands;

ix) slash and burn practices must be integrated with chemical control to prevent seedling establishment in situations where *C. odorata* is dense and grass cover is nonexistent.

### 1.8.1 *Chromolaena odorata* control internationally

From the current literature there is little information on how *C. odorata* is controlled overseas. It seems that the main areas affected overseas are cleared patches in tropical rainforests, and rice paddies in the Far East. From the current literature it would seem as if *C. odorata* is able to establish in almost any tropical or subtropical area that had been cleared for agriculture and has an annual rainfall in excess of 800 mm. When crop production in cleared patches in the rainforest becomes uneconomical, the farmers move into new areas and repeat the process. Abandoned fields are soon invaded by *C. odorata*, thus preventing forest succession (Slaats 1995).

A method of nutrient recycling by mulching with *C. odorata*, has been developed in fallow cropping in both India and West Africa (Slaats 1995). Fallow cropping with *C. odorata* is preferred to clearing virgin forest areas, the latter yielding a lower return on the energy invested during a labour intensive clearing preparation (Slaats 1995). *C. odorata* also displaces *Imperata cylindrica*, which is a serious weed of crops and fallow land in the tropics (Ivens 1975).

*Chromolaena odorata* does suppress oil palm (*Elaeis guineensis*), rubber (*Ficus elastica*), cocoa (*Theobroma cacoa*), rice (*Oryza sativa*), teak (*Tectona grandis*) and other plantation tree productions (Ivens 1974). Agricultural areas for these crops are generally cleared regularly of *C. odorata* and other weeds to avoid them from affecting the production of the crops. It seems that slashing large plants and uprooting the seedlings in the crop production areas, is the most commonly used method overseas in order to suppress *C. odorata* growth. There is very little information internationally on the use of fire, chemicals or biological control to eradicate *C. odorata*.

No information on the use of a mechanical control method for *C. odorata* could be found for South Africa. But Sheldrick (1968) reports that besides physical hand pulling and manual slashing with cutlass, a Weed Breaker (Holt Mk VIIB®) was tested in oil palm plantations in West Africa. The Weed Breaker was tractor-mounted, therefore considerable land preparation was necessary to provide access for the tractor. The control obtained reduced the *C. odorata* density, but with the passage of equipment through the plantation, bare ground was exposed which provided suitable sites for *C. odorata* germination and seedling establishment. Sheldrick (1968) also reports on the use of a Cambridge ring roller, which was used in less dense infestations. This equipment was judged to be superior to the Weed breaker (Holt Mk VIIB®), because during the rolling operation, when *C. odorata* was snapped off near the ground level, the leguminous cover crop runners were pressed to the ground, but not killed. Neither the Weed breaker nor the roller could be used along the palm lines where logs and stumps prevented access. Consequently, manual slashing had to be used in these situations.

# Chapter 2

## Study area (Munywana Game Reserve)

### 2.1 Location and history of study site in the Munyawana Game Reserve.

The Munyawana Game Reserve is situated on the coastal plain in north-eastern KwaZulu-Natal, in South Africa, in an area known as Maputaland. It is approximately 14 km north of the small town of Hluhluwe and 330 km north of Durban (Figure 2.1). The Munyawana Game Reserve is approximately 30 km in length and on average 9 km in breadth, and encompasses an area of approximately 20 000 ha in size.

The Munyawana Game Reserve, which was established at the end of 1990, is owned by the company Conservation Corporation Africa (CC Africa). The company is mainly involved with tourism throughout 'Africa's wildlife hotspots'. A chief priority of the company is the conservation of wildlife resources. The study site is located in one of the corners of the Munyawana, known as Harrowgate, which is situated on the western side of the Lebombo Mountain range in the south-western part of the reserve (Figure 2.2). The study site is approximately 40 km inland from the coast.

The Mzinene River and Zulu Nyala Game Reserve form part of the border on the south-eastern side, while Lulubush Game Ranch, Mnqobokazi Community and Makasa Community Game Reserve form the eastern border. The western border is formed by Mkuzi Game Reserve, Kubuyeni Share Block and Fanie Roberts Game Farm.

Before the Munyawana Game Reserve was established, the area was comprised of 10 smaller farms. Cattle, pineapples, cotton and game farming (for hunting purposes); were the main sources of income for the farmers. The land was degraded in many parts of the reserve by the previous land users. The reason for the degraded state of the land could be attributed to incorrect farming techniques used, such as the incorrect use of fire and animal stocking rates.

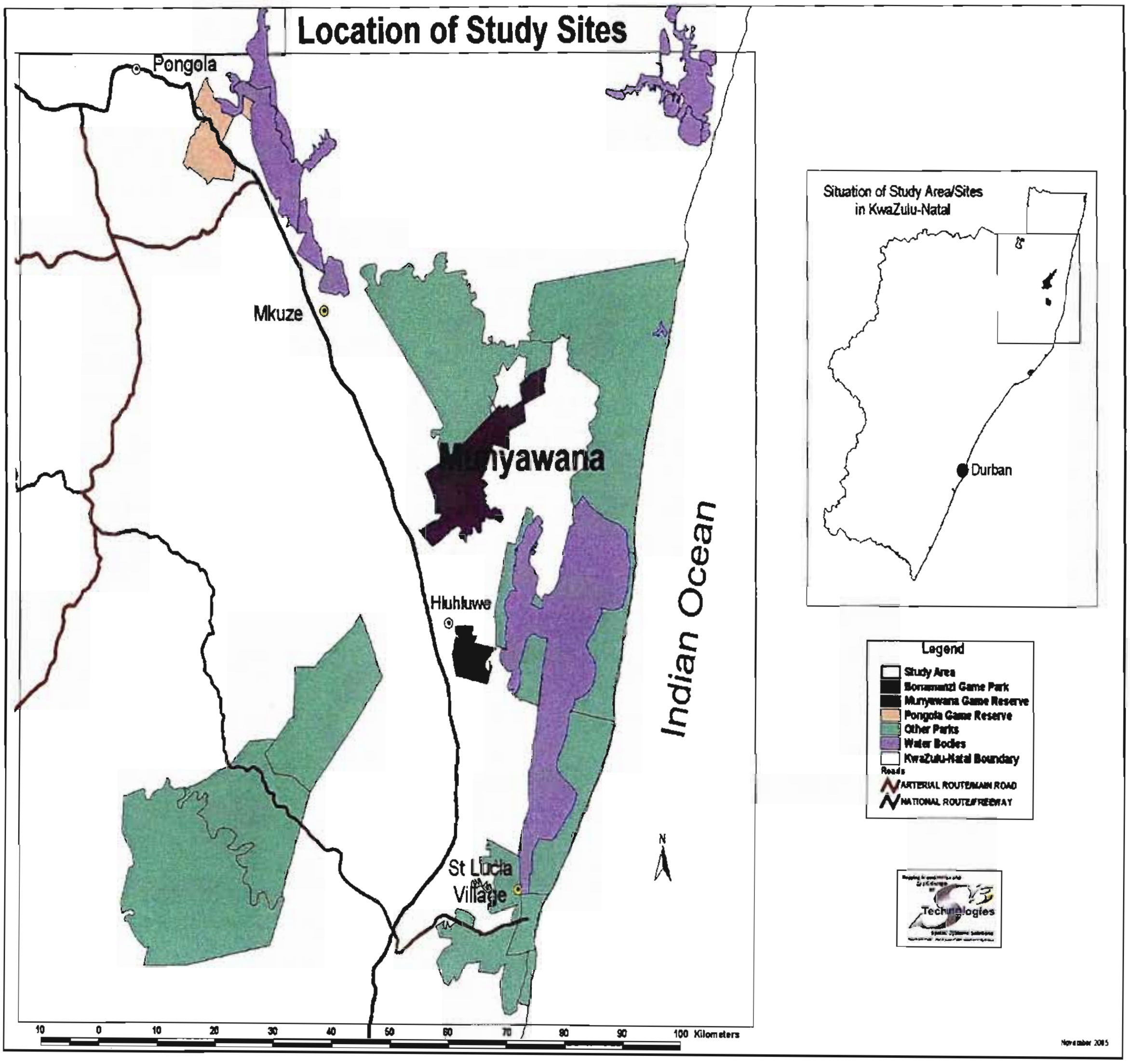
Location of Study Sites
Pongola
Mkuze
Munyawana
Hluhluwe
St Lucia Village
Indian Ocean
N
10 0 10 20 30 40 50 60 70 80 90 100 Kilometers
Situation of Study Area/Sites in KwaZulu-Natal
Durban
Legend
Study Area
Bonamanzi Game Park
Munyawana Game Reserve
Pongola Game Reserve
Other Parks
Water Bodies
KwaZulu-Natal Boundary
Roads
ARTERIAL ROUTE/MAIN ROAD
NATIONAL ROUTE/FREEWAY
Technologies
November 2005

Figure 2.1 **Munyuwana Game Reserve regional position.**

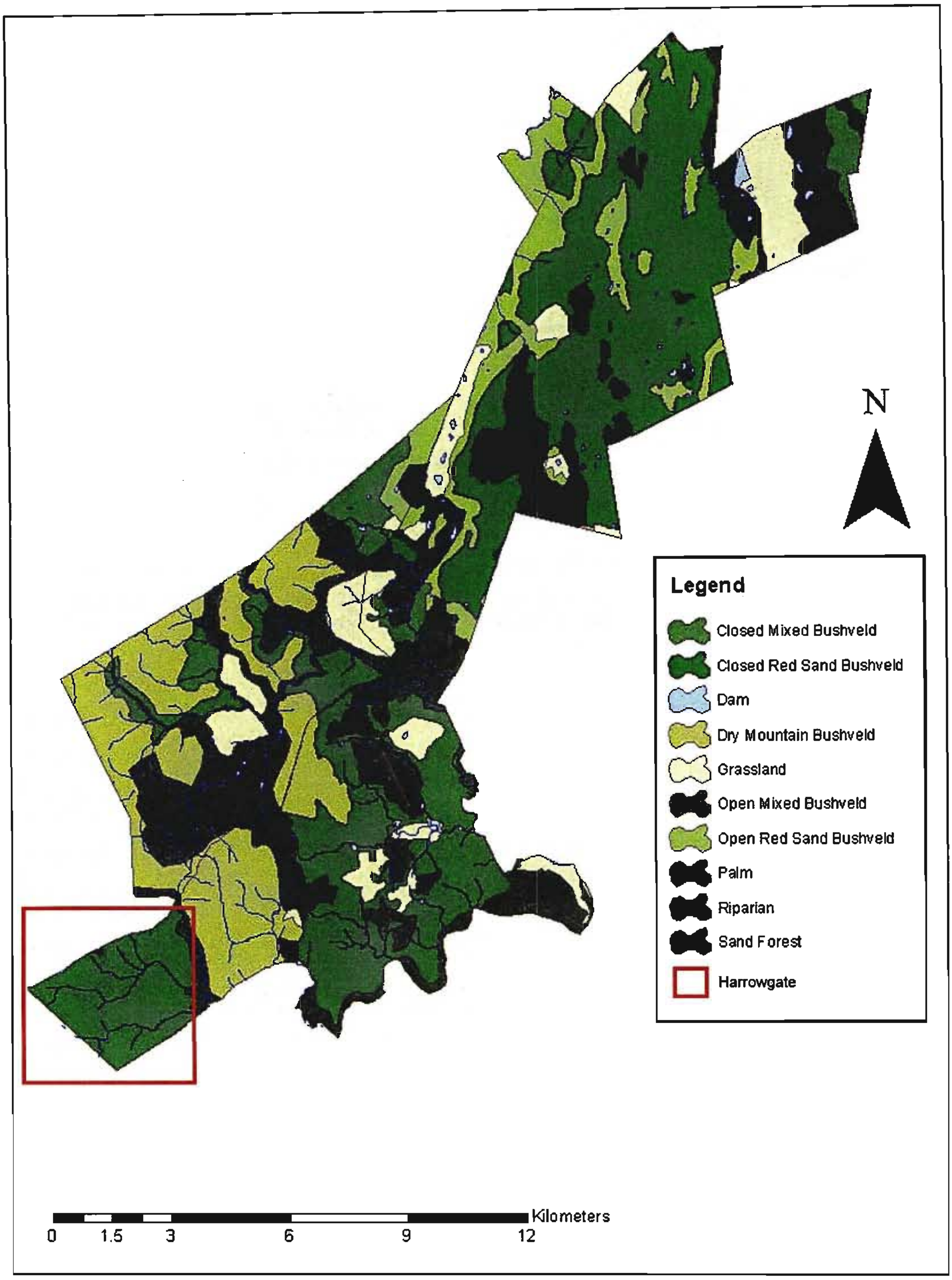
N
Legend
Closed Mixed Bushveld
Closed Red Sand Bushveld
Dam
Dry Mountain Bushveld
Grassland
Open Mixed Bushveld
Open Red Sand Bushveld
Palm
Riparian
Sand Forest
Harrowgate
Kilometers
0
1.5
3
6
9
12

Figure 2.2 **Map of Munyawana Game Reserve (study area situated inside red square).**

## 2.2 Climate

The climate is warm to hot, humid and sub-tropical (Schulze 1965), and falls into Köppen's arid zone steppe climate group. In general, the average disposition of the sub-tropical high pressure zones and the intervening low pressure troughs modified by local topography, are the determinants of climate in the area. The hot humid summer, which is from the middle of September to the end of March, coincides with the single rainy season (Figure 2.3).

Rainfall in and around Munyawana is highly seasonal. The rainfall peaks in February, with the lowest rain occurring in June (Figure 2.3). The rainy season, which are all months with >50mm of precipitation (Knoch and Schulze 1957), usually starts in October and ends in March (Goodman 1981).

The Mantuma research station in Mkuze Game Reserve is approximately 32 km directly North of the study site. The median annual rainfall recorded at Mantuma research station was 610 mm (1952-1981) with a range between 316 and 1048 mm (Goodman 1981). The mean annual rainfall for the Munyawana Game Reserve (1995-2003) is 770 mm, with a standard deviation of ± 280mm recorded at Izwelethle. The mean monthly rainfall over the experimental period (2002-2004) was generally well below the average (Table 2.1).

Table 2.1 **Monthly rainfall from 1995-2004.**

| **Month** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **Ave** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 20 | 306 | 76 | 131 | 85 | 82 | 70 | 26 | 46 | 158 | **100** |
| Feb | 23 | 283 | 125 | 201 | 83 | 248 | 137 | 65 | 48 | 95 | **131** |
| Mar | 37 | 75 | 65 | 24 | 21 | 382 | 42 | 17 | 13 | 47 | **72** |
| Apr | 90 | 72 | 30 | 44 | 36 | 61 | 66 | 77 | 33 | 43 | **55** |
| May | 42 | 75 | 50 | 31 | 17 | 58 | 30 | 0 | 21 | 0 | **32** |
| Jun | 42 | 0 | 36 | 0 | 2 | 7 | 22 | 18 | 80 | 5 | **21** |
| Jul | 0 | 7 | 12 | 8 | 7 | 13 | 31 | 37 | 0 | 46 | **16** |
| Aug | 25 | 24 | 67 | 2 | 67 | 0 | 4 | 9 | 0 |  | **22** |
| Sep | 0 | 0 | 142 | 14 | 35 | 36 | 82 | 41 | 18 |  | **41** |
| Oct | 123 | 116 | 69 | 116 | 121 | 107 | 53 | 29 | 15 |  | **83** |
| Nov | 127 | 46 | 262 | 48 | 122 | 155 | 142 | 34 | 54 |  | **110** |
| Dec | 233 | 81 | 25 | 39 | 176 | 46 | 51 | 74 | 19 |  | **83** |
| **Total** | **762** | **1085** | **959** | **658** | **772** | **1195** | **730** | **427** | **347** |  | **770** |

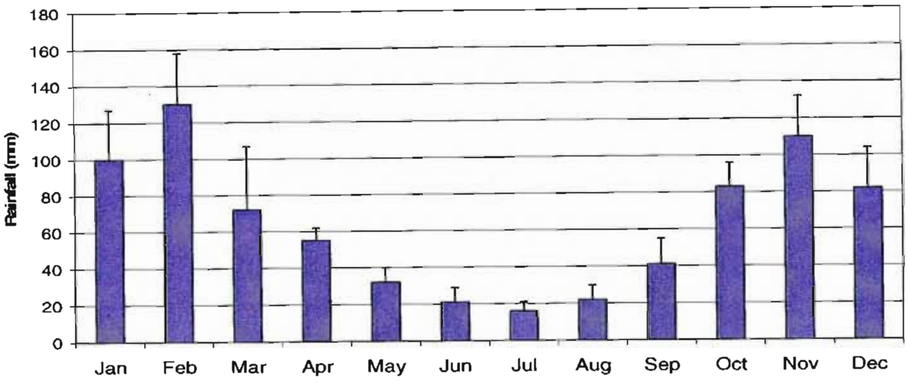

Figure 2.3 **Mean monthly rainfall taken at Izwelehle (Munyawana Game Reserve) from 1995-2004**
(error bars represent standard errors of the mean).

Goodman (1981) has found considerable spatial variation in the annual rainfall for the area, increasing considerably in an easterly direction towards the coast. The temporal behaviour of rainfall appears to be related to the mean position of the subtropical high pressure belt (Dyer 1979).

The mean annual temperature (1965-1981) for Mkuzi Game Reserve was 23.2 °C. Summers were hot, with a mean annual temperature for the hottest month being 27.1 °C, and the mean maximum temperature for this month (January) 32.5 °C (Goodman 1981). These high temperatures cause the area to have a very high evapotranspiration levels in excess of 1650mm annually.

Winters are warm with a mean daily temperature of 18.8 °C in the coldest month (Goodman 1981). The mean monthly minimum for the coldest month (July) was 11.7 °C, with an absolute minimum for that month of 5.5 °C (Goodman 1981). Frost has not been recorded at the Munyawana Game Reserve, but some signs of frosted plants have been observed in lower lying river valleys (approximately below 30m a.s.l.).

The prevailing winds in this area are north-easterly and south-westerly. The windiest period occurs during August. The calmest month is June.

## 2.3 Topography, geology and geomorphology

The topography of the reserve is closely related to physiography and geology. The area consists of mainly a flat to gentle sloping topography, with the exception of the Lebombo Mountains in the western part of the reserve. The altitude mostly lies between 50m and 150m above sea level, rising to over 250m on the mountain summits. Six broad geological units are apparent within the reserve (Goodman 1981):

i) the hilly Lebombo mountains;

ii) a gentle undulating region underlain by Early Cretaceous sediments, consisting mainly of conglomerate, sandstone and siltstone of the Zululand Group;

iii) a gentle undulating, slightly elevated, Quarternary dune complex which occurs mainly in the north-eastern part of the reserve;

iv) a low-lying essentially flat region underlain by Late Cretaceous sediment, consisting mainly of conglomerate, sandstone and siltstone of the Zululand Group;

v) a low-lying flat alluvial floodplain of recent origin, which occurs on the flood plain region where the Msudunzi River and the Mkuze River join, as well as the areas adjacent to the Mzinene, Mhlosinga and Munyawane River (the sites for the rehabilitation section were located in these areas);

vi) a clay-rich basic basalt of the Letaba basalt formation, Karoo Sequence, occurring mainly in the south-western part of the reserve (the sites for the burning trial section of the study were located).

## 2.4 Soils

In general, soils correspond closely to underlying geology and topography, but the complicated mineralogical composition of the interface between the Stormberg lavas and the early cretaceous geological deposits consisting of conglomerates, grit, sandstone and siltstone (derived from a variety of rock types including basalt, dolerite, rhyolite, granite, banded ironstone and quartzite), have resulted in soils of varying depth, textures and mineralogical composition (Goodman 1981). This, in turn, makes the precise interpretation of the soil type very difficult. In the south-western parts of the reserve, the combination of relatively steep slopes and erosion-resistant fine grained, felsic crystalline rock of the Lebombo Mountains have given rise to lithosols of various depths (Goodman 1981).

Upland sites are thus characterised by lithic soils, while bottomlands are generally characterised by brown to dark brown calcimorphic soils and vertisols. Upland soils are more leached, and have a clay fraction consisting predominantly of 1:1 lattice minerals, whilst the bottomlands are relatively unleached with high base saturation and an appreciable proportion non-expanding 2:1 lattice clay minerals (Goodman 1981). The incised valley floors are generally angular, with the area of alluvial deposition being small. These alluvia are predominantly shallow gritty clays, with the clay complex dominated by kaolinite. Large expanses of alluvial soils occur adjacent to the main river, Mzinene, and major streams, Mhlosinga, and the Munyuwane River. The predominant soil type in these areas was Valsrivier (MacVicar *et al.* 1977). The sites for the rehabilitation section of the study fell into this category. Other alluvial soils occur as fans of minor drainage channels in the more hilly sections, as well as the Lebombo Mountain range.

In the south-western part of the reserve, including Harrowgate, where the burning trials were set out, the soils were clay-rich, derived mainly from a basic basalt of the Letaba basalt formation, and were dark in colour. They were relatively shallow soils, and mainly formed part of the Bonheim and Arcadia form (MacVicar *et al.* 1977).

## 2.5 Surface hydrology

There are three rivers that flow through the Munyawana Game Reserve, namely the Mzinene, Mhlosinga and Munyuwana. As a result of a dam which was built on the Mzinene during the 1950s, it is the only one of the three rivers which has permanent water. The other two rivers are seasonal. The catchment areas for the Mhlosinga and Munyuwane River are located west of the reserve, whilst the catchments for the Mzinene are located south-west of the reserve. Ntabankosi Mountain (part of the southern tip of the Lebombo mountain range) and other smaller hills in the southern part of Munyawana have resulted in the formation of large seasonal drainage lines on Munyawana. In the northern section of the reserve there are numerous small (less than 0.25 ha) shallow clay-floored seasonal pans. These occur mainly in the depressions between the sand dunes. The reserve has a total of 20 man-made dams scattered throughout the reserve. The largest of these is Mvubu Dam, and is generally permanent. Imagine Dam in the north has water piped into it from the Mkuze River.

## 2.6 Flora and fauna

The Munyawana region is considered by White (1976) to be both a Regional Transition Zone and a Regional Mosaic, having a high proportion of endemics. According to Acocks (1975), the Munyawana Game Reserve contains two veld types, namely 1 - Coastal Forest and Thornveld and 10 – Lowveld.

The company Conservation Corporation Africa that is managing the Munyawana Game Reserve has compiled an internal map for the different vegetation categories occurring in the Munyawana Game Reserve. To make this map, they used the regional descriptions made in Werger & Coetzee (1978), Moll & White (1978), Moll (1980) as well as Acocks (1975). The vegetation types can be sub-divided into eight vegetation categories which overlap along a complex environmental gradient, and are thus not in all instances distinct. They are:

i) Dry Mountain Bushveld (Werger & Coetzee 1978) and Grassland: This is an open woodland to grassland type dominated by *Combretum apiculatum* and *Acacia burkei* trees with the predominant grass species being *Themeda triandra* and *Cymbopogon excavatus*. These plant species are associated with the lithosols of the Lebombo Mountains.

ii) Mixed Bushveld (Moll 1980): It consists of a mosaic of woodland types on soils, ranging from brown, calcimorphic sandy clay loam to vertic clays and hydromorphic gley soils. The physiognomy is an open to closed woodland, dominated to various degrees by *Acacia tortillis* and *Acacia nilotica* trees. Other trees often also associated with these areas are *Spirostachys africana* and *Schotia brachypetala*. The herbaceous layer is well developed, the main grass being *Themeda triandra, Dactyloctenium australe, Chloris virgata* and *Panicum maximum.*

iii) Thicket (Moll 1980): Thickets generally occur on vertic clays and hydromorphic gley soils where topography is flat and soils are poorly drained. This vegetation type is generally 3-4 m high, and in some places impenetrable. The two dominant woody species are *Acacia luederitzii* and *Euclea divinorum*. Important grasses include *Dactyloctenium australe, Enteropogon monostachys* and *Panicum maximum*. In places, trees such as *Spirostachys africana, Schotia brachypetala, Pappea capensis, Sideroxylon inerme, Berchemia zeyheri, Albizia anthelmintica* and *Cassine transvaalensis* emerge above the thicket, forming a dense, multi-layered woodland.

iv) Red Sand Bushveld (Moll 1980): Occurs on the ferruginous arenosols of Quarternary origin, this type is essentially an open to closed woodland, approximately 7 m tall.

The most common tree species are *Strychnos madagascariensis, Strychnos spinosa, Acacia burkei, Sclerocarya caffra, Ziziphus mucronata* and *Terminalia sericea*. The herbaceous layer is fairly sparse, the most common species being *Dactyloctenium australe, Panicum maximum, Pogonarthria squarrosa* and *Hyperthelia dissoluta.*

v) Zululand Palm Veld (Acocks 1975): Occurs mainly on sandy soils on a badly drained coastal plain. This type is essentially an open scrubby thornveld, interspersed with dense thickets. The common tree species are *Hyphaene coriacea, Combretum molle, Dichrostachys cinerea, Strychos madagascariensis* and *Albizia adianthifolia*. The herbaceous layer is dense and tall, and consists predominantly of *Themeda triandra, Andropogon gayanus* var. *polycladus* and *Hyperthelia dissoluta.*

vi) Sand forest (Moll & White 1978, Moll 1980): This is a distinctive type of dry, semi-deciduous to deciduous forest occurring on the poorly developed yellow-arenosols of Quatenary origin. Sand forest consists of a mosaic of forest patches 10 to 25 m high in a matrix of open woodland. The most important species are *Newtonia hilderbrandtii, Cleistanthus sclechteri, Hymenocardia ulmoides, Pteleopsis myrtifolia, Dialium schlechteri, Croton pseudopulchellus* and *Strychnos henningsii.* A well developed sub-canopy of small trees and shrubs, consisting mainly of *Salacia leptoclada* and *Croton pseudopulchellus*, is present. The herbaceous ground layer is extremely poorly developed.

vii) Riparian fringing forest and woodlands: This may be divided into two principle types:

a) Streambed and drainage line woodland, occurring alongside minor streams and drainage lines. The major woody species are *Schotia brachypetala, Acacia robusta, Phoenix reclinata, Spirostachys africana, Sideroxylon inerme* and *Euclea racemosa*

b) Riverine forest and woodland, varying from a fairly well-developed forest to open woodland up to 15m high, on alluvial soils adjacent to the Mzinene and Munyuwane River. The main canopy tree species include *Acacia xanthophloea, Ficus sycamorus, Acacia robusta, Schotia brachypetala* and *Trichilia emetica*. A well-developed sub-canopy of *Acacia schweinfurthii* and *Chromolaena odorata* is present in most instances, and in many places forms impenetrable thickets. In other areas where *C. odorata* and *A. schweinfurthii* haven't invaded, there is a healthy sward of *Panicum maximum* and *Eustachys paspaloides* present, with *Phoenix reclinata* growing on the banks of the river. *Acalypta glabarata*, a shrub species, can grow into a dense monostand in certain areas along the river. These stands are seldom found more than 20m from a river or drainage line.

viii) Floodplain Grasslands: These occur on the seasonally flooded undulated flats. On the Munyawana Game Reserve the Inkwazi Floodplain and Mziki Marsh fall into this section. The species which characterise this tall grassland are *Phragmites australis, Panicum coloratum, Panicum maximum, Setaria incrassata* and *Diheteropogon amplectens.*

The extremely diverse plant life and variety in vegetation types support 74 mammal species, more than 410 bird species (53% of total bird species in South Africa), 31 amphibians and 60 different reptiles. A vast number of invertebrates also occur which include 120 species of dung beetle (Anon 1990). Zoogeographically, the Munyawana Game Reserve falls into the East African Province of the Ethiopian Region (Goodman 1981).

In many respects, the fauna has tropical affinities, and Poynton (1980) comments that for amphibians at least, the region is a zoogeographical transition area between the tropical fauna occurring mainly north of the Munyawana Game Reserve and non-tropical forms occurring mainly south of the Reserve. A list of reptiles found in neighbouring Mkuzi Game Reserve is reported by Pooley (1965), and again, species found in this area have affinities with the Tropical East Littoral, Eastern Tropical Transitional, Western Tropical Transitional, Tropical Wide Ranging and Temperate Transitional Faunal Zones (Bruton & Haacke 1980).

For the birds, the area is seen to lie in a transitional zone between the Eastern Lowveld, Eastern Tropical Littoral, Eastern Littoral and the Eastern Grassveld regions (McLachlan & Liversidge 1978).

Some of the larger mammals that were re-introduced into the area include lion (*Panthera leo*), cheetah (*Acinonyx jubatus*), brown hyena (*Hyaena brunnea*), african elephant (*Loxodonta africana*) and buffalo (*Syncerus caffer*). White rhino (*Ceratotherium simum*), Burchell's zebra (*Equus quagga*), blue wildebeest (*Connochaetes taurinus*) and giraffe (*Giraffa camelopardis*) numbers were increased, through reintroduction. Large predators that are absent include the wilddog (*Lycaon pictus*).

(Appendix 1 has a complete list of all the larger mammals that are found in the Munyawana Game Reserve and their respective densities).

## 2.7 *Chromolaena odorata* on Munyawana Game Reserve

*Chromolaena odorata* has been present in the Munyawana Game Reserve since the late-1980s but in relatively low concentrations. The high rainfall experienced in the area during 2000 and 2001 caused an unprecedented increase in *C. odorata* distribution and density. By the end of 2001 the plant had invaded around 7000 hectares of the reserve in varying densities, and was spreading at an exponential rate. The following areas had the highest infestations, namely along the riverbanks and drainage lines, areas that either had Bonheim or Arcadia soils and on the slopes of the Lebombo Mountains that had very little grass cover. *C. odorata* was mostly found in the southern half of the Munyawana.

A *C. odorata* clearing programme was initiated in September 2001. In the first year R300 000 was allocated to the programme, and a total of 2800 hectares was cleared (200ha of dense, 600 ha of medium and 2000 ha of sparse infestation). Dense areas were considered to be those areas that had a large impenetrable thicket of *C. odorata*, while medium areas had four large plants per 100 $m^2$. Sparse areas had only one large plant per 100 $m^2$. In the second financial year (July 2002 to June 2003) R460 000 was allocated to the programme. The government's 'Working for Water' Programme also issued a grant of R96 000. With this budget lots of follow up work, as well as some initial clearing, was done. In the following financial year (July 2003 to June 2004) R400 000 was allocated for clearing the remaining initial areas, as well as doing follow up in all the areas where it was necessary.

It was decided to formally investigate different approaches and techniques for clearing *C. odorata* in order to improve the efficacy of clearing operations both on Munyawana Game Reserve, as well as other areas in KwaZulu-Natal.

## Chapter 3

## Mechanical clearing of *Chromolaena odorata* thickets and the subsequent rehabilitation of the area.

### 3.1 Introduction

Very little literature and information could be found on using mechanical method to clear *Chromolaena odorata*. As the Munyawane Game Reserve had access to a bulldozer (Caterpillar D6b®) it was of great interest to the habitat department to see how effective the machine was at clearing dense stands of *C. odorata*, as well as the amount of effort required to do all the necessary follow up to rehabilitation these cleared areas. Some of the main reasons for wanting to use a bulldozer were:

a) it would clear the specific areas relatively quickly;
b) lower the risk of people encountering dangerous animals, as only a single operator is required instead of a whole gang of workers;
c) lower cost for the following reasons (on hot days the bulldozer was able to operate at the same speed as on a cold day, labour did not have to be picked up from the community a distance of around 25 km on dirt road, as the bulldozer pulled the *C. odorata* up by the roots a lot less herbicides were required, the Caterpillar D6b® is well known for its excellent diesel consumption rate, around 10 litres per hour).

As mentioned already, *C. odorata* often grows in dense stands along rivers and drainage lines. The Munyawane Game Reserve proved to be no exception. These *C. odorata* stands grew so thickly that apart from the large trees that were present before the invasion no other plants were able to grow in these areas. Before the invasion many of these areas adjacent to the rivers were noted for the excellent grazing which they used to provide for the animals. *Panicum maximum, Eustachys paspaloides Dactyloctenium australe* and *Panicum deustem* made up the bulk of the grass swards. It was of great interest for the habitat team to see if these areas could be reverted back to their original state by using mechanical methods to remove the *C. odorata.*

The following questions were addressed in this chapter:

a. Is mechanical clearing, using a bulldozer, an effective method to clear dense *C. odorata* stands?
*b.* Is grass able to germinate in an area that has been cleared of dense *C. odorata* stand (where the dense stand has been in existence for the last three years)?
c. Does grass density have any effect on *C. odorata* germination?

## 3.2 Materials and Methods

A bulldozer (Caterpillar D6b®) was used to clear out three separate riverine sections. The areas chosen had to meet the following criteria, before they could be considered for clearing with a bulldozer:

i) The terrain must be flat or on a gentle gradient;
ii) No grass present under the *C. odorata* infestation;
iii) The large trees must be spaced out far enough to allow a bulldozer to move between them;
iv) Very few, small indigenous trees occurring in the *C. odorata* thicket;
v) The bulldozer blade must be positioned above the soil, thereby minimising soil disturbance.

In this type of terrain and habitat the bulldozer was found to clear approximately 0.125 ha per hour.

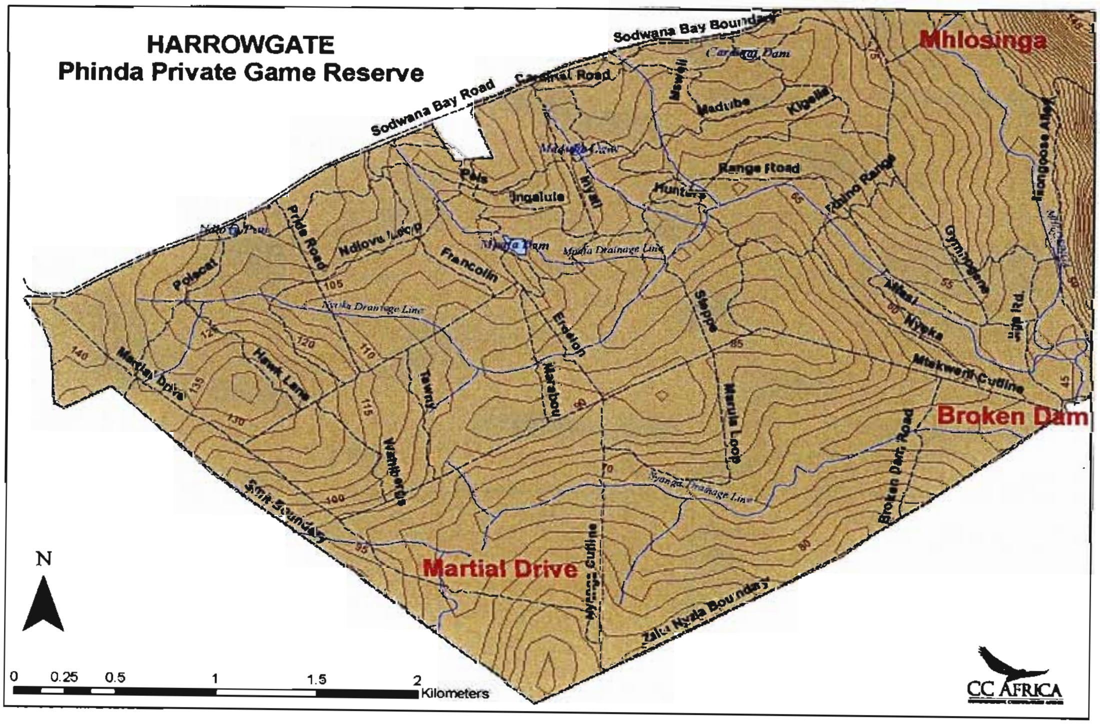
HARROWGATE
Phinda Private Game Reserve
Sodwana Bay Road
Sodwana Bay Boundary
Cardinal Road
Mhlosinga
Broken Dam
Martial Drive
Pride Road
Ndlovu Loop
Polecat
Francolin
Pals
Ingalule
Inyati
Mswili
Maduba
Kigelia
Range Road
Hunters
Rhino Range
Gymnogene
Mongoose Alley
Mbesi
Nyoka
Mtekwerti Cutline
Steppe
Marula Loop
Erdeloh
Marabou
Tawny
Hawk Lane
Martial Drive
Wambergia
Mpala Dam
Mpala Drainage Line
Nyala Drainage Line
Nyanga Drainage Line
Broken Dam Road
Nyinga Cutline
Zulu Nyala Boundary
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
N
0
0.25
0.5
1
1.5
2
Kilometers
CC AFRICA

Figure 3.1 **Map of Harrowgate rehabilitation sites**

All three sites were located in the Munyawana Game Reserve and were relatively close to one another (less than a 5 km radius). Subsequently, all three sites had similar abiotic variables (catenal position, rainfall, fauna interaction, temperature etc.), although some differences were recorded in the soil analysis, (refer to Appendix 2). The first site, Mhlosinga (27° 52' S and 32° 15' E), was 3.3 ha in size and 33m above sea level. The second site, Broken Dam 27° 54' S and 32° 15' E), was 0.63 ha in size and 31m above sea level. The third site, Martial Dam (27° 54' and 32° 14' E), was 1.4 ha in size and 39 m above sea level. The terrain was completely flat in all three sites. The soils were, as previously mentioned, alluvial in nature and relatively deep, and fell into the Valsrivier category. (Refer to Appendices 3-5 for more detailed GPS co-ordinates for each transect).

The vegetation fell into the riverine forest and woodland category. The vegetation consisted mainly of large interspersed trees, mainly *Acacia xanthophloea*, *Ficus sycamorus*, *Acacia robusta*, *Schotia brachypetala*, *Euclea racemosa* and *Euclea divinorum*. A solid infestation of *C. odorata* was found below and between these trees, growing to an average height of just over three meters. Other areas that did not have these *C. odorata* infestations had an herbaceous sward that consisted primarily of *Panicum maximum*, *Eustachys paspaloides*, *Dactyloctenium australe* and *Panicum deustem*.

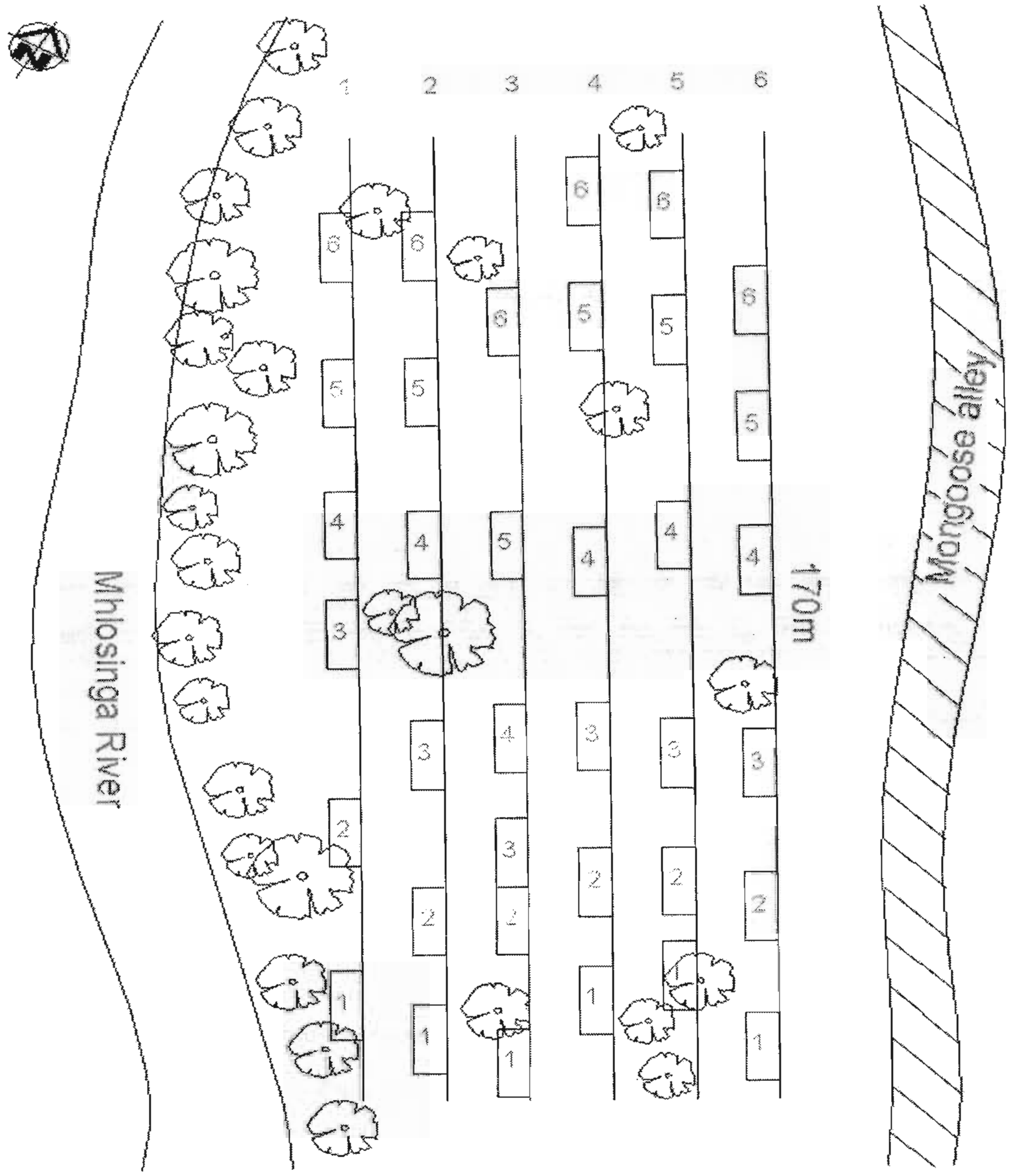

Figure 3.2 **Layout of Mhlosinga experimental trial site**

Figure 3.2 shows the layout for the Mhlosinga experimental trial site. Six permanent plots can clearly be seen on each transect. Thus each site had a total of 36 permanent plots. The layout for the other two sites was identical. Originally, it was thought that after the bulldozer had cleared the different sites, a dense mat of *C. odorata* seedlings would germinate, preventing any grass seedlings from germinating. The areas that were cleared with a bulldozer had been infested with dense *C. odorata* thickets since 1999 (at least three years before being cleared), so the viable seedbank for the indigenous herbaceous species was also questionable. It was decided to use a passive quantitative method to monitor the vegetation which emerged in the permanent quadrats and transects with special emphasis being placed on:

a) The grass and *C. odorata* density that came through in the cleared areas;
b) The speed at which grass species spread and covered the bare areas that had been cleared;
c) The available fuel mass produced by the grass for implementing a fire management programme, to kill *C. odorata* seedlings.

### 3.2.1 *Chromolaena odorata* density prior to mechanical clearing

*Chromolaena odorata* density was characterised in the vicinity of the cleared plots by selecting three representative sites, namely Bernard's fence-line, Mark's Garden and Zulu Nyala. In each one of these sites two plots (each plot 10m by 10m), were laid out. The number of *C. odorata* plants as well as their respective stem diameter (5 cm above the ground), and overall plant height were recorded.

### 3.2.2 Methods to record herbaceous densities

The study of serial patterns in species composition using permanent transects is validated by the need for exact repetition of field procedures, ensuring comparability between successive sets of data (Greig-Smith 1983, Mentis 1984). Contiguous quadrats are needed in repeat-measure experiments partly to categorise vegetation, but principally, to quantify and explain changes between temporal observations.

One problem associated with contiguous quadrats is the inherent heterogeneity of the sample area. Quadrats must be spatially independent to categorise and draw any conclusions about species associations in plant communities (Mueller-Dombis & Ellenberg 1974).

Based on this, it was decided to use six equally spaced permanent transects in each of the three sites that were cleared with a bulldozer. Transects were positioned parallel to the contour and the river. Transect length varied according to the size of each site cleared. Six permanent plots, marked with wooden stakes, were placed on each transect (refer to Figure 3.2). Each plot comprised a rectangle of five by one metres. These large rectangular quadrats were used to help reduce variance between quadrats, patchiness of the vegetation and boundary to area ratio (Greig-Smith 1983). The plots were subjectively chosen so that three of them were located in areas where the grass germination appeared sparse, and three in areas where the grass germination appeared denser. This was done to assist in evaluating whether grass density had any significant effect on *C. odorata* seed germination. Wherever possible, care was taken not to locate plots under the canopy of large trees, as shade (or partial shade) has been reported to have a significant positive effect on *C. odorata* seedling germination (Wilson 1995). The total number of plots per cleared area was therefore 36, with a combined total of 108 for the three sites together.

To record the total herbaceous and *C. odorata* seedlings emerging in each of the permanent plots, 0.5m by 0.5m quadrats were used. By placing the quadrat squarely in one corner and flipping it over continuously, the whole area could be covered in ten recordings. In each of the permanent plots, the number of grass and *C. odorata* seedlings present was recorded, as well as any other alien invasive plants such as *Senna pendulla*. Plants were only included if they were rooted inside the quadrat.

The Mhlosinga site (3.3 ha) was cleared in April 2002, the Broken Dam site (0.6 ha) in May 2002 and the Martial Drive site (1.4 ha) in June 2002. As no vegetation occurred below the *C. odorata* infestations, the sites were completely bare once they had been cleared by a bulldozer.

The plots were surveyed for the first time in November-December 2002 (Time 1 in data). They were then re-surveyed in October 2003 (Time 2 in data), because from prior observation, most *C. odorata* should have germinated by then. The final sampling took place during May-June 2004, at the end of the wet season (Time 3 in data). Most of the area in the Martial Drive site was found to be under shade that was provided by large indigenous trees. All sample plots, in the Martial Drive site, were thus placed under this partial shade. Because of this shading effect, the soils in Martial Drive were suspected of having higher moisture content than the other two sites.

### 3.2.3 Herbaceous species composition in each site

By the third and final sampling time (Time 3), the herbaceous plants were large enough to be accurately identified. Everson & Clarke (1987) had found that the wheel point method was the most suitable method for determining the grass species composition (in terms of relative abundance) in tufted grasslands. A very similar method was adopted in this study, but, instead of using a wheel apparatus, the nearest plant to a systematically placed spike was used every metre along the transect. All the grass species, *C. odorata* and other alien invasives were identified, and the distance from the spike was recorded (in cm). In situations where the nearest plant to the spike was greater than 25 cm, the reading was recorded as a bare patch. Forbs were all lumped into one category.

In assessing botanical composition, the issue of area-based versus point-based measurement becomes very important. Abundant species are likely to be readily recorded by either type of technique, but, if species are uncommon, the chances of encountering them with point samples can be very low, unless operators used very large number of points, which can be both tiring and time consuming (t'Mannetje 1978). The choice then depends on how important rare species are to assessment. In the case of this study, *C. odorata* was found to be surprisingly rare, hence the need for the large number of point samples. In quantitative analysis, it is often only possible to evaluate the more abundant species with reasonable accuracy (Mueller-Dombis & Ellenberg 1974).

In the point-intercept method, continuous transects of evenly spaced points usually give a more accurate measurement of cover or frequency than random placement of grouped points (Mueller-Dombis & Ellenberg 1974). Frequency determination is very useful in species-poor communities. Frequency is often considered a measure of abundance. Therefore, it should be related to density (Mueller-Dombis & Ellenberg 1974). However Greig-Smith (1983) has clarified that frequency rarely gives an indication of the number of individuals per species because for this to be true, individual plants must be regularly or randomly distributed. Instead, plants are usually contagiously distributed. Therefore, frequency gives a certain indication of uniformity of distribution rather than density.

Greig-Smith (1965) emphasised that the accuracy of the count is not a function of the area sampled, but a function of the number of enumerations. The number of plots to be counted is a function of the variation in individuals between plots. The greater this variation, the more plots will be required.

A disc pasture meter reading, was also recorded, every metre along the transects, in order to work out the available herbaceous fuel mass (Bransby & Tainton 1977). For calibrating the fuel mass in the rehabilitation sites at Time 3, twenty grass samples were taken in each of the three cleared sites. In an attempt to cover the whole range of fuel biomass, grass samples were actively selected. All the grass below the disc was cut with garden shears. These grass clippings were then oven-dried at 80 °C for a period of 48 hours, and then weighed with an electronic scale (in the Agricultural faculty at the University of KwaZulu-Natal, Pietermaritzburg). Linear regression analysis (refer to Appendix 6) was applied with the disc pasture meter reading (cm) as the independent variable, and grass dry matter values as the dependent variable. Great care was taken to avoid woody forbs when using the disc pasture metre on the transects, as they would bias the disc pasture readings, and in turn, make them higher than what the true fuel mass for the area really was. However, the high proportion of forbs in the Mhlosinga site, made this almost impossible. This probably caused an overestimate for the fuel mass in the Mhlosinga site.

The following regression equation was calculated from the regression analysis. The regression analysis accounted for 49.9 percent of the variation.

$$Y = 38.62 + 1.418 (X)$$

Where Y = estimated standing crop (kg/ha)
X = disc height (cm)

### 3.2.4 Data analysis

All existing live *C. odorata* were successfully removed during the clearing operation. No plants were found growing beneath the dense *C. odorata* thickets. Thus, each site was completely bare after the *C. odorata* thickets had been pulled out with a bulldozer. In the first sampling period (November 2002) all new *C. odorata* and grass seedlings that emerged, were recorded, these *C. odorata* were labelled as C1. By the second sampling period (October 2003) the one year old *C. odorata* as well as all the grass plants that were still alive were recorded. A new category (C2) was also set up to record the second season *C. odorata* seedlings emerging. Overall the *C. odorata* seedling density in all three sites was a lot lower than what was expected, these low numbers made it very difficult to test for relationship between grass and *C. odorata* densities.

#### *3.2.4.1 Ordination:*

Detrended Correspondence Analysis (DCA) using CANOCO (ter Braak & Smilauer 1998) was performed on the species-by-site data at Time 3 to examine their distribution.

The range of the axis value from an ordination graph gives an indication as to what extent the change in species composition will be. The length of the site score range will determine which ordination technique to use. Values larger than four indicate a major species change and Correspondence Analysis (CA) is recommended. When the value is smaller than two, Principal Component Analysis (PCA) is recommended (ter Braak & Smilauer 1998).

PCA is preferred to CA, because CA is very sensitive to species that occur in a few species-poor sites. CA should only be used when the sites have approximately the same number of individuals, or when one explicitly wants to give high weight to the species-rich sites (Legendre & Gallagher 2001).

PCA is based on linear regression. The first axis consists of the main environmental factors that influence the species distribution. The second axis consists of the second most influential environmental variables that are uncorrelated to the environmental variables in axis 1. The direction of the arrow indicates the direction in which the abundance of the corresponding species will increase the most (ter Braak & Smilauer 1998). The length of the arrow indicates the rate of change in that direction. In PCA, the angle between the arrow of a species to either another species or to one of the axes, gives a clear indication of the similarity between these two species or between the species and the particular axis.

Since Euclidean distance is a function of squared differences, it is more sensitive to large aberrant values (Digby & Kempton 1987). This may result in sites with no species in common, appearing more alike than stands with the same species present in both (Greig-Smith 1983). Therefore, Euclidean distance is not appropriate for species community composition data containing zeroes (Legendre & Gallagher 2001). Transformation of the species data (e.g. Chord transformation) allows ordination methods, such as PCA and Redundancy Analysis (RDA), to be used. This enables one to use Euclidean-based calculations, even if the community data contains many zeros. These transformations offer alternatives for ordination analysis of community data to Corresondence Analysis (CA) and Canonical Correspondence Analysis (CCA) that are based upon the Chi-square metric (Legendre & Gallagher 2001).

Although there were quite a few rare species found in only one or two of the sites, the pattern of the more abundant species dominated and turnover was low enough to assume a linear model of species responses. Thus, PCA rather than CA was used. Species data were transformed to ensure that Chord distance among sites could be faithfully represented by Euclidean distances in the PCA ordination. The "Chord transformation" computes the Euclidean distance after scaling the site vector to length one (Legendre & Gallagher 2001). This distance is maximised when two sites have no species in common. The "Chord transformation" allows the user to retain the identity of individual species in biplots when the Euclidean distances are computed for the different species (Legendre & Gallagher 2001). One of the big advantages of using a Chord transformation is that a low weight is given to rare species (Legendre & Gallagher 2001).

### *3.2.4.2 Indicator Species Analysis (ISA):*

ISA was also done on the herbaceous composition for the different sites at Time 3 in order to identify which species were indicators for a particular site. This method makes use of the Monte Carlo test of significance (Dufrene & Legendre 1997). From the ISA, each species gets a certain numerical value. The higher the value of the species, the greater the influence the species will have in determining a particular site.

## 3.3 Results

### 3.3.1 *Chromolaena odorata* density prior to mechanical clearing

Table 3.1 **Initial *Chromolaena odorata* density**

| Location | Density (per 100 m$^2$) | Mean stem number | Mean stem diameter (cm) | Mean plant height (m) |
|---|---|---|---|---|
| Bernard's fence-line | 40 | 3 | 2.7 ± 0.2 | 1.96 ± 0.03 |
| Mark's Garden | 83 | 3 | 1.9 ± 0.09 | 1.89 ± 0.02 |
| Zulu Nyala | 88 | 2 | 1.5 ± 0.07 | 1.88 ± 0.02 |

Mark's garden and Zulu Nyala had very similar densities, just over 80 plants per 100 m$^2$, whereas Bernard's fence-line only had around 40 large plants (Table 3.1). This highlights the wide range in number of large plants in a dense *C. odorata* infestation. Areas with higher densities had on average smaller mean stem diameters. For example Zulu Nyala, on average, had 88 plants per 100 m$^2$, but the average stem diameter was only 1.5 cm, whereas Bernard's fence-line only had 40 plants on average per 100 m$^2$, but the average stem diameter was 2.7 cm.

### 3.3.2 Soils

For more detailed soil analysis refer to Appendix 7

Table 3.2 **Soil particle size analysis**

| **Area** | **clay %** | **fine silt %** | **coarse silt %** | **texture class** |
|---|---|---|---|---|
| Mhlosinga | 38 | 22 | 40 | Clay loam |
| Broken Dam | 35 | 16 | 49 | Sandy clay |
| Martial Drive | 38 | 24 | 38 | Clay loam |

Broken Dam had a higher coarse silt % than the other two sites, namely 49 % compared to 40 % for Mhlosinga and 38 % for Martial Drive (Table 3.2). This resulted in Broken Dam falling into the sandy clay texture class, whereas Mhlosinga and Martial Drive both fell into the clay loam texture class. Mhlosinga and Martial Drive had very similar soil particle size composition. All three sites had similar clay contents.

Table 3.3 **Soil characteristics**

| **Area** | **carbon %** | **nitrate ppm** | **sodium me/L** | **Sodium Absorption Ratio** |
|---|---|---|---|---|
| Mhlosinga | 3.65 | 124.00 | 2.81 | 0.93 |
| Broken Dam | 3.88 | 147.40 | 2.73 | 0.73 |
| Martial Drive | 10.10 | 332.80 | 29.81 | 7.53 |

Martial Drive had almost three times the total carbon percentage compared to the other two sites (Table 3.3). Martial Drive had more than twice the nitrate levels compared to the other sites (Table 3.3). Martial Drive also had more than ten times the sodium level compared to the other two sites (Table 3.3). There was little difference in soil chemical composition between Mhlosinga and Broken Dam.

### 3.3.3 Herbaceous density trends over time

Table 3.4 **Mhlosinga grass and *C. odorata* densities in the permanent plots**

| Permanent plot 5m² (grass density) | Time 1 | Time 2 | Time 3 |
|---|---|---|---|
| Mean | 52.97 ± 7.59 | 46.64 ± 6.16 | 29.06 ± 2.58 |
| Range | 197 | 157 | 60 |
| Minimum | 1 | 4 | 3 |
| Maximum | 198 | 161 | 63 |
| Sum | 1907 | 1679 | 1046 |
| Count | 36 | 36 | 36 |
| | | | |
| Permanent plot 5m² (C1 density) | Time 1 | Time 2 | Time 3 |
| Mean | 2.44 ± 0.46 | 1.56 ± 0.41 | 0.25 ± 0.09 |
| Range | 12 | 10 | 2 |
| Minimum | 0 | 0 | 0 |
| Maximum | 12 | 10 | 2 |
| Sum | 88 | 56 | 9 |
| Count | 36 | 36 | 36 |
| Correlation (Grass & C1) | 0.255 | 0.115 | -0.148 |
| | | | |
| Permanent plot 5m² (C2 density) | Time 1 | Time 2 | Time 3 |
| Mean | | 0.58 ± 0.5 | 0.5 ± 0.29 |
| Range | | 18 | 10 |
| Minimum | | 0 | 0 |
| Maximum | | 18 | 10 |
| Sum | | 21 | 18 |
| Count | | 36 | 36 |
| Correlation (Grass & C2) | | -0.176 | 0.051 |

Table 3.5 **Broken Dam grass and *C. odorata* densities in the permanent plots**

| Permanent plot 5m² (grass density) | Time 1 | Time 2 | Time 3 |
|---|---|---|---|
| Mean | 86.11 ± 8.27 | 58.53 ± 4.38 | 51.44 ± 3.64 |
| Range | 230 | 95 | 104 |
| Minimum | 15 | 14 | 20 |
| Maximum | 245 | 109 | 124 |
| Sum | 3100 | 2107 | 1852 |
| Count | 36 | 36 | 36 |
| | | | |
| Permanent plot 5m² (C1 density) | Time 1 | Time 2 | Time 3 |
| Mean | 1.89 ± 0.38 | 0.5 ± 0.21 | 0.03 ± 0.03 |
| Range | 9 | 6 | 1 |
| Minimum | 0 | 0 | 0 |
| Maximum | 9 | 6 | 1 |
| Sum | 68 | 18 | 1 |
| Count | 36 | 36 | 36 |
| Correlation (Grass & C1) | -0.135 | -0.131 | -0.168 |
| | | | |
| Permanent plot 5m² (C2 density) | Time 1 | Time 2 | Time 3 |
| Mean | | 0 | 0.56 ± 0.37 |
| Range | | 0 | 13 |
| Minimum | | 0 | 0 |
| Maximum | | 0 | 13 |
| Sum | | 0 | 20 |
| Count | | 36 | 36 |
| Correlation (Grass & C2) | | No C2 plants recorded in site | 0.15 |

Table 3.6 **Martial Drive grass and *C. odorata* densities in the permanent plots**

| Permanent plot 5m$^2$ (grass density) | Time 1 | Time 2 | Time 3 |
|---|---|---|---|
| Mean | 62.58 ± 8.06 | 36.31 ± 3.8 | 76.33 ± 5.08 |
| Range | 185 | 94 | 128 |
| Minimum | 3 | 3 | 15 |
| Maximum | 188 | 97 | 143 |
| Sum | 2253 | 1307 | 2748 |
| Count | 36 | 36 | 36 |
| | | | |
| Permanent plot 5m$^2$ (C1 density) | Time 1 | Time 2 | Time 3 |
| Mean | 2.25 ± 0.62 | 1.81 ± 0.5 | 0.72 ± 0.23 |
| Range | 18 | 12 | 5 |
| Minimum | 0 | 0 | 0 |
| Maximum | 18 | 12 | 5 |
| Sum | 81 | 65 | 26 |
| Count | 36 | 36 | 36 |
| Correlation (Grass & C1) | 0.051 | 0.037 | -0.112 |
| | | | |
| Permanent plot 5m$^2$ (C2 density) | Time 1 | Time 2 | Time 3 |
| Mean | | 0.72 ± 0.56 | 1.06 ± 0.34 |
| Range | | 20 | 10 |
| Minimum | | 0 | 0 |
| Maximum | | 20 | 10 |
| Sum | | 26 | 38 |
| Count | | 36 | 36 |
| Correlation (Grass & C1) | | 0.044 | -0.2 |

#### *3.3.3.1 Grass trends over time*

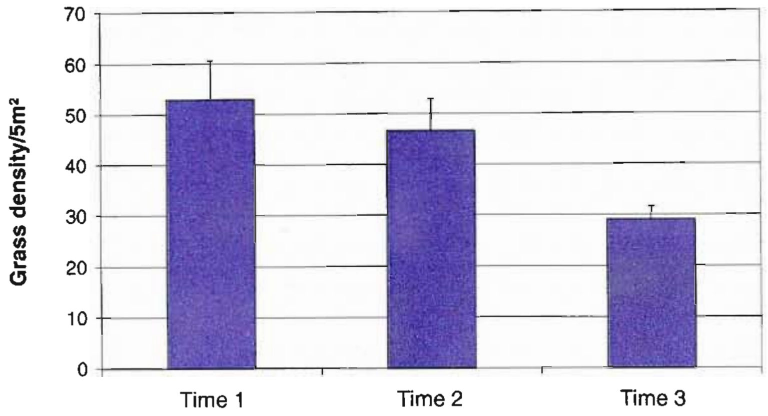

Figure 3.3 **Grass density for Mhlosinga permanent plots, over time**
(error bars represent standard errors of the mean).

In the Mhlosinga site the overall grass density kept on decreasing. By Time 3 the grass density was almost half that of which was recorded at Time 1 (Figure 3.3). There was no significant decrease between Time 1 and Time 2. However there was a significant difference in the grass density between Time 2 and Time 3 (P = 0.01, 70df). The variability recorded between the grass densities in the permanent plots over time, kept on decreasing as the area rehabilitated (Figure 3.3).

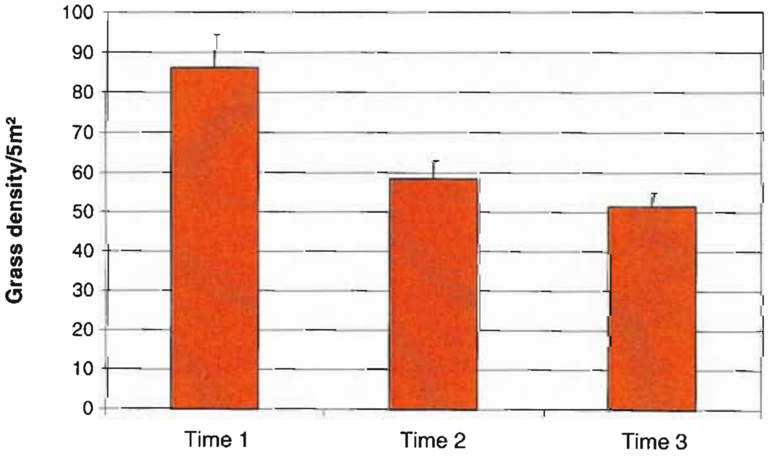

Figure 3.4 **Grass density for Broken Dam permanent plots, over time**
(error bars represent standard errors of the mean).

Broken Dam had a similar trend to that which was recorded in Mhlosinga, i.e. the grass density kept on decreasing between the different time periods (Figure 3.4). There was a significant difference in the grass density between Time 1 and Time 2 (P = 0.004, 70df), and no significant difference between Time 2 and Time 3. The variability recorded between the grass densities in the permanent plots over time, also kept on decreasing as the area rehabilitated (Figure 3.4).

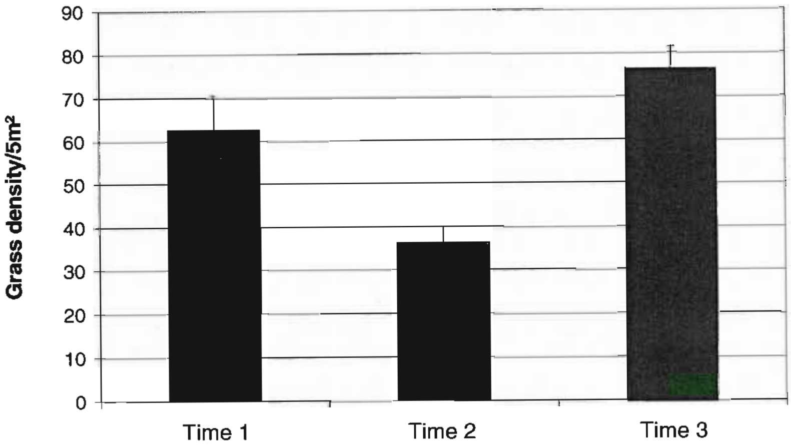

Figure 3.5 **Grass density for Martial Drive permanent plots, over time** (error bars represent standard errors of the mean).

Martial Drives' grass density deviated somewhat from the trend which was observed in the other two sites, where the grass density kept on decreasing between the different time periods. Between Time 1 and Time 2 the grass density did decrease significantly in the Martial Drive site (P = 0.004, 70 df) (the grass density at Time 2 was nearly half that which was recorded at Time 1). However, between Time 2 and Time 3 the opposite happened, the grass density increased. This increase was both drastic and significant (P = 0.001, 70df). By the time the grass density was recorded at Time 3 the overall grass density was higher than that which was recorded at Time 1, and it was more than doubled that which was recorded at Time 2 (Figure 3.5).

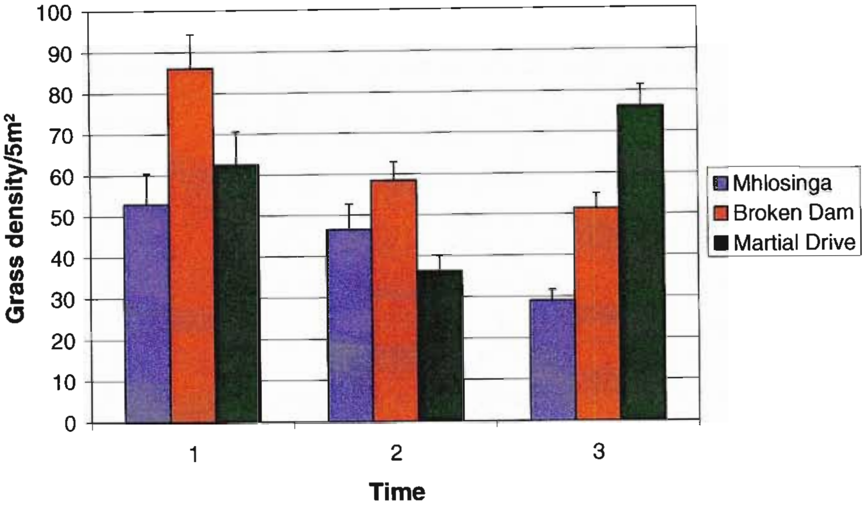

Figure 3.6 **Grass mean density for each area at the different time periods.** (error bars represent standard errors of the mean).

At Time 1, Broken Dam had the highest grass density (around 86 plants per 5m²) and Mhlosinga had the lowest (around 53 plants per 5m²) (Figure 3.6). At Time 2, Broken Dam still had the highest grass density but Martial Drive now had the lowest density (around 36 plants per 5m²) (Figure 3.6). This situation completely reversed by Time 3 where Martial Drive moved from the lowest to the highest density (around 76 plants per 5m²), whilst Mhlosinga moved again to the lowest density, almost half that which was recorded at Martial Drive (Figure 3.6).

### *3.3.3.2 Chromolaena odorata trends over time*

No relationship could be found between grass and *C. odorata* density, for any of the sites.

Mhlosinga site (Table 3.4)

The mean C1 density for the Mhlosinga dropped continuously throughout the study period, from 2.44 plants per 5m² at Time 1 to only 1 plant every 20m² at Time 3. The C2 density decreased slightly from 0.58 plants per 5m² at Time 2 to 0.5 plants per 5m² at Time 3.

Broken Dam site (Table 3.5)

The mean C1 density for the Broken Dam site dropped continuously throughout the study period, from 1.89 plants per 5m² at Time 1 to as little as 0.03 plants per 5m² at Time 3. Almost all the C1 seedlings had succumbed to the drought. The C2 density increased from zero plants at Time 2 to a very similar low density to that which was recorded at the Mhlosinga site (Time 3), namely 0.56 plants per 5m².

Martial Drive site (Table 3.6)

Similarly to the other two sites the mean C1 density for the Martial Drive site dropped continuously throughout the study period, from 2.25 plants per 5m² at Time 1 to 0.72 plants per 5m², at Time 3. Although this density is also relatively low, it was significantly higher to that which was recorded in the other two sites. The C2 density increased slightly from 0.72 plants at Time 2 to 1.06 plants at Time 3. Although this value was nearly double that which was recorded at the other two sites, it was still nonetheless very low.

### 3.3.4 Results from the final data sampling in June 2004 (Time 3).

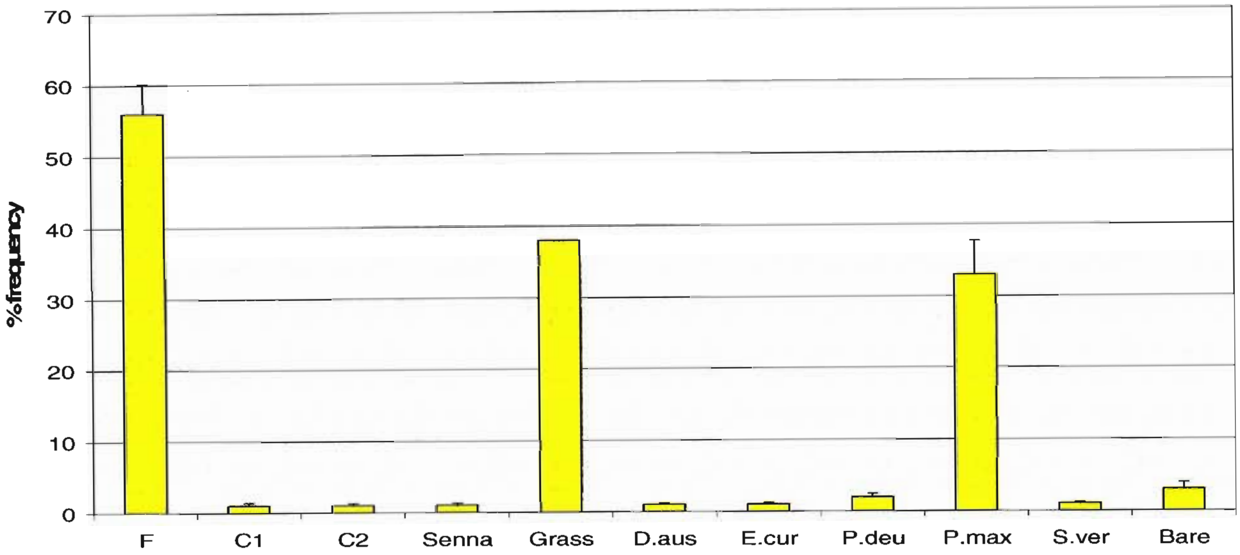

Figure 3.7 **Herbaceous composition for Mhlosinga at Time 3**
(error bars represent standard errors of mean).

Species key: C1-*Chromolaena odorata* that germinated in 2002, C2-*Chromolaena odorata* that germinated in 2003, D.aus-*Dactyloctenium australe*, E.cur-*Eragrostis curvula*, F- forbs, Grass-cumulative total of all different grass species, P.deu-*Panicum deustum*, P.max-*Panicum maximum*, Senna- *Senna pendula*, S.ver-*Setaria verticillata*

Mhlosinga had only four different grass species, namely *Dactyloctenium australe*, *Eragrostis curvula*, *Panicum deustum* and *Panicum maximum* (Figure 3.7). Forbs made up a staggering total of 56 percent of the herbaceous composition. Apart from *Panicum maximum* none of the other grass species made any significant contribution to the herbaceous composition. Both C1 and C2 plants were recorded but each made up less than one percent of the herbaceous composition. These data are similar to what was found in the permanent plots. There were very few other alien exotic species recorded in the Mhlosinga site, with *Senna pendula* making up less than one percent of the herbaceous composition and only a single *Ricinus communis* plant was recorded (Figure 3.7).

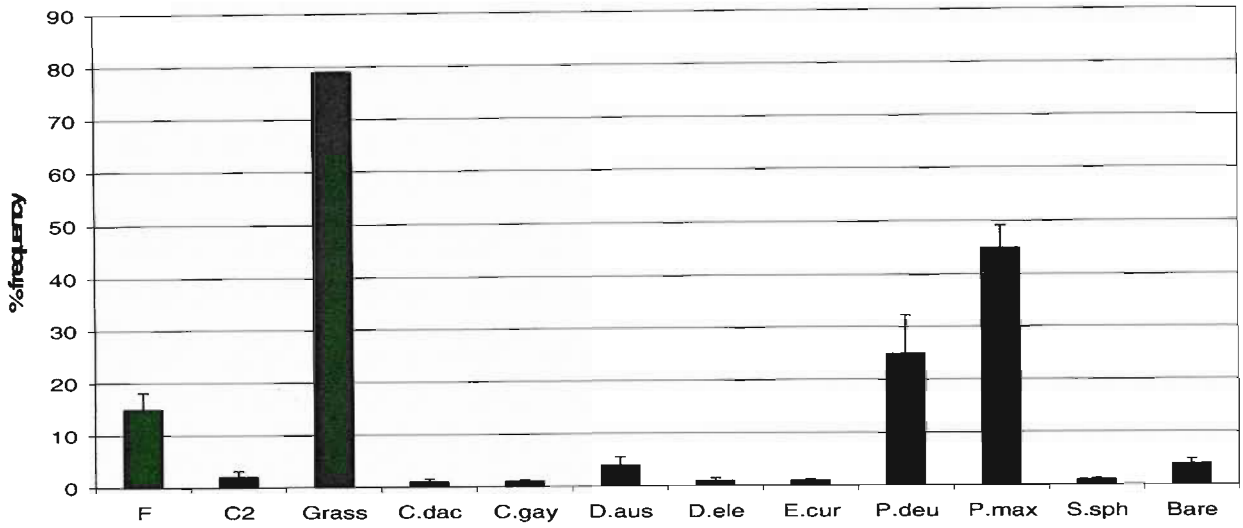

Figure 3.8 **Herbaceous composition for Broken Dam at Time 3**
(error bars represent standard errors of mean).

Species key: C2-*Chromolaena odorata* that germinated in 2003, C.dac- *Cynodon dactylon*, C.gay-*Chloris gayana*, D.aus-*Dactyloctenium australe*, D.ele- *Diplachne eleusine*, E.cur-*Eragrostis curvula*, F- forbs, Grass- cumulative total of all the different grass species P.deu-*Panicum deustum*, P.max-*Panicum maximum*, S.sph- *Setaria sphacelata.*

Broken Dam had a total of eight different grass species, namely *Chloris gayana*, *Cynodon dactylon*, *Dactyloctenium australe*, *Diplachne eleusine*, *Eragrostis curvula*, *Panicum deustum*, *Panicum maximum* and *Setaria sphacelata* (Figure 3.8). *P. maximum* was the dominant grass species, making up 47 percent of the herbaceous composition. The next dominant grass species was *P. deustum*, which made up 25 percent of the herbaceous composition. This was followed by *D. australe* which made up four percent of the herbaceous species (Figure 3.8). The rest of the grass species each made up, on average, only one percent of the herbaceous composition. No C1 plants were found, and C2 seedlings made up only two percent of the total herbaceous composition. These data are similar to what was found in the permanent plots, i.e. no C1 plants and a very low density of C2 plants. Both *P. deustum* and *D. australe* have a preference for sandy soils (van Oudtshoorn 1992). Broken Dam had a higher coarse silt percentage than the other two sites (Table 3.2), and was therefore a more suitable habitat for these two species.

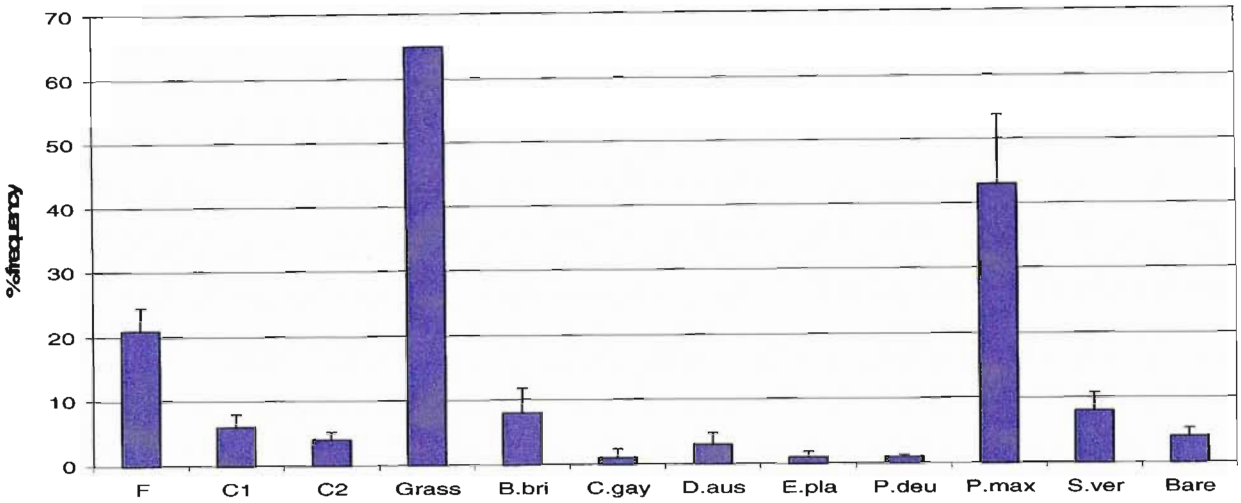

Figure 3.9 **Herbaceous composition for Martial Drive at Time 3** (error bars represent standard errors of mean).

Species key: C1-*Chromolaena odorata* that germinated in 2002, C2-*Chromolaena odorata* that germinated in 2003, B.bri-*Brachiaria brizantha*, C.gay-*Chloris gayana*, D.aus-*Dactyloctenium australe*, E.pla-*Eragrostis plana*, F-forbs, Grass- cumulative total of all the different grass species, P.deu-*Panicum deustum*, P.max-*Panicum maximum*, S.ver-*Setaria verticillata*.

Martial Drive had a total of seven different grass species, namely *Brachiaria brizantha*, *Chloris gayana*, *Dactyloctenium australe*, *Eragrostis plana*, *Panicum deustum*, *Panicum maximum* and *Setaria verticillata* (Figure 3.9). *P. maximum* was the most dominant herbaceous species in terms of density, and accounted for 43% of the herbaceous composition. This was followed by forbs which made up 21 % of the herbaceous composition. Both *B. brizantha* and *S. verticillata* each made up eight percent of the herbaceous composition and were thus the third and fourth most dominant species (Figure 3.9). C1 was fifth, making up six percent of the herbaceous sward composition. C2 was sixth, making up four percent of the herbaceous sward composition. *D. australe* made up three percent of the herbaceous composition and was thus the seventh most dominant species. The other species each made up between one and two percent of the herbaceous composition. *B. brizantha* has a high preference for shady areas (van Oudtshorn 1992), and *S. verticillata* usually grows on nitrogen-rich disturbed soils, often under trees (van Oudtshoorn 1992). This would explain why these two grass species were found in the Martial Drive site.

Table 3.7 **Fuel mass for different sites at Time 3 (June 2004)**

| Area | Mass kg ha$^{-1}$ |
|---|---|
| Mhlosinga | 3417 ± 267.12 |
| Broken Dam | 3752 ± 532.25 |
| Martial Drive | 3362 ± 329.84 |

The fuel mass varied between 3362 kg ha$^{-1}$ and 3752 kg ha$^{-1}$ for the different sites with Broken Dam having the highest fuel mass and Martial Drive the lowest (Table 3.7). The fuel mass in Mhlosinga was only slightly higher than in Martial Drive.

### *3.3.4.1 Ordination*

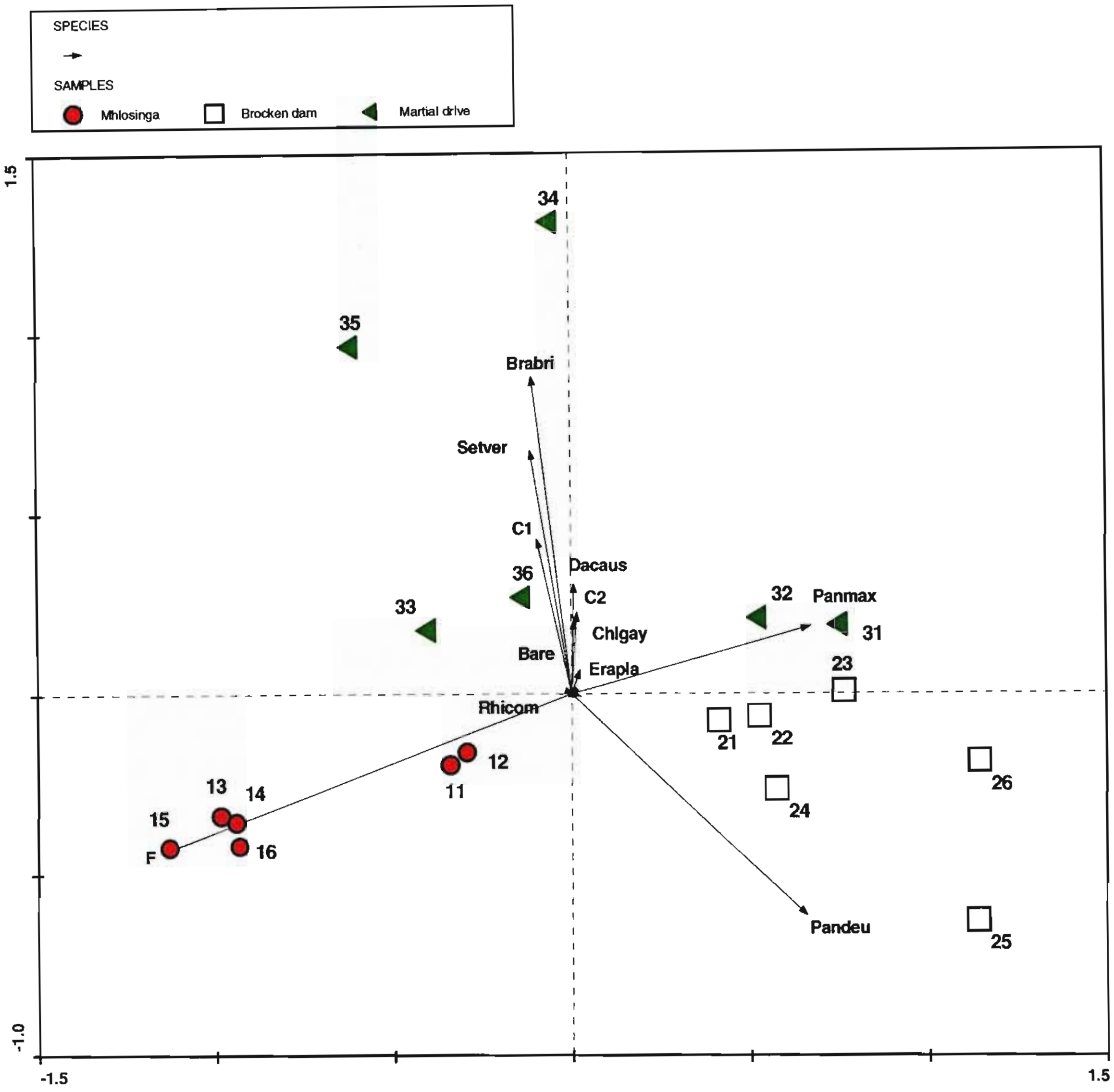

Figure 3.10 **Principal Component Analysis (PCA) for the three different sites.** Species key: C1-*Chromolaena odorata* that germinated in 2002, C2-*Chromolaena odorata* that germinated in 2003, Brabri-*Brachiaria brizantha*, Chlgay-*Chloris gayana*, Dacaus-*Dactyloctenium australe*, Erapla-*Eragrostis plana*, Pandeu-*Panicum deustum*, Panmax-*Panicum maximum*, Rhicom-*Rhicinus communis*, Setver-*Setaria verticillata*.

Species with short arrows close to the origin of the ordination were not shown. The differences among the sites are clear. The Eigenvalues of axes 1 and 2 were 0.533 and 0.222 respectively, cumulatively representing 75.5% of the total variance. Axis 1 accounted for most of the variation. Mhlosinga and Broken Dam are the most dissimilar in terms of axis 1 (Figure 3.10), with Martial Drive being approximately halfway between the two sites. Axis 2 captured the second most influential environmental variables which was completely independent of the environmental variation captured in axis 1. Axis 2 shows that Mhlosinga and Broken Dam were relatively similar to one another and Martial Drive was the least similar.

Table 3.8 **Cumulative fit for the different species**

| Species | Axis 1 | Axis 2 | Axis 3 | Var (y) |
|---|---|---|---|---|
| Forbs | 0.927 | 0.982 | 0.987 | 5.70 |
| C1 | 0.081 | 0.748 | 0.812 | 0.47 |
| C2 | 0.005 | 0.449 | 0.466 | 0.19 |
| *Senna pendula* | 0.097 | 0.144 | 0.146 | 0.00 |
| *Ricinus communis* | 0.142 | 0.190 | 0.206 | 0.00 |
| *Brachiaria brizantha* | 0.029 | 0.826 | 0.984 | 1.67 |
| *Chloris gayana* | 0.001 | 0.451 | 0.504 | 0.16 |
| *Cynodon dactylon* | 0.144 | 0.154 | 0.164 | 0.01 |
| *Dactyloctenium australe* | 0.001 | 0.411 | 0.506 | 0.39 |
| *Diplachne eleusine* | 0.228 | 0.239 | 0.240 | 0.01 |
| *Eragrostis curvula* | 0.082 | 0.210 | 0.458 | 0.00 |
| *Eragrostis plana* | 0.018 | 0.026 | 0.032 | 0.04 |
| *Panicum maximum* | 0.540 | 0.557 | 0.981 | 3.43 |
| *Panicum deustum* | 0.478 | 0.652 | 0.985 | 3.72 |
| *Setaria sphacelata* | 0.144 | 0.154 | 0.164 | 0.00 |
| *Setaria verticillata* | 0.052 | 0.811 | 0.938 | 1.03 |

Forb density was the most influential species for both Axis 1 and Axis 2, the forb cumulative fit value for Axis 1 was 0.927 and for Axis 2 was 0.982 (Table 3.8). *Panicum maximum* (0.54) was the second most influential species on Axis 1 and was followed closely by *Panicum deustum.*

For Axis 2 the second most influential species was *Brachiaria brizantha* (0.826) followed closely by *Setaria verticillata* (0.811). C1 was the fourth (0.748) and C2 was the fifth-most influential (0.449). The small angles between the arrows for *Brachiaria brizantha, Setaria verticillata,* C1, C2 and *Dactyloctenium australe* indicates that these species were closely associated with one another and were good indicator species for the Martial Drive site. The ordination also shows that Mhlosinga had a higher forb density than the other two sites, whilst Broken Dam had the highest densities of *Panicum deustum* and *Panicum maximum.*

The close proximity of the different sites to one another and the similar topographical positioning of the sites (i.e. bottom lands close to drainage lines) meant that the sites should have had similar environmental variables (e.g. rainfall, radiance, temperature etc.). Results from the soil analysis did reveal that there were some differences between the soils. Broken Dam differed from Mhlosinga and Martial Drive by having sandy clay soils as opposed to clay loam soils (Table 3.2). The ordination axis 1 shows Mhlosinga and Broken Dam as being the two most dissimilar sites, with Martial Drive being about halfway between the two (Figure 3.10). The most obvious environmental difference between Mhlosinga and Martial Drive, is soil texture: where Mhlosinga had clay loam soils, and Broken Dam had sandy clay soils. However, the soil texture for Martial Drive was very similar to that of Mhlosinga, and therefore the overall influence of soil texture on Axis 1 is questionable.

Unfortunately, rainfall levels were not measured at each site. Rainfall was only recorded at one spot on Sutton Game Farm, which was about 7 km away from the furtherest site (Martial Drive). Although rainfall was found to be very variable in the Munyawana, it was thought that the variation would be minimal over such a small distance. Rainfall was therefore presumed to be constant.

Axis 2 in the PCA shows the second main influential environmental variables that affected the ordination. The second Axis is independent from Axis 1. From Figure 3.10 it can be seen from Axis 2 that Mhlosinga and Broken Dam were very similar to one another, while Martial Drive was the most different. Mhlosinga and Broken Dam soil analysis revealed that both sites had very similar carbon, nitrate and sodium levels, but the soils of Martial Drive differed considerably from the soils of the two other sites (Table 3.3). Another possible influential factor between Martial Drive and the other two sites was the high shading effect, which is thought to have caused a higher soil moisture level in the Martial Drive site. All these factors are thought to have played a large role in determining the species composition and the variation capture in Axis 2. Table 3.8, supports this by showing that both *Brachiaria brizantha* and *Setaria verticillata* had a large influence in determining Axis 2. As mentioned before, the reason for *Setaria verticillata* being found in Martial Drive was as a result of the high shading effect, from the *Acacia xanthophloea* trees, and the nitrogen content in the soil. *B. brizantha* was also found in Martial Drive due to the high shading effect. Thus, shade and nitrogen content in the soil must have had a considerable influence on the variation captured on Axis 2.

*3.3.4.2 Multi-Response Permutation Procedure (MRPP)* (Mccune & Mefford 1999).

The MRPP showed that all the sites were significantly different to one another in terms of species composition and abundance ($P < 0.01$). Each site was significantly different to every other site, with the largest difference being between Mhlosinga and Broken Dam ($P < 0.01$), and the least difference being between Broken Dam and Martial Drive ($P < 0.01$). These results give numerical support to what can be seen in Figure 3.10.

Table 3.9 **Indicator species analysis (ISA) (Dufrene & Legendre 1997).**

| Species | Indicator value (%) | P |
|---|---|---|
| F | 54.9 ± 3.79 | 0.0010 |
| C1 | 58.1 ± 11.41 | 0.0480 |
| C2 | 53.5 ± 9.75 | 0.0500 |
| *Brachiaria brizantha* | 82.3 ± 13.13 | 0.0030 |
| *Chloris gayana* | 13.3 ± 12.35 | 1.0000 |
| *Cynodon dactylon* | 16.7 ± 0.53 | 1.0000 |
| *Dactyloctenium australe* | 29.2 ± 11.51 | 0.5680 |
| *Diplachne eleusine* | 50.0 ± 10.88 | 0.0730 |
| *Eragrostis curvula* | 22.8 ± 11.64 | 0.2990 |
| *Eragrostis plana* | 16.7 ± 0.53 | 1.0000 |
| *Panicum maximum* | 39.6 ± 2.38 | 0.1380 |
| *Panicum deustum* | 93.4 ± 11.05 | 0.0010 |
| *Setaria sphacelata* | 16.7 ± 0.53 | 1.0000 |
| *Setaria verticillata* | 81.1 ± 12.06 | 0.0030 |

In the Indicator Species Analysis Table 3.9, *Panicum deustum* had the maximum indicator value of 93.4% followed by *Bracharia brizantha* (82.3%) and *Setaria verticilata* (81.1%). Forbs, C1 and C2 all had maximum indicator values around 50-60%.

## 3.4 Discussion

### 3.4.1 Initial *Chromolaena odorata* density

Results from Table 3.1 highlight the large variation that can be found in *C. odorata* density in areas that are densely infested by this weed.

### 3.4.2 Soils

Sandy soils have a lower matric potential (pressure potential of soil at a given water content) compared to clayey soils. Clay particles bind the moisture more tightly than sand particles, thereby making soil moisture less available to plants (MacVicar 1991). Thus, if an area receives a light rain shower, even though the clayey soils will absorb a lot more moisture than sandy soils, the clayey soils bind the moisture so tightly, that plants will have great difficulty extracting this moisture. The opposite holds true for sandy soils. They are able to retain a lot less moisture, but if the area receives a light rain shower during a drought period, then sandy soils will make the moisture more readily available than clayey soils. This is particularly relevant when the whole area is experiencing a severe and extended drought. At this stage the soil will be at its wilting point (-1500kPa) (MacVicar 1991). Thus, if an area receives a light rain shower during a severe drought period, grasses growing in the sandy soil will have a higher survival rate, because more moisture will be available for them to grow. This seemed to have been the case for Broken Dam site (which had more sandy soils than the other two sites) (Table 3.2), and thus at Time 2 (during the peak of the drought, Table 2.1) Broken Dam had by far the highest grass density (Table 3.5).

The high sodium levels in the soil at the Martial Drive site were responsible for the high sodium absorption ratio (SAR) levels. As the soluble salt concentration increases, so the osmotic potential of the soil water decreases, and less water becomes available for plants to utilize. Thus, during drought periods, areas with higher salt concentrations will require more rainfall to make moisture available to plants (MacVicar 1991). This combined with the fact that Martial Drive had such a high clay content (Table 3.2 and Table 3.3), were probably the main reasons why Martial Drive had the lowest grass density at Time 2 (Table 3.6).

Clayey soils have a higher water saturation content level compared to sandy soils. The reason for this is directly related to the small clay particles size, which in turn means that they have a higher surface area compared to sand. This increases the cohesive force allowing clay particles to bind more water. Not only are clay soils able to bind more moisture, but the small size of the clay particles also slows down the drainage of water through the soil(MacVicar 1991). This allows soils with a high clay content to retain the moisture for a longer time period. Therefore, if an area receives high rainfall, and the soils become saturated with moisture, clay soils will hold a higher volume of water, and will retain it for a longer period than sandy soils.

High saline and nitrate levels in soils are characteristic of soils that have poor drainage, as was the case for the Martial Drive site. This poor water drainage in the Martial Drive site, combined with the fact that the clayey soils are able to retain a large volume of water, meant that when the Munyawana Game Reserve received good rainfall in January and February 2004, it could retain the water for a longer time period than the other two sites. This allowed plants to utilize this moisture for a longer period, and was probably the main reason for the drastic increase in grass density at Time 3 for the Martial Drive site.

Other possible explanations for the drastic and significant increase in grass densities for the Martial Drive site by Time 3 were:

1. Rainfall was highly variable in the area: rain showers sometimes poured down in one area and left another spot that was a few hundred metres away, totally dry;
2. The high shading effect, Martial Drive had a higher tree density than the other two sites (especially *Acacia xanthophloea*), this would have allowed the area to retain the soil moisture for a longer period of time;
3. Results from the soil analysis showed that Martial Drive had the highest organic matter and nitrate contents, these compounds are essential for plant growth and would have helped boost the seedlings' survival rates.

### 3.4.3 Herbaceous trends over time

All the sites still had, surprisingly, a large viable grass seed bank. The average grass density in the permanent plots for the each site at the end of Time 3 was as follows: Mhlosinga 30 plants per 5m$^2$ (Table 3.4), Broken Dam 51 plants per 5m$^2$ (Table 3.5) and Martial Drive 76 plants per 5m$^2$ (Table 3.6). These figures were far higher than expected.

When the bulldozer cleared the *C. odorata*, no herbaceous plants were found growing beneath the dense *C. odorata* mass. The bare, fertile, alluvial soils, whose crust had been broken by the tracks of the bulldozer, provided an ideal setting for the grass seeds to germinate. There was considerable variation in grass densities for each site. Drought and the large *C. odorata* plants that previously infested the areas are thought to be the main reasons for the grass patchiness. Drought would affect the grass seedling germination and the large *C. odorata* plants would have acted as a barrier to grass seeds blowing into the area. Both the Mhlosinga and the

Broken Dam sites' grass density kept on decreasing probably as a result of self thinning (which was probably exacerbated by the drought). The variability, in grass seedling density, between the different permanent plots for each area, was decreasing over time indicating that the sites were slowly reaching an optimum tuft density.

There were surprisingly very few *C. odorata* plants which germinated in the sites. At the start of the study, a large number of *C. odorata* seedlings and only a few grass seedlings were expected to germinate. It was also expected that the *C. odorata* would soon out-compete and overshadow these few grass seedlings. Soon after clearing, however, it became obvious that the area still had a large viable grass seed population that showed very promising signs of establishing in the first season. Erasmus (1985), mentioned that low rainfall will prevent *C. odorata* achenes from germinating; this was probably the reason for the low number of seedlings germinating in the study area for both the 2002 and 2003 germinating period (Table 3.4 to Table 3.6).

There was a gradual and significant decrease in the initial population of *C. odorata* seedlings (referred to as C1) at each time interval, and by Time 3 they had almost completely died out in the Broken Dam sites (Table 3.5). C1 plants in the Mhlosinga and Martial Drive sites also kept on gradually decreasing in numbers (Table 3.4 and Table 3.6). An average of only one C1 plant per 20m$^2$ was recorded for Mhlosinga by Time 3 (June 2004). As mentioned already, it was suspected that Martial Drive had more moisture than the other sites, especially in the areas under the shade of the trees. Even with this higher moisture content, C1 plants continued to decline in density in the Martial Drive site, although not as drastically as the other two sites (Table 3.6). By Time 3 there was less than one plant on average per 5m$^2$ left in the Martial Drive site.

These results highlight how sensitive *C. odorata* seedlings were to extended drought periods. Tables 3.4 to 3.6 showed that a large proportion of the *C. odorata* seedlings could survive the first year of a drought, but that the mortality rate drastically increased if the drought persisted for longer than a year as was seen in both the case of C1 and C2 plants.

The germinating period for *C. odorata*, in South Africa, is between September and October (Wilson 1995). The *C. odorata* seedlings, germinating in the second season of the study period, September-October 2003, were labelled as C2 plants. There were even fewer plants germinating in the second season compared to that in 2002. The reason for this is probably due to the fact that the drought was even more severe, in the second season, especially during the time period between September-October 2003 (refer to monthly rainfall, Table 2.1). Another possible reason for the lower number of *C. odorata* seedling germinating in the second season could be as a consequence of less viable seeds left in the area and greater competition from the established grasses.

In the second season no *C. odorata* seedlings emerged in the Broken Dam site, whilst only one plant per 10 $m^2$ emerged in the Mhlosinga site. Martial Drive also had very few seedlings emerging, with slightly less than one plant on average per 5 $m^2$. Even though these figures were low, Martial Drive had the highest number of seedlings coming through in the 2003 season, and the fact that not all the initial *C. odorata* plants died out -as was the case in the Mhlosinga and Broken Dam sites- seems to support the theory that Martial Drive had more moisture than the other two sites. The fact that *C. odorata* seedlings still germinated during the drought period highlights the importance of follow up treatment, even during drought periods.

Wilson (1995) mentions that there was a significant increase in *C. odorata* seedling germination in areas subject to partial shading as opposed to full sunlight. No differences could be detected in this study, although the low number of *C. odorata* seedlings that did manage to germinate could be responsible for the lack of significance. With more favourable germinating conditions and larger numbers of *C. odorata* seedlings emerging, this trend could be more accurately tested. However, partial shading did appear to prevent seedling mortality.

There was no consistent trend for *C. odorata* germination and mortality rates, except that most of the initial *C. odorata* plants had almost completely died out. At the start of the study it was suspected that there would be a strong negative relationship between grass and *C. odorata* seedling density. Surprisingly, no relationship could be detected in this study. Once again, had there been more favourable conditions (i.e. higher rainfall) allowing more *C. odorata* seedlings to germinate, some relationship could have probably been detected.

If grass is given an opportunity to become established and completely prevent sunlight from penetrating the ground, evidence from this study indicates that it could prevent *C. odorata* seedlings from becoming established. Grasses will also compete against *C. odorata* seedlings for limited moisture and nutrient resources. Furthemore established grasslands have the added bonus of being able to destroy *C. odorata* seedlings by providing excellent fuel masses for intense veld fires.

### 3.4.4 Discussion for the final data sampling in June 2004 (Time 3).

Results from the multi-response permutation procedure (MRPP), show that all the sites were significantly different to one another in terms of the herbaceous species composition. *Panicum maximum* was the dominant grass species in all three sites, and made up more than 40 percent of the herbaceous composition in Broken Dam and Martial Drive sites (Figure 3.8 and Figure 3.9). In Mhlosinga, *P. maximum* made up 34 percent of the herbaceous composition (Figure 3.7).

Goodall (2000) and Erasmus (1985) recorded large densities of other alien invasives coming through in areas where *C. odorata* had been cleared, for example *Lantana camara* and castor oil (*Ricinus communis*). Interestingly very few other alien exotic species where recorded, with only a single *Ricinus communis* plant being recorded in the whole of the Mhlosinga area. Another alien exotic that was recorded in Mhlosinga was *Senna pendula*, but it made up less than one percent of the herbaceous composition. No other alien species besides *C. odorata* were recorded in either of the other two sites.

Broken Dam had the highest fuel mass at Time 3 (Table 3.7). This was expected as it had the highest proportion of *Panicum* (Figure 3.8) as well as also having the highest grass density (Table 3.5). The fuel mass for Martial Drive and Mhlosinga was very similar.

## 3.5 Conclusions

If the criteria stipulated in section 3.2 Materials and Method (pg 35) for using a bulldozer are adhered to, then a bulldozer was found to be a very effective machine at clearing areas that where densely infested with *C. odorata*. Furthemore, it is speculated that when the bulldozer tracts breaks up the soil surface, that this will facilitate grass seedling germination.

Before the study was started, it was believed that there would be very few viable grass seeds left in areas that had been densely infested with *C. odorata*. This was found not to be the case, as many grass seedlings emerged throughout the cleared areas. Each site had its own optimum tuft density.

The reason for the initial grass seedling density not being more uniform was probably as a result of no grass seeds being present in that patch, due to the barrier effect from the large *C. odorata* plants. Drought could also have played a role in grass distribution not being more uniform, by inducing dormancy mechanisms in the grass seeds. The dominant grass species that emerged in all three sites was *Panicum maximum*. *P. maximum* not only provides extensive shade, thereby preventing *C. odorata* seedlings from germinating, but it also provides a high fuel mass to destroy *C. odorata* seedlings with fire.

Even during a drought period, grass was still able to grow quickly, and by the second year that the areas were cleared, the fuel mass was already over 3000 kg ha$^{-1}$. If grass is given an opportunity to establish itself in a cleared area, results from this study indicate that *C. odorata* seedlings will have great difficulty in establishing themselves.

Suprisingly no relationship could be detected between grass and *C. odorata* seedling density. The main reason for this is due to the low number of *C. odorata* seedlings that germinated in the sites. The low density of *C. odorata* seedlings recorded in the different sites could have been as a result of one of the following reasons:

1. Seed dormancy, which could have been forced onto the seeds due to a lack of moisture, caused by the drought (Erasmus 1985);
2. Seeds only germinate if conditions are ideal, otherwise they die;
3. Seeds did actually germinate, but died shortly afterwards and thus could not be detected when the field research was undertaken.
4. Competition from grass and forb seedlings, prevented the *C. odorata* achenes from germinating.

By Time 3 the sites were all significantly different to one another in terms of herbaceous composition and grass density, highlighting how even relatively close areas can differ dramatically during re-vegetation of a cleared area. Even though all the sites were significantly different, it was of great interest to see that the *C. odorata* density was low in all three sites (Refer to Appendix 9 on implementing an Integrated Alien Plant Control (IAPC) programme).

It is important that the reader bears in mind the strong influence that the drought may have had on the results which appear to have had a far more negative influence on the *C. odorata* plants than on the grass species. In years of normal to high rainfall, the opposite trend may well be observed with *C. odorata* germinating better and out-competing the grass species.

# Chapter 4

# A fire management programme to control *Chromolaena odorata*

## 4.1 Introduction

Fire favours the development and maintenance of a predominantly grassland vegetation by destroying juvenile trees and shrubs. However, in areas which have become bush encroached, fire is no longer an effective method for suppressing bush encroachment, as the fuel mass will be too low to support intense fires. Therefore, in bush encroached areas, fire is often not an effective tool to kill *C. odorata* plants, especially adult plants.

Healthy, open, vigorous grass swards are maintained by correct burning, veld resting and correct stocking densities by grazers and browsers. In an open savanna it is vital to keep grass vigorous by preventing it from going moribund or being over-utilized. If the grass loses its vigour, the veld will be more prone to alien invaders, such as *C. odorata*, and bush encroachment.

Fire is often used incorrectly on many farms as a management tool to maintain healthy grasslands, especially where the farm is broken up into many fragments and camps. This often results in several camps being neglected, which causes the grass in these camps to be either over- or under-utilized, allowing alien plants, such as *C. odorata*, to invade the camps. The encroachment of *C. odorata* accelerates the rate of grassland degradation.

### 4.1.1 Economics and energy utilization aspects of burning

The most important aspect of using fire for controlling bush encroachment (including *C. odorata*) is that it is an indirect cost technique. Burning results in the loss of potential grazing, particularly in arid savanna areas, hence the cost of a burning programme must be assessed in terms of lost profits.

However, in areas where there is a low animal stocking rate and consequently lots of moribund grass present due to under-grazing, by burning certain sections of the farm, a manager is actually increasing his profits, because he is forcing his animals to feed on the areas that he has not burnt in a less selective manner, and thereby removing moribund grass tillers. Burning in areas where the grass is moribund, will cause the grass to grow a lot more vigorously, and thereby increase the carrying capacity of the farm in the long run (van Oudtshoorn 1992).

The type of fire most suitable for controlling bush encroachment in both moist and arid savanna areas is a head fire, in other words, burning with the wind. The use of a head fire is preferred, because research has shown that this type of fire has the least detrimental effect on the grass sward (Trollope 1978) and the greatest damaging effect on the trees and shrub layer (Trollope 1979).

### 4.1.2 Behaviour of different types of fires

In grasslands and savannas, surface fires normally burn as either head– or back fires. These two types of fires behave differently with respect to rate of spread, fire intensity, flame height and the temperature of the fire, and so have different effects on the vegetation.

*a) Rate of spread*

Trollope (1978) showed the striking difference between head– and back-fires, namely that head-fires on average travel at seven and a half times the speed of back-fires, and their rate of spread was more variable than that of back-fires. Their spread was therefore more greatly influenced by environmental conditions than in back-fires.

*b) Fire intensity*

The relationship between the mean, minimum and maximum intensity of surface fires burning with and against the wind were similar to those for rate of spread because of the important role that rate of spread plays in determining the fire intensity (Trollope 1978).

*c) Flame height*

The flames from head-fires reach greater heights, and are, again, more variable than those from back-fires (Trollope 1978).

*d) Fire temperature*

At ground level, back-fires are hotter than head-fires, with temperature being higher in both types of fires at grass canopy level than at ground level (Trollope 1978).

Research and experience gained at the University of Fort Hare indicate that a sufficiently intense fire will be obtained when the grass fuel load is greater than or equal to 3 000 kg ha$^{-1}$, fuel moisture is less than or equal to 40% (fully cured), air temperature is greater than or equal to

25 ºC, relative humidity is less than or equal to 30% and soil moisture is preferably less than field capacity (Trollope 1980). The fire intensity from such a fire will normally be effective in destroying the stems and branches of trees and shrubs up to a height of approximately 2 m.

### 4.1.3 Frequency of burning

In the moist savanna areas the frequency of burning required to control bush encroachment, depends on the rate at which re-encroachment occurs in the form of recovering coppice growth and seedling development. Therefore, the frequency of burning will depend upon the period that it takes the bush to recover to a maximum susceptible height of 2 m. In the moist savanna areas burning is also necessary to periodically remove moribund and/or unacceptable grass material of the desirable grass species in the sward. Generally, the rate at which unacceptable grass material accumulates, necessitates burning once every 3 to 4 years (Trollope 1980). Hence in the moist savannas, it will often be possible to combine burning for controlling bush encroachment with the removal of moribund grass material. Because the regenerating bush is at a less advanced stage of growth with the frequent burning, it may be possible to apply less intense fires under these circumstances.

### 4.1.4 Factors affecting fire behaviour in grasslands

a) *Fuel density*

The high average surface area: volume ratio for grasslands will favour rapid ignition, and therefore spread of fire through grassland (Chandler *et al.*1983).

b) *Fuel moisture*

The moisture content of grassland fuel varies seasonally, and exerts an important influence on the amount of fuel that will be consumed by a fire. For example, burning in winter when the fuel moisture is low can result in 96% of the fuel being burnt, whereas burning in spring when there is higher moisture content, will result in only between 70 and 90% of the total fuel load being burnt. In the mid-winter period, fuel moisture content declines to very low levels (20%) during the day, giving rise to high fire hazards (Tainton 1999). The cured grass readily absorbs moisture (e.g. dew), but it loses it equally rapidly as conditions warm up. Even a small amount of rain will dramatically affect the moisture content of the grass.

### c) *Fuel load*

The grass fuel load increases as the veld is rested. The higher the fuel load, the greater the intensity of the fire and the more difficult it is to control the fire. But the fuel load will only increase for a certain number of years, thereafter it will rapidly decline, as the veld becomes moribund. In the end, woody species will invade, and the grass fuel mass will drastically decrease.

### d) *Air temperature*

The direct effect of air temperature on fire behaviour results from its influence on the temperature of the fuel, and therefore on the amount of heat energy required to raise the temperature of the material to its ignition point (Brown & Davis 1973). It will, however, also exert an indirect effect through its influence on the relative humidity and consequently on the evaporative moisture loss from fuels (Luke & McArthur 1978).

### e) *Relative humidity*

Relative humidity influences the moisture content and has a negative effect on fire intensity. High fire intensities are generally recorded when humidity is below 30% (Trollope 1983).

### f) *Wind*

Wind is important, because it determines the amount of oxygen available for combustion. Rate of energy released is positively related to wind speed. Also, wind influences pre-heating of unburnt fuel loads.

### g) *Terrain slope*

Slope significantly influences the forward spread rate of surface fires by modifying the extent to which the material ahead of the fire is pre-heated. A fire burning up-slope has the characteristic of a head-fire since the material ahead of the fire will be pre-heated. Conversely, a fire burning down-slope will have the characteristic of a back-fire since the heat generated by the fire is carried away from the unburnt down-slope material. Wind direction and wind speed will, however, modify these effects.

The following questions were addressed in this chapter:

a) Does fire have an effect on *C. odorata* plants, and to what degree does it affect different *C. odorata* plant sizes?

b) Does fire type influence the mortality rate of *C. odorata*?

c) Does fire intensity influence the mortality rate of *C. odorata*?

d) Does fire applied as a once-off treatment have any effect on the mortality rate of *C. odorata* in the long term?

## 4.2 Materials and Method

The whole burning experiment and the post-effect of fire on *C. odorata* was monitored from July 2002 through to June 2004.

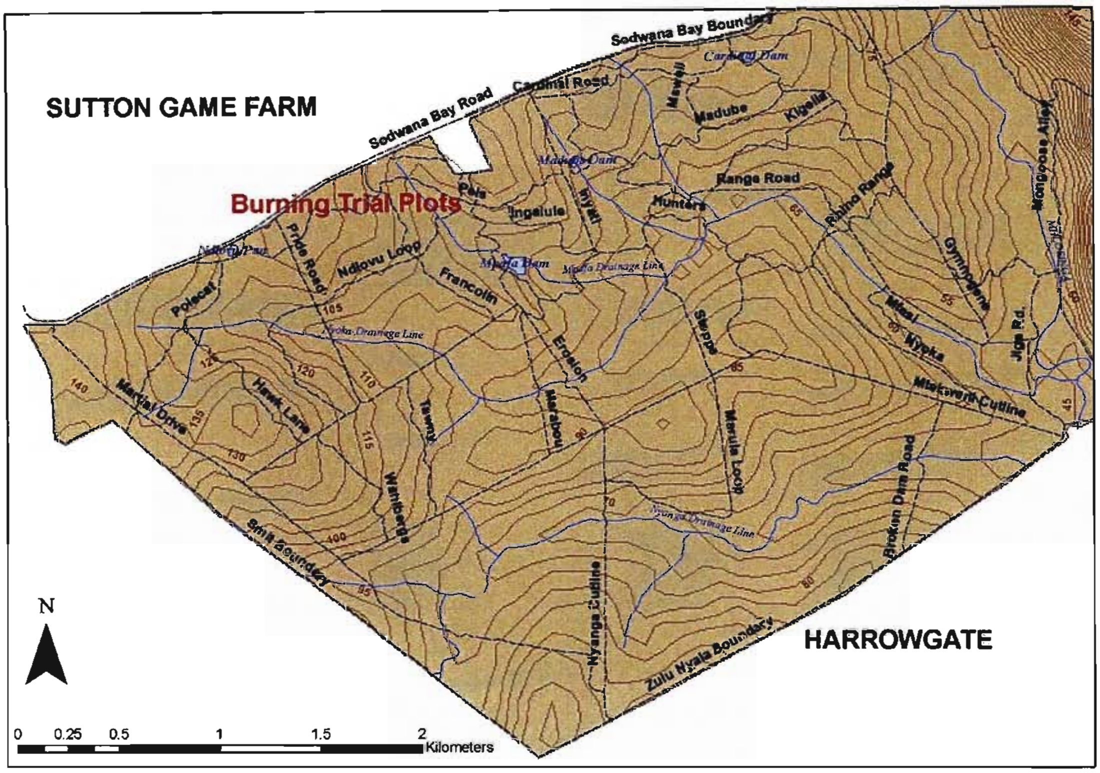
SUTTON GAME FARM
Sodwana Bay Road
Sodwana Bay Boundary
Cardinal Road
Cardinal Dam
Burning Trial Plots
Pels
Ingelule
Inyati
Mawali
Madube
Kigelia
Madube Dam
Range Road
Hunters
Rhino Range
Gymnogene
Mongoose Alley
Pride Road
Ndlovu Loop
Francolin
Mvula Dam
Mvula Drainage Line
Polecat
Nyala Drainage Line
Erosion
Marabou
Steppe
Mkasi
Nyoka
Jigs Rd.
Mkokwerth Cutline
Martial Drive
Hawk Lane
Tawny
Marula Loop
Wahlbergs
Broken Dam Road
Smit Boundary
Nyanga Drainage Line
Nyanga Cutline
Zulu Nyala Boundary
HARROWGATE
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
45
N
0
0.25
0.5
1
1.5
2
Kilometers

Figure 4.1 **Map indicating the location of the Harrowgate Burning Trial Plots**

The burning trial plots were located on the North-western boundary of Harrowgate (Figure 4.1).

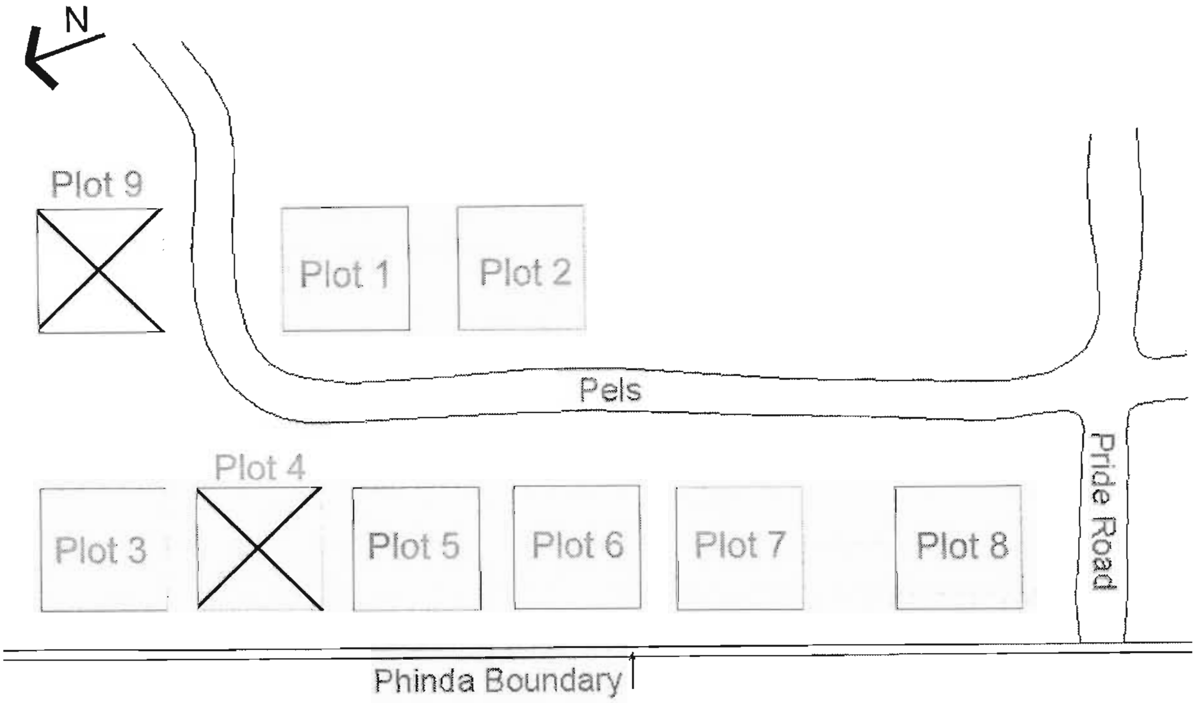

Figure 4.2 **Layout of burning trial plots**

Nine adjacent plots of 50m by 50m were laid out (Figure 4.2). Treatments were allocated so that three plots could be used to test the effects of a head burn, three for the effects of a back burn and three plots were not burnt (controls) (Refer to Appendix 8, for the GPS co-ordinates of the different plots in the burning trials). The burning treatments were applied on the 23 August 2002, during the peak of the dry season. This was done in order to get the highest possible fire intensity. A fire break was cut around the perimeter of each plot using a tractor and slasher, but unfortunately this was not wide enough as two of the three control plots burnt by accident (Plot 4 and Plot 9). The whole area around the plots also burnt, so it was impossible to set up any new control plots. All the plots were located on the northern side of the slope, close to the crest of the hill.

The soils were, as previously mentioned, of the Bonheim and Arcadia form. The vegetation type fell into the Mixed Bushveld (Moll 1980) category, and the main tree species were *Acacia nilotica, Acacia tortillas, Dichrostachys cinerea* and *Ziziphus mucronata*, whilst the common herbaceous species consisted of mainly *Aristida congesta, Bothriochloa insculpta, Brachiaria brizantha, Eragrostis curvula, Eustachys paspaloides, Panicum maximum, Setaria sphacelata* and *Themeda trianda*. The aerial grass cover assessment that was undertaken before burning the plots, revealed the area to have a grass cover just over 70%. The large and medium *C. odorata* plants varied from sparse to medium density. Small *C. odorata* plants had similar densities, but there were patches where they were denser, especially in partially shaded areas under large trees.

### 4.2.1 Grass fuel mass for the permanent plots

The fuel load was estimated using a disc pasture meter (Bransby & Tainton 1977).
Fifty disc pasture readings were taken from the area adjacent to the plots two weeks before the burning trials were done and all the grass matter below the disc was cut using garden shears. Grass samples were taken to cover the whole range of the herbaceous biomass. These grass clippings were then oven-dried at 80 °C for a period of 48 hours and then weighed using an electronic scale (at the Owen Sitholi Agricultural College close to Empangeni). Linear regression analysis was applied with disc pasture meter reading (cm) as the independent variable, and grass dry matter values as the dependent variable.

The following regression equation ($P<0.001$) was calculated from the regression analysis ($R_a^2 = 74.2$).

$$Y = 16.47 + 3.413 (X)$$

Where Y = estimated standing crop (kg/ha)
X = disc height (cm)

Fifty disc pasture readings were then recorded in each of the nine plot samples.
The fuel load estimates were done close to the time of burning because the measurements can vary markedly in the short term (weeks to months) as a result of rainfall and animal utilization (t'Mannetje 1978).

### 4.2.2 *Chromolaena odorata* size-categories

*C. odorata* plants were divided into three categories namely small, medium and large. For each of the three categories the plant height, stem diameter and canopy diameter were recorded for 25 individual plants. These plants were then oven dried for 48 hours at 80 °C to see what their potential fuel biomass was. However, even in case of the small *C. odorata* plants, it was very seldom that anything but the leaves and the stem tips burned during the burning trials. If the seedlings were surrounded by a high grass biomass the stem would sometimes be consumed by the flames. This very seldom happened to medium or large plants. It was decided after the area had been burnt that their overall contribution to the fire intensity had been minimal.

### 4.2.3 Mapping of the plots

Each plot was then subsequently mapped. This was done by further dividing the plots into three strips, with each strip being 17m wide and 50m long. Each one of these strips was then further divided into 8.5m wide by 10m long quadrats, using rope stretched out as straight as possible from one end of the sample plot to the other. Each plot therefore had a total of 30 quadrats. All large, medium and small *C. odorata* plants were recorded, in these 8.5 by 10m quadrats. Thus, the total *C. odorata* densities, in the different sizes, in each of the three strips, could be accurately calculated.

The plots were first mapped in July 2002, they were burnt in the beginning of August 2002; they were then remapped in February 2003 (Time 1) and then finally mapped again in June 2004 (Time 2).

### 4.2.4 Effect of fire and drought on specifically marked *Chromolaena odorata* plants

Wire tags were used to mark 10 large *C. odorata* plants, 10 medium *C. odorata* plants and 18 small *C. odorata* plants, in each plot, to measure the impact of fire on these individual plants. All the plants that were wire tagged occurred only in the open grassland sections and not under 'tree islands'. 'Tree islands' were heavily shaded areas under trees, especially *Euclea divinorum* and *Euclea racemosa* species. The high shading effect prevented grass from growing but led to a large number of *C. odorata* plants, especially seedlings, growing below.

### 4.2.5 Fire intensity

The fire intensity model developed by Trollope & Potgieter (1985) was used to measure fire intensity. The model incorporates fuel load, fuel moisture, relative humidity and wind speed as the factors which will have the greatest influence on the fire intensity.

The model for predicting fire intensity is:

$FI= 2729 + 0.8684\ x1 - 530\sqrt{x2} - 0.1907\ x3^2 - 596\ 1/x4$

Where:

FI = fire intensity – kJ $s^{-1}\ m^{-1}$

x1 = fuel load – kg $ha^{-1}$

x2 = fuel moisture - %

x3 = relative humidity - %

x4 = wind speed – m $s^{-1}$

The following variables were recorded on the day of the burning trials namely:

i) relative humidity (%, with a Psychrometer at the start and end of each burnt plot),
ii) ambient temperature (º C),
iii) wind speed (m $s^{-1}$, with a Casella Wind Meter),
iv) flame height,
v) rate of spread (m $s^{-1}$ time taken for the fire to burn the whole plot),
vi) moisture content of the grass. This was done using ten grass clippings (0.3m by 0.3m quadrats), from each of the permanently marked plots that was going to be burnt. These grass clippings were harvested subjectively choosing only material that appeared as if it would burn readily in a veld fire. Each harvested sample was placed into a honey jar, sealed with Vaseline. The grass in the jars were then weighed back at the Ukulinga Research Farm, University of Natal, Pietermaritzburg both before and after drying them out in an oven for 48 hours at 80 °C.

### 4.2.6 Data analysis

Each plot had three strips (17m wide and 50m long). The *C. odorata* density for small, medium and large plants was recorded in each strip. The *C. odorata* densities were recorded over three different time periods namely, July 2002, February 2003 (Time 1) and then finally in June 2004 (Time 2).

Changes in the *C. odorata* density (also referred to as the *C. odorata* mortality rate) in each strip, over the different time periods, formed the basic measure for performing linear regression and ANOVA in this study.

The *C. odorata* mortality rate, for the different size categories, was determined by how much lower the *C. odorata* density was at Time 1 and Time 2, compared to the original *C. odorata* density in July 2002 for each strip.

The number of large plants in each strip for the different plots was very low, on average only around 5 plants per strip, with some strips having as few as three plants. This made the large plants statistically very sensitive to any slight change in their overall numbers. With such low numbers the validity of the statistical analysis for large plants is questionable, and therefore at best provides only limited insight into what happens to large plants as a whole.

For the valid application of parametric analyses of variance and related parametric procedures certain basic assumptions must be met. First the data must be randomly picked from a normal population (Zar 1996). Second, the sampled populations must have equal variance (homoscedasticity) (Zar 1996). Thirdly, the effects of the factor levels must be additive (Zar 1996). Experience has shown that analyses of variance and t-tests are usually robust enough to perform well even if the data deviates somewhat from the requirements of normality, homoscedasticity and additivity. But severe deviation, especially if the range is great, can lead to spurious conclusions. When data does not conform perfectly with the assumptions, certain 'corrections', known as 'transformations' can be applied to the original data, to allow the data to be more normally distributed, improve homoscedasticity of variance and ensure that the effect of the different factor levels are additive (Zar 1996). The most commonly employed transformations are logarithmic, square root and arcsine (Zar 1996). When the yield or other variate-values observed on experimental units with the same treatment fluctuate violently, or when treatment differences of the order of 100% or more occur (as was the case in this study), variance heterogeneity and non-normality are likely and transformation may be necessary (Rayner 1967).

The measured variable for the experiment, namely mortality (alive or dead) was binomially distributed, and the mortality level ranged from 0 to a 100% for the different plots. Binomial data deviates from normality by often having large values for small or large percentages (0-30% and 70-100%) (Zar 1996), as found in the case of this study. To correct this, the square root of each proportion, in a binomial distribution was transformed to its arcsine, allowing the resultant data to have a distribution that was nearly normal (Zar 1996).

In summary the reasons for doing the arcsin transformation for the analysis of variance, were as follows

1. Data was binomial (dead or alive), therefore angular transformation was applied to help equalize the variance (Zar 1996).
2. Confidence Intervals cannot be greater than 100%, when dealing with mortalities (cannot have more than 100% of the plants dead) (Zar 1996).
3. There was a large range in data (Zar 1996).
4. The difference in treatments exceeded 50% (Zar 1996).
5. The CV in the analysis of variance exceeded 12% (Zar 1996).

#### *4.2.6.1 Regression analysis*

Linear regression analysis (Genstat 7 Committee 2003) was done on fuel mass (x), *C. odorata* mortality (y); *C. odorata* plant size (x), *C. odorata* mortality (y) and Fire Intensity (x), *C. odorata* mortality (y). Although the $r^2$ values were generally quite low, linear regression did provide the best fit for each regression tested.

#### *4.2.6.2 Analysis of variance*

Analysis of variance (Genstat 7 Committee 2003) was used to determine whether any of the following factors, namely: *C. odorata* size (independent variable), Fire type (independent variable) or Time period (dependent variable) had any influence on the arcsin transformed *C. odorata* mortality rates.

Covariance analysis (Genstat 7 Committee 2003), using fuel mass as the covariate, was used to determine whether any of the following factors, namely: *C. odorata* size (independent variable), Fire type (independent variable) or Time (dependent variable) had any significant influence on arcsin transformed *C. odorata* mortality.

## 4.3 Results

### 4.3.1 *Chromolaena odorata* mean plant size for the different size categories.

Table 4.1 **Mean plant height, canopy diameter and stem diameter for *C. odorata* in the different size class categories**

| **Size class** | **Plant Ht (m)** | **Canopy diameter (m)** | **Stem diameter (cm)** |
|---|---|---|---|
| Small | 0.5 ± 0.24 | 0.12 ± 0.09 | 0.51 ± 0.23 |
| Medium | 1.28 ± 0.2 | 0.65 ± 0.29 | 1.44 ± 0.37 |
| Large | 2.12 ± 0.65 | 2.3 ± 0.58 | 11.42 ± 4.65 |

The mean plant height for the small *C. odorata* plants was approximately half a meter, while the canopy diameter was only 12 cm often consisting of only a few leaves. The adult plants, whose height was around 2 m, had a canopy diameter which was on average 2000 % greater than that of the small plants (Table 4.1). The medium plants, whose height was around 1.2 m, had a canopy diameter that was approximately 600 % greater than the small plants.

### 4.3.2 Fuel mass and fire intensity for the different plots

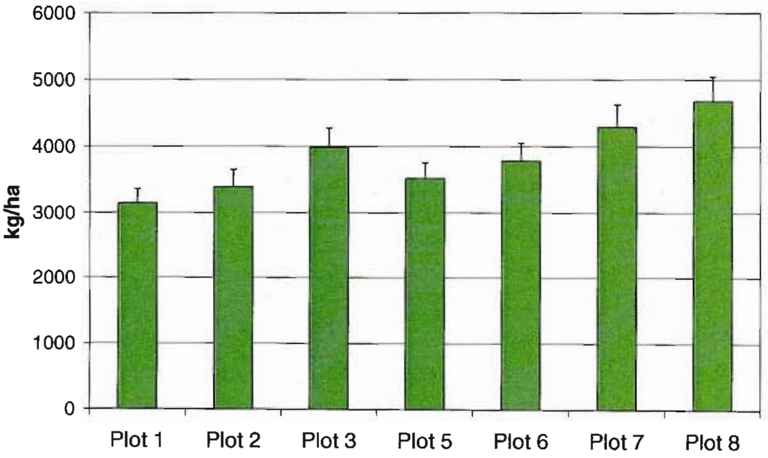

Figure 4.3 **Fuel mass for the different Plots from the burning trial** (error bars represent standard errors of the mean).

Plot 5 was the control plots and was thus not burnt. Plot 1, Plot 3 and Plot 7 were all head burns, whilst Plot 2, Plot 6 and Plot 8 were all back burns (Figure 4.3).

Table 4.2 **Mean values used to calculate the Fire Intensity, for the different plots.**

| Plots | Fire type | Fuel load kg $ha^{-1}$ | s.e. | Wind m $s^{-1}$ | Fuel moisture content (%) | RH % | ROS m $s^{-1}$ | Fire Intensity kJ $s^{-1}$ $m^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| Plot 1 | Head | 3152 | 208 | 1.133 | 46.89 | 69.51 | 0.034 | 390 |
| Plot 2 | Back | 3391 | 263 | 1.197 | 45.5 | 69.51 | 0.013 | 680 |
| Plot 3 | Head | 3985 | 294 | 1.847 | 51.03 | 51.12 | 0.045 | 1582 |
| Plot 5 | Control | 3519 | 239 | | | | | |
| Plot 6 | Back | 3783 | 269 | 2.479 | 54.68 | 53.98 | 0.018 | 1299 |
| Plot 7 | Head | 4291 | 343 | 1.25 | 48.16 | 54.03 | 0.076 | 1743 |
| Plot 8 | Back | 4682 | 367 | 1.13 | 46.46 | 61.5 | 0.017 | 1934 |

The values for fuel mass, rate of spread (ROS), relative humidity, relative fuel moisture and wind speed were all average values for the particular plot. There was considerable variation in the fuel mass between the different plots with Plot 1 (3152 kg $ha^{-1}$) having the lowest fuel mass and Plot 8 (4682 kg $ha^{-1}$) having the highest (Table 4.2). The wind speed did not vary too much, on the day that the plots were burnt, with the lowest speed of 1.13 m $s^{-1}$ being recorded for Plot 8 and the highest of 2.48 m $s^{-1}$ being recorded for Plot 6 (Table 4.2). As was expected the fuel moisture content also did not vary too much as all the samples were taken from the plots on the same day, with the mean fuel moisture content for all the plots being around 48.8 % (Table 4.2). The relative humidity changed during the course of the day, with the plots that were burnt earlier in the day, being more humid than the other plots that were burnt later in the day. The humidity varied from 69.51 % recorded at around 8 am, to 51.12 % recorded at around 12 am.

Mortality rate at Time 1 (February 2003) was taken as the percentage of plants in the respective size categories, during February 2003, compared to the original numbers recorded in July 2002. Mortality rate at Time 2 (June 2004) was taken as the percentage of plants in the respective size categories, during June 2004, compared to the original numbers recorded in July 2002. It was impossible to work out the exact mortality rate of the *C. odorata* plants in the different size categories, because although some of the plants did die, there were also some plants in the smaller size categories that grew into the larger plants and were thus recorded with the large plants. This obviously artificially increased the density of the larger plant size category and conversely decreased the mortality rate of the plants in the smaller size category. Those plants moving up into the next size category left a gap in their original size groups. This caused their original size group numbers to become smaller.

### 4.3.3 Control plots

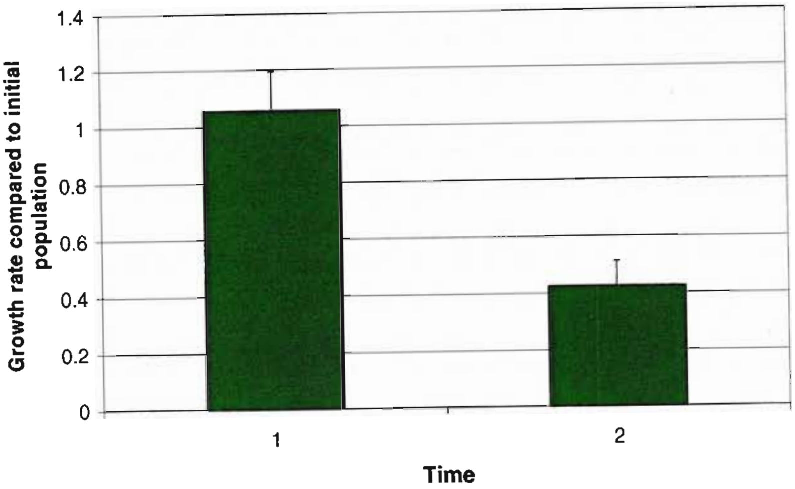

Figure 4.4 **Population growth rate for the small *C. odorata* plants in the control plots** (initial population rate being equal to one) (error bars represent standard errors of the mean).

The average density of small *C. odorata* plants increased by around 6% at Time 1, but by Time 2 the situation had reversed and the overall small *C. odorata* density was only around 42% of that which was initially recorded in the study (Figure 4.4).

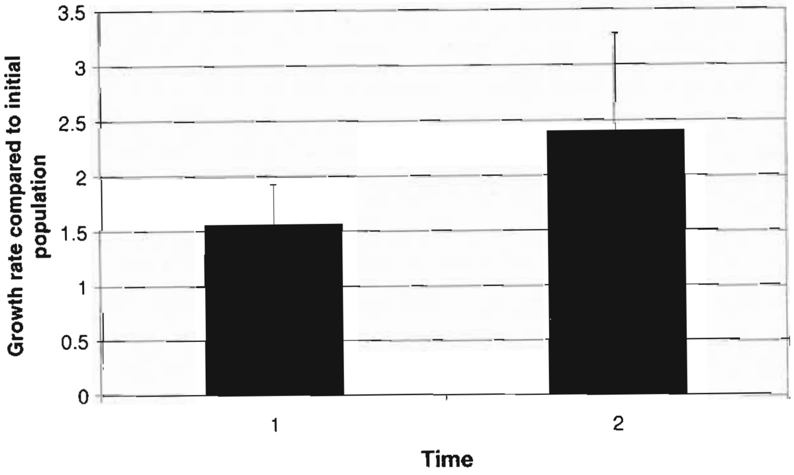

Figure 4.5 **Population growth rate for the medium *C. odorata* plants in the control plots** (initial population rate being equal to one) (error bars represent standard errors of the mean).

Results for the medium *C. odorata* population growth rate showed drastic increases for both time periods. By Time 1 the population had increased by 56% and at Time 2 the overall population had increased by a staggering 140% compared to the original density recorded at the start of the study (Figure 4.5).

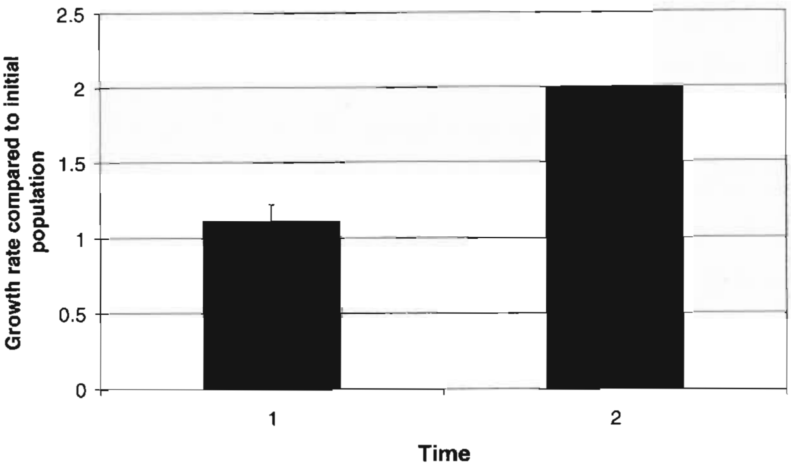

Figure 4.6 **Population growth rate for the large *C. odorata* plants in the control plots** (error bars represent standard errors of the mean).

Similarly to the medium plant the large *C. odorata* plants' population also increased for both time periods. However, at Time 1 the population density had only increased by around 11 %, whereas at Time 2 it had increased by 100% compared to that which was initially recorded in the plots (Figure 4.6).

### 4.3.4 Linear regression for *Chromolaena odorata* mortality rates in the burnt plots

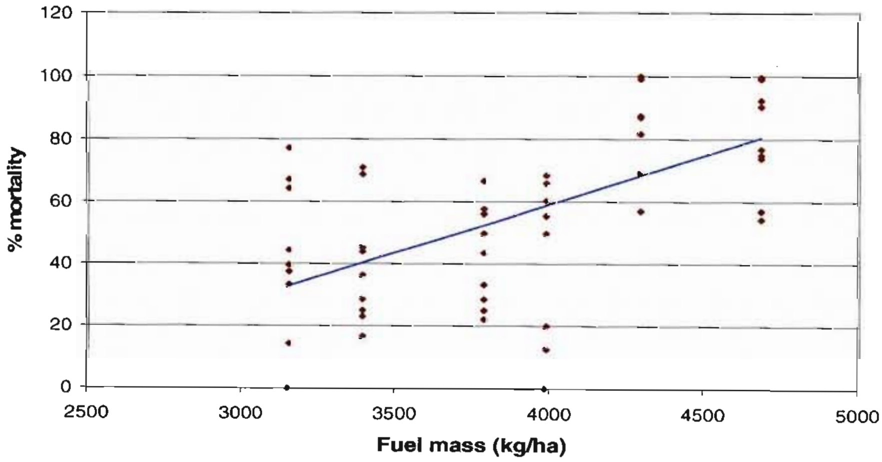

Figure 4.7 ***C. odorata* mortality rate at the different fuel masses for all size categories.** (Plot 1 = 3152 kg ha$^{-1}$, Plot 2 = 3391 kg ha$^{-1}$, Plot 3 = 3985 kg ha$^{-1}$, Plot 6 = 3783 kg ha$^{-1}$, Plot 7 = 4291 kg ha$^{-1}$, Plot 8 = 4682 kg ha$^{-1}$).

An increase in the fuel mass resulted in an increase in *C. odorata* mortality (Figure 4.7). Fuel mass accounted for 33.4 % of the variation.

Table 4.3 **Estimate of the parameter, fuel mass, in the linear regression equation for *C. odorata* mortality rate**

| | Estimate | s.e. | Prob |
|---|---|---|---|
| Constant | -65.2 | 23.2 | 0.007 |
| Fuel | 0.03113 | 0.00593 | <0.001 |

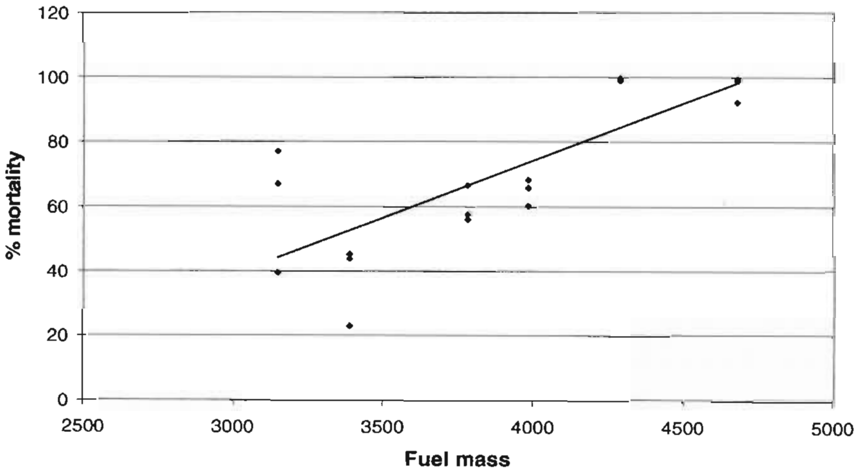

Figure 4.7a **Small *C. odorata* mortality at the different fuel masses**
(Plot 1 = 3152 kg ha$^{-1}$, Plot 2 = 3391 kg ha$^{-1}$, Plot 3 = 3985 kg ha$^{-1}$, Plot 6 = 3783 kg ha$^{-1}$, Plot 7 = 4291 kg ha$^{-1}$, Plot 8 = 4682 kg ha$^{-1}$).

An increase in fuel mass significantly increased the mortality of small *C. odorata* plants (Figure 4.7a). Fuel mass accounted for 58.6 % of the variation for small *C. odorata* mortality.

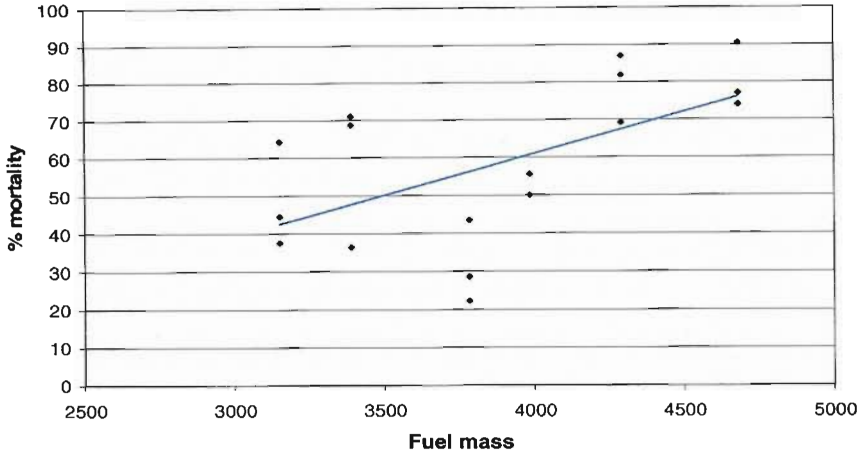

Figure 4.7b **Medium *C. odorata* mortality at the different fuel masses**
(Plot 1 = 3152 kg ha$^{-1}$, Plot 2 = 3391 kg ha$^{-1}$, Plot 3 = 3985 kg ha$^{-1}$, Plot 6 = 3783 kg ha$^{-1}$, Plot 7 = 4291 kg ha$^{-1}$, Plot 8 = 4682 kg ha$^{-1}$).

An increase in fuel mass on the whole caused an increase in medium *C. odorata* plant mortality (Figure 4.7b). The variance accounted for by fuel mass was only 28.4 %, this was the lowest percentage variance accounted for out of all the linear regression equations concerning the effect of fuel mass on *C. odorata* mortalities. Plots 3 and 6 (the intermediate fuel mass plots) played a large part in the low variance accounted for in the linear regression because both plots had lower than expected medium *C. odorata* mortality rates.

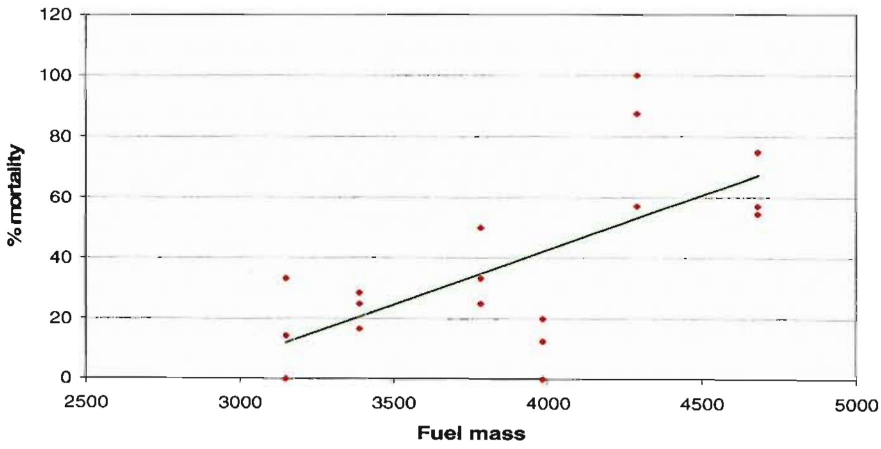

Figure 4.7c **Large *C. odorata* mortality at the different fuel masses**
(Plot 1 = 3152 kg ha$^{-1}$, Plot 2 = 3391 kg ha$^{-1}$, Plot 3 = 3985 kg ha$^{-1}$, Plot 6 = 3783 kg ha$^{-1}$, Plot 7 = 4291 kg ha$^{-1}$, Plot 8 = 4682 kg ha$^{-1}$).

An increase in fuel mass resulted in an increase in large *C. odorata* plant mortality (Figure 4.7c). Fuel mass accounted for 40.9 % of the variation for large *C. odorata* mortality. This figure was surprisingly higher than the medium plant mortality rate, as it was expected that the large plants would have a more inconsistent mortality rate than the medium plants.

Table 4.4 **Estimate of parameters from the linear regression**
(using fuel mass as the explanatory variable, for *C. odorata* mortality, in the different plant size categories).

| | Estimate | s.e. | Prob | % variance accounted for by linear regression ($R_a^2$) |
|---|---|---|---|---|
| Small | | | | 58.6 |
| Constant | -67 | 27.6 | 0.028 | |
| Fuel | 0.035 | 0.007 | <0.001 | |
| | | | | |
| Medium | | | | 28.4 |
| Constant | -26.6 | 30.9 | 0.401 | |
| Fuel | 0.022 | 0.008 | 0.013 | |
| | | | | |
| Large | | | | 40.9 |
| Constant | -102 | 39.6 | 0.02 | |
| Fuel | 0.0362 | 0.01 | 0.003 | |

The percentage variance accounted for in the regression analysis for the effect of fuel mass on the mortality of medium size *C. odorata* plants, was very low (Table 4.4). The reason for this was mainly as a result of the low mortality rates recorded in Plots 3 and 6. The reason for the low mortality rates in these two plots is most likely as a result of the following factors:

1. The relatively low overall density of the medium plants in each of the plots at the start of the survey, which made the data very sensitive to slight changes in the overall densities (Rayner 1967);
2. It was a chance event because of the small number of samples taken in each of the different fuel mass areas.
3. Grass patchiness may have influenced the results. In other words, if the medium plants were found on parts of the plot that had low fuel masses, then their mortality rates would obviously be lower, even if the average fuel mass for the plot was relatively high;

4. The fuel mass for Plots 3 and 6 may have been overestimated, as the tough lignified grass stalks can easily bias readings on a disc pasture meter (Trollope 1980).

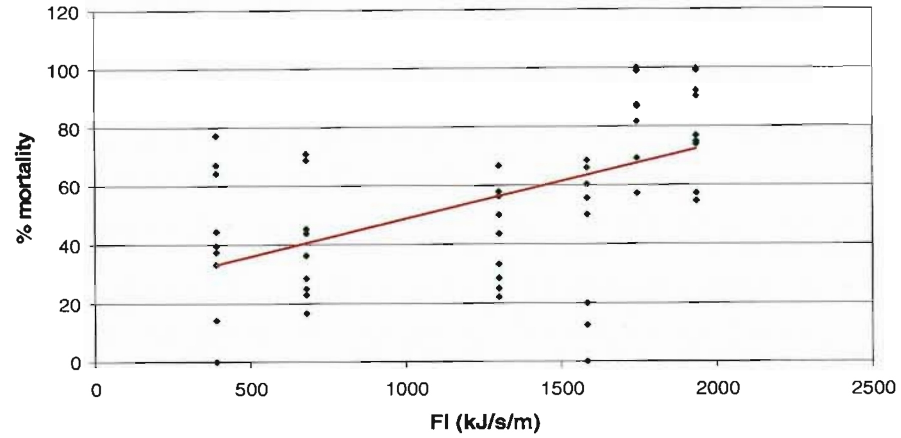

Figure 4.8 ***C. odorata* mortality rate at the different FI for all size categories.**
(Plot 1 = 390 kJ $s^{-1}$ $m^{-1}$, Plot 2 = 680 kJ $s^{-1}$ $m^{-1}$, Plot 3 = 1582 kJ $s^{-1}$ $m^{-1}$, Plot 6 = 1299 kJ $s^{-1}$ $m^{-1}$, Plot 7 = 1743 kJ $s^{-1}$ $m^{-1}$, Plot 8 = 1934 kJ $s^{-1}$ $m^{-1}$)

An increase in FI caused the *C. odorata* mortality rate to increase (Figure 4.8). The variance accounted for by FI, to explain the mortality rate was 25.6 percent. This was suprisingly lower than the variation captured by fuel mass. FI was significant at the 1% level in the regression analysis.

Table 4.5 **Estimate of the parameter, FI, in the linear regression, for estimating the mortality rate of *C. odorata*.**

| | Estimate | s.e. | Prob |
|---|---|---|---|
| Constant | 23.4 | 8.03 | 0.005 |
| FI | 0.02534 | 0.00578 | <0.001 |

Table 4.6 **Estimate of fuel mass required for 80 percent mortality of *C. odorata* plants, using the parameters**
(from the linear regression in Table 4.4).

| Size | fuel (kg ha$^{-1}$) |
|---|---|
| Small | 4161.95 |
| Medium | 4865.36 |
| Large | 5027.62 |

Larger plants required higher fuel masses to achieve similar mortality rates to those of small plants (Table 4.6). The difference between the fuel mass for small and medium plants (703.41 kg ha$^{-1}$) was a lot larger than the difference between the medium and large plants (162.26 kg ha$^{-1}$), thereby highlighting how sensitive small *C. odorata* plants were to fire.

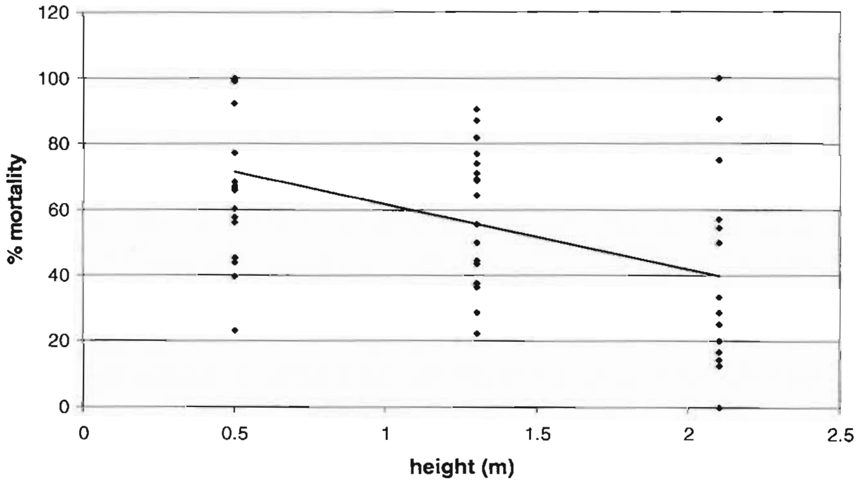

Figure 4.9 ***C. odorata* mortality rate in the different size categories.**

As the plant size increased, so the mortality rate decreased (Figure 4.9), in the burnt plots. Size accounted for 21 % of the variation for *C. odorata* mortality rates. Size was significant at the 1% level of the regression analysis.

Table 4.7 **Estimate of parameter Size on *C. odorata* mortality rate.**

| | Estimate | s.e. | Prob |
|---|---|---|---|
| Constant | 81.42 | 7.43 | <0.001 |
| Size | -19.85 | 5.11 | <0.001 |

## 4.3.5 Analysis of variance for *Chromolaena odorata* mortality rates in the burnt plots

### *4.3.5.1 Analysis of variance using only small, medium and large plants in the burnt plots*

Table 4.8 **Analysis of variance for *C. odorata* mortality**
Factors: plant size (small, medium and large), fire type (head or back) and Time (Time 1 = February 2003 and Time 2 = June 2004).

| Source | d.f. | s.s. | m.s. | v.r. | Prob |
|---|---|---|---|---|---|
| Fire (F) | 1 | 137.1 | 137.1 | 0.21 | 0.645 |
| Size (S) | 2 | 6760.5 | 3380.2 | 5.28 | 0.007 |
| Time (T) | 1 | 324 | 324 | 0.51 | 0.478 |
| F.S | 2 | 441.5 | 220.7 | 0.34 | 0.709 |
| F.T | 1 | 7.6 | 7.6 | 0.01 | 0.913 |
| S.T | 2 | 620.1 | 310 | 0.48 | 0.618 |
| F.S.T | 2 | 314.3 | 157.1 | 0.25 | 0.783 |
| Residual | 96 | 61431.4 | 639.9 | | |
| Total | 107 | 70036.4 | | | |

In the Analysis of variance, *C. odorata* size was the only significant factor, i.e. small plants had different mortality rates to medium and large plants etc. (Table 4.8). There was no significant difference in fire type i.e. head burns had similar mortality rates to back burns, nor was there any significant difference in Time i.e. mortality rates at Time 1 were similar to mortality rates at Time 2 (Table 4.8).

Table 4.9 **Covariance Analysis for *C. odorata* mortality**
Factors: Factors: Plant size (small, medium and large), Fire type (head or back) and Time (Time 1 = February 2003 and Time 2 = June 2004).

Covariate: Fuel

| Source | d.f. | s.s. | m.s. | v.r. | cov. ef. | Prob |
|---|---|---|---|---|---|---|
| Fire (F) | 1 | 1341.9 | 1341.9 | 4.46 | | 0.037 |
| Size (S) | 2 | 6760.5 | 3380.2 | 11.25 | | <0.001 |
| Time (T) | 1 | 324 | 324 | 1.08 | | 0.302 |
| F.S | 2 | 441.5 | 220.7 | 0.73 | | 0.482 |
| F.T | 1 | 7.6 | 7.6 | 0.03 | | 0.874 |
| S.T | 2 | 620.1 | 310 | 1.03 | | 0.360 |
| F.S.T | 2 | 314.3 | 157.1 | 0.52 | | 0.594 |
| Covariate (Fuel) | 1 | 32880.8 | 32880.8 | 109.41 | | <0.001 |
| Residual | 95 | 28550.6 | 300.5 | | 2.13 | |
| Total | 107 | 70036.4 | | | | |

Fuel was highly significant (P<0.001) as a covariate, i.e. it had a significant effect on *C. odorata* mortality (Table 4.9). The difference in size as a treatment effect was increased by using fuel as a covariate. Fuel as a covariate reduced the residual error by an amazing 113%. It even helped in showing a significant difference (at the 5% level) for fire type, i.e. there was a slight increase in mortality rate for a head burn compared to a back burn. Fuel as a covariate failed to show any significant difference between Time 1 and Time 2.

Table 4.10 **De-transformed means from the analysis of variance for *C. odorata* mortality using the covariate Fuel.**

| | | | | |
|---|---|---|---|---|
| Grand mean | Burnt plots | Control | | |
| | 60.56% | 10.45% | | |
| | | | | |
| Fire type | Head | Back | LSD between head and back burn (5%) | Control (Plot 5) |
| | 66.44% | 54.36% | 6.69% | 10.45% |
| | | | | |
| Size | Small | Medium | Large | LSD (5%) |
| Burnt plots | 76.94% | 58.34% | 44.95% | 8.11% |
| Control | 31.36% | 0% | 0% | 4.58% |
| | | | | |
| Time | Time 1 | Time 2 | LSD (5%) | |
| Burnt plots | 57.48% | 63.45% | 6.62% | |
| Control | 1.75% | 19.15% | 3.74% | |
| | | | | |
| Fire | Small | Medium | Large | LSD (5%) |
| Back | 67.1% | 55.4% | 40.29% | 11.49% |
| Head | 85.6% | 61.08% | 49.48% | 11.49% |
| Control | 31.36% | 0% | 0% | 4.58% |
| | | | | |
| Fire | Time1 | Time 2 | LSD (5%) | |
| Back | 51.74% | 56.96% | 9.4% | |
| Head | 63.11% | 69.7% | 9.4% | |
| Control | 1.75% | 19.15% | 3.74% | |
| | | | | |
| Size | Time 1 (Burnt plots) | Time 2 (Burnt plots) | Time 1 (Control) | Time 2 (Control) |
| Small | 76.05% | 77.96% | 5.26% | 57.46% |
| Medium | 59.2% | 57.47% | 0% | 0% |
| Large | 36.22% | 53.66% | 0% | 0% |
| LSD (5%) | 11.47% | 11.47% | 6.47% | 6.47% |

The overall mortality for all the burnt plots was 60.56%, which was considerably higher than in the control which was only 10.45% (Table 4.10). There was a significant difference in mortality rate between the different size categories from the burnt plots (Table 4.10). Head burns had a slightly higher mortality rate than back burns, in all the different size categories (Table 4.10). Small plants mortality rate, increased only slightly in the burnt plots between Time 1 and

Time 2; medium plants mortality rate decreased slightly by Time 2, in the burnt plots; and large plants mortality rate increase drastically, in the burnt plots, by Time 2 (Table 4.10).

There was considerable variation (for *C. odorata* mortality rates) between the different strips in the same plot, for each plant size categories. This large variation caused the standard error around the mean to also be very high. Some of the plots' mean *C. odorata* mortality rates (for a particular size category) deviated from the general trend, for example, the mortality rate for large *C. odorata* plants in Plot 3 (3985 kg $ha^{-1}$) was very low (only 10.83%) (Figure 4.12), as was the mortality rate for the medium *C. odorata* plants (only 31.42%) in Plot 6 (3783 kg $ha^{-1}$) (Figure 4.11). The following factors may have been responsible for these deviations, namely:

1. Each plot had different initial *C. odorata* densities;
2. As mentioned before many of the strips had very low, large or medium *C. odorata* densities. Large plants had on average around 5 plants per strip initially, and some of the strips had as little as 3 plants. These low numbers made the data very sensitive to small changes in *C. odorata* mortalities, and could easily cause the data to be biased due to chance events (Rayner 1967);
3. There were patches found in the different plots that had considerably lower grass fuel loads, than what was recorded as the average for that particular plot. If plants occurred in these patches, then they would obviously have been less affected by the fire.
4. There was often a lot less grass around the large *C. odorata* plants than around the small *C. odorata* plants. These lower fuel mass around the large plant would cause the fire intensity to be lower, and therefore bias the mortality rate for these large plants.

#### *4.3.5.2 Analysis of variance using only small and medium plants in the burnt plots*

As mentioned before, large plants occurred at very low densities in the different strips for all the plots, with some plots having as few as three plants. This caused the mortality or population growth rate, to be very susceptible to a slight increase or decrease in numbers. With such low numbers the validity of the statistical analysis for large plants is questionable. Analysis of variance was therefore repeated with just using small and medium plants. Another point of interest is the rate at which plants can grow into the different size categories, as it obviously takes less time for a small plant to grow into the medium size plant, compared to the length of time that it takes for a medium plant to grow into the large size category. This will cause a larger influx of plants into the medium size category, from the small plants, than out of the medium size category, namely medium plants growing into large plants.

Table 4.11 **Analysis of variance for *C. odorata* mortality**
Factors: Plant size (small and medium), Fire type (head or back) and Time (Time 1 = February 2003 and Time 2 = June 2004).

| Source | d.f. | s.s. | m.s. | v.r. | Prob |
|---|---|---|---|---|---|
| Fire (F) | 1 | 177.7 | 177.7 | 0.34 | 0.56 |
| Size (S) | 1 | 1 | 2397.6 | 2397.6 | 0.035 |
| Time (T) | 1 | 0.4 | 0.4 | 0.00 | 0.978 |
| F.S | 1 | 398.8 | 398.8 | 0.77 | 0.384 |
| F.T | 1 | 50.5 | 50.5 | 0.1 | 0.756 |
| S.T | 1 | 26.2 | 26.2 | 0.05 | 0.823 |
| F.S.T | 1 | 51.2 | 51.2 | 0.1 | 0.754 |
| Residual | 64 | 33189.9 | 518.6 | | |
| Total | 71 | 36292.2 | | | |

No significant effect could be detected for fire type or time. But size showed up significant at the 5% level (Table 4.11), indicating that medium plants had a lower mortality rate than small plants, (for any particular fuel mass). There was also no significant first order interaction or second order interaction that could be detected.

Table 4.12 **Covariance Analysis for *C. odorata* mortality**
Factors: Factors: Plant size (small and medium), Fire type (head or back) and Time (Time 1 = February 2003 and Time 2 = June 2004).
Covariate: Fuel

| Source | d.f. | s.s. | m.s. | v.r. | Cov.ef. | Prob |
|---|---|---|---|---|---|---|
| Fire (F) | 1 | 986 | 986 | 3.93 | | 0.052 |
| Size (S) | 1 | 2397.6 | 2397.6 | 9.55 | | <0.003 |
| Time (T) | 1 | 0.4 | 0.4 | 0.00 | | 0.969 |
| F.S | 1 | 398.8 | 398.8 | 1.59 | | 0.212 |
| F.T | 1 | 50.5 | 50.5 | 0.2 | | 0.655 |
| S.T | 1 | 26.2 | 26.2 | 0.10 | | 0.748 |
| F.S.T | 1 | 51.2 | 51.2 | 0.20 | | 0.653 |
| Covariate (Fuel) | 1 | 17371.9 | 17371.9 | 69.19 | | <0.001 |
| Residual | 63 | 15817.9 | 251.1 | | 2.07 | |
| Total | 71 | 36292.2 | | | | |

Once again, fuel was highly significant as a covariate (P<0.001), i.e. it had a very significant effect on the *C. odorata* mortality (Table 4.12). Fuel as a covariate reduced the residual error by 107%. The difference in size as a treatment effect was increased considerably by using fuel as a covariate. Fuel also almost managed to show a significant difference at the 5 % level for fire type but failed to show any significant difference for time or any interaction between the factors (Table 4.12).

Table 4.13 **De-transformed means from the analysis of variance for *C. odorata* mortality using the covariate Fuel.**

| Grand mean | Burnt plots | Control | | |
|---|---|---|---|---|
| | 68.08% | 15.68% | | |
| | | | | |
| Fire type | Head | Back | LSD between head and back burn (5%) | Control (Plot 5) |
| | 73.93% | 61.76% | 7.54% | 15.68% |
| | | | | |
| Size | Small | Medium | LSD (5%) | |
| Burnt plots | 76.94% | 58.34% | 7.46% | |
| Control | 31.36% | 0% | 5.93% | |
| | | | | |
| Time | Time 1 | Time 2 | LSD (5%) | |
| Burnt plots | 67.92% | 68.08% | 7.46 | |
| Control | 2.63% | 28.73% | 5.93% | |
| | | | | |
| Fire | Small | Medium | LSD (5%) | |
| Back | 67.43% | 55.92% | 10.59% | |
| Head | 85.23% | 60.74% | 10.59% | |
| Control | 31.36% | 0% | 5.93% | |
| | | | | |
| Fire | Time1 | Time 2 | LSD (5%) | |
| Back | 60.22% | 63.28% | 10.59% | |
| Head | 75.15% | 72.7% | 10.59% | |
| Control | 2.63% | 28.75% | 5.93% | |
| | | | | |
| Size | Time 1 (Burnt plots) | Time 2 (Burnt plots) | Time 1 (Control) | Time 2 (Control) |
| Small | 76.05% | 77.96% | 5.26% | 57.46% |
| Medium | 59.2% | 57.47% | 0% | 0% |
| LSD (5%) | 10.55% | 10.55% | 8.39% | 8.39% |

The mean mortality rate for the burnt plots was 68.08% whereas the mean mortality rate in the control plot was only 15.68% (Table 4.13). The difference between the control and the burnt plots was obvious and significant at the 1% level. The least difference between the control and the burnt plots was recorded at Time 2 for the small plants, where the control had a 57.46% mortality rate and the burnt plots had a 77.96% mortality rate. Once again head burns had a higher mortality rate than back burns in all cases (Table 4.13). Small plants had higher mortality rates than medium plants in all cases. No mortality was recorded for medium plants in the control plot at Time 1. By Time 2 the overall population of medium plants in the control plot was actually larger than the initial number recorded at the start of the survey.

### 4.3.6 *Chromolaena odorata* population trends over time

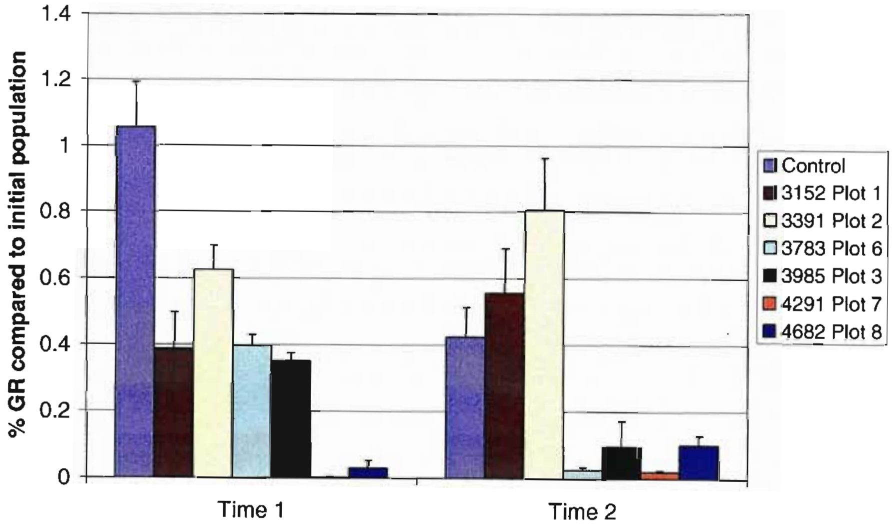

Figure 4.10 **Small *C. odorata* population growth rate at different fuel masses (kg ha$^{-1}$)** (error bars represent standard errors of the mean).

Plots with low fuel mass e.g. Plot 1 (3152 kg ha$^{-1}$) and Plot 2 (3391 kg ha$^{-1}$) actually had an increase in *C. odorata* numbers from Time 1 to Time 2 (Figure 4.10). At Time 1 only 38.68% of the initial number of small plants, recorded at the start of the survey in Plot 1, remained alive. By Time 2 this number had increased to 55.66%. For Plot 2, only 62.57 % of the small plants remained alive by Time 1, this number increased to 80.54 % by Time 2. The control plot had an initial increase of 5.61% by Time 1 but then drastically decreased to 43.54% of the initial number, by Time 2. Small *C. odorata* plants in plots that had a fuel masses greater than 3783 kg ha$^{-1}$ experienced drastic decreases in numbers for both Time 1 and Time 2, with virtually no plants left by Time 2 in any of these plots. There was very little seedling recruitment taking place in areas that had a fuel mass higher than 3783 kg ha$^{-1}$ (Figure 4.10)

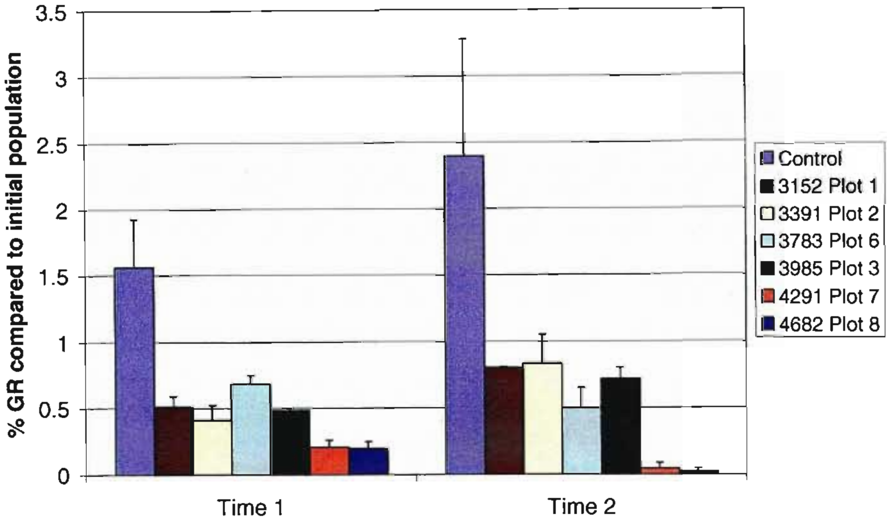

Figure 4.11 **Medium *C. odorata* population growth rate (GR) at different fuel masses (kg ha$^{-1}$)**
(error bars represent standard errors of the mean).

Medium plants in the control plot kept on increasing in numbers, for both time periods. By Time 1 the control plot had increased by 55.95 % and by Time 2 up to 139.8% compared to the initial number recorded at the start of the survey (Figure 4.11). The trend for the medium plants in the burnt plots was similar to that of the small plants (Figure 4.11), except that a lot higher FI was required to achieve the same mortality rate as in the small plants. Plots with a fuel mass of up to 3985 kg ha$^{-1}$, only had around 50 % mortality. Plot 6 (3783 kg ha$^{-1}$) had an exceptionally low mortality rate at Time 1 of only 31.42%. This low mortality rate was very much against the general trend. But by Time 2 the population in Plot 6 continued to decrease slowly, whereas in Plot 3 (3985 kg ha$^{-1}$) the medium plants continued to increase in numbers. As soon as the fuel mass exceeded 4291 kg ha$^{-1}$ there was a drastic decrease in medium plant numbers which continued to decrease drastically by Time 2.

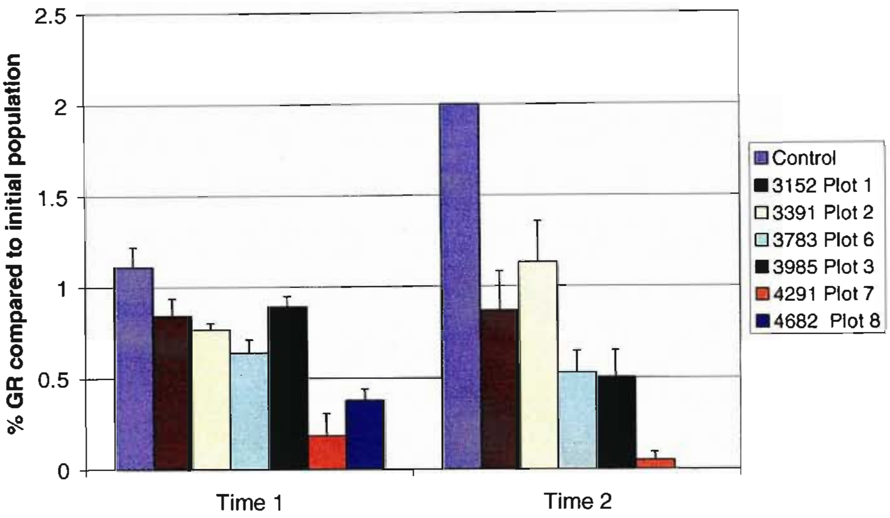

Figure 4.12 **Large *C. odorata* population growth rate (GR) at the different fuel masses (kg ha$^{-1}$)**
(error bars represent standard errors of the mean).

There was a very similar pattern between the medium *C. odorata* population growth rate (Figure 4.11), and the large *C. odorata* population growth rate (Figure 4.12). The control plot showed that the large plants had a slight increase in numbers by Time 1 and a drastic 100% increase in numbers by Time 2. It also showed, once again, that only fuel masses above 4291 kg ha$^{-1}$ were able to almost completely eliminate the large plants by Time 2. The low FI in Plot 1 and Plot 2 had very little effect in killing the plants, and by Time 2 the plants in Plot 2 were actually above the original numbers recorded at the start of the survey. The *C. odorata* mortalities at Time 1 for fuel masses lower than 4291 kg ha$^{-1}$ were a lot lower than what was recorded for medium plants. Large plants in the plots with fuel masses of 3783 (Plot 6) and 3985 kg ha$^{-1}$ (Plot 3) continued to decrease, although their mortality rates were not as drastic as those recorded in the plots with higher fire intenisities. In Plot 8 (4682 kg ha$^{-1}$), all of the large plants had died out.

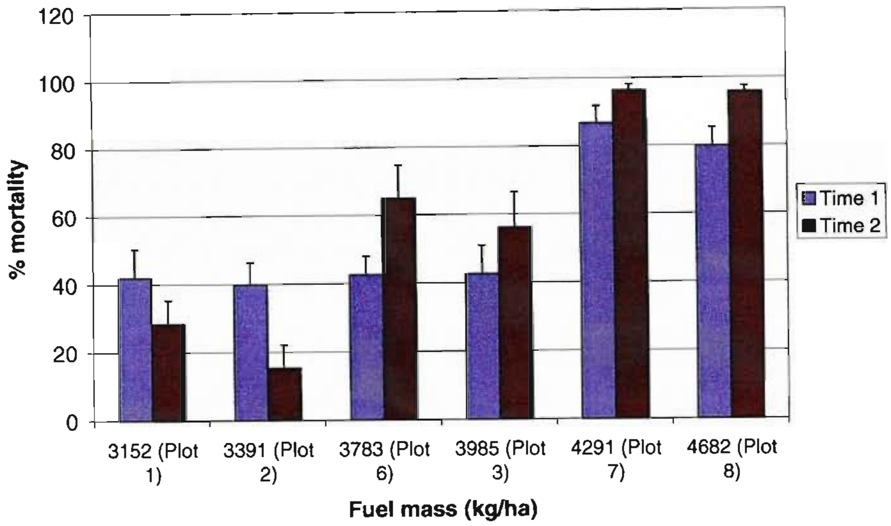

Figure 4.13 **Average *C. odorata* mortality for all size categories combined, at the different fuel masses**
(error bars represent standard errors of the mean).

Plots with low fuel loads, e.g. Plots 1 and 2, actually had a lower *C. odorata* mortality rate by Time 2 (Figure 4.13). In all the other plots, the overall mortality rate increased by Time 2 (Figure 4.13).

### 4.3.7 Wire tagged plants

It was of interest to investigate what happened to specifically marked plants in both the burnt and control plots over time. However, finding the tagged plants in June 2004 (Time 2) proved to be very difficult as the long grass concealed many of the wire tags for the small and medium plants. Some of the tags had also been pushed over or pulled out by animals. Live *C. odorata* plants were easy to spot because the green *C. odorata* stood out from the tan coloured grass. Even the small plants were easy to spot. On the other hand dead *C. odorata* plants, especially small and medium plants, were very hard to spot in the tawny coloured grass. Special emphasis was thus placed on looking for wire tags close to any of these live *C. odorata* plants. It was assumed, that if the tags had not been kicked out or pulled out by animals that all the tags that were un-recovered were mostly from dead plants hidden in the long grass.

The main differences between the wire-marked plants and the overall mortality rate in the different plots were:

1. Wire-marked plants were not affected by smaller plants growing into their size category (i.e. medium plants growing into large plants by Time 2, which would decrease the overall mortality rate of large *C. odorata* plants);

2. Wire tags were always placed on plants that were surrounded by fuel mass that closely resembled the average fuel mass for that plot (this meant that wire-tagged plants were better indicators than the mortality rates for all the plants in the plot).

Table 4.14 **Wire tags recovered at the different time periods**

| July 02 | Large | Large dead | Medium | Medium dead | Small | Small dead |
|---|---|---|---|---|---|---|
| Plot 1 | 10 | | 10 | | 18 | |
| Plot 2 | 10 | | 10 | | 18 | |
| Plot 3 | 10 | | 10 | | 18 | |
| Plot 5 | 10 | | 10 | | 18 | |
| Plot 6 | 10 | | 10 | | 18 | |
| Plot 7 | 10 | | 10 | | 18 | |
| Plot 8 | 10 | | 10 | | 18 | |
| | | | | | | |
| Feb 03 | | | | | | |
| Plot 1 | 6 | 4 | 3 | 7 | 3 | 15 |
| Plot 2 | 9 | 1 | 2 | 8 | 6 | 12 |
| Plot 3 | 8 | 2 | 6 | 4 | 1 | 17 |
| Plot 5 | 10 | 0 | 10 | 0 | 16 | 2 |
| Plot 6 | 4 | 6 | 0 | 10 | 2 | 16 |
| Plot 7 | 0 | 10 | 1 | 9 | 0 | 18 |
| Plot 8 | 5 | 5 | 1 | 9 | 0 | 18 |
| | | | | | | |
| June 04 | | | | | | |
| Plot 1 | 1 | 2 | | | | 7 |
| Plot 2 | 6 | 2 | 4 | 3 | | 3 |
| Plot 3 | 3 | 4 | 1 | 5 | 2 | 8 |
| Plot 5 | 6 | 1 | 5 | 2 | 4 | 3 |
| Plot 6 | 3 | 2 | 1 | 1 | | 3 |
| Plot 7 | | 3 | | 8 | | 7 |
| Plot 8 | | 5 | | 5 | | 13 |

#### *4.3.7.1 February 2003 (Time 1)*

Plot 1 (head burn, relatively low fuel mass)

60% of the large plants, 30% of the medium plants and only 16.66 % of the small plants had survived (Table 4.14).

Plot 2 (back burn, relatively low fuel mass)

90% of the large plants, 20% of the medium plants and 33.33% of the small plants had survived (Table 4.14).

Plot 3 (head burn, medium fuel mass)

80% of the large plants, 60% of the medium plants and 5.55 % of the small plants had survived (Table 4.14).

Plots 5 (control Munyawana Game Reserve)

100% of the large plants, 100% of the medium plants and 88.88% of the small plants had survived (Table 4.14).

Plots 6 (back burn, medium fuel mass)

40% of the large plants, 0% of the medium plants and 11.11 % of the small plants had survived (Table 4.14).

Plot 7 (head burn at relatively high fuel mass)

0% of the large plants, 10 % of medium plants and 0% of the small plants had survived (Table 4.14).

Plot 8 (back burn at relatively high fuel mass)

50% of the large plants, 10% of the medium plants and 0% of the small plants had survived (Table 4.14).

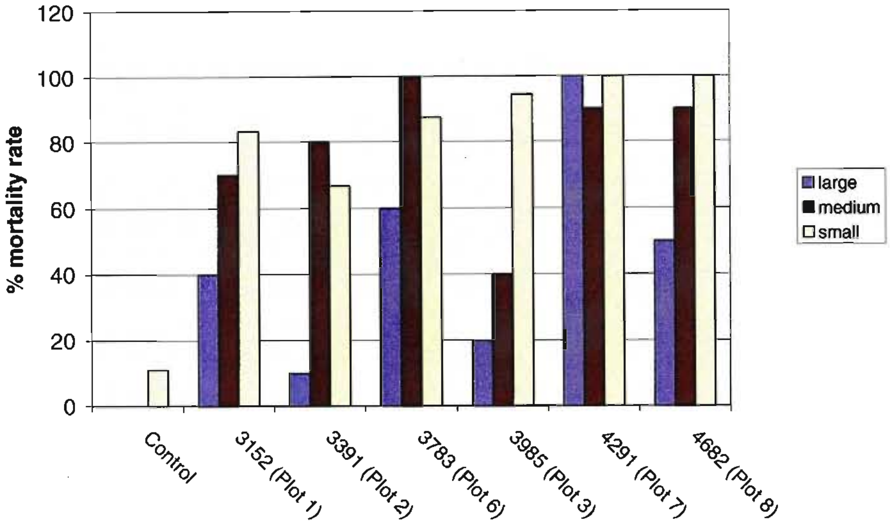

Figure 4.14 **Mortality rate of wire marked *C. odorata* plants in the different size categories at February 2003 (Time 1)**
(error bars represent standard errors of the mean).

There was a definite correlation between fuel mass and *C. odorata* mortality, with an increase in fuel mass causing an increase in *C. odorata* mortality (Figure 4.14). The correlation between fuel mass and large *C. odorata* plants was 0.623, between fuel mass and medium *C. odorata* plants 0.828 and between fuel mass and small *C. odorata* plants 0.974. Plot 3 differed slightly from the other plots, with very low mortality rates that were recorded for its medium and large plants (Figure 4.14). This could indicate that the predicted fuel mass for Plot 3 may have been overestimated

### *4.3.7.2 June 2004 (Time 2)*

Plot 1 (head burn, relatively low fuel mass)

For the large plants only three wire tags were recovered, two of which were from dead plants. No wire tags could be found for medium plants and only seven tags were recovered for small plants, all of which were on dead plants (Table 4.14).

Plot 2 (back burn, relatively low fuel mass)

For the large plants only eight tags were recovered, two of which were on dead plants. Seven tags were also recorded for medium plants, of which three were from dead plants. Only three tags were recovered for small plants, all of which were on dead plants (Table 4.14).

Plot 3 (head burn, medium fuel mass)

For the large plants seven tags were recovered, of which four were on dead plants. Six tags were recovered for the medium plants, of which five were taken from dead plants. Ten tags were recovered for the small plants, of which eight were from dead plants (Table 4.14).

Plot 5

For the large plants seven tags were recovered, with only one coming from a dead plant. Seven tags were recovered from medium plants, with two coming from dead plants. Only seven tags were recovered for small plants, with three coming from dead plants (Table 4.14).

Plot 6

For the large plants five tags were recovered, with two of them coming from dead plants. Only two tags were recovered for medium plants, with one being alive and the other dead. Three tags were found for small plants, all them coming from dead plants (Table 4.14).

For Plot 7 and Plot 8 all tags recovered in the different size categories came from dead plants (Table 4.14).

## 4.4 Discussion

### 4.4.1 Control plots

By February 2003 (Time 1), the small plant density had increased slightly, but by June 2004 (Time 2) it had decreased drastically by almost 50%. The decrease in small plants at Time 2 was probably as a result of a combination of the four following factors:

1. Many of the small plants died due to the extended drought;
2. Some were "lost" in the form of growing into medium plants;
3. Although not proven, small *C. odorata* plants probably battled to compete with grasses. Competition between species will increase during a drought situation (Burrows 1990).
4. Few *C. odorata* seeds germinated, due to the lack of moisture in the soil, as a result of the drought (Erasmus 1985).

Medium plant density increased slightly by February 2003 (Time 1) and continued to do so by June 2004 (Time 2). Large plants had a slight increase in plant numbers by February 2003 (Time 1), followed by a large increase in numbers for June 2004 (Time 2). The increase in medium plant density was higher than the increase in large plant density. The main reason for this is that it takes longer for a medium-sized plant to grow into a large plant, compared to the length of time required for a small plant to grow into a medium-sized plant, even though, per ratio, each individual medium-sized plant had a higher chance of surviving and growing into a large plant compared to the chances of each individual small plant surviving and growing into a medium-sized plant. However, the sheer quantity of small plants available, would overall have allowed for more plants to grow into the medium-size category than into the large-size category.

It must be remembered that the number of large plants at the start of the survey was very low only nine plants in Plot 5. With such low numbers, the results are obviously a lot less reliable, as a slight change in plant numbers had a large effect on the population's growth rate (Rayner 1967, Zar 1996). These low numbers also made the results very vulnerable to chance events. Grass probably had a lot less influence on a large *C. odorata* plants compared to the small or medium plants.

The results from the control plot for medium and large plants were very alarming, showing increases for both time periods. A large proportion of the small plants also managed to survive the drought, with some of them even actively growing into medium plants.

Although large and medium plants showed an overall increase in the population, results from the wire-tagged plants and from general observation whilst walking around the plot did reveal that some of these plants had succumbed to the drought, although it was significantly less (at the one percent level) than those in the plots that had been burnt.

### 4.4.2 Burnt plots

Overall fire was found to be a very effective tool in helping land managers to control *C. odorata* infestations. Results from this study indicated highly significant long term changes in plant density between the control and the burnt plots.The percentage variance accounted for by FI to explain the mortality rate for all size categories was 25.6 % (Figure 4.8), which was surprisingly lower than the variance accounted for by fuel mass (which was 33.4%) (Figure 4.7). FI should have explained the mortality rate better, as it was made up of many variables, and thus should have more accurately explained the amount of heat given off by the fire (Trollope & Potgieter 1985). The amount of heat produced would ultimately determine the *C. odorata* mortality rate. This highlights how difficult it is to derive an accurate universal equation to predict the heat given off by a fire in an open grasslands or savanna veld. Fuel mass was a highly significant factor (P = 0.001) in determining *C. odorata* mortality, with higher fuel masses having higher mortality rates.

The percentage variance accounted for by size in explaining the mortality rate, was, surprisingly, very low. This was probably as a result of a higher than anticipated proportion of large plants dying in the higher fuel mass plots (Figure 4.9). Another reason for the low percentage variance accounted for by size is from the poor mortality rate for medium plants in Plots 3 and 6 (Figure 4.7b). Nonetheless size was found to be a significant factor (P = 0.001) in determining *C. odorata* mortality, with larger plants having lower mortality rates than small plants.

A very high fuel mass was required to achieve a mortality level of over 80%, for any of the size categories (Table 4.6). FI is worked out from fuel mass, fuel moisture content, relative humidity and wind speed (Trollope & Potgieter 1985). Thus, if the fuel mass was not high enough, the same FI could be achieved either by waiting for one or a combination of the following conditions to take place, namely that the fuel moisture content drops, the relative humidity drops or that the wind speed increases(Trollope & Potgieter 1985). The fuel mass required to achieve 80% mortality in medium plants, was suspected of being a gross overestimate due to the unusually low mortality rates achieved in Plots 3 and 6, thereby lowering the slope of the trend line considerably. Plot 7 (4291 kg $ha^{-1}$) and Plot 8 (4682 kg $ha^{-1}$) support this argument as they both had mortality rates close to 80%.

The fuel mass values from Table 4.6 were incredibly high, especially for large plants (over 5000 kg ha$^{-1}$). This shows just how hot a fire will have to be in order to get 80% mortality on large plants. Yet, if an extended drought follows shortly after the burn, then the fuel mass required to achieve an 80% mortality rate, will be considerably lower.

The Covariance analysis (Table 4.9 and Table 4.12) showed that there was no significant change in the mortality rates between February 2003 (Time 1) and June 2004 (Time 2), implying that the mortality rate did not really change over time for the burnt plots. One factor, which may have influenced the results somewhat, is the fact that some plants which were recorded dead at Time 1, were actually still alive (plants that were pulled out had moist roots). However, many of these plants that were incorrectly recorded dead by Time 1 were so badly damaged by the fire, that they could not survive the extended drought, and were definitely dead by Time 2. This highlights the fact that plants which are badly damaged by a fire are more susceptible to droughts than plants that are not damaged. Many of the large and medium plants from the control plot (plot not burnt), or those plants from the burnt plots, that only had a low fuel mass, managed to survive by Time 2. On the whole, in the burnt plots, there were very few plants that grew into new size categories, especially in the higher fuel mass areas. Many of the small plants in the burnt plots, died because they could not cope with the extended drought.

The reason for small plants only having a slight increase in mortality rate by Time 2, in the burnt plots, is probably as a result of the number small plants remaining fairly stable. Small plants in Plots 1 and 2 remained stable, because even though a fair number of seedlings germinated, they also "lost" some plants which grew into the medium size category and other plants which died due to the extended drought. The higher fire intensity plots' mortality rates remained fairly stable, because they lost most of their small plants already by Time 1, and had very few new seedlings which emerged (Figure 4.10).

The low seedling recruitment that took place in the plots that had a fuel mass higher than 3783 kg ha$^{-1}$, could indicate that fires hotter than 1299 kJ s$^{-1}$ m$^{-1}$ were responsible for destroying a large proportion of the available seeds lying on or near the ground surface. This could possibly be one of the reasons why Plots 1 and 2 had more seedlings germinating than the other burnt plots.

It was very strange that the small plants in the control suffered a higher mortality rate than those in Plots 1 and 2. One possible explanation for this was that fire stunted the growth of the small plants in Plots 1 and 2, thereby preventing them from growing into the medium size category. In comparison, many small plants in the control were not affected by fire, and therefore could grow unhindered into medium-sized plants. The higher mortality rate of small plants in the control was thus mainly as a result of the plants growing into the next size group, rather than them actually dying out.

Medium plants' mortality rate in the burnt plots decreased slightly, by Time 2, due to some of the small plants in Plots 1 and 2 growing into medium plants, and thereby increasing the overall population rate, as well as some of the plants which appeared dead at Time 1, actually managing to coppice and survive, especially in the lower fire intensity plots, for example medium plants in Plot 3 (Figure 4.11). However, results for the medium plants in the burnt plots appeared very promising when compared to the control plots, especially in plots with fuel masses higher than 4291 kg ha$^{-1}$. This is because the few plants that did survive the fire by Time 1 were so badly damaged, that by Time 2 they had definitely perished.

At Time 1, the large plant mortality rate was far lower than that of the medium plants (Figure 4.11 and Figure 4.12). The drought had little effect on the large plants, in areas where the fires intensity was less than 680 kJ s$^{-1}$ m$^{-1}$. Plot 2 actually showed an overall increase in density compared to the initial population numbers, indicating that very few of the initial large plants had died, and that some of the medium plants where actually able to grow into large plants. However, large plants decreased drastically in the burnt plots by Time 2, because most of the plants completely died out in the higher fire intensity plots. Another reason for the drastic decrease by Time 2 was the fact that although some of the medium plants grew into large plants by Time 2 in the lower fire intensity plots, the actual numbers that did manage to do so were very low, because it took a lot longer for a plant to grow from a medium to a large-size category than it did for small plants to grow into a medium-size ones. It was of great interest to see that with high FI (over 1743 kJ s$^{-1}$ m$^{-1}$) large *C. odorata* plants suffered great losses from fire alone, and, if a drought followed the fire, it was possible to control large plants with fire alone.

When large plants were left out of the Covariance, the difference between the treatments (fire type, plant size and time) was less obvious (Table 4.12). The main reason for this was that both small and medium plants had very high mortality rates in plots with high fuel masses for both Time 1 and 2. This made it difficult to distinguish between the effect of fire on small and medium plants.

Although a difference at the 5 % level for "fire type" could be detected in the covariance analysis (co-variate = fuel mass) (Table 4.9), i.e. a head burns will cause a higher *C. odorata* mortality rate than a back burn in an areas with a uniform fuel mass. Nonetheless the overall difference between head and back burns in the covariance analysis was not highly significant, due to the fact that both head and back burns have their advantages and disadvantages in destroying *C. odorata*. Back burns, for example, burn a plant for a longer period of time. The heat from a back burn is concentrated a lot closer to the ground than in a head burn, meaning that back burns will have a greater effect on the meristematic part of the stem (Trollope 1980). These factors account for the main reasons why a back burn does severe damage to plants. However, head burns produce higher FI than back burns under the same environmental conditions, but most of this heat is found a lot higher off the ground than in the case of a back burn, and thus only does damage to the aerial parts of the plants, leaving the roots and lower stems unharmed (Trollope 1978). Head burns also move through an area a lot more quickly than back burns, thereby minimizing the time which a fire can actually do damage to a plant (Trollope 1978).

From the overall growth rate of *C. odorata* (all size categories included) (Figure 4.13), it can be seen that plots with low fuel masses were actually increasing by Time 2. In other words, new seedlings were germinating, some of the small plants were growing into medium plants, and some medium plants were growing into large ones. However, once the fuel mass exceeded 3783 kg $ha^{-1}$, the mortality rate started to increase over time. Thus, plants that had survived by Time 1 were so badly damaged by the fire that they could not survive the extended drought period, and were dying. There is a good possibility that if good rains had followed shortly after the fire, that many of the plants, especially those in the medium and large size categories, would have survived by Time 2.

### 4.4.3 Wire tagged plants

Data from February 2003 (Time 1) showed that there was a good correlation between fuel mass and the mortality of the wire-marked plants in the different size categories. The small size category had the highest correlation, followed by medium and, lastly, the large plants (Figure 4.13). There was no mortality recorded for any of the large *C. odorata* plants at Time 1 in the control plot.

For Time 1, it was difficult to say which of the plants had definitely died, as not all of them had started to coppice. This was highlighted by the fact that when other plants in the plots, which also appeared dead, were pulled out, that their roots were still moist, indicating that the plant was still alive, and thus had a chance of recovering. By June 2004 (Time 2) there was no doubt about the status of the plants. There were a few instances where plants which were recorded dead at Time 1 were found to actually be alive at Time 2. These plants had thus coppiced after Time 1. Examples include medium plants in Plots 2 and 6 and small plants in Plot 3. Plot 2 medium plants had an 80% mortality rate at Time 1 and only a 60% mortality rate by Time 2. Plot 6 medium plants had a 100% mortality rate at Time 1 and only a 90% mortality rate at Time 2. Plot 3 small plants had a 94.44% mortality rate at Time 1 and only had an 88.88% mortality rate at Time 2.

However, even if the mortality rate had decreased by Time 2, which was the exception rather than the rule, it always decreased only slightly. Summed up, most of the plants that were recorded dead at Time 1 were definitely dead at Time 2. Dead plants were determined on the basis of two factors: no leaves present on the plants and scraping on the stem, close to ground level. If the scrapings revealed that the stems were dry, then the plant could be considered dead. As mentioned previously, many of the wire tags could not be recovered at Time 2, and thus, it was difficult to draw any fixed conclusions for this time period, except from the tags that were recovered.

It was interesting that at Time 1 some of the small plants in the control plot (around 10% of the small plants) had already succumbed to the drought, while none of the medium or large plants had perished in the control plot (Figure 4.14). By Time 2 some of the medium plants in the control plots were definitely dead, including a small percentage of the large plants.

Overall, areas with higher fuel masses had very few live plants that could be found, and the few that were found, were checked thoroughly for any wire tags. It could thus be said with relative confidence that if the tags had not been removed by animals, then there was a good chance that the plants had actually died. The mortality rates at Time 2 for the wire marked plants in the burnt plots was a lot higher than at Time 1. Highlighting how plants which are damaged by fire are a lot more sensitive and likely to perish during an extended drought.

## 4.5 Conclusions

Only the small plants in the control plots showed a decrease in the population growth rate by Time 2, while the medium and large plants in the control plots both had an overall increase in plant density by the end of the study (Time 2). Results from the wire tagged plants did reveal that that some large and medium plants in the control plots had perised. Smaller plants in the control plots had a higher mortality rate than the larger plants. It is thought that competition from grasses and the drought were the main factors for causing *C. odorata* plants to die in the control plot.

It is suspected that if there had been more replications, there would have been a more clearly defined relationship between fuel mass and *C. odorata* mortality. The larger the plant, the higher the fuel mass required to kill the plant. Results from this study suggest that to achieve 80% mortality, the following fuel masses are recommended: for small plants a fuel mass of over 4000 kg ha$^{-1}$; for medium plants a fuel mass of over 4200 kg ha$^{-1}$; and for large plants a fuel mass of over 4600 kg ha$^{-1}$. However, by considering other environmental variables, such as lower relative humidity, lower fuel moisture content and higher wind speeds, it is possible to achieve the same fire intensity at slightly lower fuel masses. Large plants were less sensitive to fire than small plants, but nevertheless, they were affected by fire. Once fire exceeded a certain heat intensity, then even large *C. odorata* plants died. Many plants, especially smaller ones, that survived the fire initially, were so badly damaged that they died during the drought.

The number of large plants that could recover after a fire is debatable. Judging from personal observations in other areas that had also been burnt, the mortality of large plants in the experimental site was far higher than what was initially hoped for, and it is thought that the extended drought played a significant role in this. However, the high fuel loads that are required to achieve these high fire intensities are often not available. Under these circumstances it may be better to chop out all the large plants, and treat their stumps with herbicide before burning the area. Killing large plants will prevent seeds from being scattered all over the area. Luckily, large plants are easy to spot, especially in winter when the green leaves often stand out in stark contrast to the surrounding beige-coloured vegetation (Refer to Appendix 9 for more information on applying an effective integrated alien plant control (IAPC) programme.

Overall, there was very little difference between head and back burns, with both types having their advantages and disadvantages in killing *C. odorata*. When burning management blocks, back burns are often found to take too long to complete, and, thus, head burns are preferred. Back burns often cannot jump across bare or low fuel load patches, thereby preventing the fire from burning the whole block. This will allows *C. odorata* to continue to flourish and spread in these unburnt patches and thus it is recommended to use a head burn to eradicate *C. odorata*. Overall fuel mass seems to play a lot more of a significant role than fire type in causing *C. odorata* mortality.

The Control plot revealed alarming results where population growth rate of medium and large plants completely deviated from the burnt plot trends by having a drastic increase in numbers. This was found to be especially true in the case of the medium plants, even though the area was at the time experiencing a severe drought. This highlights the fact that even during a drought, the overall population of the medium and large plants will still able to increase in numbers.

The wire-marked plants had very similar mortality trends when compared to the rest of the *C. odorata* population in the different plots, with higher fuel masses having greater mortality rates. The wire-marked plants definitely experienced an increase in mortality rate by Time 2, especially in areas with a higher fuel mass.

Results from this study show that fire applied as a once off treatment does appear to have a long term effect on the *C. odorata* population, especially when in combination with a drought.

# References

Acocks JPH 1975. Veld Types of South Africa. Memoirs of the Botanical Survey of South Africa No. 40. Botanical Research Institute, Department of Agriculture Technical Services, South Africa.

Adamson RS 1938. The vegetation of South Africa. Whitefriars Press Ltd. London.

Akobundu IO (ed.) 1987. Weed science in the tropics, principles and practices. New York: John Wiley & Sons.

Alpert P, Bone E & Holzapfel C (2000) Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. Perspectives in Plant Ecology, Evolution and Systematics 3:52-66.

Anon 1990. Visitors guide, Mkuze Game Reserve. Pietermaritzburg: Natal Parks Board.

Ambika SR & Jayachandra 1990. The problem of Chromolaena weed. *Chromolaena odorata* Newsletter 3:1-8.

Bergelson J & Perry R 1989. Interspecific competition between seeds: relative planting date and density affect seedling emergence. Ecology 70:1639-1644.

Blackmore AC 1993. The occurrence and dispersal of *Chromolaena odorata* (L.) R.M. King & H. Robinson within selected areas of the Greater St Lucia. Natal Parks Board research project plan.

Bray SG, Cahill L, Paton CJ, Bahnisch L & Silcock R 1998. Can cattle spread giant rat's tail seed (*Sporobolus pyramidalis*) in their faeces. Proceeding of the Australian Society of Agronomy, [online]. Available from: http://www.regional.org.au/au/asa/1998/6/030bray.htm [12/11/2005].

Bransby DI & Tainton NM 1977. The disc pasture meter: possible applications in grazing management. Proceedings of the Grassland Society of Southern Africa. 5: 115-118.

Brown AA & Davis KP 1973. Forest fire: control and use. McGraw Hill Book Co., New York.

Bruton MN and Haacke WD 1980. The reptiles of Maputaland. In: Bruton MN and Cooper KH (Eds.). Studies on the Ecology of Maputaland. Rhodes University and the Wildlife Society of Southern Africa.

Burrows CJ (ed.) 1990. Process of vegetation change. London: Unwin Hyman.

Byers JE 2000. Competition between two estuarine snails: implications for invasion of exotic species. Ecology 81:1225-1239.

Byford-Jones C 1979. Triffids invade Natal. Farmer's weekly, November 14, 7-8.

Byram GM 1959. Combustion of forest fuels. In: Forest fire control and use. K P Davis (ed). McGraw Hill Book Company, New York.

Campbell JAE 1991. *Chromolaena odorata* in the Mkuzi Game Reserve with emphasis on seed rain dynamics. Natal Parks Board unpublished Report.

Chandler C, Cheney P, Thomas P, Traubad L & Williams D 1983. Fire in forestry. Forest fire management and organization. Wiley, New York.

Cronk QCB & Fuller JL 1995. Plant invaders. London: Chapman & Hall.

Cruttwell RE 1991. The ecology of Chromolaena odorata in the neotropics. Ecology and Management of *Chromolaena odorata*, Biotropical Special Publication 44: 1-7.

D'Antonio CM 1993. Mechanisms controlling invasion of coastal plant communities by the alien succulent *Carpobrotus edulis*. Ecology 74:83-95.

Daubenmire R 1968. Plant communities. New York. Harper & Row.

Digby PGN & Kempton RA 1987. Multivariate analysis of ecological communities. Chapman and Hall. pp15-26.

Dufrene M & Legendre P 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monograph 67: 345-366.

Egberink J. & Pickworth G 1969. *Eupatorium odoratum*: A thorny problem. Farming in South Africa 45: 25-29.

Erasmus DJ 1985. Achene biology and the chemical control of *Chromolaena odorata*. PhD Thesis, University of Natal, Pietermaritzburg.

Erasmus DJ 1991. Reclamation of coastal forest infested with *Chromolaena odorata* (triffid weed) Unpublished proceedings Meeting Rangeland Challenges in South Africa in the 1990's. Pretoria: Department of Agriculture.

Everson CS & Clarke GPY 1987. A comparison of six methods of botanical analysis in the montane grasslands of Natal. Vegetatio 73: 47-51.

Everson CS, George WJ & Schulze RE 1989. Fire effects on canopy cover and sediment yield in the montane grasslands of Natal. South African Journal of Science 85: 113-116.

Ferrar AA & Kruger FJ 1983. South African programme for the SCOPE project on the ecology of biological invasions. South African National Scientific Programme Report No. 72. CSIR, Pretoria.

Fowler NL 1984. The role of germination date, spatial arrangement, and neighbourhood effects in competitive interactions in Linum. Journal of Ecology 72:307-318.

GENSTAT (2003) *Genstat 7.1 Reference manual.* VSN international, Oxford, UK.

Goldberg DE, Turkington R, Olsvig-Whittaker L & Dyer AR 2001. Density dependence in an annual plant community: variation among life history stages. Ecological Monographs 71:423-446.

Goodman PS 1981. A preliminary summary of the climatic features of Mkuzi Game Reserve. Unpublished Natal Parks Board report, Pietermaritzburg.

Goodall JM 2000. Monitoring serial changes in coastal grasslands invaded by *Chromolaena odorata* (L.) R.M. King & Robinson. MSc Thesis, University of Natal, Pietermaritzburg.

Goodall JM & Erasmus DJ 1996. Review status and the integrated control of the invasive alien weed, Chromolaena odorata, in South Africa. Agriculture, Ecosystem & Environment 56:151-164.

Greig-Smith 1965. Notes on the quantitative description of humid tropical forest. pp 227-234. In symposium on ecological research in humid tropical vegetation, Kuching.

Greig-Smith P 1983. Quantitative plant ecology Third edition. Alden Press, Oxford pp 193-201.

Grobler H, Vermeulen JB, Dryer M, Van Zyl K 1996. A guide to the use of herbicides. National Department of Agriculture. Republic of South Africa.

Hall JB, Kumar R & Enti AA 1972. The obnoxious weed *Eupatorium odoratum* (Compositae) in Ghana. Ghana Journal of Agricultural Science 5:75-78.

Hager HA 2004. Competitive effect versus competitive response of invasive and native wetland plant species. Oecologia 139:140-149.

Hanson HC (ed.) 1961. The plant community. New York: Reinhold Publishing Corporation.

Henderson L 1989. Invasive alien woody plants of Natal and the north-eastern Orange Free State. Bothalia 19: 237-261.

Hill TA 1977. The biology of weeds. Studies in Biology No.79. Edward Arnold, Southampton.

Hoffmann JH & Moran VC 1998. The population dynamics of an introduced tree, *Sesbania punicea*, in South Africa, in response to long-term damage caused by different combinations of three biological control agents. Oecologia 114: 343-348.

Holme LG, Plucknett DL, Plancho JV & Herberger JP 1977. The world's worst weeds. Honolulu, University of Hawaii press: pp 609.

Holzner W & Numata M 1982. (eds.) Biology and Ecology of Weeds. Dr. W. Junk, The Hague.

Howard TG & Goldberg DE (2001). Competitive response hierarchies for germination, growth and survival and their influence on abundance. Ecology 82:979-990.

Huffaker CB, Simmonds FJ & Laing JE 1976. The theoretical and empirical basis of biological control. In: Theory and practice of biological control (eds.: Huffaker CB & Messenger PS) New York: Academic Press: 41-78.

Ikuenobe CE & Ayeni AO 1998. Herbicide control of *Chromolaena odorata* in oil palm. Weed Research Volume 38 (6) pp. 397.

Ivens GW 1974. The problem of *Eupatorium odoratum* L. in Nigeria. PANS 20: 76-82.

Ivens GW 1975. Studies on *Imperata cylindrical* (L.) Beauv. and *Eupatorium odoratum* L.. Technical Report No. 37 of the Weed Research Organisation, Begbroke Hill, Yarnton, Oxford.

Joubert DC 1984. The soil seed bank under Nasella Tussock infestations at Boschberg. South African Journal of Plant and Soil 1: 1-3.

Klein H 2002. Weeds, alien plants and invasive plants. Weed biocontrol. ARC-Plant Protection Research Institute. Pretoria 11: 1-4.

Klingman GC & Ashton FM 1982. Weed Science: Principles and Practices. 2nd Ed. John Wiley and Sons, New York.

Kluge RL 1983. Water Hyacinth. In: Plant invaders: Beautiful but dangerous (ed.: Stirton CH). Department of Nature and Environmental Conservation of the Cape Provincial Administration, Cape Town. pp 68-71.

Kluge RL 1990. Prospects for the biological control of triffid weed, *Chromolaena odorata* in Southern Africa. South African Journal of Science 86: 229-230.

Knoch K & Schulze A 1957. Niederschlag, und schwule in Afrika. World atlas of Epidemic Diseases. Vol. 2. Heidelberger Akademie der Wissenschaften, Heidelberg.

Kruger FJ 1983. Cluster pine. In: Plant invaders: Beautiful but dangerous (ed.: Stirton CH). Department of Nature and Environmental Conservation of the Cape Provincial Administration, Cape Town. pp. 124-127.

Legendre P & Gallagher ED 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129: 271-280.

Liggitt B 1983. Biology, ecology and control of the weed *Chromolaena odorata*. Unpublished report, Institute of Natural Resources, University of Natal, Pietermaritzburg.

Luke RH & McArthur AG 1978. Bush fires in Australia. Australian Government Publishing Service, Canberra.

MacDonald IAW 1983. Alien trees, shrubs and creepers invading indigenous vegetation in the Hluhluwe-Umfolozi Game Reserve complex in Natal. Bothalia 14: 949-959.

MacDonald IAW 1984. Infiltration of dreaded weed alarms experts. Custos 13, 33-35.

MacDonald IAW & Jarman ML 1984. Invasive Alien Organisms in Terrestrial Ecosystems of the Fynbos Biome, South Africa. South African National Scientific Programmes Report No. 85. Graphics Art Division of the CSIR, Pretoria.

MacDonalds IAW & Richardson D 1986. Alien Species in Terrestrial Ecosystems of the Fynbos Biome. In: Biological invasion in southern Africa (eds.: MacDonald IAW. Kruger FJ & Ferrar AA). Cape Town: Oxford University Press: 77-91.

MacDougall AS & Turkington R 2004. Relative importance of suppression-based and tolerance-based competition in an invaded oak savanna. Journal of Ecology, 92: 422-434.

MacVicar CN 1991. Soil classification: A taxonomic system for South Africa. Department of Agricultural Development. Pretoria.

MacVicar CN, De Villiers JM, Loxton RF, Verster E, Lambrechts JJN, Merryweather FR, Roux J Le, Van Rooyen TH and Haremse HJ Von M 1977. Soil classification. A binomial system for South Africa. Department of Agricultural Technical Services, Republic of South Africa.

Mccune B & Mefford MJ 1999. PC-Ord, Multivariate analysis of ecological data, Version 4. MjM Software Design, Gleneden Beach, Oregon USA.

McLachlan GR and Liversidge R 1978. Roberts Birds of South Africa. John Voelcker Bird Book Fund, Cape Town.

Mentis MT 1984. Monitoring in South African Grasslands. South African National Scientific Programmes Report No. 91, Council for Scientific and Industrial Research-Foundation for Research Development, Pretoria. pp 55.

Moll EJ 1980. Terrestrial Plant Ecology. In: Bruton MN and Cooper KH (Eds.) . Studies on the Ecology of Maputuland. Rhodes University and the Wildlife Society of Southern Africa.

Moll EJ & White F 1978. The Indian Ocean Coastal Belt. In: Werger MJA (Ed.) Biogeography and Ecology of Southern Africa. W. Junk. Publishers, The Hague.

Moni NS & George MP 1959. *Eupatorium odoratum* - a common weed found in the teak plantations of Kerala State. Indian Forester 85: 728-730

Mueller-Dombis D 1973. A non-adaptive vegetation interferes with water removal in a tropical forest area in Hawaii. Tropical Ecology 14: 1-16.

Mueller-Dombis D & Ellenberg H 1974. Aims and methods of vegetation ecology. John Wiley & Sons. New York.

Myers JH & Bazley DR 2003 Ecology and control of introduced plants. Cambridge University Press, Cambridge.

Neser S 1984. Theories on why only some introduced plants become ‘aggressive’ weeds. Proceedings of the Sixth National Weed Conference of South Africa, 2. Abstract.

Neser S & Fugler SR 1983. Silky hakea. In: Plant invaders: Beautiful but dangerous (ed.: Stirton CH). Department of Nature and Environmental Conservation of the Cape Provincial Administration, Cape Town. pp 76-79.

Oka H-I & Morishima H. 1982 Ecological genetics and the evaluation of weeds. In: Biology and Ecology of Weeds (eds. Holzner W & Numata M). Dr. W, Junk, The Hague. pp. 73-89.

Pickworth G 1976. Triffid weed (*Eupatorium odor*atum). An address to the Lower Tugela Farmers Soil Conservation Committee. Unpublished report.

Pooley AC 1965. A preliminary checklist of the reptiles found within Ndumu and Mkuzi Game Reserve in northern Zululand . Lammergeyer.

Poynton JC 1980. The amphibia of Maputaland . In Bruton MN and Cooper KH (Eds.). Studies on the Ecology of Maputaland. In Rhodes University and the Wildlife Society of Southern Africa.

Rai SN 1976. *Eupatorium* and weedicides. Indian Forester102: 449-454.

Rayner AA 1967. A first course in Biometry for agriculture students. University of Natal Press. Pietermaritzburg.

Ross JH 1972. Flora of Natal. Memoirs of the Botanical Survey of South Africa No. 39. Botanical Research Institute. Government Printer, Pretoria.

Sagar GR & Harper JL 1961. Controlled interference with natural populations of *Plantago lanceolata, P. major* and *P. media.* Weed Research 1: 163-176.

Sajise PE, Pallis RK, Norico NV & Lales JS 1974. The biology of *Chromolaena odorata* (L.) R.M. King and H. Robinson. I. Flowering behaviour, pattern of growth and nitrate metabolism. Philippine Weed Science. Bulletin 1:17-24.

Schulze BR 1947. The climates of South Africa according to the classification of Köppen and Thornthwaite. South African Geographical Journal 29: 32-42.

Schulze BR 1965. Climate of South Africa Part 8, General Survey. South African Weather Bureau. Government Printers, Pretoria.

Sheldrik RD 1968. The control of siam weed (*Eupatorium odoratum* L.). Journal of the Nigerian Institute for Oil Palm Research 5: 7-19.

Slaats J 1995. *Chromolaena odorata* fallow in food cropping system: an agronomic assessment in South-West Ivory Coast. Unpublished PhD Thesis, Wageningen Agricultural University.

Smith AD 1944. A study of the reliability of range vegetation estimates. Ecology 25: 441-448.

Stephens RJ 1982. Theory and practice of weed control. Macmillan Press, London.

Stirton CH 1983. Why are plant invaders successful? In: Plant Invaders: Beautiful but dangerous. Department of Nature and Environmental Conservation of the Cape Provincial Administration, Cape Town. pp. 36-37.

Tainton NM 1999. Veld management in South Africa. University of Natal Press. Pietermaritzburg.

Tainton NM, Bransby DI & Booysen P deV 1976. Common Veld and Pasture Grasses of Natal. Shuter and Shooter. Pietermaritzburg.

ter Braak & Smilauer P 1998. CANOCO Reference Manual and User's guide to Canoco for Windows: Software for Canonical Community Ordination (version 4). New York: Ithaca.

Thompson K, Hodgson JG, Grime JP & Burke MJW (2001) Plant traits and temporal scale: evidence from a 5-year invasion experiment using native species. Journal of Ecology 89: 1054-1060.

t' Mannetje L (ed.) 1978. Measurement of grassland vegetation and animal production. Commonwealth Bureau of Pasture and Field Crops. Berkshire, England.

Todd A. 1980. Aspects of the biology of *Chromolaena odorata* (L.) R.M. King and H. Robinson. Botany Honours Project, University of Durban-Westville, Durban.

Trollope WSW 1978. Fire behaviour – a preliminary study. Proceedings of the Grassland Society of Southern Africa. 13: 123-128.

Trollope WSW 1979. Ecological effects on fire in South African savannas. Proc. Sympos. Dynamic Changes in Savanna Ecosystems.

Trollope WSW 1980. Controlling bush encroachment with fire in the savanna areas of South Africa. Proceedings of the Grassland Society of Southern Africa. 15: 173-177.

Trollope WSW 1983. Control of bush encroachment with fire in the arid savannas of south-eastern Africa. PhD thesis, University of Natal, Pietermaritzburg.

Trollope WSW & Potgieter ALF 1985. Fire Behaviour in the Kruger National Park. Journal of the Grassland Society of Southern Africa. 2 (2): 17-22.

van Gils H, Delfino J, Rugege D & Janssen L 2004. Efficacy of *Chromolaena odorata* control in a South African conservation forest. South African Journal of Science 100: 251-253.

van Oudtshoorn 1992. Guide to grasses of South Africa. Briza publikasies Cc. National Book Printers, Cape Town.

Versveld DB, le Maitre DC & Chapman RA 1998. Alien invading plants and water resources in South Africa: a preliminary assessment. Report to the Water Research Commission, CSIR Division of Water, Environment & Forestry Technology, Stellenbosch.

Wager VA 1947. Kan Roes die braam uitroei? Farming in South Africa 22: 831-832.

Weerakoon L 1972. Studies on the biology and control of *Eupatorium odoratum* L. MSc thesis, Vidyodaya Campus, University of Ceylon.

Wells MJ 1983. Nassella Tussock. In: Plant invaders: Beautiful but dangerous (ed Stirtin CH) Department of Nature and Environmental Conservation of the Cape Provincial Administration. Cape Town. pp. 140-143.

Werger MJA and Coetzee 1978. In: Werger MJA (Ed.). (1978). Biogeography and Ecology of Southern Africa. W. Junk, The Hague.

White F 1976. The vegetation map of Africa: the history of a completed project. Boissiera 24: 659-666.

Wilson M 1995. Autoecology of the invasive alien plant, *Chromolaena odorata*, in the Greater St Lucia Wetland Park, Unpublished MSc Thesis, University of the Witwatersrand.

Zachariades C, Strathie-Korrubel LW & Kluge RL 1999. The South African programme on the biological control of *Chromolaena odorata* (L.) King & Robinson (Asteraceae) using insects. In: Biological control of weeds in South Africa (1990-1998) (eds.: Olckers T & Hill MP). African Entomology Memoir 1: 89-102.

Zachariades C & Goodal M 2004. Distribution, impact and management of *Chromolaena odorata* in southern Africa. Proceedings of the fifth international workshop on the biological control and management of *Chromolaena odorata*. Durban, South Africa.

Zar JH 1996. Biostatistical analysis 3rd ed. Pentice-Hall. New Jersey.

Zimmermann HG 1983. Imbricate cactus. In: Plant invaders: Beautiful but dangerous (ed. Stritin CH). Department of Nature and Environmental Conservation of the Cape Provincial Administration, Cape Town. pp 116-119.

# Appendices

## Appendix 1 List of mammals on the Munyawana Game Reserve

| | | |
|---|---|---|
| Aardvark | *Orycteropus afer* | rare |
| Baboon | *Chacma papioanubis* | common |
| Buffalo | *Syncerus caffer* | 65 |
| Bushbaby, Greater | *Otelemur crassicaudatus* | common |
| Bushbuck | *Tragelaphus scriptus* | rare |
| Bushpig | *Potamochoerus larvatus* | uncommon |
| Canerat, Greater | *Thryonomys swinderianus* | uncommon |
| Cheetah | *Acinonyx jubatus* | 15 |
| Duiker, Grey | *Sylvicapra grimmia* | common |
| Duiker, Red | *Cephalophus natalensis* | common |
| Elephant, African | *Loxodonta africana* | 80 |
| Genet, Large-spotted | *Genetta tigrina* | common |
| Giraffe | *Giraffa camelopardalis* | 45 |
| Hare, Scrub | *Lepus saxatilis (crawshayi)* | uncommon |
| Hippopotamus | *Hippopotamus amphibicus* | 3 |
| Honey Badger | *Mellivora capensis* | rare |
| Hyaena, Brown | *Hyaena brunnea* | very rare (1 introduced in 2000) |
| Hyaena, Spotted | *Crocuta crocuta* | uncommon |
| Impala | *Aepyceros melampus* | approximately 800 |
| Jackal, Black-backed | *Canis mesomelas* | rare |
| Jackal, Side-striped | *Canis adustus* | rare |
| Kudu, Greater | *Tragelaphus strepsiceros* | uncommon |
| Leopard | *Panthera pardus* | 15 |
| Lion | *Panthera leo* | 15 |
| Mongoose, Banded | *Mungos mungo* | uncommon |

| | | |
|---|---|---|
| Mongoose, Water | *Atilax paludinosus* | rare |
| Mongoose Slender | *Herpestes sanguinea* | rare |
| Mongoose, White-tailed | *Ichneumia albicauda* | uncommon |
| Monkey, Vervet | *Cercopithecus aethiops* | common |
| Nyala | *Tragelaphus angasi* | approximately 1500 |
| Polecat, Striped | *Ictonyx striatus* | rare |
| Porcupine | *Hystrix africaeaustralis* | uncommon |
| Reedbuck, Common | *Redunca arundinum* | uncommon |
| Rhinoceros, Black | *Biceros bicornis* | 14 |
| Rhinoceros, White | *Ceratotherium simum* | 50 |
| Serval | *Felis serval* | rare |
| Squirrel, Tonga Red | *Paraxerus palliates* | uncommon |
| Suni | *Neotragus moschatus* | rare |
| Waterbuck | *Kobus ellipsiprymnus* | 10 |
| Warthog | *Phacochoerus africanus* | common |
| Wildebeest, Blue | *Connochaetes taurinus* | 430 |
| Zebra, Burchell's | *Equus quagga* | 320 |

## Appendix 2:Key for the climates of South Africa according to the classification of Köppen (Schulze 1947).

*A* – Tropical savanna

*C* – Humid temperate

*BS* – Steppe

*a* – mean temperature of the warmest month above 19.9 ° C.

*b* – mean temperature of the warmest month below 19.9 ° C.

*f* – sufficient rainfall in all seasons.

*h* – hot and dry, mean annual temperature above 17.9 °C.

*l* – mean temperature in all months between 13.9 and 19.9 °C.

*w* – winter is dry.

## Appendix 3: Mhlosinga GPS positions for the different transects

Area 3.259 ha

| | Start | Midpoint | End |
|---|---|---|---|
| Transect 1 | 32º 15’ 312 E | 32º 15’ 283 E | 32º 15’ 254 E |
| | 27º 52’ 654 S | 27º 15’ 613 S | 27º 52’ 569 S |
| Transect 2 | 32º 15’ 319 E | 32º 15’ 288 E | 32º 15’ 259 E |
| | 27º 52’ 652 S | 27º 52’ 611 S | 27º 52’ 567 S |
| Transect 3 | 32º 15’ 325 E | 32º 15’ 291 E | 32º 15’ 265 E |
| | 27º 52’ 652 S | 27º 52’ 607 S | 27º 52’ 564 S |
| Transect 4 | 32º 15’ 328 E | 32º 15’ 298 E | 32º 15’ 271 E |
| | 27º 52’ 649 S | 27º 52’ 604 S | 27º 52’ 562 S |
| Transect 5 | 32º 15’ 332 E | 32º 15’ 292 E | 32º 15’ 275 E |
| | 27º 52’ 647 S | 27º 52’ 589 S | 27º 52’ 561 S |
| Transect 6 | 32º 15’ 336 E | 32º 15’ 299 E | 32º 15’ 281 E |
| | 27º 52’ 644 S | 27º 52’ 590 S | 27º 52’ 560 S |

## Appendix 4: Broken Dam GPS position for the different transects

Area 0.625 ha

| | Start | Midpoint | End |
|---|---|---|---|
| Transect 1 | 32º 15’ 327 E | 32º 15’ 373 E | 32º 15’ 401 E |
| | 27º 54’ 076 S | 27º 54’ 070 S | 27º 54’ 067 S |
| Transect 2 | 32º 15’ 329 E | 32º 15’ 356 E | 32º 15’ 401 E |
| | 27º 54’ 078 S | 27º 54’ 075 S | 27º 54’ 074 S |
| Transect 3 | 32º 15’ 328 E | 32º 15’ 362 E | 32º 15’ 401 E |
| | 27º 54’ 081 S | 27º 54’ 078 S | 27º 54’ 073 S |
| Transect 4 | 32º 15’ 328 E | 32º 15’ 367 E | 32º 15’ 402 E |
| | 27º 54’ 084 S | 27º 54’ 080 S | 27º 54’ 076 S |
| Transect 5 | 32º 15’ 330 E | 32º 15’ 362 E | 32º 15’ 402 E |
| | 27º 54’ 087 S | 27º 54’ 083 S | 27º 54’ 079 S |
| Transect 6 | 32º 15’ 331 E | 32º 15’ 375 E | 32º 15’ 398 E |
| | 27º 54’ 089 S | 27º 54’ 086 S | 27º 54’ 083 S |

## Appendix 5: Martial Drive GPS position for the different transects

Area 1.411 ha

| | Start | Midpoint | End |
|---|---|---|---|
| Transect 1 | 32º 14’ 041 E | 32º 14’ 042 E | 32º 14’ 046 E |
| | 27º 54’ 568 S | 27º 54’ 554 S | 27º 54’ 535 S |
| Transect 2 | 32º 14’ 028 E | 32º 14’ 034 E | 32º 14’ 036 E |
| | 27º 54’ 593 S | 27º 54’ 519 S | 27º 54’ 510 S |
| Transect 3 | 32º 14’ 022 E | 32º 14’ 029 E | 32º 14’ 031 E |
| | 27º 54’ 595 S | 27º 54’ 521 S | 27º 54’ 509 S |
| Transect 4 | 32º 14’ 015 E | 32º 14’ 019 E | 32º 14’ 025 E |
| | 27º 54’ 590 S | 27º 54’ 531 S | 27º 54’ 507 S |
| Transect 5 | 32º 14’ 010 E | 32º 14’ 016 E | 32º 14’ 019 E |
| | 27º 54’ 592 S | 27º 54’ 528 S | 27º 54’ 507 S |
| Transect 6 | 32º 14’ 000 E | 32º 14’ 008 E | 32º 14’ 013 E |
| | 27º 54’ 592 S | 27º 54’ 543 S | 27º 54’ 504 S |

## Appendix 6: Disc pasture meter calibration for the rehabilitation site

Regression analysis

(Percentage variance accounted for 49.9)

Estimate of parameters

| | Estimate | s.e. | Prob |
|---|---|---|---|
| Constant | 38.62 | 4.61 | <0.001 |
| Disc height | 1.418 | 0.183 | <0.001 |

The diameter of the disc pasture meter was 456mm.

## Appendix 7: Results from soil analysis

**(a)** Soil salinity analysis

| Area | Soil pH ($H_2O$) | EC mS/m | **Na** (me/L) | **Ca** me/L | **Mg** me/L | **K** me/L | SAR |
|---|---|---|---|---|---|---|---|
| Mhlosinga | 7.04 | 228.7 | 2.81 | 13.18 | 5.09 | 0.98 | 0.93 |
| Broken | 7.26 | 309 | 2.73 | 20.01 | 8.1 | 0.62 | 0.73 |
| Martial | 7.11 | 569 | 29.81 | 13.69 | 17.63 | 0.52 | 7.53 |

Where:

I /L stands for milli equivalents per litre

EC stands for electrical conductivity

SAR stands for Sodium adsorption ratio

**(b)** Soil analytical results

| Area | P mg/L | K mg/L | Ca mg/L | Mg mg/L | Exch. acid | Total cation | pH (KCL) | Zn mg/L | Mn mg/L | Cu mg/L |
|---|---|---|---|---|---|---|---|---|---|---|
| Mhlosinga | 6 | 496 | 3652 | 734 | 0.06 | 25.59 | 6.87 | 1.2 | 2 | 5.5 |
| Broken | 4 | 509 | 3952 | 526 | 0.04 | 25.39 | 6.76 | 0.8 | 1 | 5.4 |
| Martial | 10 | 175 | 2882 | 966 | 0.02 | 22.8 | 6.69 | 1.4 | 2 | 3.7 |

## Appendix 8: GPS position for all the different plots in the burning trials

Plot 1 Head burn
(32º 13’ 691 E, 27º 53’ 404 S); (32º 13’ 707 E, 27º 53’ 439 S); (32º 13’ 721 E, 27º 53’ 413 S); (32º 13’ 678E, 27º 53’ 427 S)

Plot 2 Back burn
(32º 13’ 706 E, 27º 53’ 443 S); (32º 13’ 677 E, 27º 53’ 430 S); (32º 13’ 665 E, 27º 53’ 457 S); (32º 13’ 693 E, 27º 53’ 467 S)

Plot 3 Head burn
(32º 13’ 738 E, 27º 53’ 335 S); (32º 13’ 781 E, 27º 53’ 347 S); (32º 13’ 750 E, 27º 53’ 363 S); (32º 13’ 765 E, 27º 53’ 325 S)

Plot 5 Control
(32º 13’ 686 E, 27º 53’ 399 S); (32º 13’ 713 E, 27º 53’ 385 S); (32º 13’ 703 E, 27º 53’ 358 S); (32º 13’ 672 E, 27º 53’ 374 S)

Plot 6 Back burn
(32º 13’ 671 E, 27º 53’ 376 S); (32º 13’ 684 E, 27º 53’ 396 S); (32º 13’ 665 E, 27º 53’ 412 S); (32º 13’ 646 E, 27º 53’ 390 S)

Plot 7 Head burn
(32º 13’ 670 E, 27º 53’ 424 S); (32º 13’ 652 E, 27º 53’ 442 S); (32º 13’ 627 E, 27º 53’ 425 S); (32º 13’ 648 E, 27º 53’ 401 S)

Plot 8 Back burn
(32º 13’ 618 E, 27º 53’ 432 S); (32º 13’ 632 E, 27º 53’ 455 S); (32º 13’ 605 E, 27º 53’ 470 S); (32º 13’ 593 E, 27º 53’ 443 S)

## Appendix 9: Implementing an Integrated Alien Plant Control (IAPC) Programme

When applying an effective integrated alien plant control (IAPC) programme it is important to study the biology of the plant to (a) gain an insight into how it uses environmental resources, (b) identify the weak links in its life cycles, (c) know how it responds to environmental stimuli, (d) determine if it has natural enemies and (e) identify the survival mechanism that enables it to survive in agro-ecosystems (Akobundu 1987).

Pests, like all organisms, are constantly interacting with their total environment. There appears to be a stage in the life cycle of all pests when they are unable to use environmental resources efficiently (Akobundu 1987). This is the weak link which must be exploited in a pest control programme.

Some basic components of an IAPC programme include pest identification, monitoring of the infestation level, determination of the acceptable damage and action levels of the various pest groups, and evaluation of specific control methods for a given pest (Akobundu 1987). The programme also includes an evaluation of results obtained from the programme, where careful records are kept, and an adaptive control method is applied and adjusted according to the results obtained.

The application of many pest control practices, particularly those of chemical control, has led to concern about the protection of the environment. It is therefore important that the plant protection specialist is trained to apply the correct techniques that manage the pest effectively. Public awareness programmes have to be implemented to establish ways of controlling the invasion.

In the Munyawana Game Reserve the IAPC programme consisted of three phases namely:

(i) *Initial control*: drastic reduction of the existing population;
(ii) *Follow-up control*: control of seedlings, root suckers and coppice regrowth;
(iii) *Maintenance control*: sustain low alien plant number/density with low annual costs. At this phase, alien plants are no longer considered a problem.

The areas that have been cleared and rehabilitated, should be monitored between two and three times each year (spring, mid-summer and autumn), to avoid alien plant re-infestation.

## 9.1 Initial control

a) *Cut stump treatment*: Apply the recommended herbicide mixture to the cut stump. In the Munyawana Game Reserve a 1% solution of the herbicide '*Access* ®' (active ingredient *Picloram*) was used (J. Clayton pers. comm.[4]). '*Chopper* ®' (active ingredient *Imazapyr*) is also registered for stump treatment, and should be applied as a 2% solution (Grobler *et al.* 1996; Ikuenobe & Ayeni 1998). To avoid using excessive amounts of herbicides, care should be taken not to spray the sides of the stump. The herbicide should be applied within half an hour, or the cut wound will seal. The stump height should not be cut higher than 10cm off the ground. On Munyawana the following methods were found to be effective to clear large *C. odorata* plants, namely cane knives, motorized brush cutters, tree poppers and even tractor-mounted gyro-mowers. After slashing or cutting the plant, the freshly cut stumps were treated or allowed to regrow to knee height, and then sprayed with a suitable registered, foliar-spray, herbicide. Cutting for stump treatment is suitable for low to medium density infestations, but is usually not practical for high density infestations. Stump treatment application is best done during the active growing season.

b) *Cutting for coppice:* This is suitable for medium-high density infestations. Plants should be slashed at a convenient height (10-20 cm in height). Cutting dense plants is good winter work, but is very tiring. Thus the work groups should be well organized. The coppice growth must be foliar sprayed during the active growing season when there is enough leaf cover to absorb the herbicide. In areas where the seedlings and coppice are very dense or the coppice plants are too large to hand pull, foliar spray is required. The herbicides '*Garlon* ®' (active ingredient *Triclopyr*) is registered for *C. odorata* at 0.375 % concentration. The *C. odorata* seedling or coppice should be around half a metre in height before being subject to foliar spraying (Grobler *et al.* 1996; Ikuenobe & Ayeni 1998).

'*Round Up* ®' (active ingredient *Glyphosate*) should not be used in wilderness areas, as *Round Up* ® is a non-selective herbicide, and will also kill the grass plants. It is further theorized, although there is no empirical proof, that *Round Up* ® could be negatively affecting the grass seed bank, as areas that have been sprayed with *Garlon* ® and other appropriate selective herbicides had far better grass seedling germination than adjacent areas that were sprayed with *Glyphosate* ® (J. Clayton pers. comm.[4])

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[4] J. Clayton, Bushland Agric. PO Box 100011, Scottsville, 3209

A solid cone nozzle is recommended for foliar spray, especially in light infestations, but a flat fan nozzle is also effective in densely infested areas, where the plants are all uniform in height. Where grass is present, selective registered herbicides should be used that do not harm the grass. Suitable dyes should also be used to avoid over- or under-spraying. The cleared area should be burnt once grass has become properly established and new *C. odorata* seedlings are germinating.

c) *Mechanical uprooting:* Uprooting *C. odorata* with tree poppers results in soil disturbance, especially where large plants are present in dense thickets. Disturbance promotes soil erosion, especially on steep slopes with low grass cover. Soil disturbance also results in the exposure of weed seeds. Germination of these seeds re-infests the cleared areas. Mechanical uprooting should therefore be applied only where the soil can be stabilized, for example, in dense grass cover. When the soil has been disturbed, it is advisable to sow grass seed immediately after uprooting and soil levelling have been completed.

#### *9.1.1.1 Control method in areas which are only slightly infested.*

If there is a high enough grass fuel mass to help kill all *C. odorata* seedlings, all large isolated plants should be cut and stump treated, before the area is burnt. All isolated seedlings on patches that did not burn, should either be uprooted or foliar sprayed. The veld should not be grazed for an entire growing season so that enough grass can accumulate to provide a fire that can release sufficient heat to kill *C. odorata* seedlings.

### 9.1.2 High priority areas for control

*a) Low density infestation*

Areas with low alien plant numbers should be cleared first, because maintenance control in these areas is both rapid and cost effective. Grass in these areas will therefore be protected, and further formation of *C. odorata* thickets and spread of alien plants into surrounding uninfested areas will be prevented.

*b) Areas near the top of slopes, along water courses, and on steep bare slopes.*

Start control at the top end of water courses or at the top of slopes. This prevents seeds spreading downstream or downhill to infest new areas. Plant grass on bare soil, especially in areas that have steep slopes, as this will help prevent soil erosion.

*c) Areas were initial control work is complete and regrowth is present*

Complete major follow-up control and rehabilitation work in all areas before starting initial control of new infestations. This will prevent small *C. odorata* seedlings from suppressing grass seedlings. Continued maintenance is a long-term, ongoing exercise to prevent re-infestation.

*d) Edge of dense spreading infestations*

This should be implemented when there are insufficient funds to control the whole infestation in dense areas, especially in areas where alien plants are likely to spread and invade neighbouring areas. To prevent these dense areas from spreading, all *C. odorata* plants in a 5-10m wide strip around the edge of the infestation should be cleared. This will help confine the infestation.

*e) Low density areas inside dense infestations*

This will encourage grass growth and break up the large infestation into several smaller infestations that are more easily controlled. Grass will gradually spread into the controlled areas as the alien plants are removed.

### 9.1.3 Low priority areas for control

Low priority areas are those areas where infestation could not become worse (these areas should be initially confined to prevent *C. odorata* from spreading into adjacent non-infested areas). It is important that high priority areas are identified as areas where resources could be concentrated to achieve the desired aims. Control in these areas gives the greatest total benefit, and allows the best use of limited resources.

The low priority areas are so-called 'black holes' that would consume resources with little benefit, and should therefore be re-evaluated for attention at a later date. During drought periods it is essential to clear these dense *C. odorata* stands, if all sparse areas have been cleared already, as it is a lot easier for workers to gain access into these dense stands during dry spells, because the large plants will wilt considerably. The cost of clearing these areas will therefore drop significantly during dry spells; for example, on the Munyawana Game Reserve it usually requires an average of 20 workers to clear one hectare of dense *C. odorata* per day in the wet years, whereas in the dry years the same area can be cleared with only 12 workers (personal observation).

## 9.2 Follow-up

Follow-up control of alien seedlings, saplings and coppice regrowth is essential to achieve and sustain the progress made with initial control work. If this phase is neglected, the cleared areas will quickly become infested again with *C. odorata* or other alien plants, such as Bugweed and Lantana.

Follow-up control is essential to prevent alien seedlings from suppressing planted or colonizing grasses. It is important to note that before starting any initial control operations in new infestations, all required follow-up control and rehabilitation work has to be completed or in the process of being completed.

## 9.3 Maintenance control (Rehabilitation)

It is essential that the aims of the rehabilitation efforts are defined prior to the start of a particular programme. One of the primary objectives should be to determine the desired floristic and structural attributes of the rehabilitated community. In the case of a conservation area, it should resemble the original indigenous vegetation prior to the invasion by the alien plants. It is therefore also necessary to have an understanding of the dynamics of the indigenous community.

Veld condition assessments should ideally take the ecological approach whereby the long-term stability of the community and its ability to protect the soil from unacceptable rates of soil loss, are judged to be of primary importance. Clearly, aspects that have to be considered include the propagule source of the species' composition desired in the rehabilitated community and the interaction of the species within the community. In determining species composition, it is essential to include those which are likely to provide the establishment of a uniform vegetative cover in order to exclude undesirable species such as the alien invaders (van Gils *et al.* 2004). *Panicum maximum*, which is widespread in Natal (Ross 1972), is a palatable and nutritious grass for livestock grazing (Tainton, Bransby & Booysen 1976). *P. maximum* would therefore be considered a desirable species that should be encouraged into the areas that have been cleared of alien plants.

The second major consideration is the formulation of a rehabilitation strategy, which incorporates the method of control to be used in combating the undesired weed species, the introduction of the replacement species and the resources available for the execution of the operation. Regarding the last-mentioned factor, it is crucial that allowance be made for the adequate follow-up operation, since this is a critical phase for the establishment of the desired species (Erasmus 1985).

Many studies have demonstrated the importance of emergence time in determining competitive outcomes within plant communities (Fowler 1984; Bergelson & Perry 1989; Goldberg *et al.* 2001). The earlier grass seedlings can emerge, the more competitive they can be against the *C. odorata* seedlings. Larger plants often dominate, regardless of what the species is or what the other plants' densities is (MacDougall & Turkington 2004). Active replacement of *C. odorata* with a particular species, or a number of species, could play a major role in the rehabilitation of infested areas.

Obviously, the species selected should be easily propagated, become established with a dense cover, have an abundant propagule source, be ecologically suited, be efficient at using the limited available resources and fast growing. Another factor to look for in certain situations, where appropriate, is that the species should provide a high fuel mass to allow hot fires to penetrate and kill the alien plants.

### 9.3.1 Rehabilitation islands

After clearing alien plants, grass is planted to provide a cover for the bare soil. Sometimes the areas that have been cleared are too large to plant. In these situations many small 'islands' of suitable grasses should be planted. These islands can then spread to the bare areas, either in the form of seeds, or as stolons and runners.

The problem with using veld grasses as opposed to commercial grasses is that there is usually only a limited amount available. Many of these species have dormant seeds that require a period of after-ripening, or have a low percentage viability. These grasses are therefore usually more difficult to establish.

Use of local indigenous eco-type grass is of value for rehabilitation of degraded land in areas of conservation significance. When using commercial grass seeds, only indigenous grass species that are well suited to the vegetation type, should be used.

The main aims of rehabilitation can be summarized as follows:

i) Establish a stabilizing plant cover that can reduce accelerated erosion.
ii) Encourage the re-appearance of destroyed original vegetation.
iii) Areas are returned to a state where human input is no longer required.
iv) The biotic (living) components are more or less in a dynamic equilibrium.
v) Areas are returned to a form and productivity that conform to an approved land-use plan.

vi) Areas are returned to a condition of better aesthetic value.
vii) Areas are released from negative influences.
viii) Halts or avoids further degradation.

## 5.4 Long-term control

Aim to keep the area stabilized by maintaining good grass cover and prevent further soil disturbance. Planted grass must be maintained as a healthy mat to achieve the aims of rehabilitation, for example, prevent topsoil loss, suppress seedling growth of alien vegetation and improve grazing capacity of the land. If the grass is neglected, it can become rank and moribund (dying in the centre), or be suppressed by alien plant seedlings. Rehabilitation after clearing alien vegetation requires annual maintenance control.