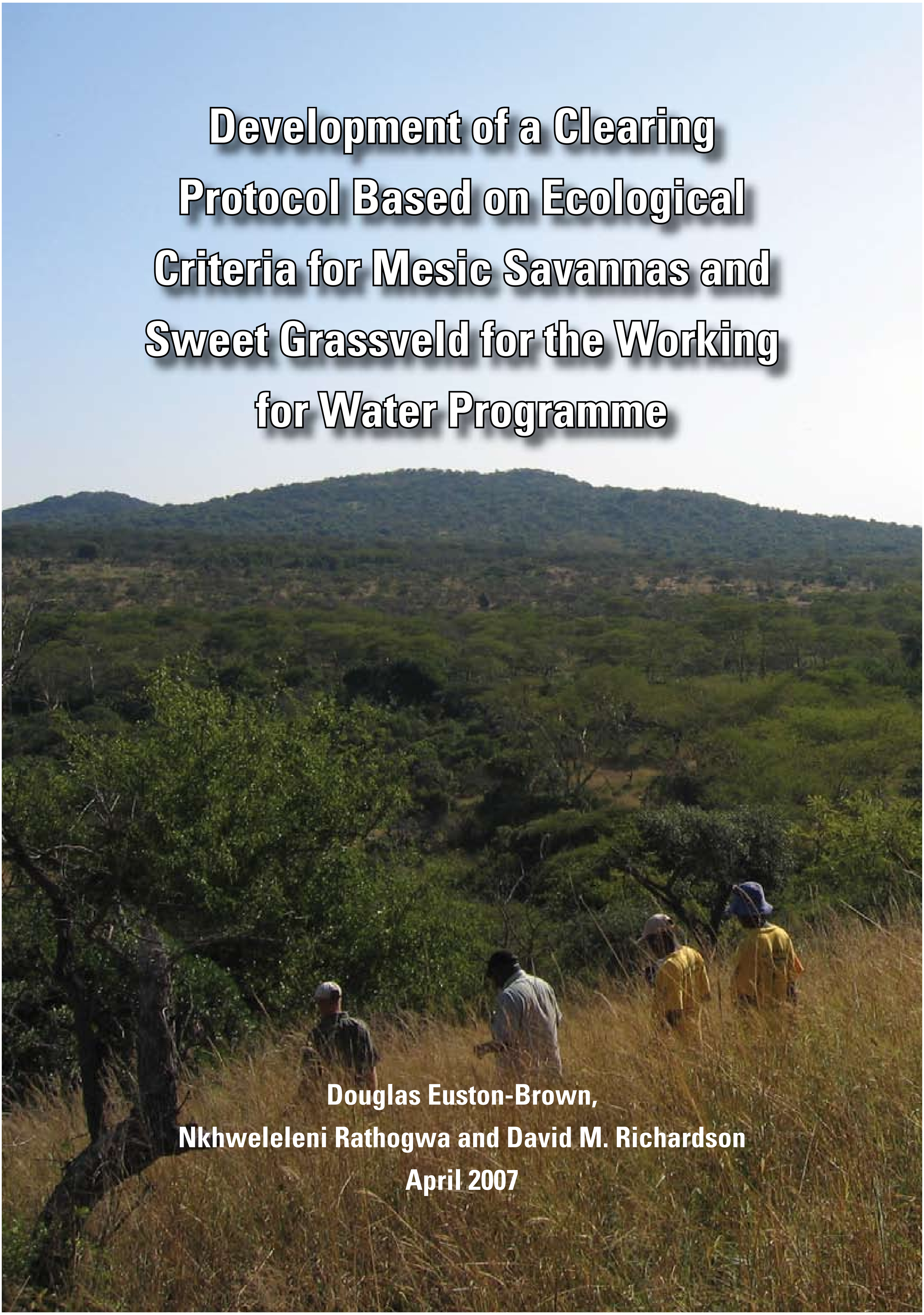

Development of a Clearing Protocol Based on Ecological Criteria for Mesic Savannas and Sweet Grassveld for the Working for Water Programme

Douglas Euston-Brown,
Nkhweleleni Rathogwa and David M. Richardson

April 2007

Final Report

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Contents

1. Executive Summary

The difficulties experienced by WfW to control chromolaena and lantana in mesic savannas and sweet grassveld stimulated the commissioning of this project. The project commenced in 2004 and used a multi-faceted approach that included field studies, a review of international literature, and informal discussions with managers and experts to develop a range of clearing options.

Savanna vegetation and ecosystem function is described and attempts to explain how the bush encroachment problem is related to the process of invasion by chromolaena and lantana. A description of the biology and ecology of the two invaders includes a summary of the traits that equip these plants to quickly invade savanna systems. Control methods such as biological (e.g. insects and fungi), mechanical (e.g. hand pulling, slashing, mowing and bulldozers), herbicidal (e.g. foliar spray and cut stump treatments) and cultural (e.g. mulching, competition and fire) are detailed. The benefits and limitations of each method are listed and practical tips for applying the treatments are provided. Features of the ecosystem that need to be considered when choosing control methods are briefly described into broad categories. These included various indigenous habitat types (e.g. Riparian forest, Open savanna, mixed bushveld of rocky hillsides), land uses (e.g. game reserves, plantations, rural areas), density/cover/height/age of aliens and seasonality.

Tables of clearing and control options are developed for four different climate scenarios and nine different habitat/land use situations. Various situations, habitat types and seasons lend themselves to a different combination and integration of the control options. The tables provide a tool that WfW managers and foremen can use to choose the best approach depending on the situation. The report also recommends an integrated approach whereby different control methods are applied in the same area to deal with the various situations that arise in the bushveld.

The report also provides the methods and results of two field studies that were done between 2004 and 2006 in the Appendices. The results of these studies show that alien plant control is effective and that indigenous diversity increases following the application of control measures, especially after high summer rainfall. Working for Water and all its staff and workers can be proud of their control efforts to date on these two invasive plants. However, control of the other invasive plant species that tend to invade freshly cleared or burnt savanna requires urgent attention. This report strives to provide information, data and ideas that can be used to enhance the efficiency and effectiveness of WfW clearing teams in the control of invasive alien plants in the savannas of the east and north east part of South Africa.

2. Introduction

Mesic Savannas and sweet grassveld are found in the summer-rainfall region in the northeastern part of South Africa and are part of the Savanna biome. The two alien invasive plants *Chromolaena odorata* and *Lantana camara*, both originating in tropical and subtropical America, are common and abundant invaders in these systems.

The Working for Water Programme (hereafter WfW), the national organization responsible for managing invasive alien plants, has experienced major difficulties in controlling these two invasive plant species in particular. In many cases, the same or other invasive plant species rapidly reinvaded sites treated to control these species. These invasive species also pose major challenges to managers in other parts of the world where they are invasive. A study was commissioned by WfW with the aim of providing managers with guidelines and tools to enable them to choose the best available clearing methods in a range of habitats.

To do this we used a multi-faceted approach that included a review of international literature, field studies, and informal interviews with managers and experts in this field. The assimilation, analysis and processing of all this information was then used to develop some basic tools for choosing the best management approach for dealing with these species in a variety of situations.

2.1 Terms of Reference

The project aims to provide an overview of the effectiveness of existing clearing methods for major invasive species in South African mesic savanna and sweet grassveld ecosystems. The degree to which ecosystems are able to recover after clearing will be assessed, taking into account the dominant alien species, the duration and density of invasion, features of the ecosystem and indigenous vegetation that affect recovery (such as soil stability and indigenous seed pools). Based on its findings the project will develop protocols that will enable land managers and Working for Water managers to select the best approach to clearing invasive plants. This will include appropriate combinations of mechanical, chemical and biological control based on the ecological features of the site. Protocols will also be developed for follow-up clearing for various habitats and invasive plants.

The project's terms of reference established by WfW are as follows:

- Provide an overview of the effectiveness of clearing methods (mechanical, chemical and biological) currently used for major invasive species in South African mesic savanna and sweet grassveld ecosystems. The species should include lantana (*Lantana camara*) and triffid weed (*Chromolaena odorata*), and any other emerging species such as pom-pom weed (*Campuloclinium macrocephalum*) identified as important by Working for Water management staff;
- The input from WfW Operational staff will be sought during the research design phase as well as through the monitoring phase, to ensure interaction between the research team and the Operations staff.

- Assess the degree to which ecosystems can recover after clearing. This assessment should take account of the density of cleared invasives, the time the site had been invaded prior to clearing, and features of the ecosystem and indigenous vegetation (such as soil stability, indigenous seed pools and so on) that affect recovery.
- Develop protocols for follow-up clearing for various habitats and invasive alien plants
- Based on the above, develop a protocol that will enable managers to assess the best approach to clearing invasive plants. The protocol should allow managers to select appropriate combinations of mechanical, chemical and biological control, based on ecological features of the site.

2.2 Key questions

This study aimed to address the following three broad questions:

- To what extent are the existing alien clearing methods or a combination thereof effective for the South African mesic savanna and sweet grassveld ecosystems?
- What is the impact of clearing operations on the indigenous vegetation?
- What influences the effectiveness of the clearing methods and indigenous vegetation recovery?

Bush encroachment obstructs game viewing in reserves. However, open roads are an easier route through dense bush, and may attract some animals, such as this lion in Kruger National Park.

3. Methodology

This project used a combination of approaches to cover all the terms of reference. Two separate field-sampling studies were undertaken to establish the effectiveness of existing clearing methods. The first was the establishment of permanently marked sites in areas where *Chromolaena odorata* and/or *Lantana camara* were being cleared in seven regions between Soutpansberg (Limpopo province) in the north to Hluhluwe (KwaZulu-Natal) in the south. The second was the establishment of experimental plots where different clearing treatments were applied and the response of the indigenous and exotic vegetation was measured. The detailed methods and results of these studies are presented in Appendix 1 and 2.

While conducting the above studies various insights were gained on the most promising approaches for clearing these two species. Insights were gained through informal discussions with land managers that have been dealing with these two invasive alien plants. In addition, a review of local and international literature was done, and this together with the field experiments provided an overview of the problem and provided the information necessary to develop the clearing protocols.

From the outset it was envisaged that a thorough understanding of the biology of the two species and the functioning and dynamics of the ecosystem that they invade would be fundamental for developing the most effective clearing methods and protocols.

Mesic savannas have a dense layer of grasses and herbacious plants in the ground layer combined with tall trees and other woody plants.

Sweet grassveld vegetation is more open with fewer trees. Trees are usually dominated by thorny Acacia species.

4. Findings

4.1 Overview of Sweet Grassveld and Mesic Savanna ecosystems

Sweet Grassveld and Mesic Savanna are both part of the Savanna Biome and are restricted to the northeastern part of South Africa, below the escarpment at mid to low altitudes (Acocks, 1988; Low & Rebelo, 1996; Mucina & Rutherford, 2006). These systems are characterised by a grass ground layer and an upper layer of shrubs, bushes and trees. There is considerable variation in the extent and dominance of the woody and grass layers. In some situations the woody component is rather sparse (but seldom absent), while in others the woody component is more dominant and forms "Bushveld" or "Woodland". In more mesic situations and in habitats protected from fire, forest or riparian forest can develop. This variation in the abundance and stature of the woody component is also dynamic in the landscape, and this complicates management that attempts to maintain a balance between grass and tree cover. This aspect is discussed further under the ecology and ecosystem function section below.

4.1.1 Description of vegetation

Sweet Grassveld tends to occur at lower elevations or below Mesic Savannas, and is limited to heavier soils (with a higher clay and nutrient content) in more arid environs. It has a higher grazing value than Sour Grassveld, but only during the summer growing season, whereas Sour Grassveld (that is generally found at higher altitudes an on sandier soils that are lower in nutrient content) has harder and more wiry grasses (while sweet grassveld has "softer" grasses) that tend to have graze value throughout the year. Sweet Grassveld is best accommodated in Low & Rebelo's (1996) Mixed Lowveld Bushvled (19) and Sweet Lowveld Bushveld (20). The vegetation varies from dense bush to open tree savannas with dense riverine woodland on the riverbanks. Dominant trees include *Combretum apiculatum, Sclerocarya birrea, Peltophorum africanum, Acacia nigrescens, Acacia nilotica, Albizia harveyi* and *Euclea divinorum*. The dominant grasses include *Themeda triandra, Panicum coloratum, Panicum maximum, Digitaria eriantha* and *Heteropogon contortis*.

Mesic Savannas tend to occur at the base of the escarpment where rainfall is slightly higher and is also distributed in the northeastern part of the country. It tends to have a higher proportion of sour grasses. Low & Rebelo's (1996) "Sour Lowveld Bushvled" accommodates Mesic Savannas. It is an open tree savanna dominated by *Terminalia sericea, Combretum collinum, Acacia sieberiana, Parinari curatellifolia, Pterocarpus angolensis, Acacia caffra* and many other bushveld trees. The grasses are dominated by *Hyperthelia dissoluta, Elionurus muticus, Hyparrhenia hirta, Setaria sphacelata* and *Heteropogon contortus*.

4.1.2 Description of ecosystem functioning

The dynamics of savanna systems are controlled by a lack of sufficient rainfall that retards the dominance of the tree layer, while the summer rainfall is still enough to maintain a grass layer and its associated fires and grazing. The fine fuels associated with grasslands can support near-annual fires. The system is well adapted to fires, and fire is an integral part of its functioning, dynamics and management. Another characteristic of savannas is the presence of both grazing and browsing ungulates, including mega-herbivores such as elephants and rhinoceros.

In mesic savannas fires tend to be more frequent because the grass fuel accumulates more quickly than in sweet grassveld where less rainfall limits the capacity for grass to carry fires on an annual basis. Thus, in more arid situations or in low rainfall years, it can be expected that fires will be patchier and burn some parts only every two to three years.

Encroachment of native woody species ("bush encroachment") has long being considered a serious management problem in savannas (Trollope, 1980). For various reasons indigenous trees and shrubs have invaded open grassland or thickened up in already wooded areas in many parts of South Africa's savanna biome. This reduces the density and diversity of the grass layer, thereby reducing grazing value. Management for cattle ranching or game farming attempts to prevent bush encroachment by using frequent and intense fires that can kill emerging seedlings and saplings (Sweet, 1982). In general, intense head fires applied at the end of the dormant season are used for bush eradication (Trollope, 1980). Although fires are used to suppress bush and tree establishment, they are also known to stimulate or trigger germination and seedling establishment of some savanna trees in the post fire rainy season (Sabiiti & Wein, 1988). Thus, unless fires are carefully managed, the process of bush encroachment is almost inevitable. Once a tree has established, it will also suppress the grass layer, which in tern reduces the intensity of fires, which increases the chances of vegetative sprouting of burnt seedlings and saplings (Sabiiti & Wein, 1988). Further, the shaded environment created by bush or tree encroachment tends to favour the grass *Panicum maximum* which is much less flammable than most other grasses, and burns at lower intensities than the more typical grasses of an open savanna. Grazing can reduce the standing crop of grasses, and thus the fire frequency and/or intensity. Subsequently, heavy grazing by cattle or game can be regarded as promoting the establishment of woody vegetation, as lower intensity fires will not kill emerging seedlings and saplings. Another factor that maybe favouring the bush encroachment problem is the current and increasing levels of carbon dioxide in the atmosphere (Higgins et al, 2007).

Considering the abovementioned factors, it is not surprising that veld managers have been struggling with the problem of bush encroachment for a considerable time. The densification and persistence of the woody component in fire-protected situations indicates that a proportion of the current mesic savannas could support forest (Bond et al. 2003). Even in Kruger National Park which has a long history of fire management, regular fires have failed to check the process of bush encroachment in many places. In the Hhluhluwe-Umfolozi Park, Watson (1995) recommended a woody plant removal programme since burning and game reduction were found to be ineffective in reversing the bush encroachment process. We know of no examples where bush encroachment has been reversed, allowing the vegetation to return to an open savanna, except for very few examples of Kruger National Parks experimental burn plots (Higgins et al, 2007). The establishment of forest in mesic savanna and thicket in sweet grassveld would historically have been in a mosaic fashion, with thicket and forest clumps in a sea of open savanna.

To further complicate matters, Iron Age farmers have been having an impact on these savanna systems for about 2000 years (Goodall & Zacharias, 2002; Bond et al. 2003). The previous farmers of Kruger National Park burnt the veld on a regular basis for grazing cattle, and were successful in maintaining an open savanna system (e.g. *Terminalia sericea* thicket at Pretoriuskop today used to be an open savanna 100 years ago, historical pictures at reception in Pretoriuskop). However, there is overwhelming evidence showing that the open savanna system predated hominid use of fire, and that open grassy systems are an even more ancient phenomenon (Bond et al. 2003).

Savanna systems are not stable. Fluctuations in species abundances are regarded as normal and are related to variability in rainfall (O'Conner, 1985). Soil moisture is regarded as most important for germination and establishment of most savanna plants. In general germination and growth occurs after spring and summer rainfall, but not that much after winter rainfall. It could also be generalised that the time that it takes a seedling to survive a fire is pivotal for determining the minimum fire-return interval that should not be exceeded if eradication of the plant is desired. Resprouting is a well-developed feature of most savanna plants allowing most species to persist through disturbances such as fire or alien plant control (Bond & Midgley, 2001).

Botanically the ecosystems have an astonishing diversity of woody trees and shrubs (Scmidt et al. 2002). In general, the bush encroachment phenomenon is one we need to consider carefully if wanting to deal effectively with the problem of Chromolaena, Lantana and many other weeds of this ecosystem. The invasion of these two plants has largely been facilitated by the bush encroachment problem because they would struggle to invade frequently burnt grasslands that were present before the thickening of some parts of these savanna systems (Goodall & Zacharias, 2002; Zachariades & Strathie, 2006).

Chromolaena was probably introduced by accident as seed in packaging material off a ship from the Jamaican islands at Durban harbour in the late 1940's. By 1980 it had spread south along the coast to Port St Johns and northwards through Swaziland and into Limpopo province. Today it is still spreading and thickening in the frost free areas of South Africa with rainfall above about 500 mm *per annum* (Zachariades and Goodall, 2002). The South African biotype is different from the biotype that is invading western/central Africa and Asia. Our biotype is more cold tolerant and it has high plasticity both in the habitats it invades and in growth form. It can form dense impenetrable thickets that replace indigenous vegetation and this impacts negatively on cattle ranching, game farms, forestry and eco-tourism.

Lantana was introduced as an ornamental from Tropical America and is one of the world's worst weeds. It was first recorded in the Western Cape in 1858, and rapidly spread eastwards and northwards into the Limpopo province. It has a much wider tolerance of climate than chromolaena, but is also restricted to frost-free areas. There are over 50 different variants within the species, with variation in susceptibility to herbicides and bio-control agents. The plant is toxic to cattle and it forms dense impenetrable thickets that replace indigenous vegetation. It impacts negatively on cattle ranching, game farms, forestry and eco-tourism.

4.2 Overview of Chromolaena and Lantana and other invasive weeds in these ecosystems

This section provides a summary of the ecology and biology of the two invasive species. An understanding of the attributes of their life cycle enables one to predict the invasiveness of these alien plants into savanna and grassveld ecosystems. This section also identifies other invasive weeds that are invading and spreading in these systems.

4.2.1 How do Chromolaena and Lantana establish and persist in these particular Savanna systems?

This is a difficult question to answer because there are a myriad of reasons why these plants are suited to the conditions that prevail in mesic savannas and sweet grassveld. In order to answer this question we first need to understand the biology and ecology of the two plants - this information is summarized in Table 1.

Field assisstant Patrick Ndlovu crawling underneath a dense infestation of chromolaena. Many indigenous plants, especially grasses, cannot survive in the shade cast by this invasive alien plant.

Lantana camara flowers and unripe fruit. Fruit turns black when ripe.

Table 1: Summary of important information on chromolaena and lantana.

Plant attributes	Chromolaena odorata	Lantana camara
Common names	Triffid weed, Parrafienbos, Siam weed	Lantana, Christmas Berry
Origin/natural distribution	South East USA to Northern Argentina and West Indies	Central and South America
Distribution in South Africa	From Port St Johns northwards along eastern seaboard and up to Soutpansberg, frost free summer rainfall areas	Higher rainfall areas along the coast from the Cape Peninsula to Soutpansberg and including Gauteng
Growth form	Scrambling shrub up to 4 m or higher, can climb up trees, forms dense thickets	Compact or untidy scrambler/bush to 2 m or higher
Flowering time	June-July	Mostly September to April but some all year
Fruiting time	July to September	December to June and all year
Fruit type and dispersal mode	Bristly achenes. Primarily wind dispersed but also on animal fur, people clothing, in mud on animal feet/fur and in car tyres	Round, fleshy drupe. Primarily birds and monkeys, also by water in rivers.
Time to first fruit from germination	One to two growing seasons	One to two growing seasons
Vegetative reproduction	Yes, but killed by fire	Yes, vigorous resprouter
Weed status in SA (CARA category and category of major invader according to Nel et al. 2004)	1; widespread-abundant	1; widespread-abundant
Why a problem a	Replaces indigenous vegetation and decreases graze/browse potential. Threat to crocodile breeding (Leslie & Spotila, 1996)	Replaces indigenous vegetation and decreases the graze/browse potential. Toxic to cattle and possibly some game.
Why a problem b	Fire hazard (when dry) and game viewing barrier	Fire hazard and game viewing barrier
Control: chemical	Yes. 19 registered herbicides (Xact Information, 2005), (see Table 3).	Yes. 11 registered herbicides (Xact Information, 2005), (see Table 3).
Control: biological	The leaf eating moth *Parachetes insulata* and the leaf mining fly *Calycomyza eupatorivora* have established on the Durban south coast at Umkomaas and Amanzimtoti respectively. Both are sensitive to winter drought, and are unlikely to spread into drier areas. The stem boring weevil *Lixus aemulus* once released and established may be more drought tolerant. Two agents from Venezuela with biology's that allow them to survive dry periods are currently being screened (Zachariades & Strathie, 2006).	Bio-control initiated after 1961. 9 insect agents established; 1 pathogen established; [11 insect agents have failed. Degree of control achieved: "Substantial" (Zimmermann et al. 2004) However, in area under study biocontrol agents are limited by climate and current impact here could be considered as moderate to poor (Alan Urban, personal comment). Four newly developed agents are waiting for authorisation to release.
Control: mechanical	Handpulling & slashing & scraping with dozer	Handpulling & slashing & scraping with dozer
Control: fire	Yes. Hot fires can kill adult plants, seedlings and seeds	Yes – but resprouts. Hot fires can kill seedlings and incinerate dense thickets to make easier access for follow up
Control: no interference	(No). Loss of grasses and bush encroachment. However, dense stands over 15 years old show dramatic decline in seed production and seed viability (Witkowski, 2002). There is also evidence to suggest dense chromolaena can facilitate succession to forest if protected from fire (Goodall & Zacharias, 2002).	No. Allelopathic effects worsen with time
Best method statement	Long term (10-20 years) strategies with integrated control methods that deal with large areas. Well-timed follow up, especially after rains. Opportunistic use of droughts	Long term (10-20 years) strategies with integrated control methods that deal with large areas. Well-timed follow up, especially after rains.

4.2.2 Biology and ecology *Chromolaena odorata*

The biotype that is invading South Africa came from islands in the northern Caribbean. Studies have shown this form to be identical with a form found in Jamaica (von Senger et al. 2002). This form is different from those that have invaded other parts of the world. However, there is still the possibility of the biotype from Central Africa spreading southwards into South Africa (Zachariades & Goodall, 2002). Recent studies in New Zealand show that the South African biotype is cool adapted, and is currently invading areas that are cooler than the other four continents where it is has spread to or is currently found. This has led some researchers to suggest that our biotype of chromolaena should be recognised as something else (Kriticos DJ 2006).

Triffid weed got its name from a story book "The Day of the Triffids" written by John Wyndham in 1951. In brief the story is about a catastrophe that strikes the human race when they become blinded by a comet that explodes. Triffids are tall three legged carnivorous plants that spread like weeds and can no longer be controlled by the blinded human race. Triffids take over the world by eating the dead and dying people, multiplying and spreading. Although chromolaena is not carnivorous and does not eat people, it is highly invasive, and if not controlled it can spread and smother the indigenous vegetation.

Chromolaena is an herbaceous shrub, with a tendency to creep onto and smother indigenous bushes and trees. Chromolaena produces massive amounts (up to 250 000 per 10 year old plant in the sun (Witkowski, 2002)) of small bristly achenes that are dispersed by the wind in July and August every year. The seed is also transported in mud that gets caught in vehicle wheels and on humans and animals (Blackmore, 1998). The disturbance to the vegetation cover and the soil surface caused by cattle (or other game) enhances seedling establishment. Heavy and/or continuous grazing can also reduce the volume of fine fuels, thereby reducing the intensity, severity and frequency of fires, thus promoting establishment for chromolaena and many indigenous woody plants (Goodall and Zacharias, 2002).

Chromolaena odorata forms dense stands that makes game viewing virtually impossible, as seen here in Hluhluwe-Umfolozi Park.

Chromolaena can grow extremely quickly under favourable conditions but is also quick to wilt in dry and hot conditions. It recovers quickly after rain and has invaded drier parts than was previously expected. It grows especially well on nutrient rich clay soils that are moist for longer periods or perennially (e.g. riparian habitats and on the edges of irrigated sugar cane plantations). However, it was also seen on deep sandy soils in the lowlands, but tends to die back after droughts in this habitat.

Chromolaena has many attributes that add to its invasiveness. Following Sharma et al.'s (2005) scheme for lantana, chromolaena has:

1) Phenotypic plasticity – it has adapted to growing in a wide range of habitats but the south African biotype is fairly uniform, and does not have the problem of different varieties like lantana, at least in South Africa.
2) Interaction with animals – the destructive foraging activities of vertebrates benefits chromolaena by creating appropriate establishment sites in the soil. However, browsing does not appear to enhance vegetation reproduction. Heavy browsing could help to limit flowering.
3) Geographical range – the wide range of habitats that chromolaena is able to spread into is more limited than for lantana. However the cool and dry adapted biotype is still spreading and the occurrence of dense infestations is increasing.
4) Vegetative reproduction – individuals can spread vegetatively by horizontal stems producing roots when they come into contact with the soil. This was only observed at one site in Swaziland, and vegetative reproduction in chromolaena can be regarded as poorly developed.
5) Fire tolerance – the plants burn readily but only when dry after cutting or drought. It does not resprout readily like lantana. However, germination and establishment is also enhanced in the post fire environment. Extremely hot fires (>100 degrees Celsius) can kill the seeds (Mbalo & Witkowski, 1997)
6) Competitive ability – once established chromolaena tends to persist and blocks the natural succession by out competing the indigenous plants. However, numerous indigenous woody plant seedlings are able to persist under chromolaena, and if thinned or cleared many of these could then grow into the canopy (unless they are burnt while still young).
7) Allelopathy – although the oils in chromolaena leaves could be allelopathic this has not been demonstrated yet. Many indigenous woody plant seedlings and young plant are able to persist under chromolaena, but unless the chromolaena thicket is disturbed or cleared, these are shaded out.

Chromolaena odorata

4.2.3 Biology and ecology *Lantana camara*

Lantana is a semi-woody shrub or bush, usually reaching 3 to 4 m tall in these systems, with attractive and many coloured flowers that form one to two seeded drupes that are first green, then purple and then blue-black when ripe. The fruit is eaten and dispersed by vertebrates - in South African savannas mostly by birds and vervet monkeys. In wooded situations it also creeps over and smothers indigenous vegetation. It is a variable species (with over 650 variants worldwide (Day et al. 2003)) that seem to have adapted to a wide diversity of habitats in over 60 countries around the world (Sharma et al. 2005). South Africa also has many hybrid forms of lantana that can co-occur in the same region. Different variants show varied responses to herbicides and bio-control agents.

Lantana camara

Lantana, like chromolaena, is able to flower in the first growing season after its establishment if rainfall is adequate and conditions are favourable. Lantana can continue flowering throughout the year, with possible peaks in wetter summers and autumns. If rainfall is very late in summer and below average, then it is more likely for new seedlings to only flower in the second growing season after germination. Thus in order to make the right decisions about when to time a follow up before the plants set seed, one will need to be monitoring the climate and rainfall as well as the plants growth and condition. Any biocontrol that attacks young plants will probably also help to slow down time to flowering. Seeds can germinate at any time of year with sufficient soil moisture, light and temperature.

Lantana is afforded a variety of attributes that relate to its invasive potential and can be summarised by following Sharma et al.'s (2005) overview:

1) Phenotypic plasticity – it has adapted to growing in a wide range of habitats and is also able to compensate for defoliation.
2) Interaction with animals – the destructive foraging activities of vertebrates benefits lantana by creating appropriate establishment sites in the soil and browsing apparently enhances vegetation reproduction.
3) Geographical range – the wide range of habitats that lantana is able to spread into is vast, and it is still in the process of spreading and the density and thickening of infestations is increasing.
4) Vegetative reproduction – individuals can spread vegetatively by horizontal stems producing roots when they come into contact with the soil. Plants are even able to establish from twigs dispersed by ground nesting birds.

5) Fire tolerance – the plants burn readily but are able to resprout. Germination and establishment is also enhanced in the post fire environment.
6) Competitive ability – once established lantana tends to persist and blocks the natural succession by out competing the indigenous plants.
7) Allelopathy – phenolic compounds in lantana results in severe reductions in seedling recruitment and growth of many species under its cover.

The toxic trierpene acids, lantandene A (rehmannic acid) and lantadene B are present in Lantana. If eaten in sufficient quantity cattle become photosensitive (sensitive to light) and can die if not treated.

4.2.4 Overview of other weeds that are problematic in this system

One of the major problems with clearing in these systems is the large number of other weed species that are able to invade the cleared areas. Thus, for the follow up operations to be effective these weeds need to be identified and controlled. This can complicate management if they require different clearing methods. Table 2 below provides a list of species that are problematic in these systems and that were found in many of the permanent plots that were established. Based on the findings of this study and other field observations we prioritised these species by categorising them into different potential threat classes (1-very bad-worst), (2-medium threat), (3–low threat).

Table 2: Other weeds that are invading savanna ecosystems, their weed status in South Africa and other information.

Species	Common name	Weed status in South Africa (Nel et al. 2004)	Growth form	Habitat preference	Priority	Notes
Acacia mearnsii	Black wattle		Fast growing tree to 15 m	Grassland and riparian habitat	3	Not often found in savanna, more often an upland species
Acanthospermum australe	Prostrate starbur	-	Prostrate perennial herb	Savannas and grassland	3	Burs contaminate sheep wool
Achyranthes aspera	Burweed	Major invader (widespread-common)	erect or procumbent, annual or perennial herb to 2 m	Moist shaded sites, riverbanks	2	Skin irritant (sharp pointed fruits)
Ageratum conyzoides	ageratum	Major invader (widespread-abundant)	Erect annual herbs with fluffy flowerheads	Coastal grassland and savannas	1	Poisonous, but not to animals (Watt & Breyer-Brandwijk, 1962). Used for medicine. Biocontrol agent *Parachaetes pseudoinsulata* uses this as secondary host.
Asclepias physocarpa	Milkweed, balbos	none	Erect perennial herbaceous shrub to 2 m	Grassland and savanna, disturbed ground and roadsides	3	Indigenous weed, prolific in parts of Hluhluwe.
Bidens pilosa	Blackjack	-	Erect herbaceous annuals to 1.5 m	Widespread, disturbed places	2	
Caesalpinia decapetala	Mauritius thorn		Robust, thorny, evergreen shrub to 4m or climber to 10 m, forming dense thickets	Warm, high rainfall areas, riparian habitat, forest and bushveld	1	Seed feeding biocontrol released

Species	Common name	Weed status in South Africa (Nel et al. 2004)	Growth form	Habitat preference	Priority	Notes
Cardiospermum grandifolium	Balloon vine	Major invader (widespread – abundant)	Perennial, softly woody climber	Forest and disturbed places in subtropical vegetation	1	
Catharanthus roseus	Madagascar periwinkle	Emerging invader (moderate-moderate)	Erect perennial herb to 1 m	Dry savannas and coastal scrub	2	Poisonous whole plant
Datura stramonium	Jimson Weed	Major invader (widespread-common)	Erect sub herbaceous annual to 1.5 m		2	Poisonous seeds and leaves
Ipomoea indica	Morning glories	Major invader (Widespread–common)	Herbaceous perennial climber	Woodland, river banks and coastal dunes	2	
Jacaranda mimosifolia	Jacaranda	Major invader (Widespread–common)	Tall tree to 20 m	Savanna, woodland, bushveld, riverbanks	1	Category 3
Melia azedarach	Seringa	Major invader (Very widespread–common)	Tall tree to 20 m	Savanna, riparian habitats, disturbed wastelands	1	Poisonous leaves, bark, ripe fruit. Flowers are respiratory irritant. Category 3
Parthenium hysterophorus	Parthenium	Major invader (localized-abundant)	Erect annual herb up to 1.5 m	Dry Savannas, overgrazed land and disturbed places	1	Irritant, whole plant, skin and respiratory tract. Herbicide registration.
Passiflora edulis	Granadilla	Emerging invader (Moderate–moderate)	Perennial climber to 15 m	Forest margins, plantations, river banks	1	Proposed declared invader
Psidium guajava	Guava, koejavel	Major invader (Widespread-abundant)	Evergreen shrub to small tree	Savannas, riparian areas, forest margins	1	Category 2. Herbicide registration
Ricinus communis	Castor-oil plant	Major invader (Very widespread–common)	Annual herb to softly wooded tree to 4 m	Riparian areas and disturbed places	1	Poisonous, whole plant. Seed is toxic and lethal
Senna bicapsularis	Rambling cassia		Scrambling to climbing shrub to 3 m	Savanna, riverbanks	2	Category 3.
Senna didymobotrya	Peanut butter cassia	Major invader (Widespread–common)	Erect shrub or small tree to 3 m	Savanna, disturbed places, roadsides	1	Category 3.
Senna occidentalis	Wild coffee, stinking weed	Major invader (Widespread–common)	Shrub or small tree to 2 m	Savanna, grassland and disturbed places	1	Sometimes poisonous
Senna pendula	-	-	Perennial shrub or small tree to 4 m	Savanna, riparian habitat, roadsides	2	Category 3.
Senna septemtrionalis	-		Softly woody shrub to small tree to 4 m	Forest margins, savanna, riverbanks	1	Proposed declared invader
Sesbania punicea	Red sesbania		Small tree up to 4 m	Open riverbanks, riverbeds, wetlands, roadside ditches under high rainfall	1	Category 1. Herbicide registration. Biocontrol agents released. Poisonous seeds, leaves and flowers
Solanum mauritianum	Bugweed	Major invader (widespread-abundant)	Shrub or small tree up to 10 m	Mesic savannas, plantations, forest margins, coastal grassland	1	Herbicide registration. Biocontrol agents released. Poisonous unripe fruits, Irritant of respiratory tract and skin

Species	Common name	Weed status in South Africa (Nel et al. 2004)	Growth form	Habitat preference	Priority	Notes
Solanum seaforthianum	Potato creeper	Major invader (widespread–common)	Slender, herbaceous, softly woody climber	Savanna, woodland, riparian habitat	1	Poisonous fruits, leaves and stems
Tagetes minuta	kakiebos		Erect herbaceous annual to 2 m	Widespread, disturbed places, cultivated lands, grassland and savanna	2	Extract from leaves used in perfume industry; Drives away nematodes in soil; Odour downgrades maize.
Tithonia diversifolia	Mexican sunflower	Emerging invader (Moderate–moderate)	Erect annual or perennial up to 3.5 m	Savanna, grassland, roadsides, open river banks	2	High visual impact
Xanthium spinosum	Spiny cockelbur	-	Spiny annual up to 1.2 m	Open river banks, cultivated lands, old lands	1	Herbicide registration. Poisonous seedlings, seeds and burs.
Xanthium strumarium	Large cocklebur	Major invader	Annual to 1.2 m	Cultivated lands, old lands, roadsides, open river banks	1	Herbicide registration. Poisonous seedlings, seeds and burs.

It is essential that managers and clearing teams learn how to identify the invasive plants listed in Table 2. It was noted that at many sites where WfW have been clearing that some of the less obvious herbaceous weeds (e.g. *Ageratum conyzoides, Solanum seaforthianum*, *Xanthium* spp etc) were left untreated. Identification of these weeds in savanna systems is not simple because there are also a large diversity of indigenous herbs, shrubs and trees some of which also display "weedy" characteristics. An alien clearing operation needs to plan to deal with these other invasive plants, especially in follow up situations when they tend to establish readily.

4.2.5 Description and assessment of the invasion problem

The invasion by these two species into the area under consideration is still fairly recent. Thus there are many suitable habitats, especially in Mpumalanga and Limpopo provinces, that are still relatively free of dense infestations. Chromolaena is virtually absent from lower rainfall areas, but there are sporadic outbreaks in drier parts after rainfall events, but these tend to die back and disappear in drought periods. Lantana appears to be more tolerant of droughts than chromolaena and can persist through drought periods.

Although there are obvious differences between the two species, the process of establishment and spreading into new areas seems to be facilitated by veld degradation through a combination of factors such as overgrazing by cattle, disruption of frequent fires, and bush encroachment that reduces grass cover and fire behaviour. Thus, if the factors leading to veld degradation are not remedied, the system remains highly susceptible to re-invasion by the same species. It is possible for the situation to become even worse because the disturbance created by clearing usually stimulates the invasion of a range of other herbaceous weeds. If follow up operations are not done in good time, or worse if they are not done at all, then it is possible to end up with a wider diversity of alien species at higher density. This situation is far more difficult to manage than the initial situation with one alien species dominating.

4.3 Summary of insights on the effectiveness of clearing methods

The results of our field studies are presented in Appendices 1 and 2. Many insights emerged from the field studies. Some of the more important findings were that:

a) Different habitats and different situations in terms of land use in these systems lend themselves to different clearing strategies;
b) There are considerable differences in the density cover and stature of the various weeds that also require different approaches to clearing;
c) Rainfall events and seasonality of rainfall has a major impact on the establishment, growth and spread of weeds in these systems and this also needs to be considered when developing a clearing strategy;
d) There are a variety of control methods that need to be considered and integrated and the careful definition and application of each method is necessary;
e) Clearing operations on the ground need to be carefully managed and co-ordinated and emphasis needs to be placed on team building and maintaining and stimulating the morale of workers. Since, with both species, effective follow up is achieved with appropriate timing, then any efforts that will save time and keep up the work rate of a clearing team need to be explored;
f) Lastly, making use of small practical tips will go a long way to making clearing operations more effective.

In the following sections we attempt to set out some crucial overriding factors that will be useful for deriving objective protocols for effective management.

4.3.1 The different control options that can be used.

This section provides a brief description of the various control methods and describes the situations in which they worked best and problems with them.

4.3.1.1 Biological control

4.3.1.1a) For chromolaena

A moth (*Parachaetes insulata*) whose larvae defoliates triffid weed, and a leaf-mining fly (*Calycomyza eupatorivora*) have been established on the KwaZulu South coast and are spreading in wetter areas (Zachariades and Strathie, 2006). Releases of the moth began in 2001. However, both agents rely on the presence of green leaves, and if dry winters cause dieback in chromolaena (as often happens) then the insect populations decline rapidly. It appears unlikely that these two agents will have a substantial and lasting effect on triffid in the mesic savanna and sweet grassveld ecosystems, both of which experience winter and sometimes even summer drought periods.

However, in certain situations such as riparian vegetation and wetland edges (and especially natural veld adjacent to sugar cane plantations or other places that tend to stay moist by perennial seeps, water leaking pipelines and/or irrigation), there is a good chance that these agents will establish. The same may be true for higher rainfall areas closer to the escarpment, and that are well shaded by tall trees. Thus, attempts at establishing populations of these two biocontrol agents are recommended in such situations (see clearing protocols below).

Zachariades & Strathie (2006) have also identified logistical criteria that need to be met for future release sites of *Parachetes insulata*. In summary these are: a) large areas of dense triffid weed; b) areas with good accessibility from roads; and c) and secure areas (safe from disturbances). Additionally, they suggest that protected areas are generally unsuitable for the release of these agents since eradication of the invasive species is the aim in reserves. Neglected areas or unutilised farms are more suitable.

Future prospects for more effective bio-control seem promising. A stem-boring weevil, *Lixus aemulus*, is ready to be released but awaits approval from DEAT. Since this insect survives in the stem of chromolaena, it is possible that it will be less sensitive to drought periods, and may spread more readily than the above-mentioned agents.

Further, a stem-boring moth and stem galling weevil from Venezuela that have biology's that will allow these two insects to survive dry periods are currently being tested. The weevil pupates in the soil over winter and may thus even be able to survive winter fires. The South African biotype of chromolaena is from Jamaica, and occurs in a tropical climate that does not experience drought periods like those in South African savannas. Since the biotype of triffid weed in Venezuela is different from the South African biotype (which comes from Jamaica and Cuba), there is some doubt as to whether these agents are going to establish easily. There are as many as seven insects that are currently being tested both in South Africa and abroad. Three Jamaican isolates of a fungal pathogen *Pseudocercospora eupatori-formosani* that are more pathogenic on chromolaena are also being tested.

4.3.1.1b) For lantana

Biocontrol of the lantana complex, by about twelve agents in South Africa since 1961, can be regarded as moderate to poor in these systems (Alan Urban, personal communication). As for chromolaena, the effective agents that have established are most effective in hot, humid maritime conditions and least effective in more arid inland areas. This is also related to many of the agents being dependant on leaves, and since lantana can shed its leaves in unfavourable conditions, agent populations are prone to collapse. Possibly the most difficult aspect of biocontrol in lantana is the hundreds of varieties and cultivars that were developed in the 18th century in Europe. The different varieties also show differences in susceptibility to agents. To further complicate matters there are pests and parasites on many of the agents.

The most effective agents in these systems are probably *Teleonemia scrupulosa, Ophiomya camarae, Epinotia lantana* and the indigenous insect *Hypaena laceratalis* and ten other species (Alan Urban, personal communication). The leaf-spot fungus, *Mycovellosiella lantanae*, has been established in the Eastern Cape, KwaZulu-Natal and Mpumalanga, but its impact and spread still needs to be assessed. There have been numerous releases of various agents that have established but failed to have any substantial and/or lasting impact. There are currently four new agents awaiting authorisation from DEAT, and researchers are confident that these will suppress lantana markedly.

A great deal of research has been undertaken on biocontrol options for lantana worldwide. In Australia there are about 26 established and 15 non-established agents (Day et al. 2003). In Hawaii, over two dozen biocontrol agents have been released. In South Africa, biocontrol research is also very active with 4 MSc or PhD theses, 26 peer-reviewed and 26 non-peer reviewed publications over the past 10 years.

During our field visits we never noticed any dramatic effects from biocontrol agents, but some of these insects are small and difficult to detect and may have been overlooked. We conclude that although prospects are reasonable for more substantial contributions to overall control from biological control agents (particularly in some habitats), other available control options will need to be optimized to ensure meaningful containment and reduction of invasive populations.

Treatment	Advantages (Benefits)	Disadvantages (Limitations)
Biocontrol	• highly selective • can suppress growth, seed production and spread • supplements other methods • cost effective – once established its free • minimal impacts (no interference) • international collaboration – networking and sharing of research and lessons learnt	• research and screening takes time to develop • does not eradicate weeds and needs to be combined with other methods • currently only functional in parts of the weeds distribution • high cost of scientific research • variable results with no guarantee of developing a successful agent • requires weed reserves that are difficult to establish/maintain • is not applicable for poverty relief funds

On a national strategic level it is obvious that dedicated funding to continued studies and research on biocontrol for these and any other weeds must form a central part of South Africa's national strategy for dealing with invasive plant species. The financial benefits of this approach are enormous (van Wilgen et al. 2001). The integration and co-ordination of biocontrol with the other control methods is a major challenge that South Africa still needs to tackle at both the macro and micro scales (see Goodall et al. 1996). The importance of this is very clear for the case of chromolaena and lantana.

4.3.1.2 Mechanical control – hand pulling, slashing, mowing, bull dozers and browsing/grazing.

4.3.1.2a) Handpulling

Handpulling of chromolaena is problematical in dry conditions because stems become brittle and break off above the roots (and then sprout after rainfall and are able to flower the same year if the rainfall is enough). Handpulling for both species is only recommended for young plants <1 m tall and in wet periods when soil is moist and plants can uproot readily. Care must be taken to grab the plant close to the base as this reduces the chance of plants breaking off above the roots and resprouting. Wearing gloves is recommended. If plants are well rooted, and if the soil is hard and compact and dry, then an implement like a weeding fork can be used to loosen the roots.

The disturbance of the soil associated with handpulling may also enhance seedling establishment, leading to more costly follow up operations. However, in places where cattle or game are few or absent,

Handpulling

disturbance of the soil will probably also stimulate the indigenous seed pool to germinate. If follow up with control burn is planned, then an initial clearing that enhances germination and establishment of alien seeds in the soil should be done beforehand. This approach should reduce the load of germinable seed in the soil, especially for weeds with longer-lived seed. It may also help to reverse bush encroachment.

A major advantage of hand pulling is that it negates the need for herbicides. It is thus most appropriate in sensitive areas with high conservation importance or on the edge of wetlands or rivers, where herbicide could affect invertebrates and fish. It is an ideal method for low-density infestations in the second or third follow up situations after the bulk of the clearing has already been done. It is also useful to integrate herbicidal control with hand pulling. With both these weeds, and others, one often finds a core infestation with lighter infestations around it. It is most effective for one or two people to hand pull the scattered individuals while herbicidal treatments are applied to the denser areas where hand pulling is too labour intensive.

Treatment	Advantages (Benefits)	Disadvantages (Limitations)
Hand pulling	• Selective • Minimises risk to native plants • Easily integrated with other methods • Effective in light infestations • Develops plant identification skills and understanding of plant biology • disturbance may enhance establishment of native plants, especially grasses • minimal equipment or protective clothing required – saves time. • no herbicide cost	• Disturbance of soil can enhance weed establishment • Limited to wet periods when soil is moist • Limited to light (low to medium density) infestations < 1m tall • Risk: stems that break above the roots grow back • Labour intensive • Risk: need to ensure that roots not in contact with soil or they can sprout under favourable conditions • Worker fatigue and back pain – reduced work rate

4.3.1.2b) Slashing

Slashing is generally done with a panga or sharp blade at the end of an arm-length stick or short handle. This method may be appropriate when integrated with an appropriately timed follow up to deal with coppice. The aim here is to stress weeds or to prevent them from flowering and producing seed, and giving the native plants a competitive edge. With both chromolaena and lantana, slashing only also stimulates vigorous fresh growth (after enough rain). This new growth may be more responsive to herbicide treatments, and the site is also easier to access and is more quickly covered after being slashed. For chromolaena the most appropriate time to use this method is just before or as

An alien clearing worker in Phinda Game reserve equipped with a panga for slashing.

the plants are about to flower which typically occurs in June and July. For lantana the best time is at the beginning of summer. However, in general this method is used as a last alternative, and is done as a preparatory measure to enhance the effectiveness of the follow up treatment.

In Swaziland this method is used extensively in riparian areas invaded with chromolaena adjacent to sugar cane plantations. Follow up usually involves controlled burns done at the height of the dry season. (See before and after pictures for peg no. 57 on page 62.)

4.3.1.2c) Mowing

Mowers, such as weed eaters, are appropriate in dense infestations in disturbed situations such as old lands or road verges on young plants with thin stems < 1 m tall. In our field studies we found no examples of this method being used by WfW or other agencies. However, it is used extensively on road verges and also in urban areas – usually as a fire prevention/control measure. Since our savanna systems are well adapted to grasslands and bushveld fires, it is unlikely that mowing will have a significant impact on overall biodiversity. If this method were to be pursued special vehicles would have to be designed to cope with the native terrain and vegetation structure of the different types of savanna. In the Western Cape, blade cutters have been used to slice through dense infestations of *Acacia saligna* sprouts. Such tools should also be investigated for lantana and chromolaena.

Treatment	Advantages (Benefits)	Disadvantages (Limitations)
Mowing	• Selective – although mistakes easily possible • Can be applied when herbicides can't • Can move through larger areas faster – especially mowing • Effective in dense infestations • Minimal soil disturbance • No herbicide cost	• Limited to dense infestations with thinnish stems that are easily slashed/mowed • Limited to heavy (high density) infestations < 3m tall • Risk: accidental damage to native plants (especially with mowing) • Labour intensive • Worker fatigue – reduced work rate • Risk: coppice needs to be followed up soon after this treatment if applied at start of growing season • mowing machinery can break down • mowing not applicable or tested in natural veld • extremely hard and tough woody plants break and blunt equipment.

4.3.1.2d) Bulldozing

Scraping with bulldozers with a front-mounted blade plough has been used extensively in Australia (Natural Heritage Trust, 2004) for *Acacia nilotica* and *Parkinsonia aculeata*. There is one known and documented example of this method being used successfully in Phinda Game Reserve near Hluhluwe (Wessels, 2006). In this case, the blade of the dozer was kept just above the surface so that the plants were uprooted and minimal disturbance of the soil occurred as it was not cut or dugout. This could be considered an appropriate method in this habitat, but not in other savannas where the grass and herb layer is better developed or the woodland/bushveld component is low (<10 m) and too dense for the machine to fit through. It might be applicable in other flat riparian forest areas in the lowveld, if done carefully by avoiding larger trees and well established thicket clumps.

Due to the legislation protecting natural systems and virgin soil, this method may only be suitable in situations where the natural system has been disturbed or transformed (eg. cultivated land, fire breaks, road verges).

Acacia xanthophloea (fever tree) habitat in Phinda Game Reserve. A dense infestation of chromolaena at this site was bulldozed a few years prior to this photograph.

Treatment	Advantages (Benefits)	Disadvantages (Limitations)
Bulldozing	• Rapid clearing of large dense infestations • Site easily accessible for follow up • Skilled operator – one man and his machine (simple contract) • Effective in dense and old (>10 years) impenetrable infestations • No herbicide cost	• Limited to particular habitat/terrain in dense infestations • disturbance to soil significant • loss of indigenous diversity • accessibility and petrol costs • Risk: disturbance causes reinvasion of other weeds. • Risk: unforeseen impacts of soil compaction

4.3.1.2e) Browsing/Grazing

Browsing and grazing by game and cattle can also be regarded as a form of control if carefully managed. This method is only applicable to chromolaena, as lantana is toxic to cattle and probably most game. However, even if this is the case, cattle and game also learn quickly to leave lantana alone. Herding a large herd of cattle or game through a dense infestation can be used to open up the infestation making it more accessible for humans to access and apply the appropriate treatment.

Treatment	Advantages (Benefits)	Disadvantages (Limitations)
Browsing/ Grazing	• low cost implementation • renders site easily accessible for follow up • No herbicide cost • Reduced labour cost and time • appropriate in inaccessible areas far from roads • heavy browsing of chromolaena by Nyala and Kudu can reduce flowering in lightly infested areas	• does not clear the weeds • disturbance to soil significant • toxic weeds – sick animals • Risk: disturbance causes reinvasion and spread of other weeds (remedy-clean cattle/game before taking in and out of infested area, and allow resting period before and after move to defecate any seed).

Buffalo (or game or cattle) can be herded through areas of dense infestation which make the sites more accessible to clearing teams. Kudu and nyala are known to browse on chromolaena.

4.3.1.3 Herbicidal control – Foliar spray, cut & treat and aerial spraying

Herbicides are absorbed into a plants sap system through its leaves and this kills the plant. Herbicides are poisons and the risks associated with herbicide preparation, use, handling and storage need to be understood. The use of herbicides is controlled by legislation in which each weed species in each province has a set of herbicides and their appropriate use in a specified manner is defined (Table 3). There are different ways of applying herbicides. Each method is briefly described in the sections below. Herbicides are mixed with additives to improve their performance. These are termed adjuvants, surfactants and penetrants; when combined with the herbicides, the result is called a herbicide formulation. Sometimes a herbicide on its own can be relatively safe, but the additive is not. The general rule with herbicides is to follow the label instructions carefully.

There is no room for error when producing herbicide formulations for application.

Table 3: Herbicides registered for the control of chromolaena and lantana in South Africa (Xact Information, 2005).

Species	Active ingredient	Site of application	Herbicide mixture (% concentration) and application	Product names
Chromolaena	Clopyralid/triclopyr 90/270 g/ℓ SL	Cut stump and Foliage	200 mℓ (Cut stump); 50 mℓ (Foliage) + 50 mℓ Actipron Super/10 ℓ water.	Confront 360 SL
Chromolaena and lantana	Fluroxypyr/picloram[1] (tri-isopropanolamine salts) 80/80 g/ℓ ME	Cut stump and foliage	Chro: 75 mℓ + 50 mℓ Actipron Super/10 ℓ water Lant: 150 mℓ + 50 mℓ Actipron Super/10 ℓ water	Plenum 160 ME
Chromolaena and lantana	Imazapyr 100 g/ℓ SL	Cut stump and foliage	200 mℓ/10 ℓ water	Chopper, Hatchet
Chromolaena and lantana	Picloram[1] 240 g/ℓ SL	Cut stump	100 mℓ + 50 mℓ Actipron Super/10 ℓ water.	Accesss 240 SL
Chromolaena	Tricolpyr (butoxy ethyl ester) 240 g/ℓ EC	Cut stump	200 mℓ/10 ℓ diesel[2]	Ranger 240 EC
Chromolaena	Tricolpyr (butoxy ethyl ester) 240 g/ℓ EC	Cut stump	100 mℓ/10 ℓ diesel[2]	Garlon 480 EC, Triclon, Viroaxe
Chromolaena	Triclopyr (triethylamine salt) 360 g/ℓ SL	Cut stump	200 mℓ + 50 mℓ Actipron Super/100 ℓ water.	Timbrel 360 SL
Chromolaena and lantana	Glyphosate (ammonium) 680 g a.e./kg WG	Foliage	Chro: 80 g/10 ℓ Lant: 160 g/10 ℓ	Roundup Max
Chromolaena and lantana	Glyphosate (isopropylamine) 360 g a.e./ℓ SL	Foliage	Chro: 100 mℓ/10 ℓ water Lant: 300 mℓ/10 ℓ water knapsack sprayer Lant: 400 mℓ/10 ℓ water mistblower	Bounty, Buggie 360, Erase, Glyphogan, Glyphosate 360, Mamba, Profit, Roundup, Scat, Springbok
Chromolaena and Lantana	Glyphosate (isopropylamine) 480 g a.e./ℓ SL	Foliage	Chr:120 mℓ/10 ℓ water Lant: 240 mℓ/10 ℓ water	Roundup Turbo
Chromolaena and Lantana	Glyphosate (isopropylamine) 480 g a.e./ℓ SL	Foliage	Chro:110 mℓ/10 ℓ water Lant:220 mℓ/10 ℓ water	Mamba Max 480 SL
Chromolaena and Lantana	Glyphosate (potassium) 500 g a.e./ℓ SL	Foliage	Chro:70 mℓ/10 ℓ water Lant:200 mℓ/10 ℓ water	Touchdown Forte Hi Tech
Chromolaena and Lantana	Glyphosate (sodium) 500 g a.e./kg SG	Foliage	Chro:75 g/10 ℓ water Lant:220 mℓ/10 ℓ water knapsack sprayer Lant:290 mℓ/10 ℓ water mistblower	Kilo WSG
Chromolaena	Metsulfuron methyl 500 g/kg WP	Foliage	3 g + 50 mℓ mineral oil/10 ℓ water.	Nicanor 50 WP
Chromolaena	Tricolpyr (butoxy ethyl ester) 240 g/ℓ EC	Foliage	75 mℓ + 50 mℓ Actipron Super/ 10 ℓ water	Ranger 240 EC
Chromolaena	Tricolpyr (butoxy ethyl ester) EC 480 g/ℓ	Foliage	37,5 mℓ + 50 mℓ Actipron Super/ 10 ℓ water	Garlon 480 EC, Triclon, Viroaxe
Chromolaena	Tricolpyr (butoxy ethyl ester) EC 480 g/ℓ	Foliage	50 mℓ/10 ℓ water	Garlon 4
Lantana	Glyphosate (isopropylamine) 240 g a.e./ℓ SL	Foliage	300 mℓ/10 ℓ water	Tumbleweed

1 *Picloram is only used with Working for Water management approval.*

2 *Working for Water actively avoids using diesel as a surfactant in herbicides.*

Although there are herbicides that are registered for chromolaena and lantana, the prescribed concentrations are usually doubled for lantana, owing to its tough resilience and sprouting ability. For a recent review see Erasmus (2006). In mixed stands, which is quite often the case, it is recommended that the more concentrated mixture for lantana is also applied to chromolaena.

People who work with herbicides need to undergo special training in safety and in use and application of herbicides. This is extremely important and even people that are not involved with herbicide application need to understand the hazards associated with it. The sensible use of herbicides is often essential to effective clearing with these two weeds.

4.3.1.3a) Foliar spray

The non-selective (kills all kinds of plants) application of glyphosate (e.g. Roundup, Mamba) is most effective as an overall foliar spray for chromolaena and lantana. Another commonly used herbicide for foliage is triclopyr (e.g. Access, Garlon), which only kills broadleaf plants (grasses and other monocots are not killed). The plants need to be actively growing to absorb the chemicals into their sap. This limits the use of this method to summer growing season when adequate soil moisture is available after rainfall.

The foliar spray method is often applied when the weeds are accessible from the ground (<3 m tall) and so dense that the cut & treat method is unfeasible and too time consuming. This situation often arises in the first follow up after the initial clearing of a dense infestation. This (or any other method) should thus take place in the summer before the seedlings or coppicing plants

Foliar spray application with a knapsack sprayer.

What is glyphosate?

Glyphosate is a broad spectrum, non-selective systemic herbicide. It kills all kinds of plants by acting on various enzyme systems that inhibits amino acid metabolism. The chemical spreads throughout the plant so no parts survive. The active ingredient is isopropylamine salt. It was first reported in 1971 and patented by Monsanto. Since the patent expired, glyphosate has been sold in a wide variety of products such as Roundup, Mamba 360 SL, Touchdown and Tumbleweed. Glyphosate is not toxic to animals, except at extremely high doses that do not tend to occur naturally. However, it is the surfactants contained in marketed formulations of glyphosate that have a less benign reputation. These surfactants prevent the chemical from forming into droplets and rolling off the leaves which are sprayed. Some of them are toxic to fish, and may contain contaminants, which are carcinogenic to humans. Non-toxic surfactants have been developed but these are more expensive so the old toxic ones still tend to be used. Glyphosate is inactivated when it comes into contact with the soil since it is adsorbed onto soil particles. Glyphosate has been found to inhibit anaerobic nitrogen fixation in the soil. Further, glyphosate may be released from soil and taken up by indigenous plants years after its application. Of nine herbicides tested for their toxicity to soil micro organisms, glyphosate was found to be second most toxic to a range of bacteria, fungi, actinomycetes and yeasts (Carlisle & Trevors, 1988). In Australia most formulations of glyphosate have been banned from use in or near water because of their toxic effects on tadpoles and frogs. In summary, glyphosate is generally regarded as non-toxic, environmentally friendly herbicide, but its extensive and widespread use may be introducing more subtle indirect forms of damage (understudied in SA) of which users need to be aware.

flower and set seed. To apply foliar spray to taller/older plants they first need to be slashed and the fresh regrowth is then sprayed.

Treatment	Advantages (Benefits)	Disadvantages (Limitations)
Foliar spray	• relatively quick and requires less labour • as herbicides are very diluted (usually 1-2 % concentration with water) may use less herbicides • if correctly applied it is highly effective • many small teams can cover large areas relatively quickly	• Requires access to good quality clean water • Heavy backpacks – worker fatigue • Mixing of herbicides and equipment preparation requires technical proficiency and takes time. • potential negative impact on biocontrol agents • if applied to older plants it requires slashing first and then spraying regrowth – two operations (more time more expensive) • Risk: drift onto and death of non-target plants. Remedy: don't use herbicides or use non-selective herbicides • Risk: rainfall washes herbicides into rivers and is toxic to invertebrates and fish • Risk: heavily dependent on weather conditions and rainfall season – mistakes possible. • Risk: unstudied potential impacts on soil dwelling invertebrates, fungi and other organisms in the soil. • Risk: high chance of accidents, spillage that can result in negative impacts on native ecosystem. • Risk: health hazards

Practical tips for foliar spray applications: 1) timing – tune into the local weather patterns, make sure that plants are growing actively or regrowth is "ready" for foliar spray, don't spray if dew or rain drops are on the leaves – use another control method until they are dry 2) training – make sure users are properly trained 3) use clean water – dirty water clogs equipment, 4) preventing spray drift – only spray in suitable weather conditions - milder temperatures and higher humidity are best. Consistent very light winds (5-15 kph) blowing away from risk areas (e.g. sensitive natural habitat, crops, settlements) is preferable 5) do spot spraying – because of the risks and unforeseen impacts of herbicides on the environment avoid blanket spraying an entire area if possible by integrating with cut & treat and hand pulling where possible. 5) dust on leaves can prevent absorption of the herbicide – apply treatments to roadsides after rainfall when the leaves are

What is triclopyr?

Triclopyr is a selective herbicide for broadleaf plants (it does not kill monocots such as grasses and bulbs). Product names include Garlon, Access, Ranger, Triclon, Viroaxe, Timbrel. This chemical imitates a plant hormone that causes the growing tips to elongate, followed by distortion, withering and death of the plant (Cox 2000). Grasses survive because they are able to transform triclopyr into compounds that do not have hormonal activity. Triclopyr can be acutely toxic to humans with symptoms including lethargy, in coordination, weakness, difficult breathing, tremors and diarrhoea. It is corrosive to eyes with damage lasting for three weeks and is a skin irritant. Laboratory tests on dogs and rats result in the development of kidney problems. It also known to slow down frogs, inhibits the growth of mycorrhizal fungi, inhibits nitrogen cycling, and damages mosses and lichens. The chemical can last in the soil for about 100 days, but reports of persistence for more than a year are also present. The chemical is mobile in the soil, so is easily washed into rivers and even ground water. Contamination of urban streams with tricolpyr may be widespread in the USA (Cox 2000). The breakdown product of triclopyr is TCP. TCP in concentrations of only 0.2 ppm disrupt growth in human foetuses. TCP is also very mobile in the soil and is toxic to soil bacteria. However, other sources of information such as Dow AgroSciences indicate that there should not be a problem with the use of this herbicide. Conflicting reports on the impacts of tricolpyr should be regarded as a warning sign that a lot is still to be learnt about the impacts of tricolpyr on humanity and the environment. We need to be aware that there are unknown risks associated with using these herbicides and their formulations.

clean and dry. 6) dry leaves - do not spray if leaves are wet from dew or rainfall as this will change concentration of herbicide and increase chance of it dropping off the leaf, decreasing effectiveness. 7) use cattle or game to open up vegetation prior to application. 8) if rain is forecast do not spray – the herbicide will be washed off and your efforts, time and money will be wasted, rather use cut & treat or hand pulling methods.

4.3.1.3b) Cut-and-treat-stump

The cut-and-treat-stem method is generally applied to older (more than three years) stands that can be at various densities. The plant stems are cut near the base and are immediately (within 10 seconds, although some herbicides prescribe within three hours) sprayed with a dyed non-selective herbicide, most often glyphosate. The concentration for cut stump treatments is usually higher, and also differs

Cutting with loppers requires an additional person to apply the herbicide. Slashing with a panga enables the same person to apply herbicide to the cut stump, allowing the same job to be done by one person.

from one species to another. If the stems are thin (<1 cm diameter) then a single person can cut with a large flat blade or clippers/loppers and spray with a small bottle.

If stems are thicker it may be better to have pairs operating together. A risk with the cut & treat method is that cut stumps can be missed and escape being killed by the herbicide. Dyes are used in herbicides so that workers can see what has and has not been sprayed, but this does not help to find stumps that may be difficult to detect in dense undergrowth with lots of leaf litter.

Treatment	Advantages (Benefits)	Disadvantages (Limitations)
Cut-and-treat-stump	• Minimises soil disturbance • Uses less herbicide • Highly selective – very little to no drift onto non-target plants • Not as dependant as foliar spray on weather conditions at time of application and plant growth/condition • Can leave cut vegetation in situ – this can be used to fuel a hot fire that can kill plants and make site more accessible for follow up • Biocontrol agents can migrate intact	• Labour intensive • Risk: cut stems are overlooked and not treated (remedy: one person does both cutting and treating; use of dyes) • Risk: more concentrated or neat herbicides are used, and this may have greater impact in the soil. • Risk: cut vegetation left as is can fuel fires into the canopy scorching and killing large indigenous trees (remedy: attempt to drag foliage into piles on the ground after cutting)

4.3.1.3c) Aerial spraying

Vehicle or aircraft could also apply foliar spray if the appropriate conditions prevail. This method has been used on lantana in Australia (Clark et al. 2006). Situation of old dense monospecific stands in remote inaccessible areas are most appropriate. Aerial Application of **Bushwacker GG** (bromacil) is registered in South Africa for many indigenous species regarded as bush encroachers (Xact Information, 2005). It is unclear as to why these two weeds do not have aerial applications registered. The risks associated with aerial spraying on non-target native flora needs to be considered. However, if carefully executed it can prove to be an economical method on a large scale, but only if combined with the appropriate follow up.

Treatment	Advantages (Benefits)	Disadvantages (Limitations)
Aerial spraying	• Minimises soil disturbance • can cover vast areas quickly • can detect isolated population in remote areas in plane • simple contract – one man and his plane/chopper.	• potential negative impact on biocontrol agents • Risk: drift onto and death of non-target plants. Remedy: don't use herbicides or use non-selective herbicides • Risk: rainfall washes herbicides into rivers and is toxic to invertebrates and fish • Risk: heavily dependent on weather conditions and rainfall season – mistakes possible. • Risk: unstudied potential impacts on soil dwelling invertebrates, fungi and other organisms in the soil. • Risk: high chance of accidents, spillage that can result in negative impacts on native ecosystem

4.3.1.4 Cultural control – mulching, competition and fire

4.3.1.4a) Mulching

We found no cases of mulching or solarisation in South Africa. This method involves using vegetative material such as bark or wood chips or synthetic materials such as plastics to smother the soil after an initial clearing treatment. This could help to reduce weed seedling establishment, reduce erosion and enhance indigenous recovery. If mulch is not available then solarisation with black plastic sheeting can be used. This method is potentially practical at small spatial scales in gardens or plots or near sensitive areas where herbicides are not appropriate. Solarisation may be particularly useful for destroying seed banks after clearing dense infestations, but impacts on indigenous seed banks need to be assessed. This is a method that should be explored further before it can be recommended.

4.3.1.4b) Competition

If savanna systems are managed with fire, and the indigenous vegetation is able to persist, then this should keep weed numbers down to manageable levels (Goodall & Naude, 1998). South African Savanna systems are extremely resilient to disturbances, and should recover rapidly if given the chance. If indigenous seed pools have been lost under old and dense infestations, then it may be necessary to sow indigenous seed, especially indigenous grasses (Campbell, 2000). This is referred to as rehabilitation. A very useful tool has been developed in South Africa that includes a dial for choosing the appropriate grass species for sowing in different habitats (Campbell, 2000).

A Phd thesis by Mariske Te Beest on chromolaena in Hlulhluwe-Umfolosi Park includes a field and greenhouse experiments on chromolaena seedling growth under competition from grasses. Preliminary results indicate that chromolaena struggles to grow with grasses, and so maintaining a healthy grass sward should be a fundamental part of chromolaena control.

4.3.1.4c) Fire

Annual fires can be used to convert a dense infestation of chromolaena to diverse coastal grassland in only five years (Goodall and Zacharias, 2002). However, dense infestations of chromolaena can be resilient to fire because of the absence of fine fuels (grasses and herbs). If chromolaena is dry it can be highly flammable. In old dense stands chromolaena should first be slashed and dried in situ before being burnt. Follow up burns on an annual basis should then occur before July the following year for chromolaena, and within a year from the date of the fire for lantana. If grass has not recovered adequately to support a fire after the first year then alternative clearing methods can be used until adequate fuels have accumulated.

A field experiment using fire as a control method was done in Hluhluwe-Umfolozi park (Te Beest & Olf, 2003). Te Beest found that an initial clear followed by a hot fire should be enough to restore a healthy sward of panicum grass, and competition with this grass is likely to suppress the growth of chromolaena. This Phd study is due to be completed in 2008. A permanent plot in Swaziland (peg 57) also had a dramatic recovery of *Panicum maximum* after a very dense infestation of both weeds were burnt in October 2005 (see pictures on page 62).

There are often practical limitations to conducting control burns. Firebreaks can be expensive to maintain. The legal implications of controlled fires that cause accidental damage are also discouraging. Thus, although fires seem to offer a wide range of benefits as a control method, the practical implementation of a fire management plan is not straightforward. For this reason, we cannot rely on using fire solely as a solution to the alien control problem.

There are several aspects to consider when planning to use fire as a control method: 1) suitability of the habitat – some habitats or situations should not be burnt and efforts to protect riparian forests and heavily wooded areas from fire is sometimes required. A detailed natural vegetation map should include guidelines on appropriate fire regimes for the different habitats in each area. 2) Response of weed to burning – lantana resprouts readily after fire while chromolaena plants are more easily killed by fires (Goodall, Kluge & Zimmermann, 1996) – thus it should be possible to eliminate chromolaena without using herbicides but with lantana herbicides are essential. 3) the season of the fire – in general fires burn in winter when the grass is dry, but burning in summer, and most especially in spring needs more study. The indigenous bush encroacher, sickle bush, has been found to struggle to recover from summer burns when the plants are actively growing. In winter when they are dormant their resources are buried underground, so surviving fires in winter is easier for them. More research is needed on the impacts of fire season on lantana. 4) fire regime – the most appropriate fire regime for eradicating weeds may also be deadly for certain indigenous plants and more research is needed on this.

Treatment	Advantages (Benefits)	Disadvantages (Limitations)
Fire	• opens up area for access to follow up • stimulates germination of indigenous seeds • stimulates weed seedbank (for well-timed follow up) • intense fires can kill chromolaena seed bank • relatively inexpensive • also useful for reversing bush encroachment	• limited to certain habitats • limited by timing and season • maintenance of fire breaks costly • Risk: increased erosion potential • Risk: accidental damage from runaway fires

Practical tips for using fire: 1) make use of opportunities created by unplanned fires – about 2 months after the fire (or two months after the first growing season following the fire) the burnt area needs to be assessed for the timing and method of follow up. In general, this follow up should occur between 5 and 17 months after the fire. 2) Use knowledge of authorities and specialists – when planning a control burn seek the advice of a specialist or a professional fire team. Make sure you know the regulations and the risks involved. 3) Communicate with neighbours – make sure that neighbouring landowners are advised of your burning plans. Where feasible, collaborate and share knowledge and resources to carry out cross-boundary burns.

4.3.2 The different situations or conditions in terms of habitat type and land use

Chromolaena and lantana can become very problematical in certain habitats and under some conditions (e.g. edge of sugar cane plantations, forestry plantations, urban edges etc). For effective planning, one needs to categorize landscapes; here, we provide a framework for such a categorization. Firstly, one needs to define baseline indigenous habitats so that meaningful and achievable targets for rehabilitation can be set. Obviously if the target for clearing is simply to clear the stand of invasive species (e.g. with a view to establishing crops) the methods one uses will be different from the methods one uses if the target is to restore elements of the natural system to achieve some conservation target.

Each area where clearing is done should have a base map of the major vegetation types and variations within them. A vegetation map at 1:10 000 scale would be required to indicate the distribution of these systems in the landscape, and most maps available are at least 1:50 000 or finer. This map represents baseline information on the original vegetation state that is required in order to plan the most appropriate clearing method based on any given situation. The delineation of wetland and riparian habitats is most important in this regard, as invasive alien plants are particularly abundant, problematical, and difficult to control in such habitats. A fine scale vegetation map is also very important tool for conservation planning and in being able to prioritise areas for biodiversity conservation.

Table 4: Broad vegetation/landscape categories that would need to be mapped

Habitat type	Vegetation features	Indicator species	Typical fire-return interval (years)
1. Flat riparian savanna	20 m tall trees well spaced	*Acacia xanthophloea*	1-2
2. Steep riparian forest	10 –20 m tall trees dense woodland	*Combretum apiculatum*	10-20
3. Lowveld riparian forest	10-20 m tall trees, grass and thicket understorey	*Combretum imberbe*	2-15 and none (on islands)
4. Open savanna dry lowveld (low rainfall) e.g. Clay Thorn Bushveld and Lowveld Bushvled (Schmidt et al. 2002)	10 m tall trees well spaced, with thicket patches and sweet grasses	*Sclerocarya birrea*, *Acacia nigrescens*, *Dalbergia melanoxylon*	2-15
5. Open savanna lower to mid slopes (medium rainfall) e.g. Sour Bushveld ((Schmidt et al. 2002)	10 –20 m tall trees fairly dense with mixed to tall sweet and sour grasses	*Combretum* spp. *Terminalia sericea*, *Antidesma venosum*, *Piliostigma thoningii*	1-3
6. Bushveld on rocky hills e.g. Mixed Bushveld (Schmidt et al. 2002)	5-10 m tall trees, dense woodland with grasses sparse	*Combretum* spp., *Sterculia rogersii*, *Kirkia wilmsii*	1-7
7. Forest	Fire-intolerant trees	*Podocarpus* sp., *Ficus* sp.	>50

4.3.2.1 Brief description of each unit in terms of habitat and clearing options.

4.3.2.1a) Flat riparian savanna

This habitat is on sandy alluvial soils. In our field studies it was sampled at Phinda Game reserve, where a dozer was used to do an initial clear of a dense infestation of chromolaena. The soil moisture associated with the floodplain is especially vulnerable to invasion by chromolaena and lantana, and other weeds.

Phinda game reserve, with flat riparian savanna on the alluvial plain below.

4.3.2.1b) Steep riparian forest

The steepness of the terrain limits the number of control methods that can be applied here, as well as the sensitive nature of the habitat.

4.3.2.1c) Lowveld riparian forest

The sandy soils make the use of hand pulling feasible. Fairly open with tall trees in flatter areas allows dozers to access.

Lowveld riparian forest along the Sabie river in the Kruger National Park.

4.3.2.1d) Open savanna – lowveld

Fire is regarded as a major control method here, but its use is hampered by droughts and overgrazing.

4.3.2.1e) Open savanna – lower and mid slopes

Fire is the ultimate control method in this habitat. The use of summer fires should be investigated to reverse bush encroachment problems.

Open savana of lower to mid slopes at Hluhluwe-Umfolozi Park. Carpet of light green plant in the distance is chromolaena invading.

4.3.2.1f) Mixed Bushveld on rocky hillsides

Here fire is not as applicable, and differences in aspect and rockiness complicate the choice of control method.

Mixed bushveld of rocky hillsides near Tzaneen adjacent to the Hilltop Study site where experimental clearing of a dense infestation of chromolaena and lantana was done (see Appendix 2).

4.3.2.1g) Forest

The absence of fire as a control method is a major feature in this habitat. Managing fuels at forest edges to prevent fires (fuelled by dry alien litter) from penetrating into the forest is identified as a priority.

Each of these habitats may or may not have a variety of human land uses adjacent to them (cultivated lands, cities, semi-urban areas, rural areas, plantations). Each of these also needs to be considered when planning a clearing operation (Goodall & Erasmus, 1996). Here follows our proposed system of situations or conditions that tend to prevail (see Table 5)

Table 5: The various situations or land use categories and the habitat types where they occur.

Situation	Habitat types						
	1. Flat riparian savanna	2. Steep riparian forest	3. Lowveld riparian forest	4. Open savanna dry lowveld	5. Open savanna –lower to mid slope	6. Bushveld on rocky hills	7. Forest
1. Natural veld. Game reserves/ cattle ranch.	Y	Y	Y	Y	Y	Y	Y
2. Natural veld. Edge of non irrigated land	Y	N	N	Y	Y	N	N
3. Natural veld. Edge of irrigated land (sugar cane)	Y	N	Y	Y	N	N	N
4. Plantations	N	N	N	N	Y	N	Y
5. Fallow lands	Y	N	N	Y	Y	N	N
6. Rural areas	N	N	N	Y	Y	Y	N

Not all situations occur in every habitat, the table indicates where both exist together. This thus defines the different situations for which clearing protocols may need to be developed.

4.3.3 The different densities and cover of chromolaena and lantana

From a clearing perspective, three major categories were devised for which there should be differences in the clearing method used. These were:

a) Low density, <5 % cover,

Low density <5 % cover chromolaena at a permanently marked plot (peg 68) at De La Rey Farm near Tzaneen.

b) Medium density 5-75 % cover

Medium density 5 - 75 % cover chromolaena at the Theuns Botha experimental site near Tzaneen.

c) High density, 75-100 % cover

High density 75-100 % cover chromolaena at the Hilltop experimental site near Tzaneen.

High density 75-100 % cover lantana at a permanently marked plot (peg 142) at Casa do Sol near Hazyview.

The height of the stand was also considered important and divided into taller than 3 m or less than 3 m.

4.3.4 The influence of season and climate on the choice and timing of control method

One needs to create a time schedule over several years following a disturbance for the various control measures and the integration of them. For example, herbicidal control and especially foliar spray are not appropriate unless the plants are actively growing. This effectively eliminates this form of control during winter and/or drought periods. Thus, one may be forced to apply mechanical or cultural control measures at this time. Unfortunately, "hand pulling" of young plants in dry periods is also unfeasible, as stems tend to break off at the roots, and if these are left behind they tend to resprout. This leaves fire as the next best control measure, and there is considerable evidence to suggest that this may also have the most desired effect on the savanna ecosystem.

It is important to understand and follow the weather patterns so that the appropriate clearing methods are chosen. It is necessary to be continually monitoring the rainfall in the area where you are doing clearing. Rainfall data can be obtained from the South African Weather Bureau Website (www.weathersa.co.za). The timing of herbicidal control should only coincide with growth spurts after summer rainfall between September and March. However, these particular weeds may be stimulated to sprout after slashing in winter. Further, foliar spray application in the dry season when many plants and insects are dormant may result in less impact of herbicides on biodiversity. This aspect may require more research.

Table 6: Appropriate control methods based on season and rainfall.

Rainfall	Spring	Summer	Autumn	Winter
Above average	# $	# $	# $	(#$)
Average	# $	# $	$	*
Below average	*	*	*	*
Drought	(*)	(*)	(*)	(*)

*# Herbicide * fire $ Hand pulling ( ) – indicates high probability of control method not succeeding*

After above-average rainfall it may still be possible to apply herbicidal treatments and hand pulling, but in average and below average rainfall years these methods are more likely to be ineffectual. Table 6 above was further simplified to define four major categories of climate in this ecosystem:

a) wet spring/summer
b) dry spring/summer
c) wet autumn/winter
d) dry autumn/winter

These various categories of climate, habitat type, land use, and different states of invasion were developed into tables of control options in the following section

4.4 Development of clearing protocols

4.4.1 The control options under four different climate scenarios

Based on the above findings a table of control options was developed for each broad climate category. To avoid producing too many tables we only developed seasonal protocols for one habitat type – open savanna on lower to mid slopes. This generic pattern relating to season and rainfall can be applied across most of the habitats, so this was not done for each and every habitat.

4.4.1a) Generic clearing options in spring and summer with above average rainfall

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	**Low density <3m tall**	**Low density >3m tall**	**Medium density <3m tall**	**Medium density >3m tall**	**High density <3m tall**	**High density >3m tall**	**Low density - coppice**	**Low density - no coppice**	**Medium density - coppice**	**Medium density - no coppice**	**High density -coppice**	**High density -no coppice**
Biocontrol	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Foliar spray	☺☺	☹	☺☺	☹	☺☺	☹	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Slash only	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Hand pull	☺☺	☺	☺☺	☺	☹	☹	☺	☺☺☺	☺	☺☺☺	☹	☺
Fire	☺	☺	☺	☺	☹	☹	☺	☺	☺	☺	☺	☺
Scraping with dozer	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
No interference	☹	☹	☹	☹	☺☺	☹	☹	☹	☹	☹	☹	☹
Time to follow up	July following year	July following year	After 4 months or July following year	After 4 months or July following year	After 4 months or July following year	After 4 months or July following year	After 4 months or July following year	July following year	After 4 months or July following year	July following year	After 4 months	July following year
Best Management Approach	Cut & treat stump	Cut & treat stump	Cut & treat stump	Cut & treat stump	Cut & treat stump	Cut & treat stump	Cut & treat	Hand pull	Foliar spray	cut & treat; hand pull	Foliar spray	Foliar spray

Biocontrol is favourable in most situations under these conditions. The cut & treat stump method is preferred over foliar spray because a) it is less prone to failing as a result of unforeseen circumstances such as rainfall, and with this as a rainy period then this is likely to be a problem b) It uses less herbicide c) It is less likely to kill other existing indigenous plants (non-target plants) d) it produced the best results in the clearing experiment (see Appendix 2). Slashing is only appropriate if followed up timorously. Hand pulling is most appropriate in low to medium density follow up of seedlings with no coppice. Fire is not ideal at this time. It is generally unfeasible to burn in wet conditions when the grass is green, but it can be done and is generally under-explored as this is not the typical burning season. Under situations of severe bush encroachment, a dedicated burning programme is required to restore the open savanna system, if it is possible to burn during the growing season this might help to suppress encroaching woody plants.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.1b) Generic clearing options in spring and summer with below average rainfall or drought

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	**Low density <3m tall**	**Low density >3m tall**	**Medium density <3m tall**	**Medium density >3m tall**	**High density <3m tall**	**High density >3m tall**	**Low density - coppice**	**Low density - no coppice**	**Medium density - coppice**	**Medium density - no coppice**	**High density -coppice**	**High density -no coppice**
Biocontrol	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂
Foliar spray	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁
Slash only	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂	🙂
Cut & treat	🙂🙂	🙂🙂	🙂🙂	🙂🙂	🙂🙂	🙂🙂	🙂🙂	🙂🙂	🙂🙂	🙂🙂	🙂🙂	🙂🙂
Hand pull	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙂🙂	🙁	🙂	🙁	🙁
Fire	🙂🙂🙂	🙂🙂	🙂🙂🙂	🙂🙂	🙂🙂🙂	🙂🙂	🙂🙂🙂	🙂🙂🙂	🙂🙂🙂	🙂🙂🙂	🙂🙂🙂	🙂🙂🙂
Scraping with dozer	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁	🙁
No interference	🙂	🙂	🙂	🙂	🙂	🙂🙂	🙂	🙂	🙂	🙂	🙂	🙂
Time to follow up	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year
Best Management Approach	Burn only	Slash first and burn 1 week later	Burn only	Slash first and burn 1 week later	Burn only	Slash first and burn 1 week later	Burn only	Burn only	Burn only	Burn only	Burn only	Burn only

During a dry growing season fire is the most rewarding method to use. If fire is unfeasible cut & treat is the next best method. Try to do burn or clearing towards the end of the growing season as this will mean fewer plants will establish if there is late season rain – if one burns at the beginning of summer (e.g. October), and rains do follow, then one needs to follow up within 10 months. If one burns in February, the accumulation of fuel should be more (supporting a hotter fire), and even if there are late rains, the emerging seedlings of chromolaena will not be big enough to flower in June, so follow up will only be required the following year, 17 months later (effectively saving or buying 7 months). N.B. this does not apply to lantana as it can flower year round. Scraping with a dozer is never an option in this habitat type.

Where (🙂🙂🙂) indicates that suitability of the method is high; (🙂🙂) indicates that it is moderate; (🙂) indicates that it is low and (🙁) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.1c) Generic clearing options in autumn and winter with below average rainfall or drought

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	**Low density <3m tall**	**Low density >3m tall**	**Medium density <3m tall**	**Medium density >3m tall**	**High density <3m tall**	**High density >3m tall**	**Low density - coppice**	**Low density - no coppice**	**Medium density - coppice**	**Medium density - no coppice**	**High density -coppice**	**High density -no coppice**
Biocontrol	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
Foliar spray	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
Slash only	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Hand pull	☹	☹	☹	☹	☹	☹	☹	☺☺	☹	☹	☹	☹
Fire	☺☺☺	☺	☺☺☺	☺	☺☺	☹	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Scraping with dozer	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
No interference	☺	☺	☺	☺	☺	☺☺	☺	☺	☺	☺	☺	☺
Time to follow up	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year
Best Management Approach	Burn only	Slash first and burn 1 week later	Burn only	Slash first and burn 1 week later	Burn only	Slash first and burn 1 week later	Burn only	Burn only	Burn only	Burn only	Burn only	Burn only

Foliar spray and biocontrol are regarded as unfeasible at this time because of the dry winter season. Fire is the most suitable method in autumn and winter with below average rainfall, mainly because other methods are only moderately suitable or unfeasible at this time. If fires are not feasible as a control method, then cut & treat or slash only (to stimulate fresh growth for foliar spray) is recommended. If it is a severe drought, no interference might be applicable for chromolaena, as considerable natural die back should occur. Hand pulling are unfeasible in this situation, although hand pulling might be appropriate in a low density follow up if plants are still young and below 1 m tall, and the soil is relatively loose/sandy.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.1d) Generic clearing options in autumn and winter with average or above average rainfall

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	Low density <3m tall	Low density >3m tall	Medium density <3m tall	Medium density >3m tall	High density <3m tall	High density >3m tall	Low density - coppice	Low density - no coppice	Medium density - coppice	Medium density - no coppice	High density -coppice	High density -no coppice
Biocontrol	☹	☹	☺	☺	☺	☺☺	☹	☹	☹	☹	☹	☹
Foliar spray	☺	☹	☺	☹	☺☺	☹	☺	☺	☺	☺	☺	☺
Slash only	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Hand pull	☺☺	☹	☺☺	☹	☺	☹	☺	☺☺	☺	☺☺	☹	☺
Fire	☺☺☺	☺	☺☺☺	☺	☺☺	☹	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Scraping with dozer	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
No interference	☹	☹	☹	☹	☹	☺☺	☹	☹	☹	☹	☹	☹
Time to follow up	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year	July following year
Best Management Approach	Fire; cut & treat	Cut & treat	Fire; cut & treat	Cut & treat	Cut & treat	Cut & treat	Fire; cut & treat	Fire; cut & treat	Fire; cut & treat	Fire; cut & treat	Fire; cut & treat	Fire; cut & treat

Biocontrol release is not appropriate at this time of year, however, if autumn has high rainfall biocontrol release in medium and dense stands might be worthwhile for some agents. Foliar spray may be applicable if chromolaena and lantanas are still actively growing. Slashing only is of low suitability, but may be applicable for creating out of season new growth for foliar spraying. Cut & treat is highly applicable across all situations. Hand pulling is moderately suitable in medium to low-density situations, but not for older or coppicing plants. Fire is the most suitable method in autumn and winter with above average rainfall. Once again this is mainly because other methods are only moderately suitable at this time. If fires are not feasible as a control method, then cut & treat is recommended. "No control" is not a feasible option, except for dense infestations of about 7 years old. This is because it may be worth waiting for the stand to become senescent between 10 and 15 years before applying a control method, following findings of Witkowski (2002) at St Lucia. If this were done then the dense stand must be fenced off from game and cattle to minimise its spread.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.2 Control options in different habitats and land use

4.4.2a) Clearing options for the edge of irrigated lands in a flat riparian situation.

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	**Low density <3m tall**	**Low density >3m tall**	**Medium density <3m tall**	**Medium density >3m tall**	**High density <3m tall**	**High density >3m tall**	**Low density – coppice**	**Low density - no coppice**	**Medium density - coppice**	**Medium density - no coppice**	**High density -coppice**	**High density -no coppice**
Biocontrol	☺	☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☹	☹	☹	☹	☹	☹
Foliar spray	☺☺	☹	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Slash only	☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Hand pull	☺☺☺	☹	☺	☹	☹	☹	☺	☺☺☺	☺	☺☺☺	☹	☺
Fire	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Scraping with dozer	☺	☺	☺☺	☺☺☺	☺☺☺	☺☺☺	☺	☺	☺☺	☺	☺☺☺	☺
No interference	☹	☹	☹	☹	☹	☺☺☺	☹	☹	☹	☹	☹	☹
Best Management Approach	Hand pull, Cut & treat, Fire	Fire; cut & treat	Biocontrol, Fire, Cut & treat	Fire, Cut & treat, biocontrol, scraping	Fire, Cut & treat, biocontrol, scraping	Fire, Cut & treat, biocontrol, scraping, no interference	Fire, Cut & treat	Handpull, Fire, Cut & treat	Fire, Cut & treat	Handpull, Fire, Cut & treat	Scraping, Fire, Cut & treat	Fire, Cut & Treat

Seepage from the edge of irrigated lands results in perennial soil moisture, so the limitations of dry seasons are not as applicable as in natural settings. This means that biocontrol release may be feasible year round, depending on the agent. Foliar spray is moderately suitable all year because wilting and die back may not occur, however the risks associated with this method close to sugar cane and threat to wetlands and rivers renders it moderately suitable. The suitability of slash only is moderate to low, unless integrated with an appropriate follow up, and is most applicable in initial clearing of medium and dense infestations. The cut & treat method is most suitable in all situations. Hand pulling is only applicable to younger plants in medium to low-density situations. Fire is most applicable in all situations, although care should be taken to manually remove material that climbs into trees to prevent fires from scorching the forest canopy. Hot fires at the end of the dry season are recommended. Scraping with a dozer is only applicable in certain situations where old dense infestations are present. No interference is only applicable in dense old stands that are older than 7 years, but this should be accompanied by biocontrol release at these sites. The invasion of a wide variety of weedy pioneers (e.g. khakibos, black jack, datura etc) is also typical of riparian sand banks.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.2b) Clearing options for steep riparian forest in a nature reserve

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	Low density <3m tall	Low density >3m tall	Medium density <3m tall	Medium density >3m tall	High density <3m tall	High density >3m tall	Low density - coppice	Low density - no coppice	Medium density - coppice	Medium density - no coppice	High density -coppice	High density -no coppice
Biocontrol	☺	☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☹	☹	☹	☹	☹	☹
Foliar spray	☺☺	☹	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Slash only	☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Hand pull	☺☺	☹	☺	☹	☹	☹	☺	☺☺	☺	☺☺	☹	☺
Fire	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
Scraping with dozer	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
No interference	☹	☹	☹	☹	☹	☺	☹	☹	☹	☹	☹	☹
Best Management Approach	Cut & treat	Cut & treat	Biocontrol, Cut & treat	Biocontrol, Cut & treat	Biocontrol, Cut & treat	Biocontrol, Cut & treat	Cut & treat	Cut & treat	Cut & treat	Cut & treat	Cut & treat	Cut & treat

Riparian forest in steep sided kloofs or gullies is more limited in the control options that can be used. Fire is not recommended as a control method as it seldom burns into these habitats. However, if unplanned fires do burn in these habitats, follow up control within the first year following the fire is a priority. Steep riparian sites are also relatively unstable so the risk of erosion needs to be considered. The inaccessibility and steepness of the terrain also eliminates the use of bulldozers or other machinery. If the site is very rocky then hand pulling is also not appropriate, as stems tend to break off, leaving roots to resprout. Thus biocontrol and herbicidal control are the best options in this situation. The proximity to a freshwater river and the sensitive nature of riparian habitats also means that herbicides need to be used with extreme caution. Thus, the cut & treat method is likely to be the most suitable control measure in this situation. Doing nothing is seldom regarded as an option because of the importance of conserving riparian habitats.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.2c) Clearing options for lowveld riparian forest in a nature reserve

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	Low density <3m tall	Low density >3m tall	Medium density <3m tall	Medium density >3m tall	High density <3m tall	High density >3m tall	Low density - coppice	Low density - no coppice	Medium density - coppice	Medium density - no coppice	High density -coppice	High density -no coppice
Biocontrol	☺	☺	☺☺	☺☺	☺☺	☺☺	☹	☹	☹	☹	☹	☹
Foliar spray	☺☺	☹	☺☺	☹	☺☺	☹	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Slash only	☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Hand pull	☺☺☺	☹	☺☺☺	☹	☺☺	☹	☺☺	☺☺☺	☺☺	☺☺☺	☹	☺
Fire	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺
Scraping with dozer	☹	☹	☹	☹	☹	☺☺	☹	☹	☹	☹	☹	☹
No interference	☹	☹	☹	☹	☹	☺	☹	☹	☹	☹	☹	☹
Best Management Approach	Hand pull or cut & treat	Cut & treat	Hand pull or cut & treat	Cut & treat	Cut & treat	Cut & treat	Cut & treat	Hand pull or cut & treat	Cut & treat	Hand pull or cut & treat	Cut & treat	Cut & treat

Biocontrol is of low to moderate suitability because of aridity, however, well-shaded sites near water may provide suitable sites. Nature reserves are reluctant to support biocontrol sites (reserves of alien vegetation that are maintained for biocontrol agents) since the policy is usually eradication of alien invasive plants. However, although it is currently unsuitable, this could change at any time as new agents are released so biocontrol always needs to be considered as an option. In follow up situations biocontrol is not recommended because sites should be cleared annually until the weeds are gone. Foliar spray is moderately suitable because of non-target impacts and proximity to rivers. Slashing only is moderately applicable to initial medium to dense infestations, but not in low density or follow up situations. Cut & treat is highly suitable across all situations and hand pulling also works well because soils are generally sandy and plants uproot readily (see picture-insert picture of uprooted chromolaena). Fire is of low use here as fires seldom burn annually and can be patchy, however responding to unplanned fires is critical. Scraping with a dozer may be applicable in flatter more open sites for initial clearing of dense infestations. "No interference" is not a good idea because of the sensitive habitat, the adjacent river system and the nature reserve policy. Care must be taken to also control for a wide diversity of other exotic herbs that are common on riparian sand banks, many are highly toxic and need special control effort to eradicate, solarisation of particular sand banks should be investigated.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.2d) Clearing options for lowveld open savanna and sweet grassveld in a nature reserve/cattle ranch/game reserve

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	**Low density <3m tall**	**Low density >3m tall**	**Medium density <3m tall**	**Medium density >3m tall**	**High density <3m tall**	**High density >3m tall**	**Low density - coppice**	**Low density - no coppice**	**Medium density - coppice**	**Medium density - no coppice**	**High density -coppice**	**High density -no coppice**
Biocontrol	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺
Foliar spray	☺☺☺	☺	☺☺☺	☺	☺☺☺	☺	☺☺☺	☺☺☺	☺☺☺	☺☺	☺☺☺	☺☺
Slash only	☺	☺	☺	☺	☺	☺	☹	☹	☹	☹	☹	☹
Cut & treat	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Hand pull	☺☺	☹	☺☺	☹	☹	☹	☹	☺☺	☹	☺☺	☹	☺
Fire	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Scraping with dozer	☹	☹	☹	☹	☹	☺☺	☹	☹	☹	☹	☹	☹
No interference	☺	☺	☺	☺	☺	☺☺	☺	☺	☺	☺	☺	☺
Best Management Approach	Fire; cut & treat; foliar spray	Fire or cut & treat	Fire; cut & treat; foliar spray	Fire or cut & treat	Fire; cut & treat; foliar spray	Fire or cut & treat	Fire; cut & treat; foliar spray	Fire; cut & treat; foliar spray	Fire; cut & treat; foliar spray	Fire; cut & treat; foliar spray	Fire; cut & treat; foliar spray	Fire; cut & treat; foliar spray

There are more options here than in most other habitats. Fire is the most useful control method across all situations as grass fuel can accumulate quickly enough to support annual fires if rainfall is adequate, and there is not overgrazing. Cut & treat is the next best method followed by foliar spray, although the latter is limited by growing season. Biocontrol is of low suitability here because of aridity and frequent droughts. No interference is considered an option here in drought years because of natural die back that could happen. Scraping with a machine may be possible in more open situations, or to clear Sickle-bush infestations. Hand pulling is regarded as moderately suitable because of arid conditions that tend to prevail, and the prevalence of heavier and harder soils that makes uprooting of plants more difficult.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.2e) Clearing options for mixed bushveld on rocky hillsides

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	**Low density <3m tall**	**Low density >3m tall**	**Medium density <3m tall**	**Medium density >3m tall**	**High density <3m tall**	**High density >3m tall**	**Low density - coppice**	**Low density - no coppice**	**Medium density - coppice**	**Medium density - no coppice**	**High density -coppice**	**High density -no coppice**
Biocontrol	☺	☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☹	☹	☹	☹	☹	☹
Foliar spray	☺☺	☹	☺☺	☹	☺☺	☹	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Slash only	☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Hand pull	☺	☹	☺	☹	☹	☹	☺	☺	☺	☺	☹	☹
Fire	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺☺	☺☺
Scraping with dozer	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
No interference	☹	☹	☹	☹	☹	☺☺	☹	☹	☹	☹	☹	☹
Best Management Approach	Cut & treat	Cut & treat	Biocontrol, Cut & treat	Biocontrol, Cut & treat	Biocontrol, Cut & treat	Biocontrol, Cut & treat	Cut & treat	Cut & treat	Cut & treat	Cut & treat	Cut & treat	Cut & treat

Mixed bushveld on rocky hillsides encompasses a variety of habitats that may require different control methods. For example, steep south slopes will be more mesic and chromolaena and lantana may keep growing into the dry season on south facing slopes (enabling herbicide use in autumn and winter). North facing slopes are more arid and probably limit the growth and spread of weeds here, and herbicide use will be more limited to summer periods with high rainfall. The rockiness of the terrain also means that hand pulling might be less effective. Fire is also likely to be of limited use in this habitat for the following reasons 1) fires do not tend to burn here on an annual basis and are much less frequent than in open savannas 2) the rockiness of the terrain limits the accumulation and density of fine fuels, and this limits the effectiveness of fire as a clearing tool because fires tend to be patchy and there are numerous micro-sites where plants can escape being burnt. Thus, once again, the cut & treat method is the best method across all densities and heights. Biocontrol release on cooler, well wooded south facing slopes, is probably best for current agents.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.2f) Clearing options for forest

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	Low density <3m tall	Low density >3m tall	Medium density <3m tall	Medium density >3m tall	High density <3m tall	High density >3m tall	Low density - coppice	Low density - no coppice	Medium density - coppice	Medium density - no coppice	High density -coppice	High density -no coppice
Biocontrol	☺	☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☹	☹	☹	☹	☹	☹
Foliar spray	☺☺	☹	☺☺	☹	☺☺	☹	☺☺	☺☺	☺☺	☺☺	☺☺☺	☺☺☺
Slash only	☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Hand pull	☺☺☺	☹	☺☺☺	☹	☺☺	☹	☺	☺☺☺	☺	☺☺☺	☺	☺☺
Fire	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
Scraping with dozer	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
No interference	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹
Best Management Approach	Hand pull, Cut & treat	Cut & treat	Biocontrol, hand pull, cut & treat	Biocontrol, cut & treat	Biocontrol, cut & treat	Biocontrol, cut & treat	Cut & treat	Hand pull, Cut & treat	Cut & treat	Hand pull, Cut & treat	Cut & treat, foliar spray	Cut & treat, foliar spray

In this system, fire, scraping with a dozer and no interference are not suitable. This is because fires very seldom burn into forest and fire is not part of the forest ecosystem. Forests are also specially protected in South Africa, so special precaution must be taken not to disturb the process of natural regeneration of forest trees when clearing chromolaena and lantana. Since forests tend to develop in mesic sites, and because the forest itself creates a cool shaded environment with deeper soils, hand pulling of young plants in this habitat is highly recommended especially at low and medium density. However, in rocky areas rather use the cut & treat method. Lantana is not shade tolerant, and only establishes in canopy gaps or on the edges of forest. Chromolaena seems to be slightly more shade tolerant, but its growth is still inhibited in the shade. Thus, if the forest is undisturbed these invaders are unlikely to be problematic in this system. However, they have the potential to seriously reduce the size and composition of forests by burning in drought conditions after above average summer rainfall. Thus all attempts should be focused on prioritising clearing at the forest edge and stacking fuel in such a way that forest edges and canopies are unlikely to be scorched in the fire that follows.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.2g) Clearing options for plantations

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	**Low density <3m tall**	**Low density >3m tall**	**Medium density <3m tall**	**Medium density >3m tall**	**High density <3m tall**	**High density >3m tall**	**Low density - coppice**	**Low density - no coppice**	**Medium density - coppice**	**Medium density - no coppice**	**High density -coppice**	**High density -no coppice**
Biocontrol	☺	☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺	☺	☺	☺	☺	☺
Foliar spray	☺☺☺	☺	☺☺☺	☺	☺☺☺	☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Slash only	☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺	☺☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Hand pull	☺☺	☹	☺☺	☹	☺☺	☹	☺	☺☺	☺	☺☺	☺	☺
Fire	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Scraping with dozer	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
No interference	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Best Management Approach	Foliar spray	Cut & treat	Biocontrol; foliar spray	biocontrol	Biocontrol, foliar spray	biocontrol	Foliar spray	Foliar spray	Foliar spray	Foliar spray	Foliar spray	Foliar spray

Plantations tend to occur in more mesic situations and are usually well shaded so biocontrol release may be particularly applicable here. Further, it is more likely for plantations to accommodate alien reserves for biocontrol (relative to reserves or cattle ranches), so they may serve an important function in this regard. Since plantations are not aiming to preserve natural plant diversity, it thus becomes feasible to use foliar spraying more liberally, without having concern for drift onto non-target plants. Cut & treat and hand pulling are regarded as moderately suitable because they are more time consuming without offering any benefits. Fire is feasible if done in a careful manner that ensures the plantation trees are not damaged. However, this limits the use of hot fires to kill seed banks. Scraping with a dozer might be applicable if clear felled areas are invaded. No interference is more applicable here, as these areas might not be regarded as priorities for conservation.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.2h) Clearing options for fallow lands

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	**Low density <3m tall**	**Low density >3m tall**	**Medium density <3m tall**	**Medium density >3m tall**	**High density <3m tall**	**High density >3m tall**	**Low density - coppice**	**Low density - no coppice**	**Medium density - coppice**	**Medium density - no coppice**	**High density -coppice**	**High density -no coppice**
Biocontrol	☺	☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺	☺	☺	☺	☺	☺
Foliar spray	☺☺☺	☺	☺☺☺	☺	☺☺☺	☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺	☺☺☺
Slash only	☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺	☺	☺	☺	☺	☺
Cut & treat	☺☺	☺☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Hand pull	☺☺	☹	☺☺	☹	☺☺	☹	☺	☺☺	☺☺	☺☺	☺	☺
Fire	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Scraping with dozer	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
No interference	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Best Management Approach	Foliar spray	Cut & treat	Biocontrol; foliar spray	biocontrol	Biocontrol, foliar spray	biocontrol	Foliar spray	Foliar spray	Foliar spray	Foliar spray	Foliar spray	Foliar spray
Fallow lands have similar clearing options to plantations. However, since they occur in a wide variety of habitats, the best management approach will need to be manipulated accordingly. Mulching needs to be investigated in this situation, especially for chromolaena, as this is practised in West Africa.												

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.2i) Clearing options for rural areas

	Situation – density and height of chromolaena and/or lantana.											
	Initial situation for control						Follow-up situation for control					
Control option	**Low density <3m tall**	**Low density >3m tall**	**Medium density <3m tall**	**Medium density >3m tall**	**High density <3m tall**	**High density >3m tall**	**Low density - coppice**	**Low density - no coppice**	**Medium density - coppice**	**Medium density - no coppice**	**High density -coppice**	**High density -no coppice**
Biocontrol	☺	☺	☺☺	☺☺	☺☺	☺☺	☺	☺	☺	☺	☺	☺
Foliar spray	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺	☺
Slash only	☺	☺☺	☺☺	☺☺	☺☺☺	☺☺☺	☺☺	☺	☺	☺	☺	☺
Cut & treat	☺☺	☺☺☺	☺☺	☺☺☺	☺☺	☺☺	☺☺☺	☺☺	☺☺☺	☺☺	☺☺	☺☺
Hand pull	☺☺☺	☹	☺☺☺	☹	☺☺	☹	☺	☺☺☺	☺	☺☺☺	☺	☺☺
Fire	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺	☺☺
Scraping with dozer	☹	☹	☺	☺	☺	☺	☹	☹	☹	☹	☹	☹
No interference	☹	☹	☹	☺☺	☺☺	☺☺	☹	☹	☹	☹	☹	☹
Best Management Approach	Hand pull	Cut & treat; slash & burn	Hand pull	Cut & treat; Slash & burn	Slash & burn	Slash & burn	Cut & treat; Slash & burn	Hand pull	Cut & treat; Slash & burn	Hand pull	Cut & treat; Slash & burn	Cut & treat; Slash & burn

In rural areas there is a wide diversity of situations. The use of herbicides in such areas is regarded as moderate to low because of health hazards and to favour methods that people can use without needing herbicides. The cut & treat method is regarded as a safest if herbicides are used. Fire is of moderate use because of risk of damage to property and also because overgrazed areas tend not to support annual fires. Hand pulling is regarded as the best method in low to medium density for younger plants, and can include digging if necessary. Mulching and solarisation need to be investigated and possibly promoted in rural areas. Rehabilitation following clearing by sowing appropriate grass species may be necessary in places where the natural veld is severely degraded and soil erosion is happening. Planting and nurturing of indigenous hardy, spiny and thicket forming bushes and trees should be done in barren parts.

Where (☺☺☺) indicates that suitability of the method is high; (☺☺) indicates that it is moderate; (☺) indicates that it is low and (☹) indicates that it is unfeasible based on its effectiveness and practicality.

4.4.3 Exploring different alternatives and combinations of methods

The above tables only serve as a rough guide that stimulates thought on the best procedure to follow when clearing chromolaena and lantana. The most important aspect of clearing these two aliens is that one may have to follow up an initial clear annually for five years to reach an acceptable maintenance phase.

However, the key to effective alien plant management is good teamwork on a day-to-day basis. The foreman of each team needs to have people skills and a good knowledge of the range of available control options. The integration of the different options such as hand pulling, foliar spray and cut-and-treat within the same area is likely to produce the best results. It also allows workers to rotate between different clearing methods. Such an approach is also suited to the nature of early infestations of these weeds, which tends to be fairly patchy and variable across the landscape. Effective management demands "thinking on one's feet" and the capacity to adapt control operations to situations as they arise. For example, three workers are handpulling and come to a rocky patch where the plants they are uprooting break off at the base. Rather than continuing, they call a cut-and-treat worker and show him the place where cut-and-treat is the preferred method, and proceed at the point where plants are once again uprootable.

A good understanding of weather patterns and being able to mobilise many teams to seize opportunities created by catastrophic fires or floods or droughts is also very important for effective clearing and ecosystem recovery.

Working for water alien clearing team ready to apply clearing treatments.

5. Discussion

5.1 Discussion of the protocols

A set of tools has been produced. We are confident that these should provide Working for Water project managers and workers with enough information to make the right decisions about which control method to use. The protocols are useful in that they tend to accommodate a wide variety of control options that are feasible. The worthiness of the tools developed here will only be realised once they have been tried and tested in the field, and further developed and refined by the appropriate experts.

5.2 Discussion of the field studies.

The project has successfully set up two long-term monitoring programmes that have the potential to continue operating. We are confident that we have collected the necessary data and taken the necessary steps to allow these studies to be repeated. As far as we know, this is the first time this kind of study has been done in the region, and it has potential to be used as a guide for establishing further monitoring plots for assessing the effectiveness of clearing operations in the Savanna Biome.

Relocation of pegs has been fairly successful; at only 12 sites (13%) could the pegs not be found. Of these 12 only two plots have been lost to agricultural development in the Soutpansberg. All other plots were still sampled after careful repositioning of the pegs based on the photographic records from 2004. The re-sampling of the plots two years after they were established was achieved.

The project has networked with various participants, and the measures are in place to ensure that the connections made are maintained. This could help for the findings of this study to be well distributed across the landscapes where this is needed. Direct contacts that should receive the products of this project are found in Table 7.

Table 7: The people that were involved with locating the sites for the study and for past and future clearing operations that take place.

Region	Contact Person	Affiliation	Contact Number
Soutpansberg	Andre Sevenster	Previous WfW project manager	0155162934; 0833009708
Soutpansberg	Lukas Maremba	Current WfW project manager	0155162934; 0828029283
Tzaneen	Brendon Mashabane	Current WfW regional manager	0828028796
Hazy View	Peter Binney	Previous Casa do sol reserve manager	0827437546
Hazy View	Lady Smith	Current Casa do sol reserve manager	0826749644
Hazy View	Allan White	WfW project manager	0834388701
Swaziland	Ngwane Brilliant Dlamini	Mlawula NR manager	092683838453; 092686124032
Swaziland	Philip White	RSSC environmental manager	09268-3134000/629
Swaziland	Sandile Dlamini	Swaziland Department Agriculture	09268-3134763
Swaziland	Allan Howland	Isis livestock farm	09268 6029171
Phinda	Matthias Wessels	Phinda reserve, past clearing manager	035-5620271; 0731556545

Region	Contact Person	Affiliation	Contact Number
Phinda	Brett Pearson	Current clearing manager	035-5620271; 0833390654
Hluhluwe	Zanele	Past WfW project manager	0723416836
Hluhluwe	Sue Van Rensburg	KZN Wildlife, director research	0355620606 ext 214/ 0845488134
Hluhluwe	Andrew Whitley	WfW GIS specialist	033302051
Kruger Park	Zebulon Shlingwani	WfW project manager	0826849856
Kruger Park	Llewellyn Foxcroft	Alien weed research	0829082676

6. Recommendations

If the long-term potential of this project is to be realised, then it should investigate re-marking the plots with pegs that cannot be moved, but are also reasonably easy to find. This would be the priority step to take if this project were to be continued. The next step would be to do another sampling and treatment at the Tzaneen experimental sites in June 2007. The permanently marked sites should be resampled in 2008.

7. Summary

The vegetation and ecosystem function of sweet grassveld and mesic savannas are described. The problem of bush encroachment and how this tends to be part of the invasion process is detailed. The biology and ecology of the two focus weeds, chromolaena and lantana, are described. A list of the other weeds that are invasive in this ecosystem are provided. The various control methods that can be used are described and the advantages and disadvantages of each method are listed. Practical tips to consider when applying the different treatments are also provided. Following this the various aspects of the ecosystem that need to be considered when choosing clearing methods are briefly described in broad categories. These included various indigenous habitat types, land uses, density and height/age of aliens, seasonality and variation in rainfall. Finally clearing protocols are developed for four different climate scenarios and nine different habitat/land use situations. These could be used by WfW managers to choose the best approach to clearing based on a wide range of factors and situations.

The report also provides the methods and results of two field studies that were done between 2004 and 2006 in the Appendices. The results show that alien plant control is effective and that indigenous diversity increases following the application of control measures. The results indicate that WfW can be proud of their control efforts to date. This report provides information, data and ideas that can be used to enhance the effectiveness of WfW clearing teams in the control of invasive alien plants in the savanna ecosystem.

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9. Appendices

9.1 Appendix 1: Results from permanent sample plot study

9.1.1 Introduction

This field study was done to establish an overview of the clearing problem in different regions. It also involved informal discussions with a wide variety of people involved in alien clearing. This enabled us to develop an understanding of the different clearing methods that were being used and measuring the impact these were having on the indigenous recovery.

9.1.2 Methods

9.1.2.1 Site Selection

In the original or proposed sampling design we had envisaged a detailed and stratified sampling design for this study (Annexure 1). However, during the first field trip in May 2004 it became quickly apparent that adhering to this sampling design was impossible. We took the approach of asking the relevant personnel in each region to show us areas where there was a known clearing history and where there was clearing planned for in the future. We selected our sites in these areas in places where either *Chromolaena odorata* and/or *Lantana camara* was present. It will not be possible to do any rigorous statistical analyses on the data collected on these plots, and they were not designed to be able to do this. They were selected to be suitable sites for us to assess the effectiveness of clearing that would be done in the two-year period before revisiting the sites.

Figure 1 and Table 1 provide basic information on the 59 permanently marked plots, from seven different regions namely Soutpansberg, Tzaneen, Hazy View, Kruger Park, Swaziland, Phinda and Hluhluwe. Most of these plots fall within the Savanna Biome under the Lowveld Bioregion, but Lowveld riparian forest and forest habitats were also included (Mucina & Rutherford, 2006). The reason for setting up the sites over such a wide area was to try and cover a range of climates as well as incorporating different clearing treatments and veld management practises from the different areas. The plots were resurveyed in June 2006.

The plots were marked with one steel peg hammered into the earth at the centre of the circular plots. The pegs were made of 10 mm diameter steel rods of 30 cm lengths. A uniquely numbered steel cap was welded onto the top of the rod to ensure that the pegs were "animal friendly". The pegs protruded only 5 cm above the ground in an attempt to make them difficult to see (and therefore safer from theft) or from being knocked out by animals.

In order to facilitate the relocation of the pegs the following measures were taken. A hand drawn sketch was made of roads leading to the plots, and the distances measured using the car speedometer. A written description of how to locate the pegs indicates the major trees present and the distance and direction of their bases from the peg. A GPS co-ordinate was taken at each peg in 2004 and 2006. Red spray paint was used to mark trees close to the peg in 2004 and this paint was still visible in 2006. In 2006 danger tape was tied around the peg to make it easier to find, and also to mark the access point from the road. Four fixed point photographs were taken from a tripod with the camera lens at 125 cm above the ground in a north, east, south and west direction in 2004 and 2006. Photographs were also taken from the access road towards the plot with a person standing on the peg in 2004 and 2006. A photograph was also taken from about 1.5 m above the ground directly down to the peg and by placing the camera on the ground next to the peg and taking a picture directly upwards. The photograph numbers were recorded on the data sheets and are provided in the excel spreadsheets submitted with this report.

The data recorded at each plot was captured on data sheets that are summarised in Annexure 1. Two circular plots were laid down around the peg. One was a small 1.5 m radius plot where the density and height of all plants was recorded and the second a larger 10 m radius plot where the diversity of different growth forms and other information on indigenous and exotic plants was recorded.

Soil samples were also taken from these sites in 2006 by taking three shallow spade fulls of the top 3 cm of soil from three different places in the plot. The soil is stored in brown paper packets in a drying room in Skukuza. Unfortunately the germination studies planned for the soil samples were not done.

Permanent plot (peg 57) is located in Swaziland in a riparian habitat alongside a sugar cane plantation. It was sampled on 17 May 2004. It had no grass cover, 100 % cover of chromolaena and 75 % cover of lantana. The site was slashed in November 2004. The copice was then sprayed with glyphosate before the site was burnt in a very hot fire in October 2005.

The site was resampled on 14 June 2006. The plot had 100 % cover of Panicum maximum grass, 8 % cover of chromolaena and 5 % cover of lantana. Other weeds emerging included Tagetes minuta, Solanum seaforthianum, Ricinus communis, Melia Azedarach.

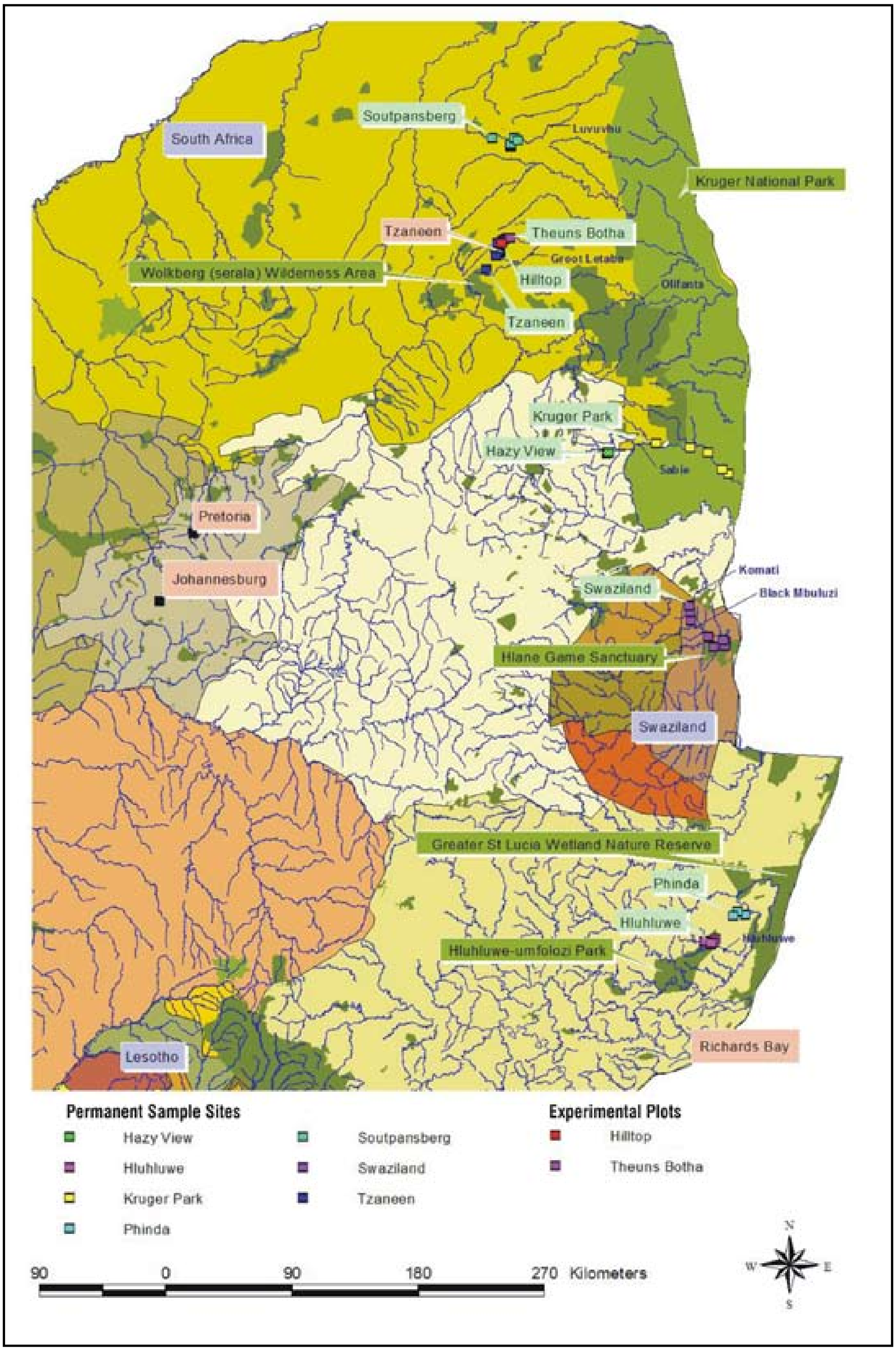


Figure 1: Map of the study area showing the location of permanent sample sites and experimental plots

Table 1: Plot data for the regions and sites sampled during May 2004 and June 2006. See Annexure 1 for summary data pertaining to these plots

Region	Site Name	Peg	GPS South (o)	GPS East (o)	SA Vegetation type	Notes and insights: Show case best approaches
Soutpansberg	Albasini Dam	70	23.10445	30.13066	Tzaneen Sour Bushveld (SVI8)	Site disturbed
Soutpansberg	Beaufort Farm 1	144	23.14775	30.25571	Tzaneen Sour Bushveld (SVI8)	Peg removed (missing)
Soutpansberg	Beaufort Farm 2	50	23.14915	30.26320	Tzaneen Sour Bushveld (SVI8)	Natural, uninvaded veld
Soutpansberg	Along road to Brown House	163	23.13470	30.26082	Tzaneen Sour Bushveld (SVI8)	Bulldozed, peg missing
Soutpansberg	Next to Storeroom: B/House	145	23.13984	30.25884	Tzaneen Sour Bushveld (SVI8)	Cleared for agriculture
Soutpansberg	Next to Dam: Brown House	69	23.13372	30.26060	Tzaneen Sour Bushveld (SVI8)	Re-invasion
Soutpansberg	Termite mound: Brown House	63	23.13389	30.26038	Tzaneen Sour Bushveld (SVI8)	Partly disturbed by powerline construction
Soutpansberg	Levubu : Road E29 – 1	59	23.09810	30.28091	Tzaneen Sour Bushveld (SVI8)	Re-invasion showcase, follow up overdue
Soutpansberg	Levubu : Road E29 – 2	55	23.09799	30.28101	Tzaneen Sour Bushveld (SVI8)	Peg not found
Soutpansberg	Levubu Caravan Park	40	23.10972	30.30533	Tzaneen Sour Bushveld (SVI8)	Thickening of chromolaena in shade
Tzaneen	Boet Booysens-Greystone	72	23.74036	30.26321	Tzaneen Sour Bushveld (SVI8)	Re-invasion
Tzaneen	Koekwe (Theuns Botha)	128	23.73272	30.28231	Tzaneen Sour Bushveld (SVI8)	Still low alien cover
Tzaneen	Cheviot House	67	23.94105	30.14468	Tzaneen Sour Bushveld (SVI8)	Peg moved during clearing and repositioned. Effective clearing
Tzaneen	Guinea Flower 1	77	23.85192	30.20860	Tzaneen Sour Bushveld (SVI8)	Re-invasion
Tzaneen	Guinea Flower 2	82	23.85172	30.20919	Tzaneen Sour Bushveld (SVI8)	Re-invasion
Tzaneen	Delarey 1	68	23.75451	30.24345	Tzaneen Sour Bushveld (SVI8)	Effective clearing
Tzaneen	Delarey 2	99	23.75432	30.24352	Tzaneen Sour Bushveld (SVI8)	Effective clearing
Tzaneen	Mieliekloof Abattoir	73	23.76883	30.21447	Tzaneen Sour Bushveld (SVI8)	Thickening of chromolaena
Tzaneen	Guinea Flower 3	78	23.85156	30.20951	Tzaneen Sour Bushveld (SVI8)	Peg removed
Tzaneen	R36 Tzaneen	121	23.85156	30.20951	Tzaneen Sour Bushveld (SVI8)	Only seedlings, next follow up due june2007
Hazy View	Casa do Sol Reserve	135	25.05541	31.07450	Legogote Sour Bushveld (SVI9)	Thickening of Lantana
Hazy View	Casa do Sol 2	142	25.05531	31.07373	Legogote Sour Bushveld (SVI9)	Thickening of Lantana
Hazy View	Casa do Sol 3	80	25.05536	31.07401	Legogote Sour Bushveld (SVI9)	Chromolaena starts to increase
Hazy View	Casa do Sol 4	147	25.05284	31.07776	Legogote Sour Bushveld (SVI9)	No clearing, chromolaena increases
Hazy View	Casa do Sol 5	85	25.04878	31.07891	Legogote Sour Bushveld (SVI9)	No clearing, but decrease in lantana and chromolaena (browsing??)
Hazy View	Casa do Sol Bush	49	25.04895	31.07880	Legogote Sour Bushveld (SVI9)	No clearing, but decrease in lantana and chromolaena (browsing??)

Region	Site Name	Peg	GPS South (o)	GPS East (o)	SA Vegetation type	Notes and insights: Show case best approaches
Hazy View	Casa do Sol Woods 1	76	25.05111	31.08279	Legogote Sour Bushveld (SVl9)	No clearing, indigenous diversity increases
Hazy View	Casa do Sol Woods 2	169	25.05048	31.08271	Legogote Sour Bushveld (SVl9)	No clearing, chromolaena and lantana increases
Swaziland	Mlawula Riparian 1	134	26.19275	32.00876	Lowveld Riverine Forest (Foa1)	No clearing, loss of grass and tree diversity
Swaziland	Mlawula Riparian 2	126	26.19266	32.00910	Lowveld Riverine Forest (Foa1)	No clearing, no change
Swaziland	Siphiso 1	122	26.21215	32.00233	Northern Lebombo Bushveld (SVl5)	No clearing, Parthenium weed invasion
Swaziland	Siphiso 2	109	26.21184	32.00214	Northern Lebombo Bushveld (SVl5)	No clearing, Parthenium weed invasion
Swaziland	Sugarcane Riparian 1	161	26.17033	31.88710	Lowveld Riverine Forest (Foa1)	No clearing, thickening of chromolaena and loss of grass and tree diversity
Swaziland	Sugarcane Riparian 2	148	26.17031	31.88710	Lowveld Riverine Forest (Foa1)	No clearing, chromolaena seedlings abundant
Swaziland	Mbuluzi Control	57	26.16618	31.87825	Lowveld Riverine Forest (Foa1)	Slashed, sprayed and burnt, showcase grass recovery, peg not found
Swaziland	Sandile1	81	26.22690	31.92758	Granite Lowveld (SVl3), Riparian	Slashed only, increase in chromolaena, peg removed
Swaziland	Sandile2	123	26.22632	31.92759	Granite Lowveld (SVl3), Riparian	No clearing, increase in chromolaena, peg removed
Swaziland	Mbuluzi Viewpoint South	52	26.17460	31.98958	Granite Lowveld (SVl3), Riparian	Clearing done, chromolaena decreases
Swaziland	Isis L13	51	26.01845	31.73949	Granite Lowveld (SVl3)	No clearing, chromolaena has disappeared??
Swaziland	H6	95	26.07014	31.75029	Granite Lowveld (SVl3)	No clearing, increase in lantana
Swaziland	T6 Canal	151	25.97843	31.73182	Granite Lowveld (SVl3)	Seepage from canal, no clearing, increase in chromolaena
Phinda	Finfoot Fenced in Area	124	27.89610	32.31630	Zululand Lowveld (SVl23)/ Riparian	No clearing since Feb 2004, follow up overdue, chromolaena abundant and flowering
Phinda	Mongoose/ Ubombo road	92	27.88313	32.25814	Zululand Lowveld (SVl23)/ Riparian	Hand pulled in 2005, effective control
Phinda	Marshall Drive	170	27.90900	32.23367	Zululand Lowveld (SVl23)/ Riparian	Initially bulldozed, burnt in Dec 2005, chromolaena still present
Hluhluwe	Fusula / Hilltop Camp	111	28.08990	32.04662	Scarp Forest (Foz5)	Effective control
Hluhluwe	Below Hilltop	112	28.08711	32.04784	Scarp Forest (Foz5)	High cover indigenous herbs, effective control
Hluhluwe	Magangeni A	159	28.06519	32.12084	Zululand Lowveld (SVl23)	Clearing done, decrease in lantana and increase in indigenous diversity
Hluhluwe	Magangeni B	96	28.06467	32.12072	Zululand Lowveld (SVl23)	Combination hand pull and cut & treat, showcase effective control
Hluhluwe	Manzimnyama	176	28.08749	32.10990	Zululand Lowveld (SVl23)	Peg and plot not found, elephant disturbance of trees
Hluhluwe	Sitezi Cleared	66	28.10481	32.09365	Zululand Lowveld (SVl23)	No clearing done, chromolaena 20 cm tall, < 1 % cover
Hluhluwe	Sitezi Uncleared	110	28.10507	32.09349	Zululand Lowveld (SVl23)	Dense chromolaena to 3.5 m tall was cleared by cut & treat, so far effective
Hluhluwe	Zincakeni B	65	28.09411	32.09391	Zululand Lowveld (SVl23)	No clearing, small increase in chromolaena cover
Hluhluwe	Zincakeni A	108			Zululand Lowveld (SVl23)	No clearing, low chromolaena cover

Region	Site Name	Peg	GPS South (o)	GPS East (o)	SA Vegetation type	Notes and insights: Show case best approaches
Kruger Park	Sabie River Pump Station	103	24.01881	31.24925	Granite Lowveld (SVl3), Lowveld Riverine Forest (Foa1)	Lantana cleared, but 5 other alien weeds have increased cover
Kruger Park	Lower Sabie on S3		24.97004	31.40896	Granite Lowveld (SVl3), Lowveld Riverine Forest (Foa1)	Clearing done, six more (total 10) other alien weeds have invaded, Peg missing, site burnt
Kruger Park	Lower Sabie Road	165	24.97934	31.64558	Granite Lowveld (SVl3), Lowveld Riverine Forest (Foa1)	Chromolaena gone but many weed species are still present, peg missing
Kruger Park	Lower Sabie Bridge	74	25.12238	31.92529	Granite Lowveld (SVl3), Lowveld Riverine Forest (Foa1)	Lantana cleared, browsing by hippo
Kruger Park	"Lower Sabie Camp"	143	25.09870	31.88118	Granite Lowveld (SVl3), Lowveld Riverine Forest (Foa1)	Effective clearing, peg missing
Kruger Park	Picnic Spot	158	25.00010	31.77221	Granite Lowveld (SVl3), Lowveld Riverine Forest (Foa1)	No clearing, other exotic weeds increasing cover

9.1.3 Results

9.1.3.1 Assessment of the effectiveness of clearing methods currently used

A summary table of the data is provided in Annexure 1. This data has been very briefly analysed below by grouping the plots into those that were cleared and not cleared during the sample interval (2004-2006). Based on this and the clearing experiments the conclusion is that most clearing methods currently being used are effective.

Table 2: The average and standard deviation of the difference in cover or number of species between 2004 and 2006 for a range of growth forms and aliens. Results show averages for plots where no clearing happened (no interference occurred) compared with where clearing did happen between 2004 and 2006 (interference).

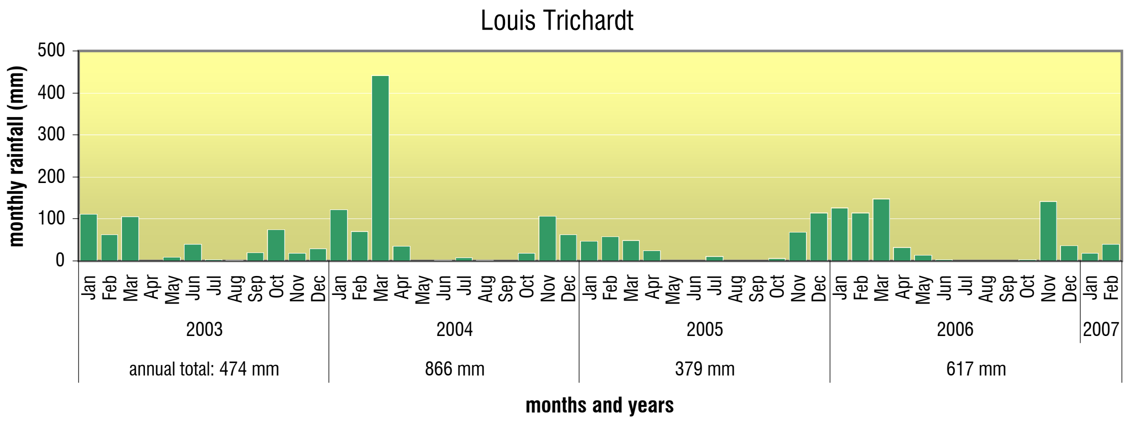
		Difference in % cover and number of species for a range of alien and indigenous vegetation categories between 2006 and 2004 (2006 minus 2004)							
		% grass cover	% chromo-laena cover	% lantana cover	% other alien cover	no. of other alien spp	tree diversity	grass diversity	herb diversity
No interference	N=32	2 ± 25	15 ± 30	1 ± 11	7 ± 16	1 ± 1	3 ± 4	1 ± 2	2 ± 5
Interference	N=25	23 ± 36	-14 ± 41	-6 ± 21	11 ± 19	1 ± 3	3 ± 5	1 ± 2	2 ± 3

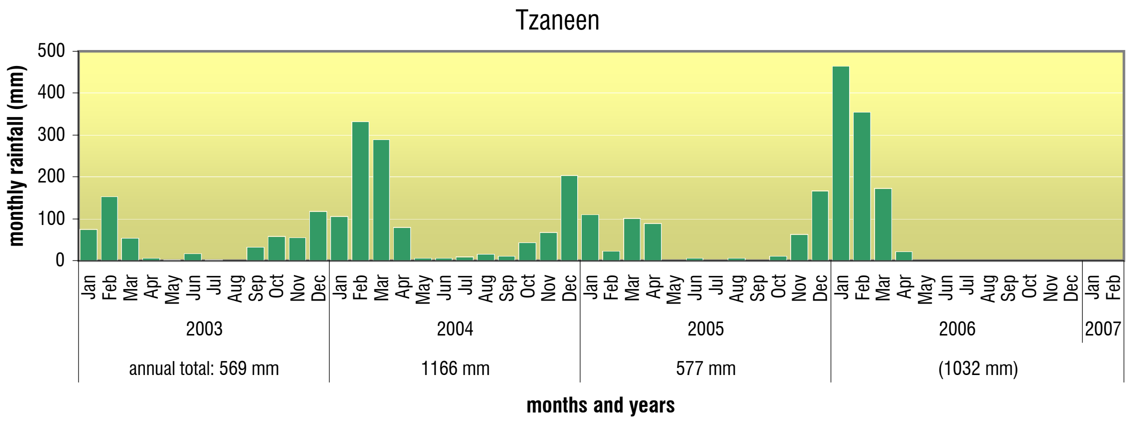
Table 2 shows that overall, clearing does reduce the cover of chromolaena and lantana, but not other alien invasive plants. This is probably related to the phenomenon whereby recently cleared plots are open to invasion, and accumulate opportunistic weed species as well as indigenous plants, especially after good summer rain (see Figure 1). Indigenous grass cover increased more where clearing happened. There was a slight increase in tree, grass and herb diversity for both cleared and uncleared sites. The increase in grass cover could be regarded as a positive sign in terms of using fire as a control method.

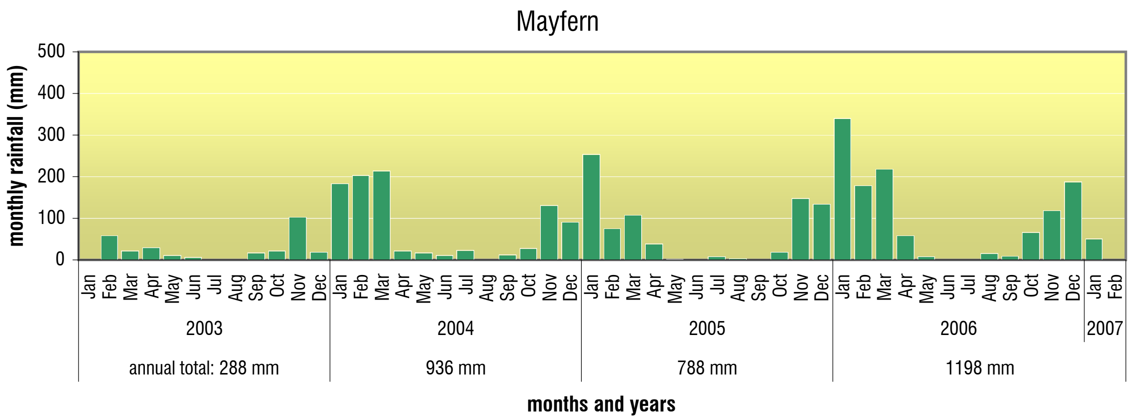
Based on the increase in other alien plants in even cleared plots, there does appear to be a shortage of understanding of the threat posed by other emerging weeds. In many cases these weeds are left alone, and only specified target species are controlled. This is a flaw in training and management that urgently needs to be rectified.

9.1.3.2 The influence of rainfall

Rainfall figures were accessed for the nearest weather stations to the sites (see Figure 2). These show the seasonality of rainfall with summer rainfall and dry winters that is typical of savanna climate. The rainfall figures also show the variation between years, with some years having below average rainfall and others having above average rainfall. In summary 2003 and 2005 were relatively dry years and 2004 and 2006 had above average rainfall. Rain in the 2004/2005-summer rainfall period was late (at the end of summer) while 2005/2006-summer season had good rainfall in spring, summer and autumn. The 2006/2007-summer season has recorded below average rainfall, although March 2007 rainfall has not been recorded yet.







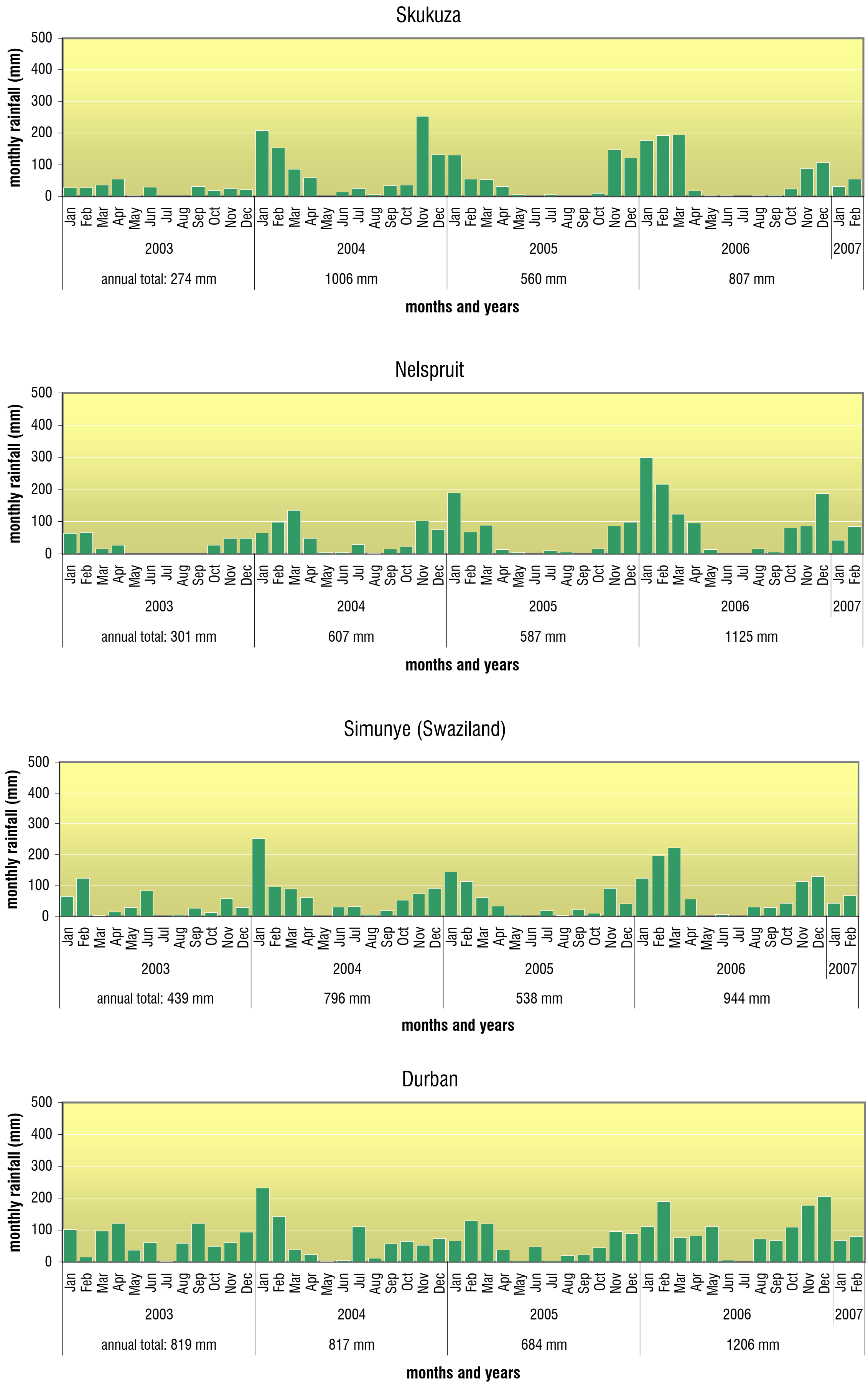


Figure 2: South African Weather Service monthly rainfall figures from seven weather stations nearest to the permanent plots. Simunye rainfall data was provided by Philip White, RSSC Environmental Manager at Simunye. Annual rainfall totals are also shown

The slight increase in indigenous diversity in both cleared and uncleared plots that was recorded in 2006 can be partly attributed to the good 2005/2006-summer rainfall season.

9.1.4 Discussion

These results demonstrate the ecological benefits of alien clearing. The informal discussions about the problem at the various sites, and interacting with people that deal with alien vegetation management on a day-to-day basis were very helpful. It allowed the project to develop clearing protocols that are realistic and practical.

Annexure 1: Summary data for the 59 permanently marked sites

			Historical cover aliens	Was clearing done between 2004 and 2006?	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006
PLOT No	PEG No	SITE/PLACE	(%)		% cover grasses 2004	% cover grasses 2006	% cover chro-mo-laena 2004	% cover chro-mo-laena 2006	% cover lantana 2004	% cover lantana 2006	% cover other aliens 2004	% cover other aliens 2006	number of other alien species 2004	number of other alien species 2006	Number of tree species 2004	Number of tree species 2006	Number of grass species 2004	Number of grass species 2006	Number of native herb species 2004	Number of native herb species 2006
1	70	Soutpansberg: Albasin Dam	100	yes	0	10	0	0	30	4	36	57	3	4	22	17	2	6	9	10
2	144	Soutpansberg: Beaufort Farm	100	yes	1	80	90	20	5	1	1	15	1	4	10	13	5	1	7	8
3	50	Soutpansberg: Beaufort Farm	0	no	90	95	2	0	0	0	5	1	3	1	8	8	7	6	14	14
4	163	Soutpansberg: Brown House (Store Room)	100	yes	0	80	100	60	10	1	0	0	0	0	9	1	0	1	4	2
5	145	Soutpansberg: Brown House (Store Room)	100	-	0	no data	100	no data	20	no data	2	no data	1	no data	9	no data	1	no data	1	no data
6	69	Soutpansberg: Dam Langs	100	yes	0	60	0	1	100	40	0.11	14	2	4	9	17	1	2	0	4
7	63	Soutpansberg: Dam Langs	-	no	50	80	1	20	0.5	5	2.1	4	2	1	7	6	9	6	12	23
8	59	Soutpansberg: Levubu Road (E29B)	100	no	5	4.5	0	80	0	20	5	33	5	4	5	8	2	1	2	0
9	55	Soutpansberg: Levubu Road (E29A)	100	no	90	10	2	100	3	20	17	1	2	1	3	3	2	1	2	0
10	40	Soutpansberg: TJ Grassdakke Caravan Park	-	no	3	1	80	80	10	1	0	1	0	1	13	24	2	2	5	3
11	72	Tzaneen: Boet Booysens_Grey-stone	100	no	3	40	80	75	30	40	17	31	3	6	8	13	2	4	4	1
12	128	Tzaneen: Theuns Botha Farm	0	no	90	80	10	20	0	0	0	2	0	1	10	14	8	10	5	1
13	67	Tzaneen: Cheviot House 1	100	yes	4	80	100	5	0	0	46	60	3	3	9	13	1	2	4	6
14	77	Tzaneen: Guinea Flower 2	100	no	25	40	60	80	5	30	2	12.5	2	4	19	19	3	5	7	6
15	82	Tzaneen: Guinea Flower	100	yes	??	50	75	45	0	5	1	18	1	4	14	19	3	5	7	7
16	68	Tzaneen: De Larey Farm	50	yes	100	100	2	0	2	10	1	12	1	3	17	18	5	7	6	9
17	99	Tzaneen: De Larey Farm	50	yes	100	100	3	2	3	0	0	5.5	0	2	9	12	6	7	4	9
18	73	Tzaneen: Mieliekloof Abatour	100	no	2	2	100	100	100	60	2	3	1	1	10	11	1	2	2	4
19	78	Tzaneen: Guinea Flower 3	100	yes	2	10	5	15	3	40	0	16	0	2	9	14	1	4	7	8
20	121	Tzaneen: Guinea Flower - R36 road	100	yes		80	100	40	50	20	0	30	0	1	8	13	5	7	2	6
21	135	Hazy View: Casa do Sol 1	100	no	10	30	3	4	100	95	4	1.5	2	2	13	19	7	5	5	8
22	142	Hazy View: Casa do Sol 2	100	no	35	10	0	0	100	100	2	12.5	2	4	18	15	5	6	6	6
23	80	Hazy View: Casa do Sol 3	0	no	100	100	0	0	1	4	0	8.5	0	1	12	17	6	8	12	10
24	147	Hazy View: Casa do Sol 4	50	no	35	60	10	20	40	40	0	2	0	2	24	29	9	10	12	13
25	85	Hazy View: Casa do Sol 5	50	no	90	70	25	2	5	1	0	1	0	1	19	23	6	14	10	17
26	49	Hazy View: Casa do Sol 6	50	no	15	15	60	30	3	0.5	0	0.5	0	1	21	29	8	14	5	15
27	76	Hazy View: Casa do Sol 7	50	no	1	15	65	90	2	3	0	2	0	1	16	28	4	10	6	15

			Historical cover aliens	Was clearing done between 2004 and 2006?	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006	2004	2006
PLOT No	PEG No	SITE/PLACE	(%)		% cover grasses 2004	% cover grasses 2006	% cover chro-mo-laena 2004	% cover chro-mo-laena 2006	% cover lantana 2004	% cover lantana 2006	% cover other aliens 2004	% cover other aliens 2006	number of other alien species 2004	number of other alien species 2006	Number of tree species 2004	Number of tree species 2006	Number of grass species 2004	Number of grass species 2006	Number of native herb species 2004	Number of native herb species 2006
28	169	Hazy View: Casa do Sol 8	50	no	1	2	40	60	10	15	2	52	2	5	20	28	4	6	6	16
29	134	Swaziland: Mlawula Riparian 1	100	no	40	5	90	100	0	0	0	2	0	2	14	8	1	4	7	7
30	126	Swaziland: Mlawula Riparian 2	100	no	3	1	80	70	5	3	0	1	0	2	9	13	1	2	4	14
31	122	Swaziland: Mlawula - Siphiso 1	20	no	40	70	10	30	0	1	0	50.5	0	2	14	19	4	5	8	13
32	109	Swaziland: Mlawula - Siphiso 2	20	-	65	80	15	3	2	2	0	45	0	1	17	21	1	4	8	13
33	161	Swaziland: Sugar Cane Riparian 1	100	no	3	0.5	30	85	2	1	10	5.5	3	4	12	10	2	1	4	3
34	148	Swaziland: Sugar Cane Riparian 2	100	no	0	0.5	2	70	2	0	5	3	1	3	8	11	0	2	2	4
35	57	Swaziland: Sugar Cane Contro	100	yes	0	100	100	8	75	5	5	23	1	10	11	8	0	1	0	5
36	81	Swaziland: Sandile 1	100	yes	50	60	2	60	0	0	4	4.5	2	5	14	18	4	4	9	1
37	123	Swaziland: Sandile 2	100	no	90	50	1	60	1	1	8	11.5	3	4	10	13	7	5	7	8
38	52	Swaziland: Mbuluzi	0	yes	90	10	15	1	1	2	2	1	2	2	14	26	6	11	5	10
39	51	Swaziland: Isis L13	15	no	85	95	1	0	0.5	0	2	4	2	3	14	18	3	5	10	13
40	95	Swaziland: Isis H6	-	no	85	80	2	0	15	40	5	3	1	5	13	16	5	6	6	11
41	151	Swaziland: Isis T6 Canal	100	no	95	95	5	70	0	0	0	8	0	3	13	17	4	4	5	11
42	124	Pinda :Finfoot Fenced in Area	100	yes	0	15	0	80	0	0	3	5	3	1	13	12	1	4	4	6
43	92	Pinda :Mangopose Alley/Ubombo Road	10	yes	100	90	0	0	0	0	0	0	0	0	6	13	4	3	6	7
44	170	Pinda :Marshall Drive	100	yes	95	98	10	20	0	0	1	5.5	1	3	8	9	6	5	7	5
45	111	Hluhluwe: Below Hilltop Camp	15	-	30	50	1	0.5	0	0	20	2.5	1	2	21	21	4	4	7	12
46	112	Hluhluwe: Below Hilltop Camp	15	-	??	15	1	1	0	0	0	0	0	0	15	21	1	3	4	4
47	159	Hluhluwe: Magangeni A	25	yes	95	95	5	1	0	0	2	0	2	0	11	17	8	7	6	10
48	96	Hluhluwe: Magangeni B	25	yes	50	35	20	1	0	0	0	0	0	0	14	21	1	3	7	10
49	176	Hluhluwe: Manzimnyama	-	yes	40	no data	2	no data	0	no data	7	no data	2	no data	21	no data	4	no data	9	no data
50	66	Hluhluwe: Sitezi - Cleared	70	no	60	75	7	0	0	0	1	0.5	1	1	20	12	4	3	17	10
51	110	Hluhluwe: Sitezi - Uncleared	-	yes	85	80	75	0.5	0	0	12	1	3	1	12	19	2	7	12	14
52	65	Hluhluwe: Zincakeni B	100	-	40	95	1	0.5	0	0	2	0.5	1	1	21	24	3	5	13	10
53	108	Hluhluwe: Zincakeni A	-	no	100	100	2	0.5	0	0	7	21	3	4	13	23	3	5	9	20
54	103	Skukuza: Sabie River Pump Satation	-	yes	80	80	0	0	1	0	4	66.5	4	8	17	18	5	6	7	9
55	Not re-corded	Skukuza: Along Lower Sabie Road	-	yes	90	80	0	0	1	0	4	27	4	10	11	8	4	3	12	15
56	165	Skukuza: Along Lower Sabie Road	-	yes	40	30	5	0	1	0.5	5	0	5	2	12	18	2	5	6	10
57	74	Skukuza: Next to Lower Sabie Bridge	-	yes	80	95	0	0	1	0	0	1	0	2	12	16	4	6	10	19
58	143	Skukuza: Picnic Sport	-	yes	80	90	2	0	1	0	0	59	0	5	13	10	4	5	7	14
59	158	Skukuza: Along Lower Sabie Road	-	yes	40	100	0	0	0	0	22	0	4	0	11	15	6	8	13	14

Annexure 2: Original sampling plan for monitoring site selection that was found to be impracticable in the field

Invasion History	Clearing History	Fire History	Habitat Type	Replicate 1	Replicate 2
No invasion	None	Frequent (1-3 years) fires	Riparian Forest		
No invasion	None	Infrequent (>5 year) fires	Riparian Forest		
5-10 years old	Not cleared	Frequent (1-3 years) fires	Riparian Forest		
5-10 years old	Not cleared	Infrequent (>5 year) fires	Riparian Forest		
5-10 years old	Cleared once	Frequent (1-3 years) fires	Riparian Forest		
5-10 years old	Cleared once	Infrequent (>5 year) fires	Riparian Forest		
5-10 years old	Cleared 3+ times	Frequent (1-3 years) fires	Riparian Forest		
5-10 years old	Cleared 3+ times	Infrequent (>5 year) fires	Riparian Forest		
>10 years old	Not cleared	Frequent (1-3 years) fires	Riparian Forest		
>10 years old	Not cleared	Infrequent (>5 year) fires	Riparian Forest		
>10 years old	Cleared once	Frequent (1-3 years) fires	Riparian Forest		
>10 years old	Cleared once	Infrequent (>5 year) fires	Riparian Forest		
>10 years old	Cleared 3+ times	Frequent (1-3 years) fires	Riparian Forest		
>10 years old	Cleared 3+ times	Infrequent (>5 year) fires	Riparian Forest		

Annexure 3: Data Sheets

Data Sheet for Sample Plots in 2004

Date ……………………… Site and Peg No …………………… Site Name ....

Alien species present ....

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GPS point .... S ....E

Digital photo 1.N……., 2. S……….., 3. E…………., 4. W……………; 5. Ground………...……….

Age of invasion ....

Date of last fire ....

Geology/ soil description .... depth(cm) ....

Soil colour ....

Soil texture ....

Tree diversity .... Dominant tree species.......................................

....

....

Grass diversity .... Dominant grass species ....

....

Bush/thicket diversity .... Dominant bush species ....

....

Herb/Shrub diversity .... Dominant herb/shrub spp ....

....

Plant diversity index ....

% Grass cover ....

% leaf litter cover .... leaf litter depth ....

Alien species and density ....

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Alien species and height ....

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Notes ....

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Site No ....

Time ....

Region ....

Location ....

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Location Map

Vegetation description ....

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Landscape description ....

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Vegetation management history and changes that have occurred ....

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Data Sheet for 2006 Sample Plots

Date……………………….Peg No…………………………Site Name…………………………………

Photo 1.N……..,2. S……….,3. E…………..,4. W……………; 5.ground…………6 plot……………

Other photos:..

Notes on what has happened since May 2004 ....

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10 m radius plot – number of species

Trees ……………Grasses…………Herbs…………….Creepers…………Insects……………

....

....

% Cover 10 m radius plots

% ind tree canopy cover……………………% Grass cover……………% Alien litter cover…………

....

% cover Chromolaena .... % cover Lantana ....

% cover other aliens ....

1.5 m density plots

Alien species density and height (m)...

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Indigenous species density and height (m)...

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9.2 Appendix 2: Results from field experiment near Tzaneen

9.2.1 Introduction

This experiment was done in August 2004 to try and test a range of control methods to determine which method produced the best results for controlling chromolaena. This was needed to be able to assess the impact that different clearing methods have on ecosystem recovery. The results of this experiment were used as baseline information for developing the clearing protocols.

9.2.2 Methods

In this study we used Working for Water clearing teams to apply different clearing treatments to permanently marked plots set up in two sites in the Tzaneen area. The Tzaneen region was chosen for this study because *C. odorata* is a major alien invasive in the entire Tzaneen region, and appears to be spreading rapidly here. We also found that the Tzaneen office were interested and keen to participate in the project that relied on their assistance. The treatments were applied to two different study sites. The sites were within 5 km of each other and both were chosen together with Brendon Mashabane, our contact and manager for the Tzaneen WfW office (Ph 0828028796).

The Theuns Botha sites were on a game farm in Tzaneen Sour Bushveld with canopy trees up to 10 m tall including *Pseudolachnostylis maprouneifloia, Terminalia sericea, Euclea schimperi, Pilliostigma thonningii* and *Bauhinia galpinii*. A dense sward of *Panicum maximum* with numerous forbs and abundance of younger trees were present. The site was on a gently sloping hill at 557 m asl with approximately 1 m deep red clay soils with a 30 cm layer of brown loam on the surface. This site was densely covered with *C. odorata* and had already been cleared once in 2003, one year before we applied our experimental follow up treatments in 2004,2005 and 2006.

The Hilltop site was on the upper slopes of a steep hill with shallower stony soils at 774 m asl. The plots were heavily infested with both *C. odorata* and *L. camara* that had never been cleared before. The hilltop vegetation was also a mixed bushveld dominated by *Trichilia emetica* and *Acacia spp.*

The 4m radius circular plot locations were carefully chosen and they were spanned across several hectares of natural bushveld. We chose plots that appeared to have a similar density and cover of *C.*

The capped and numbered steel pegs that were used for marking the plots. The soil was bored out at 10 cm intervals with a soil auger and placed in piles that were given numbered labels in order from the top downwards. For example, 2 is between 10 cm and 20 cm below the surface.

odorata and *L. camara*, as well as representing a similar habitat type. Soil augors were done to ensure that the sites all had similar soils, and although soils did vary slightly between the plots, this was recorded. The centres of the plots were marked with steal pegs similar to that used for the former study (see Appendix 1). The plots were circular and had a radius of 4 m. Danger tape was used to demarcate the plots for the clearing teams. GPS co-ordinates were taken for each plot and photographs of the plot, the peg and the augered soil were taken in 2004 and 2006. After the initial treatments in August 2004, two additional follow up treatments and sampling was done in June 2005 and June 2006. This data was submitted in three excel files together with this report.

Within each 4 m radius circular plot all the indigenous plants (i.e. trees, shrubs, herbs, lianas, creepers, forbs and grasses) were identified and the tree diversity (i.e. number of indigenous trees and shrubs, herb diversity (i.e. number of herbs), and grass diversity (i.e. number of grasses) per plot were established and recorded. Other plot variables such as percentage (%) canopy cover, % grass cover, % *C. odorata* cover and % *C. odorata* flowering were also estimated and recorded. The presence of other invasives within the 4 m radius plot was also investigated and recorded. Soil samples were also taken here in 2004 and in 2006 in order that seed banks could be determined. The botanical data was recorded before the treatments were applied.

The WfW team was then asked to apply the different treatments following their normal clearing methods and schedule. The foremen were also requested to record the time spent per plot and the number of people who were involved during clearing. Table 1 shows the different treatments that were applied at the two sites.

Table 1: Treatments applied to Tzaneen region during August 2004, June 2005 and June 2006.

Site	No. of replicates	Treatments applied
Cleared before	3	Control (no clearing)
Cleared before	3	Hand pulling
Cleared before	3	Hand pulling and stack
Cleared before	3	Foliar spray with GARLON
Cleared before	3	Cut & treat stem with GARLON
Cleared before	3	Cut & treat stem with GARLON and stack
Cleared before	3	Foliar spray with ROUNDUP
Cleared before	3	Cut & treat stem with ROUNDUP
Uncleared before	4	Control (no clearing)
Uncleared before	4	Cut & treat stem with CHOPPER
Uncleared before	4	Cut & treat stem with CHOPPER and stack

A further 1 m radius circular plot was resampled from each 4 m radius circular plot using the centre as the reference point. Within the 1 m radius subplot, the grass cover was estimated and each plant was identified, its density and average height measured. The density of *C. odorata* within this small plot was also counted.

A summary of the treatments applied during August 2004 at Tzaneen and their matching peg numbers are shown in Table 2.

Table 2: Plot identification data for the treated sites at Tzaneen.

Site	Peg No	GPS (South)	GPS (East)	Treatments
Theuns Botha	178	23°44.05′	30°17.36′	Cut & treat stem with GARLON and stack
Theuns Botha	93	23°44.06′	30° 17.40′	Control
Theuns Botha	152	23°44.08′	30°17.42′	Foliar spray with GARLON
Theuns Botha	60	23°44.09′	30° 17.42′	Cut & treat stem with ROUNDUP
Theuns Botha	168	23°44.09′	30°17.42′	Foliar spray with ROUNDUP
Theuns Botha	125	23 °44.09′	30° 17.43′	Cut & treat stem with GARLON
Theuns Botha	174	23°44.07′	30°17.43′	Hand-pulling
Theuns Botha	149	23°44.09′	30°17.43′	Hand-pulling and stack
Theuns Botha	84	23°44.08′	30°17.43′	Cut & treat stem with ROUNDUP
Theuns Botha	131	23°44.07′	30° 17.44′	Foliar spray with ROUNDUP
Theuns Botha	141	23°44.08′	30°17.45′	Cut & treat stem with GARLON and stack
Theuns Botha	94	23°44.09′	30°17.44′	Hand-pulling
Theuns Botha	140	23°44.08′	30°17.40′	Cut & treat stem with GARLON
Theuns Botha	139	23°44.08′	30°17.39′	Control
Theuns Botha	116	23°44.06′	30°17.39′	Foliar spray with GARLON
Theuns Botha	90	23°44.07′	30°17.40′	Hand-pulling and stack
Theuns Botha	106	23°44.07′	30°17.42′	Foliar spray with GARLON
Theuns Botha	101	23°44.08′	30°17.43′	Cut & treat stem with ROUNDUP
Theuns Botha	166	23°44.10′	30°17.42′	Hand-pulling
Theuns Botha	157	23°44.10′	30°17.41′	Foliar spray with ROUNDUP
Theuns Botha	104	23°44.10′	30°17.41′	Control
Theuns Botha	102	23°44.10′	30°17.43′	Hand-pulling and stack
Theuns Botha	130	23°44.09′	30°17.45′	Cut & treat stem with GARLON
Theuns Botha	150	23°44.12′	30°17.42′	Cut & treat stem with GARLON and stack
Hilltop Farm	105	23°46.16′	30°14.24′	Cut & treat stem with CHOPPER and stack
Hilltop Farm	87	23°46.15′	30°14.23′	Cut & treat stem with CHOPPER
Hilltop Farm	86	23°46.16′	30°14.24′	Control
Hilltop Farm	162	23°46.15′	30°14.23′	Cut & treat stem with CHOPPER
Hilltop Farm	164	---	---	Control
Hilltop Farm	177	---	---	Cut & treat stem with CHOPPER and stack
Hilltop Farm	173	---	---	Cut & treat stem with CHOPPER and stack
Hilltop Farm	171	---	---	Control
Hilltop Farm	137	---	---	Cut & treat stem with CHOPPER
Hilltop Farm	175	---	---	Cut & treat stem with CHOPPER and stack
Hilltop Farm	*38*	---	---	Control
Hilltop Farm	*40*	---	---	Cut & treat stem with CHOPPER

9.2.3 Results

Results after 2005 suggested that the cut & treat method was most effective for indigenous recovery, but it did tend to take longer than hand pulling or foliar spray methods.

At the Theuns Botha site a statistical test of stacking versus no-stacking with all variables measured was done and found no significant trends. Stacking does not appear to offer any advantages for indigenous recovery in the follow up situation. Stacking should then only be done if fire damage to trees wants to be minimised, and this is usually only necessary for cases of initial clearing in dense stands.

No significant differences were found between the different herbicides. The Theuns Botha sites were thus analysed under four treatments: control (no treatment); cut & treat; foliar spray and hand pulling. A Kruskal-Wallis ANOVA by ranks was run on the data and found that variables that showed significant differences from the control included a) the % grass cover in 2006 was higher for the cut & treat method ($p=0.01$), b) the % cover chromolaena in 2005 and 2006 was less for the cut & treat method ($p=0.003$ and $p=0.037$) c) the total number of indigenous plants was higher for the cut & treat and foliar spray methods ($p=0.02$ and $p=0.048$) d) chromolaena density in 2005 and 2006 was less for the cut & treat method ($p=0.007$ and $p=0.029$).

The difference between measures of plant variables taken in 2004 and 2005 and also between 2004 and 2006 were calculated and standard deviations around the mean are shown for the different control methods in Figure 1. Between 2004 and 2005 there was little recovery in indigenous vegetation, while the difference between 2004 and 2006 is more dramatic with a pronounced increase in indigenous diversity across all treatments (Figure 1). This can be attributed to relatively low rainfall on 2004/2005 summer season and above average rainfall during the 2005/2006 growing season (see Figure 2). Tree diversity is able to increase under uncleared chromolaena if there is good rainfall, but native herb diversity does not increase and grass cover decreses under chromolaena (Figure 1). Chromolaena cover increased in the control in 2006, but was dramatically reduced in all the sites where clearing treatments were applied.

Hilltop experimental site. The initial cut-and-treat and stack treatment took seven people 53 minutes at this plot (peg 175).

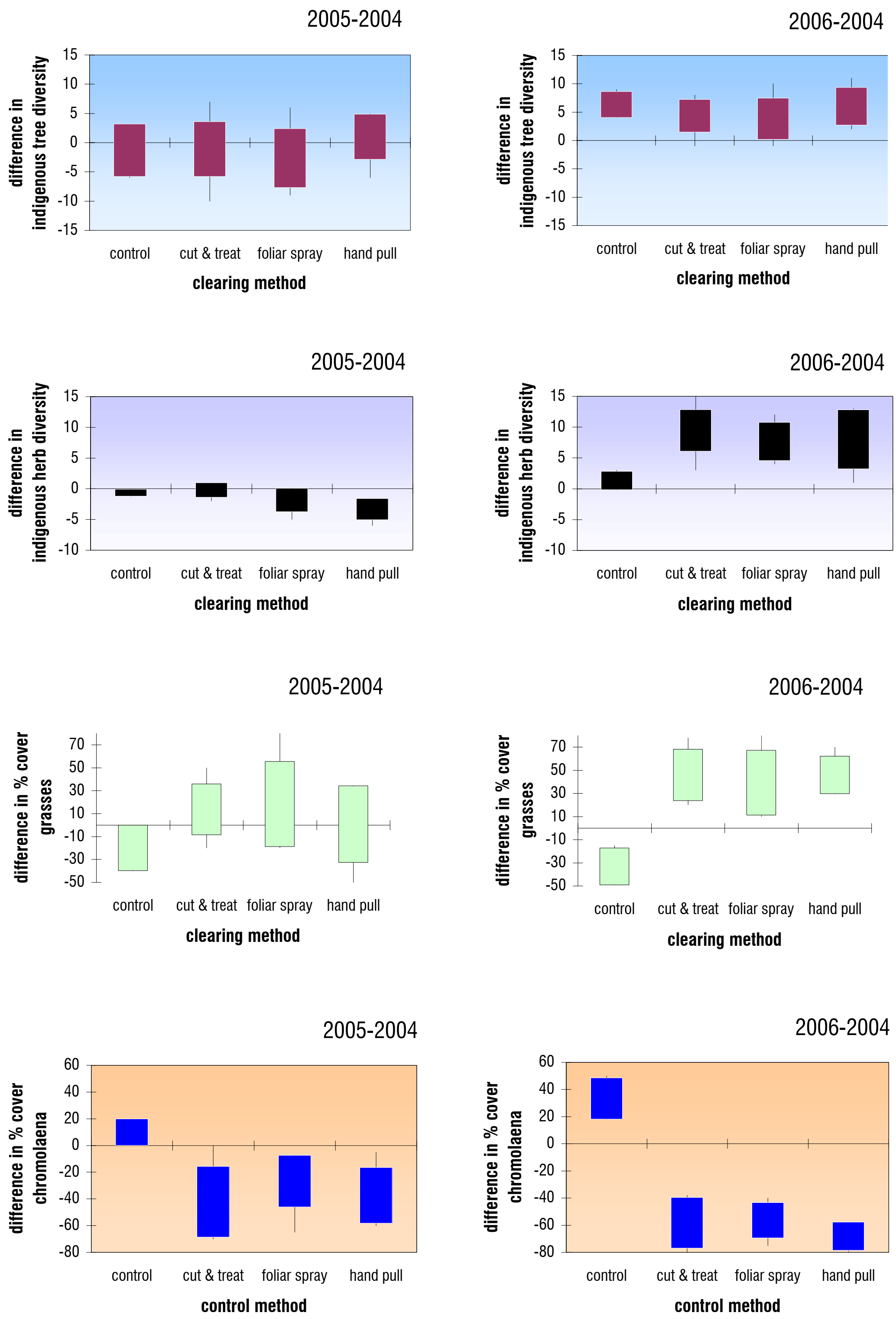


Figure 1: Differences between 2005 and 2004 and between 2006 and 2004 for four different plant variables: indigenous tree diversity, indigenous herb diversity, % cover grasses and % cover chromolaena for the different clearing treatments. Blocks are standard deviations around the mean and lines are maximum and minimum values. Sample numbers are: control - 3; cut & treat - 9; foliar spray - 6; hand pulling - 6.

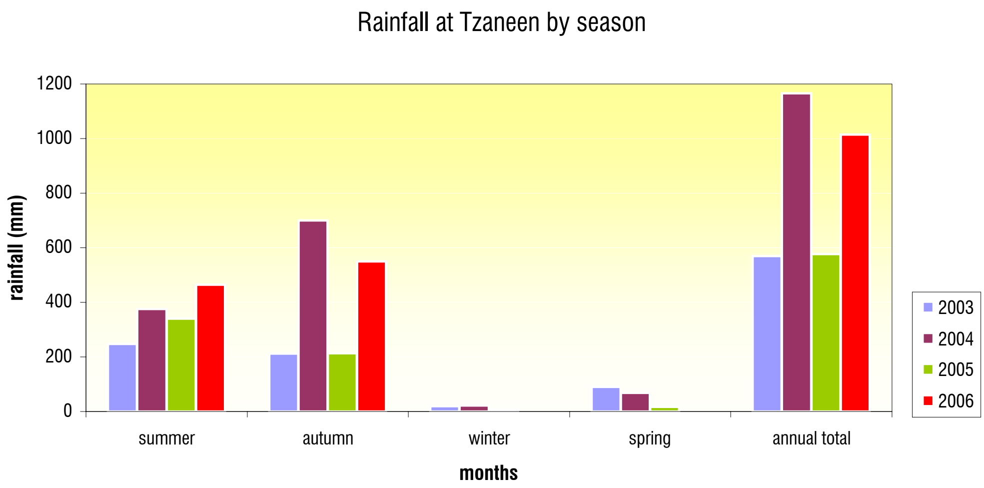
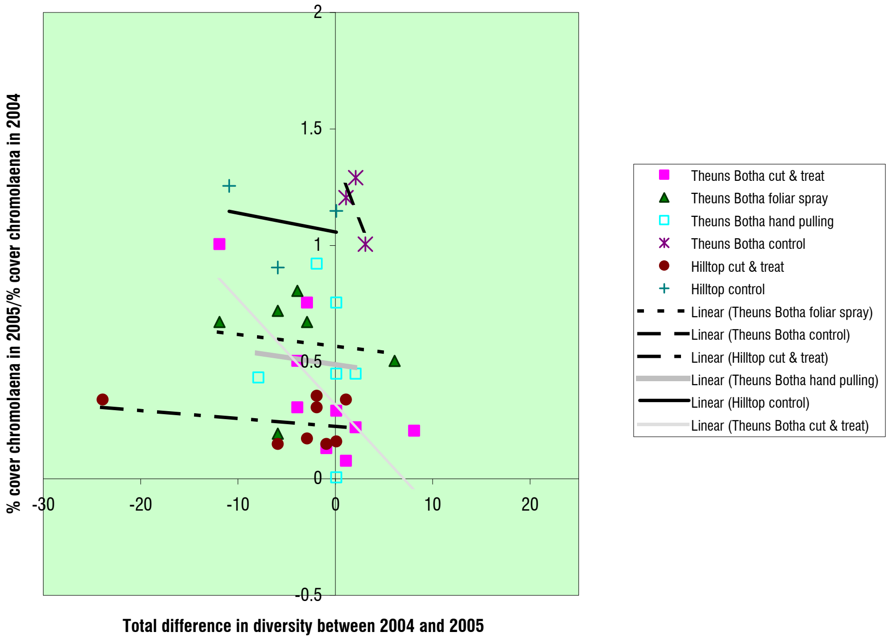


Figure 2: Rainfall by season over four years at Tzaneen. The annual total is also shown. Data supplied by the South African Weather Service (no data available for winter and and spring 2006).

The time and number of people it took to apply the various treatments to the plots was recorded and this was converted to person days per hectare. The follow up treatments were consistently quicker to do than the initial treatments, taking on average one eighth of the time. The foliar spray method was the quickest method while the cut & treat method takes about two times longer (Kruskal-Wallis ANOVA by ranks, p=0.01).

Figure 3a and b provides a broad summary of the results obtained at both sites between 2005 and 2004. and between 2006 and 2004. The cut & treat method was the most effective clearing method at both the Hilltop and Theuns Botha Sites in 2005 (Figure 3a). The foliar spray and hand pulling treatments are also effective but not as effective as the cut & treat method. In 2005 all treatments resulted in an average loss of indigenous species, but by 2006 this had changed to an overall increase in diversity. In 2006 all treatments were very effective for clearing chromolaena, except for the stacking treatment for cut & treat with chopper which had a high recovery of chromolaena at the Hilltop site.



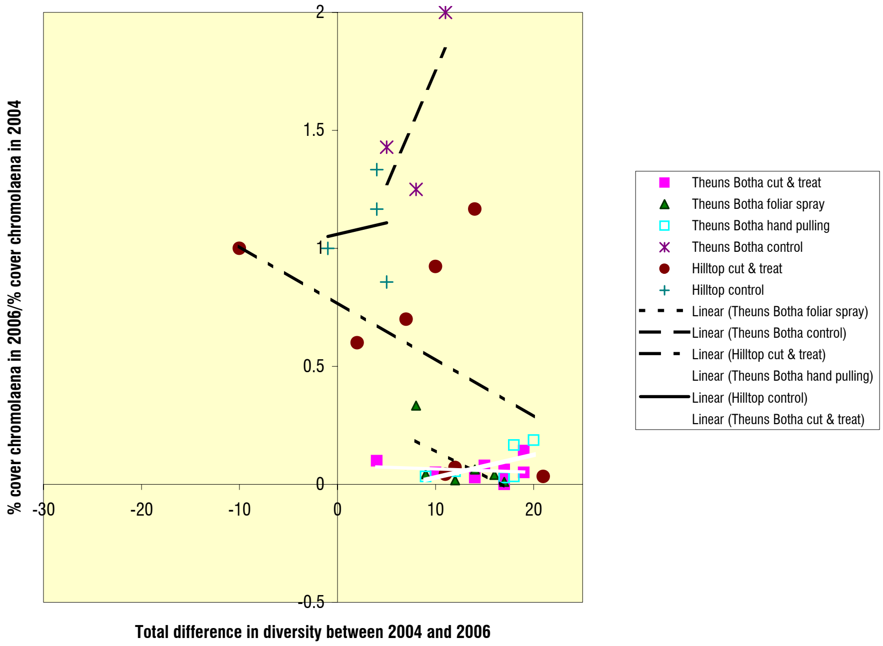


Figure 3a and b: Data was collected from permanently marked experimental plots in Tzaneen in August 2004, June 2005 and June 2006. Clearing effectiveness on the y axis was measured by the ratio produced by dividing the percentage cover of *C. odorata* in 2005 by that in 2004 (Figure 3a) and the % cover C. odorata in 2006 by that in 2004 (Figure 3b) (a lower ratio indicates more effective clearing). The x-axis is the sum of the differences between 2005 and 2004 and between 2006 and 2004 for the indigenous tree, grass and herb diversity recorded in 10 m radius plots centred around the peg (more negative indicates a loss in indigenous species, and more positive indicates an accumulation of indigenous species).

Figure 3b also illustrates how the initial stacking treatment at Hilltop resulted in a higher recovery of chromolaena in 2006, but not for the no stacking treatments.

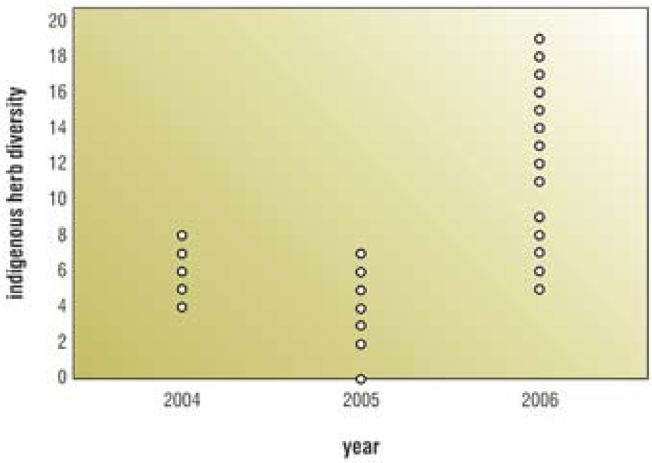


Figure 4: Theuns Botha site. Herb diversity in 10 m radius plots in 2004, 2005 and 2006. ($r^2 = 0.4290$; $r = 0.6550$, $p = 0.0000$; $y = -7636.7153 + 3.8125*x$)

Figure 4 above show how indigenous herb diversity declined after the initial clear but two years later (in 2006) herb diversity had increased significantly.

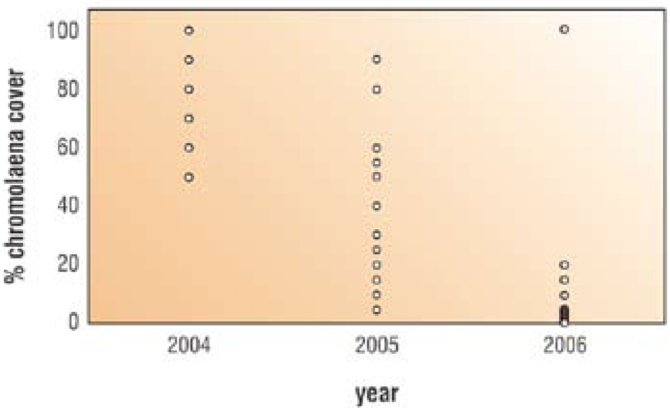


Figure 5: Theuns Botha site. Chromolaena cover (%) showed a significant decrease over three years for all treatments. ($r^2 = 0.4077$; $r = -0.6385$, $p = 0.000000002$; $y = 48974.4397 - 24.4062*x$)

At Theuns Botha the average grass cover across all sites was not significantly different between 2004 and 2005, but in 2006 the average grass cover (72 %) was almost twice as much as the grass cover in 2004 (Figure 1). The density of chromolaena seedlings in 2006 was about eleven times less than its density in 2004 (Figure 7).

The Hilltop sites also produced interesting results. At this site the dense infestation of chromolaena in the surrounding area was not cleared (while at Theuns Botha sites the cromolaeana surrounding the plots was cleared in 2004). This meant that cleared plots were seeded by the surrounding chromolaena. There was also no overall significant decrease in chromolaena density between the different years at Hilltop, and the higher rainfall in 2006 also resulted in an abundance of new seedlings (see Figure 7 below). Further, It was found in 2006 that the sites where stacking was done had more chromolaena seedlings and a higher cover of chromolaena than sites where no stacking was done. This might suggest than mulching by spreading cut chromolaena on the ground might be a useful way of limiting seedling recruitment. The stacked plots also took longer to clear in 2006 because of the higher number and cover of chromolaena and lantana plants that had emerged. (see Figure 6 below).

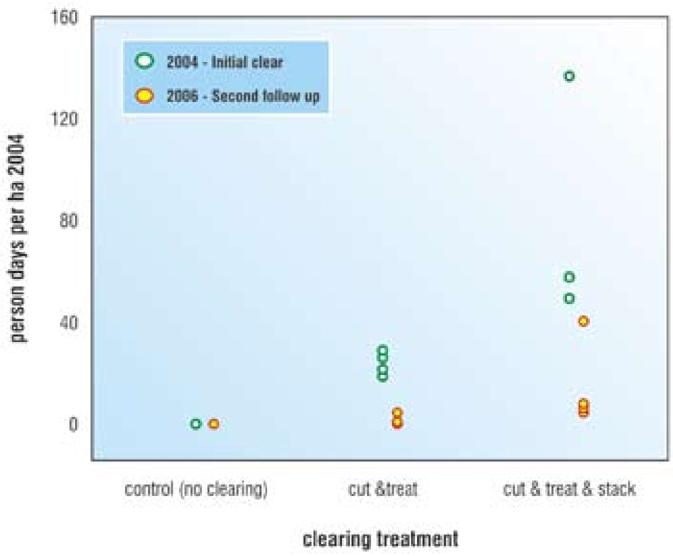


Figure 6: Hilltop site. Person days per ha to apply initial clearing treatments in 2004 and follow up treatment in 2006.

In 2004 the Hilltop sites took an average of 55 person days per ha to clear while in 2005 they took an average of 9 days per ha, which is about six times less. There was a significant average increase in grass diversity at the hilltop site between 2004 and 2006 (T-test p=0.005). The average % cover chromolaena in 2005 (35 %) was significantly less than its average cover in 2004 (74 %) (p=0.001).

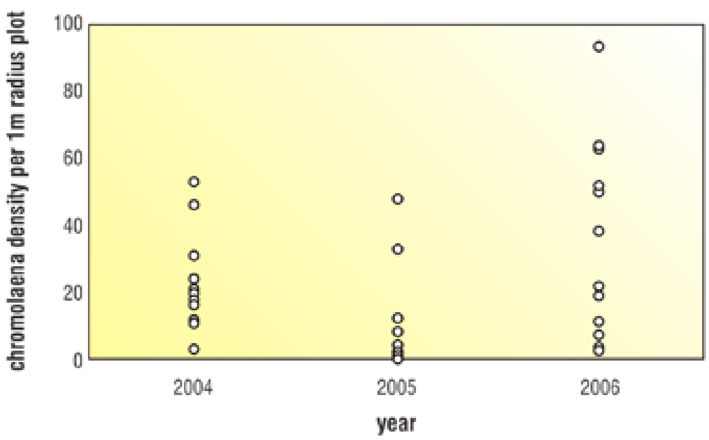


Figure 7: Hilltop site: the change in chromolaena density across all plots in 2004, 2005 and 2006.

9.2.4 Discussion

These results have only briefly analysed the data that has been collected. The experiment has shown that the current clearing methods used by WfW on these two weed species is effective. It has also illustrated how the indigenous vegetation can recover following clearing in both the initial and follow up situations. These results allow managers and field workers to have a sense of pride in their work, and that there efforts are making a positive impact on the indigenous vegetation.

The results are useful in that it stimulates thought in certain aspects that may deserve more careful research. For example, the concept of using slashed material, as mulch for reducing the follow up burden deserves more field studies to verify it as a feasible recommendation.

9.3 Appendix 3: Project budget and logistics

9.3.1 Project schedule, budget and expenditure up to end March 2007

ITEMS	Personnel	Budget Time 2004	Actual time 2004	Budget Time 2005	Actual Time 2005	Budget Time 2006/7	Actual time 2006	Rate (Rh-1)	BudgetCost (R)	Time Spent	Cost
Literature review and methodology development	DMR	10	3	10	1	15		250	8750.00	4	1000.00
	NR	80	60					118.43	9474.40	60	7105.80
	DEB	20	50					118.43	2368.60	50	5921.50
	MA	20	20					100.00	2000.00	20	2000.00
Field surveys	NR	115	115	150	85	115	214	118.43	45003.40	414	49030.02
	DEB	115	152	150	0	115	192	118.43	45003.40	344	40739.92
	AM	115	115	150	92	115	160	12.50	4750.00	367	4587.50
	PN	115	115	150	85	115	160	12.50	4750.00	360	4500.00
Data analysis and report production	DMR	5	2	5	0	20	13	250.00	7500.00	15	3750.00
	NR	100	100	200	50	100	273	118.43	47372.00	423	50095.89
	DEB	50	50	50	38	200	283	118.43	35529.00	371	43937.53
	MA	60	20	60	0	120	0	100.00	24000.00	20	2000.00
Telephone and Stationery	DEB, NR, MA, AM and PN								6000.00		7945.24
Equipment and computer use	DEB, NR								4000.00		2879.95
Accommodation and Subsistence	DEB, NR, AM and PN								20000.00		21474.82
Transport									68500.00		35733.97
Total cost									335000.80		282702.14
Balance											52298.66

9.4 Appendix 4: Acknowledgements

We are grateful for the assistance we got from the following groups of people for their immeasurable assistance during the project period.

1. Working for Water Area Managers, Conservation Bodies and IAP Project Managers

Andre Sevenster	Soutpansberg	Previous WfW Project Manager
Lukas Maremba	Soutpansberg	Current WfW Project Manager
Brendon Mashabane	Tzaneen	Current WfW Regional Manager
Peter Binney	Hazy View	Previous Casa do sol Reserve Manager
Lady Smith	Hazy View	Current Casa do sol Reserve Manager
Allan White	Hazy View	WfW Project Manager
Ngwane Brilliant Dlamini	Swaziland	Mlawula Nature Reserve Manager
Philip White	Swaziland	RSSC Environmental Manager
Sandile Dlamini	Swaziland	Swaziland Department Agriculture
Allan Howland	Swaziland	Isis livestock farm
Matthias Wessels	Phinda	Phinda reserve, past clearing manager
Brett Pearson	Phinda	Current clearing manager
Zanele	Hluhluwe	Past WfW project manager
Sue Van Rensburg	Hluhluwe	KZN Wildlife, director research
Andrew Whitley	Hluhluwe	WfW GIS specialist
Zebulon Shlingwani	Kruger Park	WfW project manager
Llewellyn Foxcroft	Kruger Park	Alien weed research

2. Farmers who offered their farms for the project to be done there without demanding anything in return
3. Field Research Assistants from Skukuza:

   Patrick Ndlovu, Annoit Mashele, South African National Park Field Guards
4. People who assisted in meetings, telephonic discussions etc:

   Ian McDonald, Ed Witkowski, Stefan Neser, Alan Urban, Brian van Wilgen, Costas Zachariades, Lorraine Strathie, Mariske te Beest, Mandisa Mgobozi, Jeremy Goodall, Ahmed Khan, Nceba Ngcobo, Tony Poulter, Budu Manaka, Arne Purves, Ashley Richardson

5. Clearing Teams who did the clearing treatments at Tzaneen

Team A	Team B
Calvin Raseale (Forman)	Moses S. Palane (Foreman)
Phillip Malatjie	Maitje Diale
Simon Boima	Maasodi Mahlo
Obed Leswiswi	Mapeu Diale
Joyce Semosa	Makole Maponya
Olga Ramatladi	Potledi Phoshoko
Grace Nakana	Kgashane Pilusa
Constance Sekoto	Refilwe Sekgobela
	Mmatoto Mogoboya