Control of Invasive *Chromolaena odorata*

An evaluation in some land use types in KwaZulu Natal, South Africa

Phoebe Luwum

February 2002

Control of Invasive *Chromolaena odorata*

An evaluation in some land use types in KwaZulu Natal, South Africa

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information and Earth Observation, Environmental Systems Analysis and Management.

Degree Assessment Board:

Chairman	Dr. J. de Leeuw	NRS Department,	ITC
External examiner	Dr. D. M. Pegtel	Laboratory for Plant Ecology	Universiteit Groningen
Internal examiner	Dr. Y. Hussin	NRS	ITC
Primary supervisor	Dr. I. van Duren	NRS	ITC
Secondary supervisor	Dr. H. van Gils	NRS	ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

ENSCHEDE, THE NETHERLANDS

For mama

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS/ACRONYMS

ARC-PPRI	Agricultural Research Council - Plant Protection Research Institute
CARA	Conservation of Agricultural Resources Act
DWAF	Directorate of Water Development and Forestry
ESKOM	South African electricity company
NBAL	Natural Biological Alien (Mapped unit of WfW in which alien species are controlled)
SAFCOL	South African Forest Company Limited
TELKOM	African communications company
WFW	Working for Water Programme

ACKNOWLEDGEMENTS

I wish to acknowledge the important contribution of Dr. Iris van Duren, my primary supervisor, Dr. Hein van Gils my secondary supervisor and Dr. Jan de Leeuw who offered valuable advice. I would also like to thank Dr. Denis Rugege of the University of Natal in Pietermaritzburg who co-ordinated many aspects of the fieldwork in South Africa.

Staff of the Working for Water Programme and the Lubombo Spatial Development Initiative were most helpful in providing information and contacts during fieldwork. Special thanks to Ms. Samgerisiwe, Carl Myhill, Sakhi and Qolane.

Interviews with various companies and offices provided important information for the study. I would like to especially thank Mondi Limited, SAPPI Limited, SiyaQhubeka Forests, SAFCOL, Mtubatuba Municipality, Derek of Monzi Agri-chemicals, the Induna of KwaMsane and various farm managers who took some time off to talk to me about their work.

Finally, I want to thank Abaye Kindie Feleke and Michael Mwangangi with whom I shared so much in South Africa.

ABSTRACT

Chromolaena odorata (L.) R. M. King and H. Robinson, is a neotropical Asteraceae considered to be one of the most aggressive invasive plants in tropical and sub-tropical areas. *Chromolaena odorata* is said to be a particular threat in KwaZulu Natal - South Africa, hindering biodiversity conservation by changing vegetation composition, reducing grazing for large herbivores and reducing tourism potential by obstructing game and bird viewing in recreation areas. In silviculture *C. odorata* is a problem during the establishment and harvesting phase, increasing costs of production, and adversely affecting crops. The plant reduces the acreages that can be effectively managed by farmers, particularly in small-scale agricultural land. The fire hazard potential of *C. odorata* due to its flammable foliage is frequently emphasized.

Different management programmes aimed at elimination of plant invasions have been in operation for more than a decade, managed by government agencies within the conservation areas and urban areas, two major forestry companies within the production forestry areas and private and communal land owners within the subsistence agriculture areas. Varying degrees of success have been achieved, with some rapid (re-)infestation taking place in some areas. It has been suggested that this lack of success stems from the differences in management and strategies within different land use types.

The study assesses the link between land use/management and the control of *C. odorata* within conservation, production forestry, subsistence agriculture, commercial/residential and commercial agriculture land use types.

Using a combination of remote sensing, GIS and statistical techniques, a comparison is made of the status of *C. odorata* across and within land use types. *Chromolaena odorata* abundance is taken as the main response variable and indicator of success in management of the alien plant. Differences in control strategies are investigated as a possible explanatory variable.

The current state of *C. odorata* on different land use types investigated differs considerably, especially between the highly infested conservation and production forestry and other land use types.

Strategies used in the control of *C. odorata* range from relatively intensive and institutionalised strategies within the conservation and production forestry areas, to more ad hoc arrangements within the commercial agriculture, subsistence agriculture and urban centres.

The conclusion is that differences in control strategies used within the conservation areas or the production forest seem to have only a marginal effect on the state of *C. odorata*. Significant differences are seen between land use types and attendant differences in land management practices.

1. INTRODUCTION

1.1. Invasive species

There are numerous definitions of invasive species. Coblentz (2002) defines an invasive species as one that has extensive recruitment into a population without human intervention. Stirton (1979) defines plant invaders as 'alien plants that invade and oust native vegetation', while (Mack, 1989)classifies any new entrant to a territory as an invader. Invaders have also been referred to as exotics, colonisers, xenophytes, neophytes or simply weeds (Coblentz, 2002; Joshi, 2001). These concepts have areas of overlap. 'Alien', 'exotic' 'xenophyte', 'neophyte' all imply introductions (intentional or accidental), to a particular ecosystem, community, habitat or land mass, while 'Colonisers' are organisms that appear early in the successional series. The term 'weed' implies undesirability and extensive recruitment into. Therefore, classification of any species as a weed is ultimately a value judgement.

Invasive species can, therefore, be said to be exotic, often colonising organisms that exhibit weedy behaviour. This behaviour seldom manifesting itself in their native environment, where they exist in competition or association with a complex of closely associated species (McFadyen, 1991).

Natural movements of species into most areas are uncommon. Most exotics arrive in association with human activity: transport, agriculture, tourism, etc (Coblentz, 1990; di Castri, 1989)

Impacts of biological invasions on ecosystems are still a source of debate. (di Castri, 1989) asserts that the central European flora has undergone an enrichment of diversity over historical time as a result of human induced plant invasions and Jacobs (1975) in (McNeely, 2000) cites Lake Nakuru's transformation from an ecosystem of very low diversity to one of much higher diversity by the introduction of *Tilapia grahami.* Moreover, many scientists have argued that alteration of relative abundance of native species cannot always be taken as deleterious.

Nevertheless, numerous studies indicate that invasions, by altering biogeochemical cycles, hydrological cycles, fire regimes and the balance of competition, predation, parasitism and disease, by altering landscapes and entire ecosystems have resulted in thousands of extinctions of endemic species in the past few hundred years (Drake, Mooney, & Castri, 1989; Mooney & Drake, 1987).

McNeely (2000) suggests that, globally, in cases where the cause of species extinction is identifiable, biological invasions are the leading cause and that almost 20% of vertebrates considered to be in danger of extinction are threatened by invasive species. The overall picture, then, is one of global movement of species with unpredictable long-term results.

Invasions follow three phases - arrival, establishment and spread. Knowledge of the processes that take place within each stage, in terms of plant ecology, human activities and stochastic events is therefore of fundamental importance in management of plant invasions.

Most exotics, once established are permanent. Eradication is possible in a few instances, but only at great expense and effort. Most others require control, which may be said to be successful when the plant no longer exceeds a threshold level determined by the objectives of the managers. Others may not be controllable by any practical means (Coblentz, 2002; Coblentz, 1990; Groves, 1989)

One method used in controlling invasive species is the promotion of policies aimed at preventing *arrival* of potentially troublesome species. An allied method is the enactment of laws declaring certain plants 'noxious', stipulating methods for their management and giving management authorities legal powers to control them once they have 'arrived', established and spread (Groves, 1989).

Methods of managing invasive plants have evolved with land use systems over time. Control methods used in agricultural systems usually differ from those used in natural systems because of different objectives. The former usually aims to simplify the system, while the latter aims to maintain diversity in the longer term (Groves, 1989).

Mechanical removal of plants is widely used in both systems. It involves cutting, planned burns, ploughing or hand pulling. These methods are usually used in conjunction with other methods and have been known to have some success in controlling invasive species. However, except for fire, they are usually labour intensive and may be expensive for extensive and dense infestations (Groves, 1989; Zachariades, Strathie-Korrubel, & Kluge, 1999).

Chemical control has also been widely used with success, and can be cost effective and quick particularly in agricultural lands. However, specialised equipment and training of operators is needed. Weather and plant status can affect results of chemical treatment. In addition, aerial and foliar application may affect the environment. High costs also significantly reduce the suitability of this method. Chemical control is also rarely effective in the long term (Erasmus, 1988; Groves, 1989; Moore, 2002).

Biological control is seen as a long term, cost effective and environmentally friendly method in controlling invasive species, and has had some impressive successes in the long term. However, a survey of terrestrial and aquatic control programmes show that only 25% - 40% of programmes can be considered effective (Julien, 1982 in (Levin, 1989). When effective, the method provides low cost control with minimal disturbance, but it has a low level of predictability.

Individual methods of control are rarely effective in controlling invasive plants. The trend is, therefore, to adopt a combination of methods, usually chosen with the ecology of the plant as the major determinant. Other considerations include cost, environmental and social implications.

1.2. *Chromolaena odorata* (L.) R. M. King and H. Robinson

Chromolaena odorata, a neotropical Asteraceae introduced to many parts of the tropics is considered to be one of the most aggressive invasive plants in tropical and sub-tropical areas (McFadyen, 1991; Witkowski & Wilson, 2001). *Chromolaena odorata* is widely distributed in its native range, stretching from Florida, USA (29^{o}N) to Paraguay in Argentina (31 ^{o} S), including most of the West Indian islands.

Chromolaena odorata (uhalahala, uboyana or sandanezwe in Zulu) is thought to have been introduced into Natal Province of South Africa in the early 1940s, through Durban harbour (Erasmus, 1988).

Since establishment, this shrub has spread rapidly along the Natal Coastal belt and is now present as far south as Hluhleka Nature Reserve and north as far as Mozambique (Anon., 1999/2000). Anecdotal reports indicate that the study area was invaded in the early 1980s. It is evident that *C. odorata* has not reached its full potential range of distribution and many areas are threatened by invasion (Erasmus, 1988; McFadyen, 1991).

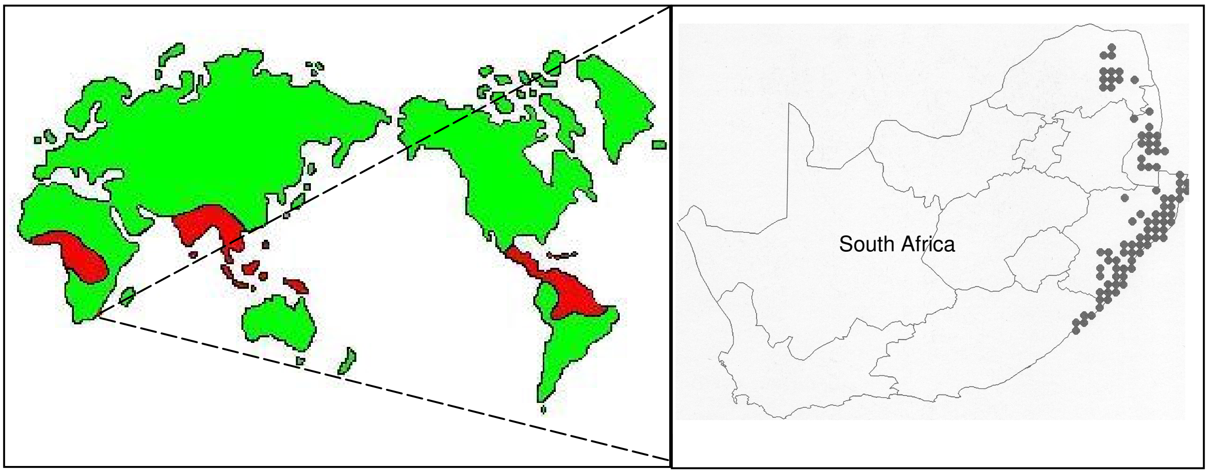


Figure 1: Distribution of *C. odorata* - red areas (slightly adapted from Plant Biosecurity, 2002; Zachariades et al., 1999)

Life form

Chromolaena is a multi-stemmed perennial shrub, forming monospecific stands up to 2.5 m tall in the open and dense scrambling bushes up to10 m high among trees. The fibrous root system is extensive and shallow (20 – 30 cm). Leaves are sparsely hairy, occur in pairs and are pointed ovate to triangular. They vary in colour from light to medium green and have three conspicuous veins. They have a distinctive smell when crushed. Flowers are clusters of mauve to off-white (Bingelli, Hall, & Healey, 1998; Caldwel, 2000; McFadyen, 1991).

Reproductive biology

Chromolaena odorata reproduces sexually. In South Africa a small proportion of plants begin seed production in the first year, increasing to 100% in the third year. Plants are apomictic. Flowering is short and fairly synchronous, beginning in June/July, and appears to be initiated mainly by the onset of the dry season. Terminal cymes bear about 70 insect-pollinated flowers. *C. odorata* produces a large number of light weight (2.54 ± 0.11 S.E. mg seed^{-1}) pappus bearing seeds that are released in July/August (Witkowski & Wilson, 2001). The seeds (achenes) are dispersed by wind up to about 80 m. However, as the seeds have small spines and can cling to fur, feathers and clothes, long distance dispersal also occurs. Seeds can also travel great distances with contaminated crop plants or vehicles (Blackmore, 1996; Plant Biosecurity, 2002; Witkowski & Wilson, 2001).

Chromolaena odorata germination is positively influenced by light intensity (Witkowski & Wilson, 2001). Reports of seed viability vary from 1 - 2 years. In South Africa, *C. odorata* reaches senescence at about 15 years when fire is excluded from the ecosystem (Bingelli et al., 1998; Erasmus, 1988; Witkowski & Wilson, 2001).

Resilience

Growth rates of up to 20 mm per day have been recorded in *C. odorata*. Mature stems are photosynthetic and able to re-sprout (MacFadyen, 2000; Plant Biosecurity, 2002), surviving mechanical damage and mild fires through coppicing. Intensive fires will kill both emergent plants, and seeds in the soil. *C. odorata* contains *N*-oxides of 5 pyrrolizidine alkaloids (PAs), which defends the plant against herbivory, and probably against micro-organisms and fungi (Witkowski & Wilson, 2001). Over 240 arthropods have been recorded on *C. odorata* in Trinidad where the species was investigated in detail for potential bio control agents (Zachariades et al., 1999).

Environmental requirements

Chromolaena odorata tolerates a variety of temperate and tropical climates. In its native range (South America, on the western side of the Andes) the species does not spread south of 7^{o}S as the conditions are too dry. In Trinidad (native range), on open land *C. odorata* is a successional species, which supersedes the pioneer ephemeral herbs, then is displaced by shrubs and small trees and dies as soon as the forest canopy closes. It flourishes in disturbed habitats on freely drained grounds (Bingelli et al., 1998). In South Africa it occurs along the Natal coast below 1000m, but is particularly invasive below 600m. Distribution is probably limited by frost and, to a lesser extent, by rainfall under 500mm/year (Caldwel, 2000). It has invaded forest, grassland and savannah ecosystems. The species does not appear to have special soil requirements (Richardson, Macdonald, Hoffman, & Henderson, 1997).

Genetic variation

Chromolaena odorata exhibits wide variety worldwide and is thought to be a species complex. The invasive populations of *C. odorata* in South Africa have not been completely matched with any other population from other parts of the world. The closest match so far is from specimen collected in Jamaica (Zachariades, Strathie-Korrubel, & Kluge, 1999.).

Impact

Chromolaena odorata is said to be a particular threat to biodiversity conservation in South Africa (Zachariades et al., 1999), reducing grazing for large herbivores and reducing tourism potential by obstructing game and bird viewing in recreation areas (Erasmus, 1988).

In silviculture and plantations in general *C. odorata* is a problem during the establishment and harvesting phase, increasing costs of production, and adversely affecting crops (Anon., 1999/2000; Toa-Kwapong, 1984). The plant reduces the acreages that can be effectively managed by farmers (Erasmus, 1988; Toa-Kwapong, 1984), particularly in small scale agricultural land

The fire hazard potential of *C. odorata* due to its flammable foliage is frequently emphasized (Ambika & Jayachandra, 1989; Erasmus, 1988).

Management

Mechanical control is a common method used for control of *C. odorata* in many situations. In some arable situations in West Africa a combination of slashing and burning, followed by frequent hoeing and uprooting is used. Are and Folarin, 1976 in (Muniappan & Marutani, 2000) report slashing up to four times a year in cocoa plantations. Hand weeding up to three times a year in plantation forests in India was reportedly ineffective in achieving control.

Mulching in plantations has been used in combination with mechanical methods. The use of cover crops to suppress germination and growth of *C. odorata* in coconut, rubber and oil palm plantations in Sri Lanka, West Africa and India (Selagao 1972; Komolafe 1978; Rai 1976 in (Muniappan & Marutani, 2000) and pastures in China (Wu Renrun & Xu Xuejun, 2000) have been reported. Cover plants include *Tephrosia purpurea, Pueraria phaseoloides, Calopogonium mucunoides, Centrosema* *pubescens* and *vigna unguiculata* in West African plantations and *Brachiaria decumbens* in pastures in China. Cover cropping is also used in combination with other methods.

Chemicals are widely used in the control of *C. odorata*, especially where resource constraints are low. An eradication programme in Australia reduced *C. odorata* infestation by 98% in a five year programme using herbicidal treatment. However, this was a small infestation confined to a single watershed (Waterhouse, 2000). In West Africa many chemicals reportedly fail to give 100% mortality, becoming a costly alternative (Hoevers & M'Boob, 2000).

Where control is less than 100%, the relationship between incomplete shoot mortality and seed production is not clear. Studies in a forest in northeastern India show a complete reduction in seed production after more than five years, as the forest reverts to its former state. Substantial reduction in plant density took longer to occur in these systems, established plants being long lived (Groves, 1989).

Numerous attempts at introduction of biological predators to control *C. odorata* have been made in West and Central Africa, the Philippines and Indonesia without success (MacFadyen, 2000). Partial control has been achieved in Sri Lanka with *Pareuchaetes pseudoinsulata*. Evaluation of recent attempts in to reintroduce *P. pseudoinsulata* in Ghana, however seem promising (MacFadyen, 2000; Timbillah & Braimah, 2000).

1.3. Control of *Chromolaena odorata* in KwaZulu Natal

In KwaZulu Natal different management programmes aimed at control of *C. odorata* have been in operation for more than a decade, managed by the Forest Department on the western shores, the Working for Water Programme (WfW) on the eastern shores and various forestry companies, private and communal land owners (Dobkowski, Gallegos, Hoffman, & Mapa, 2001).

Legislation

The main legislation regulating management of invasive plants is the Conservation of Agricultural Resources Act (CARA), 1983 of South Africa. CARA states that 'invader plants are of alien origin and, except for their aggressive nature to invade into niches in a wide range of ecosystems, they may serve useful purposes….'

Chromolaena odorata is declared a category 1 invasive plant under CARA, 1983, which stipulates that '(1) Category 1 plants shall not occur on any land or on any inland water surface, and (2) Such plants shall be *eradicated* and the *control methods* stipulated … shall apply'.

'*Eradicate*' is defined as meaning 'to treat plants by any suitable method in order to prevent such plants from growing, multiplying and propagating'.

Methods stipulated include chemical, mechanical and biological control.

The release of the biological control agents is done in accordance with the stipulations of the Agricultural Pests Act, 1983 (Act No. 36 of 1983), and the Environment Conservation Act, 1989 (Act No. 73 of 1989). The use of chemicals is governed by legislation.

Working for Water

WfW is a multi-departmental initiative led by the departments of Water Affairs and Forestry, Environmental Affairs and Tourism, and Agriculture, with a legal mandate to tackle the problem of invading alien plants and unemployment. The programme aims to enhance water security, improve ecological integrity, restore the productive potential of land and promote sustainable use of natural resources and invest in the most marginalised sectors of South African society.

It started in 1995 and has grown into one of the Government's key Poverty Relief Fund initiatives. Its direct budget through government funding for 2000/01 was R323.5 million. Up to 90% of the budget was spent in almost 300 alien species control projects across the country, employing over 18 000 people. These figures exclude the contributions being made through partnership programmes.

WfW has developed a clear set of guidelines in the management of *C. odorata* in KwaZulu Natal for their own use in the conservation areas as well as dissemination to other stakeholders.

Mechanical and chemical removal

An integrated approach (Table 1) involving a combination of mechanical and chemical treatment is the most widespread approach in use (Anon., 1999/2000; Erasmus, 1988). Mechanical options include uprooting, slashing and sometimes removal from the site by burning. Hand-held machetes, axes, slashers and brush cutters are mainly used. This is labour intensive, slow and costly for large areas or dense infestations where it requires repeated follow-up operations. Untargeted species may be mistakenly destroyed in dense infestations (Moore, 2002). On the other hand, it requires little training or supervision, and with care the environment is unharmed.

Chemical treatment is often used in combination with mechanical methods. Permitted herbicides (Appendix 9*)* are applied to prevent resprouting of cut stems or to kill seedlings germinating after a clearing operation. The cut-stump method is recommended, where the herbicide is applied to a freshly cut stump (less than 12 hours old). The advantage of this method is that the herbicide is placed inside the target plant and there is rarely need to return to the same plant. The environment is also protected. Foliar application is used to kill seedlings, usually in follow-up operations. The herbicide, mixed with a sticking agent is sprayed onto leaves and stems of the target plant. The plant must be healthy, with enough foliage to absorb lethal levels of herbicide. Spraying of previously cut re-growth is done after plants have reached a height of 50 – 100 cm.

After clearing of infested areas rehabilitation using 'cultural' methods is recommended in order to prevent re-invasion. This mainly involves burning and over sowing using grass and other native plant species.

Target Stage	Method	Product	Rate	Estimated product/ha
Seedlings	Hand pull			
	Foliar spray	Mamba (Glyphosate 360 g/l)	100 ml/10l water	4 l/ha
		Touchdown (Glyphosate trimesium 480 g/l)	100 ml/10l water	4 l/ha
		Garlon 4/Viroaxe (Triclopyr ester 480 g/l)	37.5 ml/10l water	1.5 l/ha
Established plants	Slash and spray re-growth when 50 cm tall	Chopper (Imazapyr100 g/l)	200 ml/10l water	1.5 l/ha
	Cut stump			

Table 1: Summary of WfW guidelines for control of *C. odorata* (WfW, 2002)

Biological control

Mechanical and chemical methods of control are recognised as sustainable only in the short term and over relatively small areas. Bio control aims to reduce the vigour of *C. odorata* to a level at which other management approaches become cost-effective. The plant has many attributes that make it suitable for bio control, and between 1988 and 1998 research has been undertaken by ARC-PPRI (Plant Protection Research Institute) on several insect species and pathogens collected in the Americas and West Indies.

Zachariades et al. (1999) discuss the practical difficulties of rearing capitulum-feeding insects on *C. odorata* given the plants' short, synchronous, annual flowering period. In addition, such insects may not reduce infestation significantly due to the vast number of seeds produced by the plant. Priority has, therefore, been placed on finding a suite of insects that damage leaves, stems and roots. These would remove potential growth and flowering points. *C. odorata* has photosynthetically active stems that regenerate after defoliation, therefore stem borers are regarded as key in controlling infestation. Since root-feeding insects would weaken or kill young plants in particular, they are regarded as of high priority, given that propagules play an important role in the competitive ability of *C. odorata.*

Attempts have been made to culture sixteen insect species in nine genera and mites. Preliminary host-specificity tests have been conducted on some of these species (Table 2). Two of these species (*Pareuchaetes pseudoinsulata* and *p. aurata aurata*) were released, but did not establish in the field. Reasons cited include egg predation and poor climate matching for the former and host incompatibility or disease for the latter.

At present *Lixus aemulus* and *Carmenta* sp., prob. *flavinotum* are undergoing specificity testing while another two, *Conotrachelus* sp. and *Longitarsus s* sp. prob. *horni,* have been cultured for the first time (Zachariades et al., 1999).

Agent	**Type**	**Damaging Effect**	**Success Rate**
Pareuchaetes pseudoinsulata	Moth	Defoliation	Unsuccessful
Pareuchaetes aurata aurata	Moth	Defoliation	Unsuccessful
Actinote thalia pyrrha	Butterfly	Defoliation	Unsuccessful
Pareuchaetes insulata	Moth	Defoliation	Tested, authorised
Calycomyza eupatorivora	Fly	Leaf miner	In culture, undergoing testing
Lixus aemulus	Weevil	Stem borer	In culture, undergoing testing
Conotrachelus reticulatus	Weevil	Stem galler	In culture
Longitarsus horni	Flea beetle	Root borer	In culture
Polymorphomya basilica	Fly	Stem galler	Under consideration
Carmenta sp.	Moth	Shoot tip borer	Under consideration

Table 2: Insects released for control of *C. odorata* in South Africa (Zachariades et al., 1999)

1.4. Management of *Chromolaena odorata* in conservation areas

A catchment area approach was used by WfW to demarcate project areas for clearing of alien species within Futululu State Forest and conservation areas within the production forestry area. This is on the premise that water bodies are areas of higher infestation and are also more affected by infestations. A buffer area around water bodies constitutes the Natural Biological Alien (NBAL) areas that are cleared of alien invasions. In Futululu forest this is an area around the periphery of about 31% of the total forest area (Figure 4).

A detailed weed management plan based on information such as weed species, density, life stage, ecosystem features and available resources, is drawn up for each project. The plan outlines methods of control with estimated effort, monitoring, follow-up, and rehabilitation (Appendix 8). This information is managed within a GIS with projects broken down into sub-project units (NBAL) that may be as small as 0.35 ha. **Monitoring**, carried out every three months provides data for updating the information system.

Clearing begins at the top of the catchment to prevent downstream re-infestation. Areas of low invasive plant density are prioritised over areas of high density since the latter no longer has potential to increase. Follow-up activities are also prioritised over initial clearing operations.

Young and adult plants are cut and stumps hand painted with chopper, a non-selective and residual herbicide. Seedlings are uprooted or treated with foliar spray. The selective herbicide *Garlon 4* is used in a mixture with *actipron,* an adjuvant oil, to improve reliability and effectiveness. Uprooting of seedlings is possible if the topography is not too steep and if soils are soft or sandy. Managers are encouraged to use this option whenever feasible. Dead plant material is left on-site to minimise ecosystem disturbance.

Follow-up operations are carried out not more than three months (usually two months) after initial clearing. Re-sprouting plants and seedlings from soil seed banks are about 0.5 metres high and foliar spray and/or hand pulling is used. Four to six follow-up operations are usually necessary.

Rehabilitation is not usually carried out in KZN since the natural growth rate of indigenous plants is sufficiently high to outstrip that of *C. odorata* after effective clearing (Samgerisiwe, pers. comm.).

Work is carried out by contractors trained in plant identification, herbicide use and environmental awareness. Priority is given to companies from poor and disadvantaged sections of the public, in line with the poverty eradication goal of WfW.

1.5. Management of *Chromolaena odorata* in production forestry area

Silviculture

Eucalypts in both SAPPI and Mondi Forests are propagated from genetically modified material, and include *Eucalyptus nitens* (GN), *E. urophylla* (GU) and *E. camaldulensis* (GC) hybrids and/or clones of *Eucalyptus grandis*.

Regeneration is by means of planting seedlings and clonal plants or coppice. Plantations are normally clear-felled at harvest, but selective felling is sometimes carried out. Rotation lengths are an average of six to twelve years, with trees at an average felling height of twenty-four metres.

SAPPI forest management system

SAPPI planning horizons comprise three levels, i.e., operational (the annual plan of operations - APO), tactical (three to five years) and strategic (twenty years) (SGS Forestry, 2000).

The APO is a rolling plan that consists of a register detailing all silvicultural operations within each compartment, for the current year at the district/plantation. It is part of the three to five year plan. The APO is updated monthly, according to reports based on ground operations and monitoring provided by the plantation office.

Control of alien invasive plants is integrated with the operational planning and takes place inside timber compartments and adjacent conservation areas concurrently with silvicultural operations. In addition, environmental management plans, or overviews, contain a description of the physical and biotic environment, main issues and priorities, and monitoring and management prescriptions. This information is captured on the GIS (Arc Info) - based mapping and database system, which permits integrated planning for timber production and conservation management. Plantation maps, which show the road networks, plantation compartments, unplanted conservation areas, firebreaks and infrastructure, have a 1:10,000 or 1:20,000 scale.

Follow-up treatment of *C. odorata* is carried out every six months, and timed to take place before June/July when flowering occurs. A new silvicultural regime of manual herbicide application is being implemented in some areas.

SAPPI has a no-burn policy for slash management and slash remains on the site. Integrated manual and chemical techniques are used for control of *C. odorata*. Activities are carried out using contractors

SAPPI carries out long-term bio-monitoring of biological control agents in conjunction with the PPRI (SGS Forestry, 2001).

Mondi forest management system

The current control strategy in Mondi Forests is designed to integrate control activities into general silvicultural work, thereby minimising costs. This is done by taking advantage of *C. odorata*'s environmental requirements. Weeding in forests compartments is carried out according to age-class, on the premise that *C. odorata* thrives within young forest compartments in which canopy cover is low, is suppressed as forest canopy becomes dense and begins to thrive again as trees reach harvesting age.

Intensive weeding (six weed control programmes) takes place in the year of (re-) establishment of eucalyptus, when the canopy cover of tree seedlings or coppices is sparse, with a follow-up in the fourth and fifth year when crown cover begins to thin again in older trees. Maintenance weeding is done in which, once a year, weeds in the compartments are slashed/cut.

This procedure is set out in a GIS-based information system. In addition, non-commercial compartments are linked to special management and relevant information through the ECDB

(Environmental Conservation Data Base). Maps indicate areas of special interest including weed infestations and are accompanied by a schedule and progress of activities (Qualifor Programme Associated Documents, 2001).

Management prescriptions are integrated into fire protection and weed plans. Monitoring takes place for all cover types within the Mondi property.

Mondi has a regulated burning policy, with necessary burns carried out every three years.

Regulations

State Legislation regulates plantation forestry activities in South Africa. The relevant Acts are the National Forests Act (Act 84 of 1998), the National Water Act (Act 35 of 1998), the National Veld and Forest Fires Act (Act 101 of 1998) and the National Environmental Management Act (Act 107 of 1998)

1.6. Management of *Chromolaena odorata* in commercial agriculture areas

Sugarcane plantation managers do not have a programme specifically aimed at control of *C. odorata*. A combination of dense cover provided by the sugarcane crop and various management practices, common to all the commercial sugarcane farms, contributes in keeping the sugarcane blocks free of *C. odorata*. Sugarcane plantation compartments are burned at harvest every year. Regular weeding involving a combination of hoeing and herbicide application is carried out. Herbicide application is once or twice, depending on the herbicide used. Common herbicides include MSMA, sencor, velpar, MCPA, glyphosate, paraquat and merlin (details in Appendix 9) singly or in various combinations. Aerial and ground equipment – knapsacks and hose-end applicators are both used in application.

C. odorata tends to occur within the non-planted areas and along watercourses of commercial agriculture areas. A combination of slashing and herbicidal treatment is used to treat these areas. However, despite legal provisions, control of invasive species is often ad hoc at the owners' discretion.

1.7. Management of *Chromolaena odorata* in urban and subsistence agriculture areas

Perhaps because of the relatively low levels of infestation municipal and tribal authorities of Kwamsane and Mtubatuba view *C. odorata* invasion as of low priority compared to other social issues. The problem in these areas is, therefore, only addressed at the individual level, if at all. Mechanical removal including burning of *C. odorata*, carried out as part of general farming activities, is the only method reported here (Sakhi pers. comm.).

1.8. Partnerships

WfW has developed partnerships with SAPPI and Mondi, in order to improve alien species management in conservation areas. In a partnership agreement SAPPI and Mondi, together with the Forest Owners Association, agreed to clear all alien vegetation on riverbanks and in wetlands on their land in the next ten years (Anon. 1999/2000). In addition to this, they provide technical expertise and training for staff involved in management of alien species. In return, WfW contributes R2 million to a clearing programme with the two companies. As part of the partnership, a technical advisor and mentor has been seconded to WfW by Mondi Forests to initiate a self-assessment programme and improve health and safety aspects.

1.9. Problem definition

In South Africa extensive knowledge exists about control of invasive species including *C. odorata*, yet after more than a decade of control efforts only limited success has been achieved. Rapid re-infestation of cleared and an increasing area and density of infestation has proved expensive for control programmes. In order to maintain the densities of *C. odorata* to that of pre-1980, alien plant eradication budget had to be increased 10 fold (early 1990) and again by eight fold in 1995 (Anonymous, 1996).

Several studies provide some clues about the reasons for the limited success in managing *C. odorata*. (Blackmore, 1996) observed that, other than the patches of *C. odorata* along the estuary, *C. odorata* occurs along tracks within and along rotovated firebreaks surrounding the production forestry area on the Eastern and Western Shores. He goes on to suggest that the invasion of the Greater St Lucia Wetland Park and the Eastern Shores section has been significantly assisted by activities of the timber industry. (Witkowski & Wilson, 2001) reason that the eradication of *C. odorata* seed banks by mechanical or chemical methods is possible once other seed sources that can potentially re-infest cleared sites are fairly distant and names forest plantations in the area as the major seed source. In an evaluation of control efforts in Futululu State Forest, KZN, (Majam, 2002) mentions a number of factors affecting successful control of *C. odorata*: lack of co-operation among land owners, poor location of *C. odorata* management blocks in relation to *C. odorata* distribution, inconsistency in monitoring and inaccessibility of infested areas.

Some of these factors may relate to simple inefficiency in management. However, it is evident that differences of approach in tackling the *C. odorata* problem exist among land managers within the different land use types. While all stakeholders would like to see *C. odorata* eliminated, their different priorities and capabilities result in differences in strategy, which affect the results of control programmes. Since *C. odorata* is capable of long distance dispersal, this lack of a systematic approach renders the more successful programmes ineffective because adjacent areas harbour the weed (van Wilgen, Richardson, & Higgins, 2000).

While the land use issue seems to be of great importance in effective control of *C. odorata*, no literature was found that focuses on the differences in land use/management practices, and the consequences for control of *C. odorata*.

1.10. Objective

The aim of the study is to assess the link between land use/management and the control of *C. odorata* in Dukuduku, Futululu, Mtubatuba and Kwamsane areas of KwaZulu Natal Province.

Specific Objectives

1. Map *C. odorata* abundance in relation to land use types;
2. Investigate the variation between strategies used in control of *C. odorata* within different land use types;
3. Investigate the variation in effectiveness of *C. odorata* control strategies between and within different land use types

1.11. Research questions

To achieve these objectives, the following questions will be addressed:

1. What strategies are used in the control of *C. odorata* on conservation, plantation forest, commercial agriculture and subsistence agriculture types?
2. What is the relative state of *C. odorata* under each of the different land use types?
3. What strategy is most successful in control of *C. odorata*?

1.12. Research hypotheses

1. Abundance of *C. odorata* does not vary with land use type.

   H_o: $\eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5$

   H_α: At least one η is different

   Where $\eta_1, \eta_2, \eta_3, \eta_4, \eta_5$ are the abundance of *C. odorata* in conservation, production forestry, commercial agriculture, subsistence agriculture and urban land use types.

2. Abundance of *C. odorata* does not vary with the type of control strategy used.

   a) H_o: $\eta_1 = \eta_2 = \eta_3$

      H_α: At least one η is different

      Where η_1 is the abundance of *C. odorata* in the Futululu State Forest, η_2 is the abundance of *C. odorata* in the SAPPI/Mondi conservation areas and η_3 is the abundance of *C. odorata* in the commercial agriculture areas.

   b) H_o: $\eta_1 = \eta_2$

      H_α: $\eta_1 \neq \eta_2$

      Where η_1, η_2 are the abundance of *C. odorata* under each of the different control strategies used by SAPPI and Mondi in the forest plantation compartments.

3. Abundance of *C. odorata* plant stage does not vary with control strategy used.

   a) H_o: $\eta_1 = \eta_2 = \eta_3$

      H_α: At least one η is different

      Where η_1, η_2, η_3 is the abundance of *C. odorata* seedlings, young, adult and resprouting plants in the Futululu State Forest, the SAPPI/Mondi conservation areas and the commercial agriculture areas respectively.

   b) H_o: $\eta_1 = \eta_2 = \eta_3 = \eta_4$

      H_α: At least one η is different

Where η_1, η_2, η_3, η_4 are the abundance of *C. odorata* seedlings, young, adult and resprouting plants under each of the different control strategies used by SAPPI and Mondi in the forest plantation compartments.

2. STUDY AREA

2.1. Location

The study area covers about 13,300 hectares from about 32°11″ East to 32°33″ East and 28° 35″ South to 28° 48″ South, within the Mtubatuba Municipality, situated on the coastline of north - eastern KwaZulu - Natal Province, South Africa (Figure 2). It lies within the environs of the Greater St. Lucia Wetland Park. The N2 national road follows approximately half of the western boundary of the municipality, as does the railway line to the Swaziland border to the north.

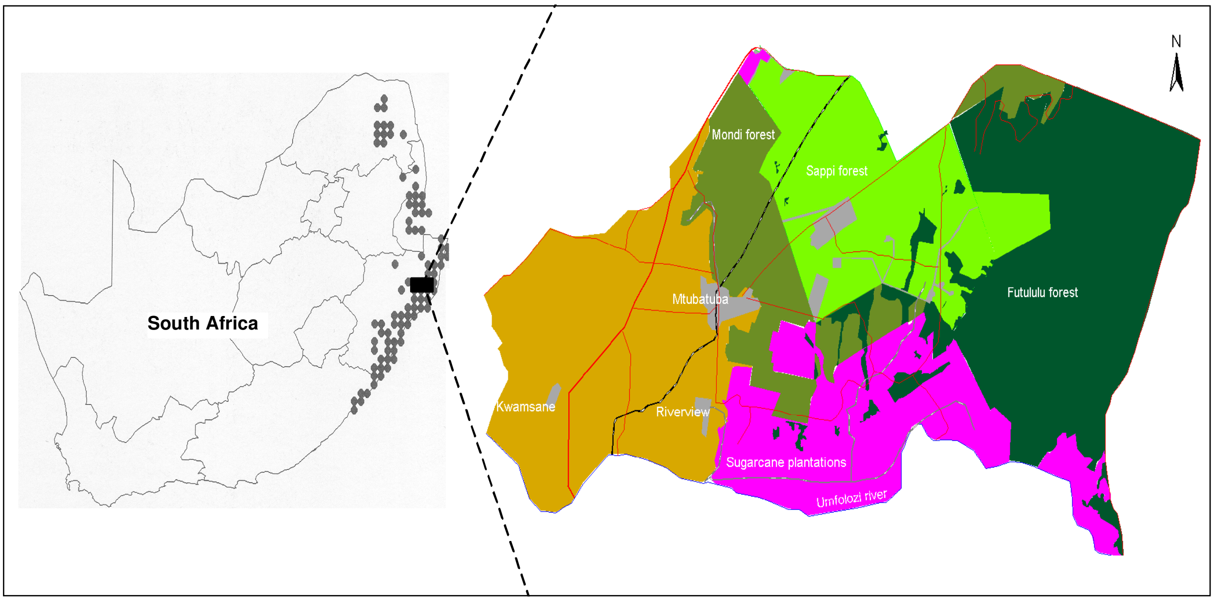


Figure 2: Location of study area

2.2. Topography

The area is within the long coastal plain, extending to the Lebombo mountain range in the west and, in the east, to a continuous barrier dune complex that separates it from the shoreline. The plain is associated with a complex mosaic of lakes, pans, relic dunes and forests (Anon., 1998). **Soils** are generally sandy and have marine origin, increasing in nutrient status from east to west (Blackmore, 1996).

2.3. Climate

The area is situated at the interface between tropical and sub-tropical climates (Blackmore, 1996) within the lowland coastal bio-climatic zone, with warm winters (Taylor, 1982).

Rainfall varies between 1120mm in the southwest to 1330 mm in St. Lucia town and 1045 mm at Sodwana Bay in the northeast and 650 mm at Mkuze Game Reserve in the northwest (CCWR data in (Blackmore, 1996). Episodic large-scale floods occasionally occur (Anon., 1998).

Mean annual **temperature** for the St. Lucia area is 21.5°C, while that for Kwazulu Natal Province is 18.1°C. The warmest months are January to March (Anon., 1998).

Relative **humidity** is 66% (daily mean) for the Province of Kwazulu Natal, while the Greater St. Lucia area has a daily mean of 70%.

Prevailing winds tend to be north-east or south-west (Taylor, 1982).

2.4. Vegetation

The low-lying areas fall within the sour lowveld/bushveld vegetation type, which includes savanna (bushveld), riverine scrub forest and *Phragmites spp.* dominated wetlands (Cowling, 1997).

2.5. Land tenure and land use

Production forestry

About 4,000 hectares or thirty percent of the study area comprises eucalyptus forest plantations managed by international forestry giants SAPPI and Mondi.

This is arguably the most commercially important land use type in the area, contributing about eight percent to the gross value of the country's manufacturing output. SAPPI Forests owns and manages nineteen percent (545,000 hectares) of man-made forest plantations in southern Africa, while Mondi owns twenty five percent (including the SiyaQhubeka and Imbokodvo Lemabalabala forests).

Commercial agriculture

The South African sugar industry is one of the world's leading cost-competitive producers of high quality sugar. It is an industry combining sugarcane cultivation with the industrial production of refined sugar and a range of by-products. Irrigated commercial sugarcane plantations on freehold property occupy about 2,200 hectares or seventeen percent of the study area to the east and west of Riverview and Mtubatuba, along the Mfolozi River and on the Mfolozi Flats. A few small-scale growers produce sugarcane on tribal land.

Sugarcane from here is processed at the nearby RiverView Mill.

Conservation

Climate and effect of fires have confined indigenous forests to approximately 327,600 hectares or 0.2% of South Africa's land area. Thus, the conservation value of South Africa's natural forests is high. The state-owned Futululu State Forest covers about 3640 hectares and is an important watershed area and one of the last remnants of natural coastal low-veld forests. As such, the forest is conserved under the Natal Nature Conservation Ordinance No. 15 of 1974. The Directorate of Water Affairs and Forestry (DWAF), is the principal authority responsible for the forest. Activities permitted in the forest are limited to research and eco-tourism.

Within production forestry sector, Guidelines for Environmental Conservation Management for Commercial Forests in South Africa restrict planting on sub-marginal sites (shallow soil, steep slopes, dry aspects, rocky sites etc.), closer than fifty metres from wetlands or thirty metres from perennial streams and springs. About 220 hectares of natural areas within the forest plantations are managed according to these guidelines as conservation areas by SAPPI and Mondi, monitored by DWAF.

About ninety-six hectares of fragmented indigenous habitats also occur within the commercial agriculture area.

Urban areas

Kwamsane and Mtubatuba (being Mtubatuba, Riverview and Norwood) consist of a generalised land use, which consists of small subdivisions of land in private and public ownership. They comprise formal township and general plan areas, which are used for a variety of purposes associated with formal urban settlement. Most of the human settlement occurs astride the N2 and provincial main road to St Lucia at KwaMsane - the Msane tribal area, Mtubatuba, Riverview, Norwood and Monzi (Anon., 2001).

The market town of Mtubatuba is the commercial and service focus of the municipality. KwaMsane is a residential area, created under the former apartheid legislation as a dormitory town to Mtubatuba, with some 1800 houses. Riverview, to the south of Mtubatuba town centre, is a residential sugar mill village, while Norwood is a former Indian and Coloured residential suburb located approximately two kilometres to the east of the Mtubatuba town centre (Anon., 2001).

Subsistence agriculture

This type of land use is typical of the traditional settlement zone concentrated around the formal township of Kwamsane and directly east of the N2 between Kwamsane and Riverview. The main farming activities include mixed cropping and grazing. Most of inhabitants are employed elsewhere, and the area has a relatively low settlement density of fifty-three people per square kilometre (Anon., 2001).

3. METHODS

Data from remote sensing and field survey are used in a comparison, involving GIS and statistical techniques (Figure 3), of the status of *C. odorata* across conservation, production forestry, subsistence agriculture, commercial agriculture and urban land use types. *C. odorata* abundance is taken as the main response variable and indicator of success in management of the alien plant. Different control strategies, land use types and vegetation cover are investigated as possible explanatory variables.

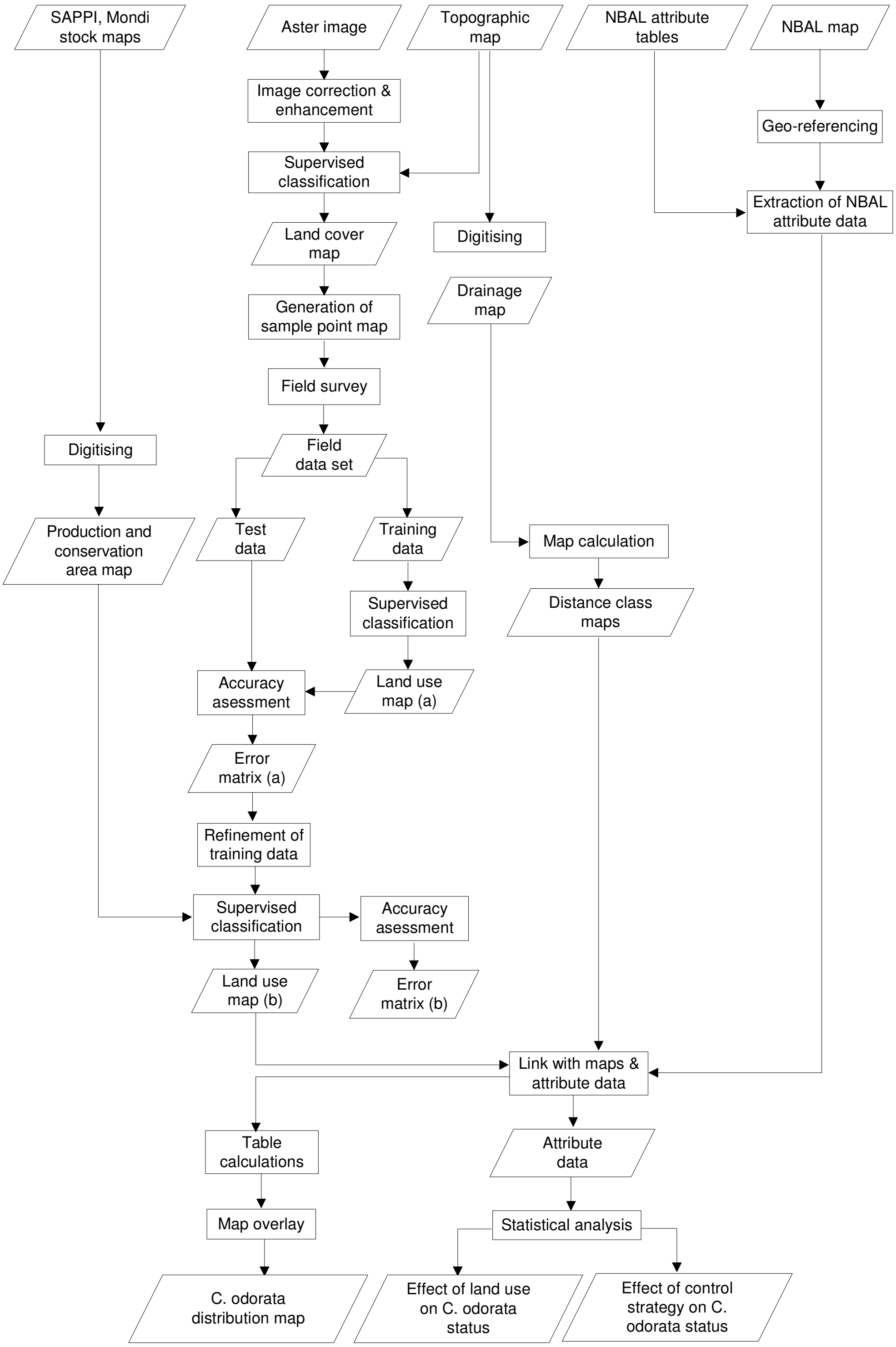


Figure 3: Overview of research method

Extraction of preliminary information

A land use map (Figure 8) was generated from an Aster image (bands 3, 2, 1) of June 8, 2002 using maximum likelihood classifier in supervised classification (error statistics in Appendix 5). Training information was obtained from topographic maps of the area. Criteria used in assigning land use classes are given in Appendix 6.

The Aster image was chosen because it provides the necessary spatial, spectral resolution and coverage (Lillesand & Kiefer, 2000) for detecting the different land cover and land uses necessary for proper analysis of the problem. The image was also available over the Internet at no cost.

Classes identified include:

1. Conservation
2. Production forestry
3. Commercial agriculture
4. Subsistence agriculture
5. Urban area
6. Wetland
7. Open water

Sampling design

Stratified random sampling was used in order to take into account the variation in representation of the different land use types. Strata are based on the classes 1 to 5 identified in the preliminary land use map. Sample sizes were planned according to relative proportion of strata (Appendix 6) and also relative homogeneity.

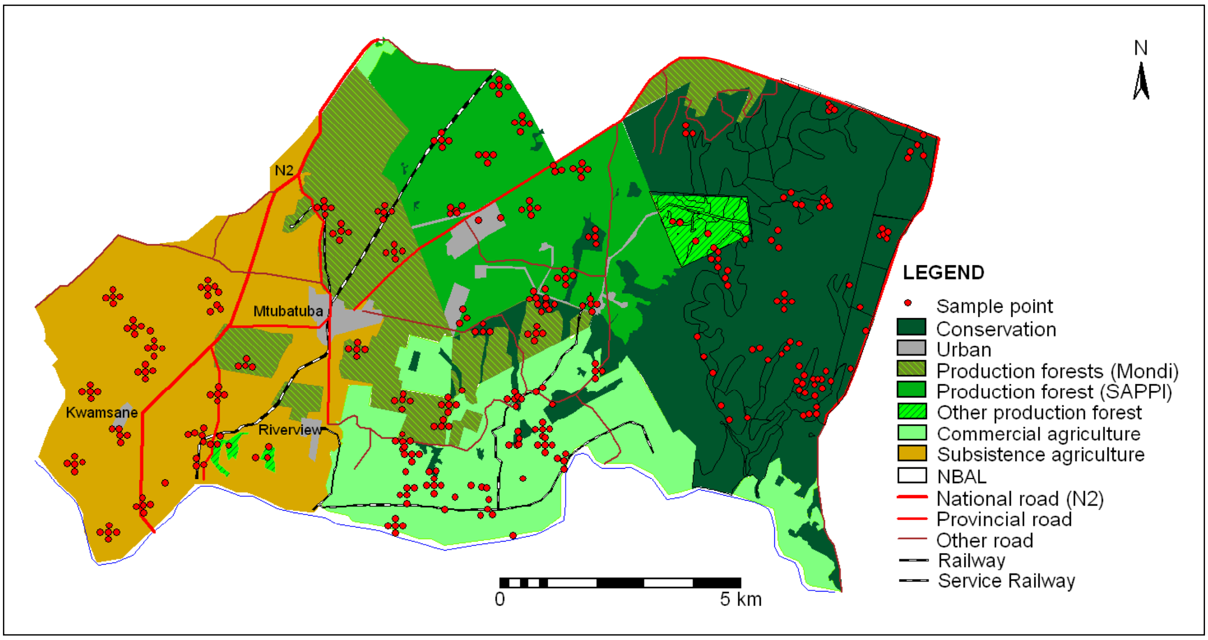


Figure 4: Location of sample units

A clustered sampling design (Figure 4) was used in order to save travel time in the field. Sample unit centre locations were randomly generated in ILWIS. In the design every sample unit consists of five sample plots 150 m apart in each direction north, east, west and south (Figure 5). Centres of sample units are at least one kilometre apart.

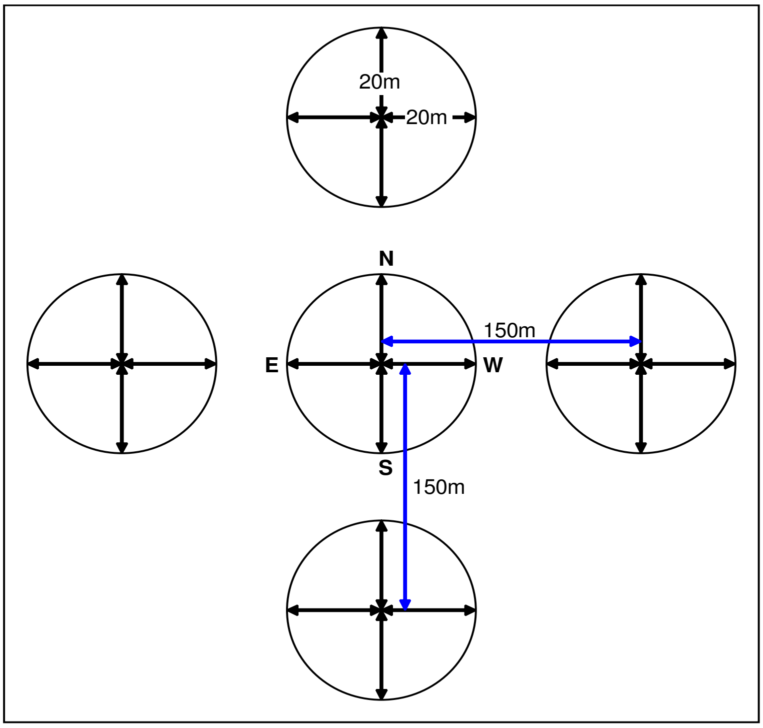


Figure 5: Sample unit design

To estimate *C. odorata* abundance a 20 m tape measure was laid out and every 10 cm, *C. odorata* 'hit' along the tape measure at a height of 50 cm was counted. This was done in the north, east, west and south direction from the centre of each plot.

A representative area within this area was used in visually estimating total cover percentage of tree canopy, shrub and herb/grass. *Chromolaena odorata* cover was excluded from shrub cover estimates.

Chromolaena odorata was classified as seedling, young, etiolated shrub, bushy shrub or resprout according to predetermined criteria (Appendix 3).

A checklist of questions (Appendix 2) was used in semi-structured interviews to collect secondary data relevant to control of *C. odorata.* Forest managers from SAPPI, Mondi, SiyaQhubeka, and SAFCOL were interviewed, as well as a sugarcane plantation manager, Mondi Agrochemical suppliers, TELKOM, ESKOM and WfW project staff.

3.1. Data collected

Data collected include

1. *Chromolaena odorata* state: abundance, life stage, health indicators, seed/flower production
2. Land use/management information
3. Land cover type
4. Total percentage cover of tree, shrub, grass/herb, crop
5. Control methods, strategies

3.2. Data processing/ analysis

Data processing and analysis was carried out using ILWIS 3.1 Academic, Arc View 3.2, MS Excel, Minitab 13.1 and SPSS 11.

Field data was split into two sets. One set was used to create training samples for re-classification of the Aster image. Maximum likelihood classifier was selected based on comparison of results of four classification methods. The second data set was used to compute error statistics for the map (Appendix 5).

A drainage map was obtained by digitising topographic maps of the area. Distances to watercourse classes are based on dispersal distance of *C. odorata*. Distance calculations were done using ILWIS.

In the case of the NBAL, SAPPI and Mondi area information was extracted from relevant maps obtained from WfW, SAPPI and Mondi. NBAL blocks were grouped according to treatment date before analysis.

'Percentage of plots invaded' is the percentage out of the total number of sample points in the relevant stratum.

Data were standardised by dividing each case by the area of the relevant stratum obtained from the classified land use map or the distance calculation maps.

Conservation areas under SAPPI and Mondi have been pooled in comparing control strategies. This is because *C. odorata* control within these areas is done according to similar legislation and guidelines set and supported financially by DWAF (WfW). However, these areas differ from Futululu State Forest NBALS in that SAPPI and Mondi allow grazing in their forests. The SAPPI/Mondi conservation areas have, therefore been treated as a separate population from the Futululu State Forest NBAL.

Chromolaena odorata abundance data were not normally distributed, with a large number of zero values and bigger spread about the line for lower values (Figure 6), therefore rank transformation was considered appropriate (Potvin & Roff, 1993). Simple rank transformation was used, using SPSS, with rank 1 assigned to the smallest value and the mean assigned for ties.

3.3. Assumption

Telephone lines, power lines and roads are land use types that have not been dealt with in this study. It has been assumed that since they are similar features (elongated) and each is managed by in a similar way throughout the study area, their effect is uniform across the land use types.

4. RESULTS

4.1. Exploratory Analysis

Chromolaena odorata abundance data were not normally distributed (Kolmogorov-Smirnov statistic 0.394, df = 356), with numerous zero values (Figure 6). Rank transformation did not normalise the distribution (Kolmogorov-Smirnov statistic 0.454, df = 356).

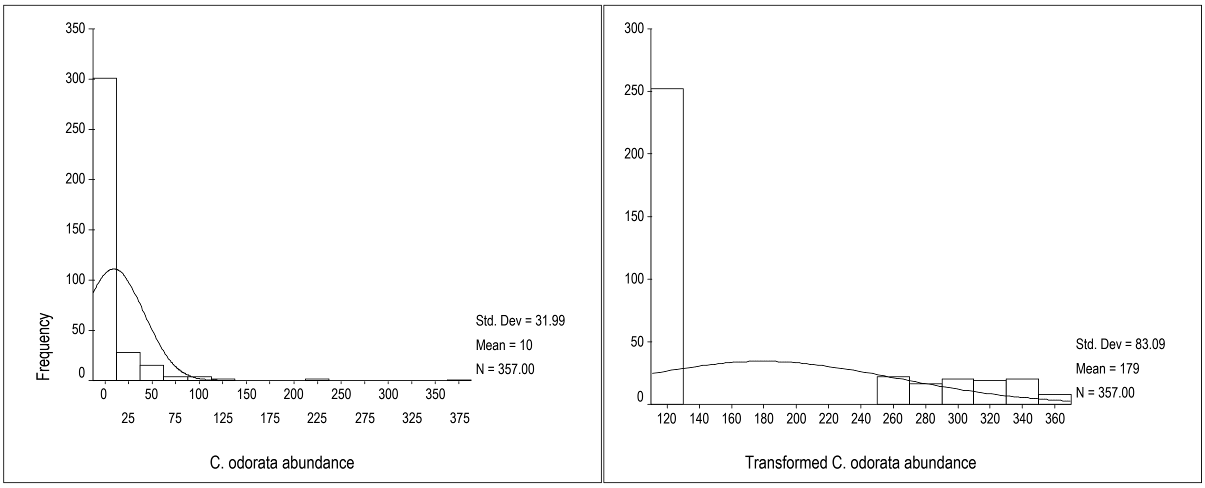


Figure 6: Untransformed and transformed histograms of *C. odorata* abundance data

4.2. Analysis of vegetation cover and *Chromolaena odorata* abundance

Regression analysis shows that *C. odorata* abundance has a weak negative correlation with tree and grass/herb cover in the conservation area. Comparison between Futululu NBAL and the non-treated area shows that in the latter a weak negative relation exists with tree cover, while no relation is significant within the Futululu NBAL. This is similar to the subsistence agriculture area where no significant relation was observed. *C. Odorata* abundance in the commercial agriculture area and the production forestry has a weak positive relation to shrub cover (Table 3).

	(CI 95%)	Tree cover	Shrub cover	Grass/herb cover
Conservation area	Adjusted R^2	0.130 (-)	-0.007	0.047 (-)
	P	0.001	0.676	0.012
Futululu NBAL	Adjusted R^2	0.030	-0.025	0.009
	P	0.224	0.699	0.241
Futululu non-treated area	Adjusted R^2	0.218 (-)	0.050	0.000
	P	0.025	0.180	0.798
Subsistence agriculture	Adjusted R^2	0.014	-0.010	0.023
	P	0.893	0.578	0.109
Production forestry	Adjusted R^2	0.019	0.297 (+)	-0.006
	P	0.094	0.000	0.499
		Crop	Shrub	Grass/herb
Commercial agriculture	Adjusted R^2	0.041	0.331 (+)	0.009
	P	0.089	0.000	0.241

Table 3: Regression statistics (best fit of quadratic) of *C. odorata* abundance and vegetation cover

4.3. *Chromolaena odorata* abundance in different land use types

	N	Mean Rank	SE Mean
Conservation	117	211.70	9.01
Production forestry	113	185.08	7.63
Subsistence agriculture	59	148.24	7.27
Urban	20	146.40	13.80
Commercial agriculture	48	136.38	5.69

There is a significant difference in abundance between conservation, plantation forest, urban, subsistence agriculture and commercial agriculture land use types (Kruskall-Wallis Test: H = 28.45, P = 0.000), with abundance descending in that order (Table 4).

However, a bigger percentage of invaded plots were found in the subsistence agriculture than in the urban area (Figure 7).

Table 4: Relative abundance of *C. odorata* within different land use types

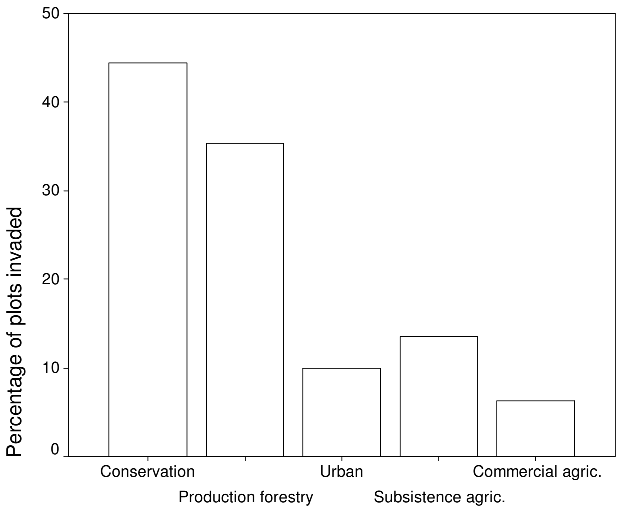


Figure 7: Distribution of *C. odorata* within different land use types

A pair wise test shows that the difference between *C. odorata* abundance is significant between conservation and all other land use types and for production forest and commercial agriculture and production forest and subsistence agriculture areas (Table 5).

	Production forestry	**Commercial agriculture**	**Subsistence agriculture**	**Urban**
Conservation	U = 5381.000 P = 0.004	U = 1616.000 P = 0.000	U = 2162.000 P = 0.000	U = 740.000 P = 0.005
Production forestry		U = 2008.500 P = 0.000	U = 2722.500 P = 0.004	U = 913.500 P = 0.055
Commercial agriculture			U = 1311.000 P = 0.212	U = 460.000 P = 0.552
Subsistence agriculture				U = 576.000 P = 0.785

Table 5: Mann-Whitney test results for *C. odorata* abundance in different land use types

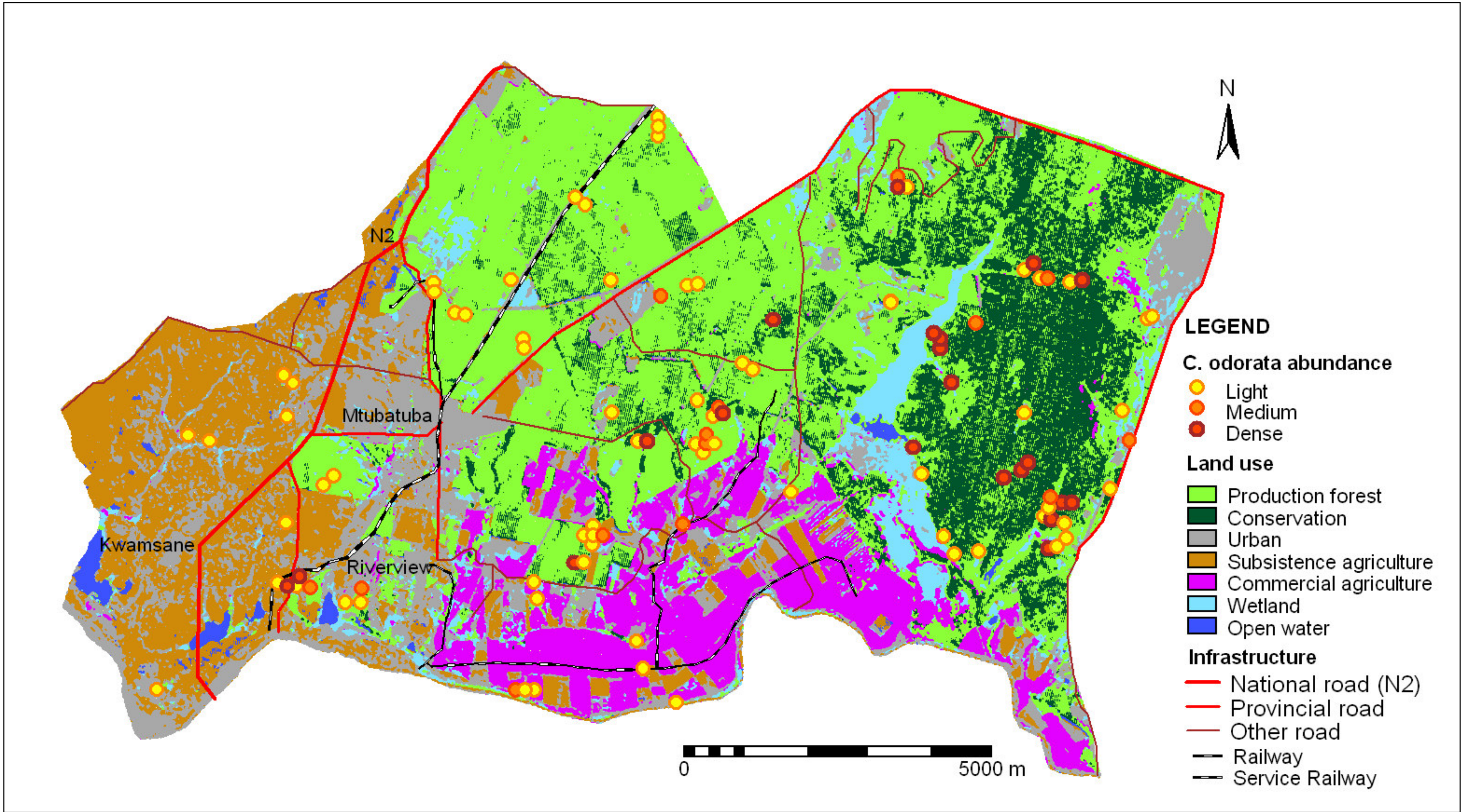


Figure 8: Distribution of *C. odorata* within different land use types

4.4. *Chromolaena odorata* abundance in production forests

H_o: $\eta_{SAPPI} = \eta_{Mondi}$

H_α: $\eta_{SAPPI} \neq \eta_{Mondi}$

where $\eta_{SAPPI,}$ $\eta_{Mondi,}$ are the abundance of *C. odorata* under each of the different control strategies used by SAPPI and Mondi in the forest plantation compartments.

Chromolaena odorata abundance within SAPPI planted forest compartments is not significantly different from that within the Mondi compartments (Mann-Whitney Test: U = 1055.000; P = 0.220)

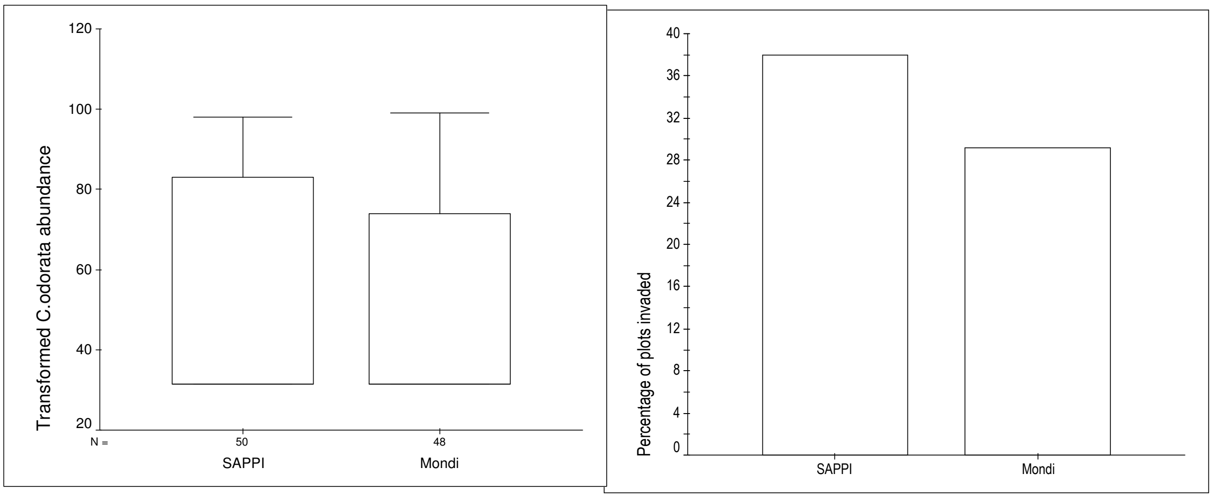


Figure 9: Relative abundance and distribution of *C. odorata* within SAPPI and Mondi production forests

4.5. *Chromolaena odorata* plant morphology in planted forest compartments

H_o: $\eta_{SAPPI} = \eta_{Mondi}$

H_α: $\eta_{SAPPI} \neq \eta_{Mondi}$

where $\eta_{SAPPI,}$ $\eta_{Mondi,}$ are the abundance of *C. odorata* seedlings, young, etiolated shrubs and bushy shrubs within the SAPPI and Mondi production forest compartments.

Kruskall-Wallis test showed that abundance of different stages of *C. odorata* (seedlings, etiolated shrubs, bushy shrubs, re-sprouts) is not significantly different between SAPPI and Mondi production forests (Table 7).

	Strategy	N	Transformed mean	Transformed median	SE mean
Seedlings	SAPPI	50	49.01	47.0	1.94
H = 0.002; P = 0.966	Mondi	48	50.11	47.0	1.76
Young	SAPPI	50	49.51	49.5	1.42
H = 01.021; P = 0.312	Mondi	48	49.50	49.5	0.00
Etiolated shrub	SAPPI	50	45.62	40.5	2.49
H = 02.367; P = 0.124	Mondi	48	52.82	40.5	3.14
Bushy shrub	SAPPI	50	51.12	39.0	3.29
H = 0.675; P = 0.411	Mondi	48	47.41	39.0	2.77
Resprout	SAPPI	50	50.96	46.0	2.50
H = 0.495; P = 0.482	Mondi	48	48.13	46.0	1.49

Table 6: Kruskall-Wallis Test statistics for morphological types (SAPPI, Mondi production forests)

4.6. *Chromolaena odorata* abundance in the conservation areas

H_o: $\eta_1 = \eta_2 = \eta_3$

H_α: At least one η is different

where η_1, η_2, η_3 are the abundance of *C. odorata* under each of the different control strategies used by WfW within Futululu State Forest (WfW1), SAPPI and Mondi within their conservation areas (WfW2), and commercial farmers in the conservation areas.

Chromolaena odorata abundance is not significantly different under WfW strategies and commercial agriculture management within the natural/conservation areas (Kruskal-Wallis Test: H = 2.89; DF = 2; P = 0.236).

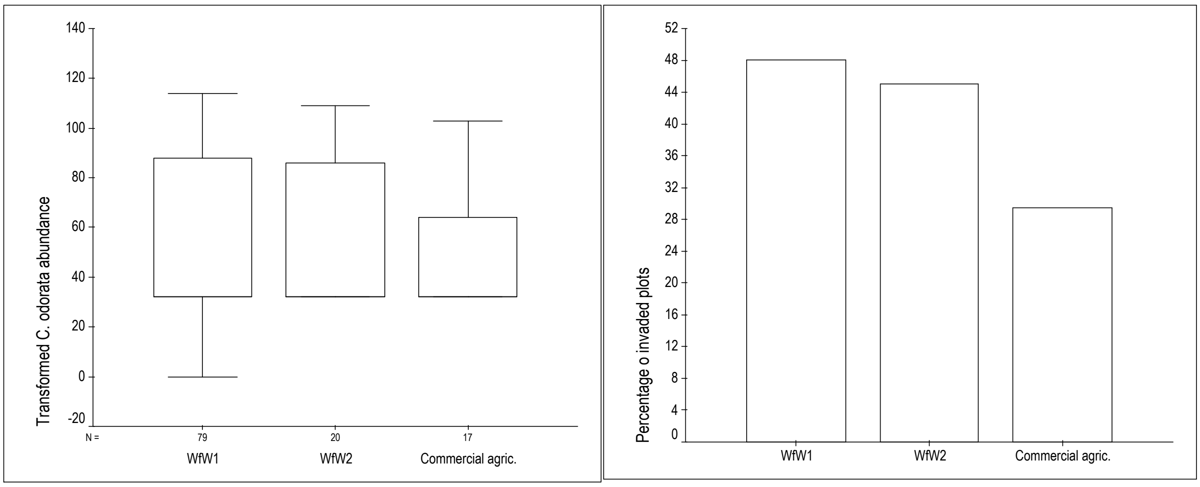


Figure 10: Relative abundance of *C. odorata* and distribution within the conservation areas

4.7. *Chromolaena odorata* morphology in the conservation areas

H_o: $\eta_1 = \eta_2 = \eta_3$

H_α: At least one η is different

Where η_1, η_2, η_3 are the abundance of *C. odorata* seedlings, young, etiolated shrub, adult and resprouting plants under each of the different control strategies used by SAPPI, Mondi, WfW and commercial farmers in the conservation areas.

Kruskall-Wallis tests shows their abundance is not significantly different when compared under the different WfW strategies and commercial farmers strategies within the natural/conservation areas.

	Strategy	Transformed mean	Transformed median
Seedlings H = 2.60 P = 0.273	WfW1	55.04 ± 2.83	45
	WfW2	59.65 ± 4.68	45
	Commercial agriculture	42.35 ± 4.68	45
Young H = 2.20 P = 0.333	WfW1	51.52 ± 2.42	49
	WfW2	57.10 ± 4.44	49
	Commercial agriculture	49.00 ± 5.94	49
Etiolated shrub H = 0.77 P = 0.682	WfW1	51.52 ± 2.42	49
	WfW2	57.10 ± 4.44	49
	Commercial agriculture	49.00 ± 5.94	49
Bushy shrub H = 2.74 P = 0.254	WfW1	54.87 ± 3.00	43
	WfW2	49.40 ± 4.41	43
	Commercial agriculture	55.29 ± 7.61	43

	Strategy	Transformed mean	Transformed median
Resprout	WfW1	55.24 ± 2.63	43
H = 2.32 P = 0.314	WfW2	50.50 ± 2.50	43
	Commercial agriculture	52.59 ± 7.26	43

Table 7: Relative abundance of morphological stages within the conservation areas (N =79, 20, 17 for WfW1, WfW2 and commercial agriculture respectively)

4.8. *Chromolaena odorata* reproduction in the conservation areas

H_o: $\eta_1 = \eta_2 = \eta_3$

H_α: At least one η is different

Where η_1, η_2, η_3 are the abundance of plants in seed under each of the different control strategies used by SAPPI, Mondi, WfW and commercial farmers in the conservation areas.

Comparison of abundance of *C. odorata* adults in seed across Mondi, SAPPI, Futululu and conserved areas within commercial agriculture land showed no significant difference (Kruskal-Wallis Test: H = 2.29, DF = 2, P = 0.318). The abundance of non seeding plants were also not significantly different (Kruskal-Wallis Test: H = 1.01, DF = 2, P = 0.602)

	Strategy	N	Transformed mean	Transformed median
Plants in seed	WfW1	79	51.06 ± 2.71	45.5
H = 0.002; P = 0.966	WfW2	17	54.74 ± 7.44	45.5
	Commercial agriculture	20	51.53 ± 4.15	45.5

Table 8: Relative abundance of seed bearing plants within conservation areas (Kruskall-Wallis Test)

4.9. *Chromolaena odorata* abundance within Futululu State Forest NBAL

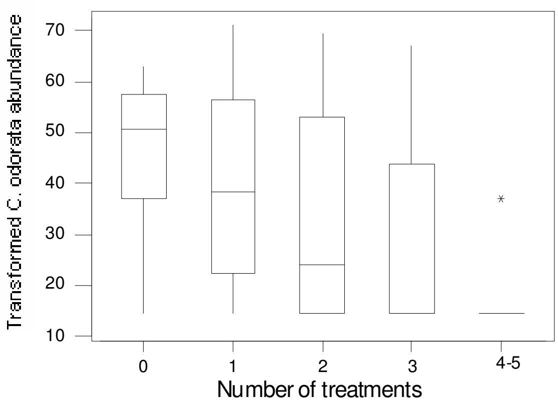
H_o: $\eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5$

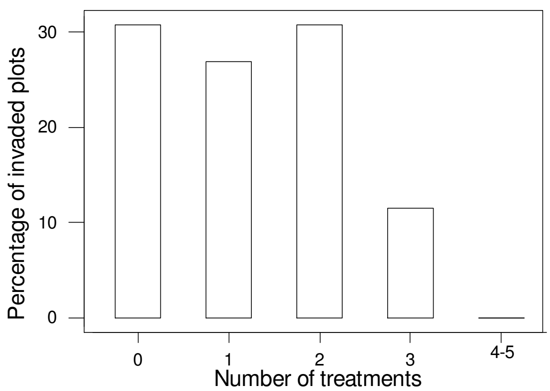
H_α: At least one η is different

where $\eta_1, \eta_2, \eta_3 = \eta_4 = \eta_5$ are the abundance of *C. odorata* under blocks treated 0, once twice, three time and four to five times

Chromolaena odorata abundance is not significantly different across areas at stages of treatment 1, 2, 3 and 4 -5 in Futululu Forest (Kruskal-Wallis, H = 5.36 DF = 3 P = 0.147). A pair wise test reveals a significant difference between the non-treated and the stages treated 4-5 times (Mann-Whitney U = 16.000; P = 0.003).

C. odorata abundance shows a weak negative correlation with number of treatments (Pearson





correlation = -0.433; P = 0.000).

Figure 11: Relative abundance of *C. odorata* in Futululu forest with increasing numbers of clearing operations

4.10. *Chromolaena odorata* morphology within Futululu State Forest

H_o: $\eta_0 = \eta_1 = \eta_2 = \eta_3 = \eta_{4-5}$

H_α: At least one η is different

Where η_0, η_1, η_2, η_3, η_{4-5} are the abundance of *C. odorata* seedlings, young, etiolated shrub, adult and resprouting plants in each of the areas treated 0, 1, 2, 3 or 4-5 times.

Comparison within Futululu State Forest of abundance of different morphological types also showed no significant differences in blocks treated once, twice, three times, four to five times or not at all.

	Number of treatments	N	Transformed mean	Transformed median
Seedlings	0	20	26.75 ± 2.67	21.0
H = 7.402; P = 0.116	1	9	40.33 ± 5.11	44.0
	2	16	29.09 ± 3.64	21.0
	3	7	28.64 ± 4.95	21.0
	4-5	6	24.50 ± 3.50	21.0
Young	0	20	29.00 ± 0.00	29.0
H = 2.625; P = 0.622	1	9	29.00 ± 0.00	29.0
	2	16	30.81 ± 1.81	29.0
	3	7	29.00 ± 0.00	29.0
	4-5	6	29.00 ± 0.00	29.0
Etiolated shrub	0	20	31.38 ± 2.71	25.5
H = 3.366; P = 0. 498	1	9	25.50 ± 0.00	25.5
	2	16	30.97 ± 2.95	25.5
	3	7	29.36 ± 3.86	25.5
	4-5	6	25.50 ± 0.00	25.5
Bushy shrub	0	20	26.65 ± 2.17	23.5
H = 3.139; P = 0.535	1	9	32.78 ± 4.67	23.5
	2	16	29.47 ± 3.23	23.5
	3	7	34.57 ± 5.27	23.5
	4-5	6	28.25 ± 4.75	23.5
Resprout	0	20	24.73 ± 1.23	23.5
H = 7.068; P = 0.132	1	9	33.67 ± 5.09	23.5
	2	16	28.78 ± 2.87	23.5
	3	7	35.93 ± 5.96	23.5
	4-5	6	33.58 ± 6.40	23.5

Table 9: Relative abundance of *C. odorata* morphological types in areas treated 0 to 5 times

4.11. *Chromolaena odorata* reproduction within Futululu State Forest

H_o: $\eta_0 = \eta_1 = \eta_2 = \eta_3 = \eta_{4\text{-}5}$

H_α: At least one η is different

Where $\eta_0, \eta_1, \eta_2, \eta_3, \eta_{4\text{-}5}$ are the abundance of plants in seed under different numbers of treatments.

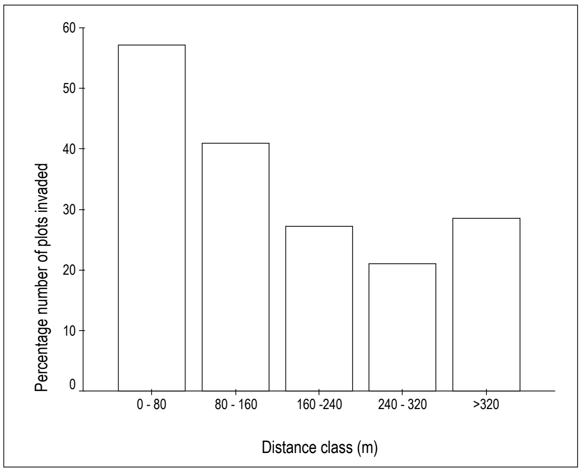
Comparison of Futululu State forest NBAL and the non treatment area also shows that the difference is not significant (Mann-Whitney U = 283.000; W = 493.000; P = 0.291)

	Number of treatments	N	Transformed mean	Transformed median
Plants in seed H = 2.12; DF = 4; P = 0.713	0	9	28.10 ± 2.14	25
	1	7	31.33 ± 4.20	25
	2	9	28.94 ± 2.69	25
	3	7	36.29 ± 5.33	25
	4-5	5	25.00 ± 0.00	25

Table 10: Relative seed production in areas treated 0 to 5 times (Kruskall-Wallis Test)

4.12. Proximity to water bodies and abundance of *Chromolaena odorata*

Comparison within the conservation area



C. odorata abundance is not significantly different across the different distance classes within the conservation areas (Kruskal-Wallis Test: H = 7.96; P = 0.093 (adjusted for ties)).

However a plot of number-of-plots-invaded per distance class shows that the number of plots invaded increases as the distance to water decreases (Figure 12).

Figure 12: Distribution of *C. odorata* at different distances to water bodies (conservation areas)

Distance classes	N	Transformed mean	Transformed median
0-80	28	56.89 ± 4.82	63.75
80-160	22	49.57 ± 5.35	29.50
160-240	11	40.55 ± 5.97	29.50
240-320	19	38.87 ± 4.39	29.50
>320	14	42.64 ± 6.10	29.50

Table 11: Abundance of *C. odorata* at different distance-to-water classes (conservation area)

Comparison within the commercial agriculture area

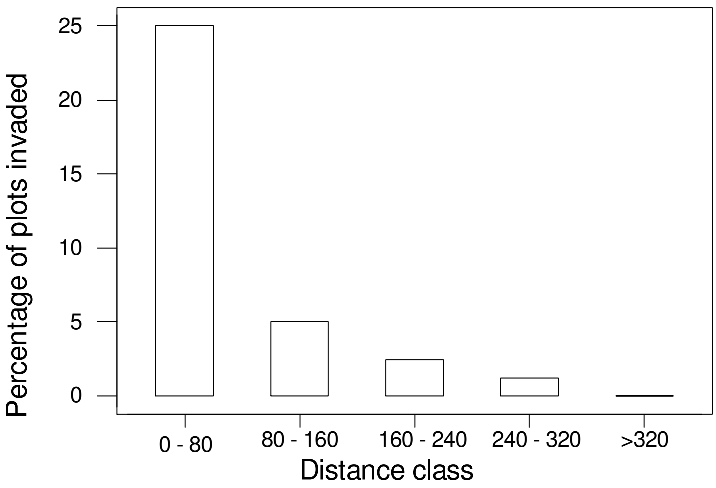
Only one sample plot was found invaded in the commercial agriculture area. No further analysis was carried out. A Kruskall-Wallis Test showed no significant difference between distance classes (H = 6.95; DF = 3; P = 0.139).

Comparison within subsistence agriculture area

H_o: $\eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5$

H_α: At least one η is different

Where η_1, η_2, η_3, η_4, η_5 are the abundance of *C. odorata* within the different distance classes.



No significant difference was found in abundance of *C. odorata* between the different distance classes tested within the subsistence agriculture area (Kruskal-Wallis Test: H = 5.12, DF = 4, P = 0.275 adjusted for ties). A plot of plots invaded by *C. odorata* at different distance classes shows a trend towards more invaded plots and abundance closer to water (Figure 13).

Figure 13: Distribution of *C. odorata* at different distance-to-water classes (subsistence agriculture area)

Distance class	N	Transformed mean	Transformed median
0-80	32	45.75 ± 3.21	35.5
80-160	19	37.79 ± 2.29	35.5
160-240	15	40.77 ± 3.59	35.5
240-320	10	39.65 ± 4.15	35.5
>320	6	35.50 ± 0.00	35.5

Table 12: Relative abundance of *C. odorata* at different distance-to -water classes (subsistence agriculture area)

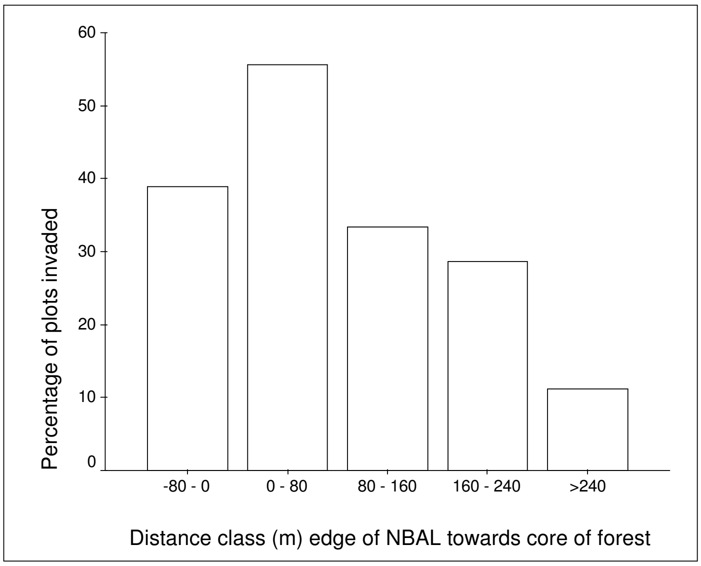
Comparison of NBAL and non NBAL periphery

Visual investigation of the spatial distribution map of *C. odorata* (Figure 8) revealed that, in Futululu forest, abundance is relatively higher in non-NBAL areas close to the NBAL. The distribution of *C. odorata* at the interface of NBAL and non-NBAL was, therefore, investigated.

H_o: $\eta_{1NBAL} = \eta_{1nonNBAL} = \eta_{2nonNBAL} = \eta_{3nonNBAL} = \eta_{4nonNBAL}$

H_α: At least one η is different

Where $\eta_{1NBAL,}$ is abundance of *C. odorata* in the distance class on the inner edge of NBAL, $\eta_{1-4\ nonBAL}$ are distance classes outside the NBAL.



Distance classes are significantly different (Kruskal-Wallis Test: H = 8.75; P = 0.033 (adjusted for ties)). Pair wise testing shows that *C. odorata* abundance in the 80m NBAL strip inside the periphery is significantly lower than in the non-NBAL strip immediately outside. The NBAL strip, however, has a significantly higher abundance than the last distance class >240m away from the NBAL edge. The trend is one of increased invasion on the outer edge of the NBAL, decreasing towards the core of the forest.

Figure 14: Distribution of *C. odorata* at different distance classes in relation to the NBAL edge

	0 – 80 Mean = 25.28 Median = 29.00 SE Mean = 2.71	80 -160 Mean = 21.17 Median = 19.00 SE Mean = 4.31	160 – 240 Mean = 16.86 Median = 12.00 SE Mean = 3.17	>240 Mean = 13.33 Median = 12.00 SE Mean = 1.33
(0 - 80) Mean = 20.00 Median = 11.00 SE Mean = 2.93	W = 88.500 P = 0.018	U = 35.000 P = 0.182	U = 45.000 P = 0.253	U = 62.500 P =0.0318

Table 13: Comparison of different distance classes with respect to distance from NBAL edge

5. DISCUSSION

5.1. Vegetation cover and *Chromolaena odorata* abundance

C. odorata abundance is not well explained by vegetation cover. Tree cover explains only 10.3% within the conservation area (Table 3). This is comparable to (Delfino Abeya, 2002) who found that tree cover explained 10.1% of *C. odorata* distribution within Futululu Forest. Joshi, (2001) in a study in Central Nepal found a stronger relationship of 42%. Within the non-treated area of Futululu State Forest the relation observed is stronger (21.8%). The weaker relation within the treatment area is almost certainly due to the effect of the *C. odorata* control programme of WfW that removes *C. odorata* from infested forest gaps.

The relation between grass/herb cover within the conservation area is in the same direction, but also weaker than that observed by (Delfino Abeya, 2002) within the same area.

Within the production forests a weak positive relation was observed between *C. odorata* and shrub cover. This relation probably results from the fact that forest managers clear all non-eucalyptus shrubs or trees from the plots when weeding. Compartments with any shrubs are, therefore, an indicator of laxity in weeding, giving an opportunity for *C. odorata* as well as any other shrubs to establish. The same argument applies for the sugarcane area, where *C. odorata* was observed in the more natural areas with shrubs, and not in the well-kept sugarcane fields.

5.2. Effect of land use type on *Chromolaena odorata* abundance

Significant difference in *C. odorata* abundance exists between conservation and all other land use types and between production forestry and sugarcane; forest plantation and subsistence agriculture. The relative levels of abundance are highest in the conservation and production forestry, followed by urban, subsistence agriculture and commercial agriculture (Table 4). This hierarchy is similar to patterns observed by (Witkowski & Wilson, 2001) in experiments of micro-sites in grasslands and dune forests in KZN. *C. odorata* seeds had better germination ability and longevity in the shade and semi shade than in the sun, indicating ill effects of exposure to sunshine but adult plant density was highest in semi shade followed by sun, and lowest in the shade, indicating low seedling survival in shade.

Futululu State Forest is characterised by a fairly dense core, with gaps in the regenerating disturbed areas towards the periphery, where the denser infestation occurs. Although reports from locals indicate that the nature of the forest has always been quite open it is clear that alien species management activities have increased the level of disturbance within and close to the NBAL, creating suitable conditions for *C. odorata.*

In the production forests tree canopy cover is intermediate between the denser natural areas and open grasslands of the subsistence agriculture areas. This factor, coupled with the sustained disturbance typical of production forest management, favours proliferation of *C. odorata*. (Yadav & Tripathi, 1999) in a study of five-year fallows observed that the population of *C. odorata* begins to decline after six years. Within the production forestry area the rotation length of eucalyptus trees (six to twelve years) would create an environment that would enhance the vigour of *C. odorata* plants. The practice of selective felling of mature tress also aids establishment of *C. odorata*. This corresponds with observations by (Groves, 1989) who observed that in India, *C. odorata* regenerated freely in gaps left by selective logging. The cover of *C. odorata* was found to be positively related to that of other shrubs, implying that the generally dirty compartments are also more likely to be infested with *C. odorata*. Weeding effort is, therefore very important in keeping *C. odorata* abundance low within the production forest compartments.

Chromolaena odorata would be expected to have fewer favourable niches within the urbanised areas because of their built up nature. In the sugarcane area the dense sugarcane crop, intensive weeding, annual harvesting and ploughing keeps *C. odorata* almost non-existent. The subsistence agriculture area is a more complex mosaic of grazed grassland, mixed crops and semi-permanent residences, where *C. odorata* might be expected to be higher than observed. *C. odorata* distribution is known to be largely unaffected by soil differences (Delfino Abeya, 2002; Majam, 2002), or rainfall differences above 600mm/annum (Caldwel, 2000). Geological attributes within the subsistence farming area, however, differ from that of other areas. This has been found to have some influence on distribution of *C. odorata* (Kindie Feleke, 2003). This and land management practices such as burning and grazing may have the effect of keeping *C. odorata* abundance low.

5.3. Effect of control strategy on *Chromolaena odorata*

Comparison across planted compartments

Mondi has an intense weed control programme in the year of eucalyptus establishment, lessening to a yearly maintenance weeding after the first two years, while SAPPI follows a more sustained routine with more frequent follow-ups. In theory, the SAPPI strategy of six-monthly follow-up treatments, timed before flowering occurs, would eliminate *C. odorata* from plantations if treatments are consistent and outlast the seed longevity period of 1 – 2 years. According (Caldwel, 2000) a small proportion of plants do reproduce within the first year, and both these strategies risk having some early reproducing plants depositing seeds in the soil before they are cleared. Although statistics show that difference in the abundance of young plants or seedling stages between the two forestry companies is not significant, a comparison of number of plots invaded suggests that the Mondi infestations are more localised (Figure 9), while those of SAPPI are widespread. This implies that the Mondi strategy is marginally more effective than the SAPPI.

According to (Groves, 1989) in Indian fallows *C. odorata* recruitment peaks after 3 years and ceases in 10 to 20 year old fallows. Plant vigour is higher in younger fields and decreases after 5 years. It is conceivable that similar dynamics are at play within the production forests. The Mondi strategy would then be a good control option if combined with the more frequent maintenance weeding carried out by SAPPI.

Comparison across conservation areas

Conservation areas managed by WfW, forest companies and commercial sugarcane farmers do not differ significantly from each other in *C. odorata* abundance, plant stages predominating or in abundance of plants-in-seed (4.6; 4.7; 4.8).

The implication is that the more focused and organised approach adopted by WfW and the forestry companies is not any more effective than the more ad hoc approach of the commercial farmers. However, the conserved areas within the commercial farmland consist of small patches, which would be more accessible and easier to manage effectively than those managed by the forestry companies and WfW. These areas are also fragmented and isolated, probably reducing chances of cross re-infestation.

Comparison within Futululu State Forest between treated and non-treated areas

There is no difference in *C. odorata* abundance in Futululu Forest between areas treated once, twice, three or four to five times. However, there is a weak negative correlation between *C. odorata* abundance and increasing number of treatments. This result differs from that of (Delfino Abeya, 2002) who observed a positive correlation between *C. odorata* cover and number of treatments. Areas treated 4-5 times have significantly lower *C. odorata* abundance than non-treated areas (4.9). This is consistent with WfW guidelines which indicate that, using a combination of mechanical and chemical means, four to six treatments are necessary to control *C. odorata* and studies by (Nortje, 2001).

Abundance of different plant stages is similar within the Futululu state forest. Comparison of Futululu State forest showed no significant differences in blocks treated once, twice, three times or four to five times, or not at all in abundance of different plant stages (Table 9). A comparison in terms of abundance of *C. odorata* plants in seed showed they are not significantly different (Table 10). There is therefore no apparent difference in the effect that the strategies used in these areas affect reproduction of *C. odorata*. This result is unexpected as a difference might be expected within the classes that differ in terms of abundance.

5.4. Proximity to water bodies and abundance of *Chromolaena odorata*

Although there is a visible trend towards higher abundance within plots closer to water (Figure 12, Figure 13), statistical tests show that distance of plots from water bodies has no significant effect on abundance of *C. odorata*. These results are contrary to the commonly held concept within KZN that *C. odorata* abundance is higher close to water bodies. This disparity is, again, probably due to management activities that take place within these areas. Within the conservation areas *C. odorata* is specifically targeted for removal, while many parts of the subsistence agriculture areas experience grazing and annual burning, which may kill off the weed. This is consistent with studies by (Goodall, 2000), who observed that sparse to moderate infestations of *C. odorata* in more than 30% grass cover are killed off by fire. The dynamics here require further investigation, however.

5.5. NBAL and non-NBAL periphery

In the non-NBAL area in Futululu forest, abundance of *C. odorata* increases as the spatial distance to the NBAL decreases (Figure 15). A significant difference was observed within distance classes contiguous to each other at the periphery of the Futululu forest NBAL, with significantly higher abundance of *C. odorata* in the outer strip (Table 12). This increase outside the treatment area is an indication that the NBAL does not cover all the worst areas of infestations (anymore). These areas outside the narrow treated buffers around the water bodies are probably sources of new infestation into the NBAL, negating control efforts. The WfW strategy can therefore only be effective if the non-NBAL areas can be isolated, an impossible task.

5.6. Conclusion

The current state of *C. odorata* on different land use types investigated differ considerably, especially between the highly infested conservation and production forestry and other less infested land use types.

Strategies used in the control of *C. odorata* range from relatively intensive, well organised and documented integrated strategies within the conservation and production forestry areas, to more ad hoc arrangements within the commercial agriculture, subsistence agriculture and urban centres.

The state managed programme within the conservation areas is more intensive than any other, but lack complete coverage of infested areas. The effect of control measures, though apparent, is marginal and the problem of *C. odorata* persists. It is not clear what role new infestations play in maintaining infestations compared to seed banks maintained by inefficiencies in clearing operations. Existence of all morphological stages of *C. odorata* within the NBAL indicates that inefficient clearing does occur. It is therefore worth reviewing current management approaches to address these issues. Since the treated and non-treated areas are adjacent this increases the chances for re-invasion of cleared NBAL blocks at the periphery.

SAPPI and Mondi programmes have complete coverage and management of *C. odorata* may present fewer problems because of better accessibility within the production forests. However management here is aimed at keeping *C. odorata* density low only with the objective of maintaining profitability. This approach is reflected in timing and frequency of weeding operations, which is a compromise between effectiveness and profitability considerations. Hence, even where there may be a possibility of eradication, *C. odorata* is simply ‘controlled’. The same holds true for the sugarcane farmers. These commercially driven objectives will need special incentives or enforcement in order to change.

Success in controlling an invasive may be said to be attained when the effects of the invasion no longer exceed a threshold level. This level may be economically, agronomically or ecologically determined. If this definition is taken strictly the subsistence agriculture and urban areas and, to some extent, the commercial agriculture areas cannot be included in assessing success since no specific control measures are carried out there. None of the strategies therefore is significantly more successful.

As a land use type, however commercial agriculture is most successful in controlling *C. odorata* invasion. The main differences between the commercial agriculture areas with the other land use types are the dense sugarcane crop, a strictly regular herbicidal and weeding programme and regular ploughing. These practices also take place over the whole sugarcanes crop area.

Although the set-up in sugarcane farming is different from that of eucalypts some lessons from here may benefit both the production forestry and the conservation areas. Using appropriate plant cover to rehabilitate cleared areas or under tree crops may improve control within the production forestry area where weeding is carried out less often. In the conservation NBAL areas the use of vegetation cover to control *C. odorata* is not emphasised and areas cleared of *C. odorata* are commonly left bare (pers. observation), which increases their vulnerability to re-infestation from both old and new sources. This might be reduced by speeding up the process of forest regeneration by carrying out rehabilitation planting in these areas.

REFERENCES

Ambika, S. R., & Jayachandra. (1989). The Problem of Chromolaena Weed. *Newsletter on Biocontrol and Managment of Chromolaena odorata, 1*.

Anon. (1998). *St. Lucia System Information sheet*: Ramsar.

Anon. (1999/2000). *The Working for Water Programme Annual report* (Annual report).

Anon. (2001). *Mtubatuba Municipal Council IDP Phase 1: Analysis Report*. Mtubatuba: Mtubatuba Municipal Council.

Anonymous. (1996). *Natal Parks Board Internal Report: Natal Parks Board Year Book 1995 -1996*. Pietermaritzburg: Natal Parks Board.

Bingelli, P., Hall, J. B., & Healey, J. R. (1998). Overview of Invasive Woody Plants in the Tropics, *The Invasive Woody Species Database* (1998 ed., Vol. 13): School of Agricultural and Forest Sciences, University of Wales, Bangor.

Blackmore, A. C. (1996). *Seed dispersal of Chromolaena odorata reconsidered.* Paper presented at the Fourth International Workshop on Biocontrol and Management of Chromolaena odorata, Bangalore, India.

Caldwel, P. (2000, Feb/Mar 2000). *Triffid Weed*. Kloof Conservancy. Retrieved Dec. 20, 2002, Vol 7, from the World Wide Web: www.ceit.co.za/kc/inv/triffd.htm

Coblentz, B. (2002, January 7, 2002). *Exotic Organisms, Course module lecture: Principles of Wildlife Conservation*. Department of Fisheries and Wildlife, Oregon State University. Retrieved 11 July 2002, from the World Wide Web: http://www.orst.edu/instruct/fw251/notebook/exotic.html

Coblentz, B. E. (1990). Exotic organisms: a dilemma for conservation biology. *Conservation Biology, 4*(3), 261-265.

Cowling, R. M. (1997). Vegetation of southern Africa. In R. M. Cowling & D. M. Richardson & S. M. Pierce (Eds.). Cambridge etc.: Cambridge University Press.

Delfino Abeya, J. A. (2002). *Control of Invasive Chromolaena odorata (L.) R. M. King and H. Robinson: An Evaluation of its Efficacy in Futululu State Forest, South Africa.* Unpublished MSc Thesis, ITC, Enschede.

di Castri, F. (1989). History of Biological Invasions with Special Emphasis on the Old World. In J. A. Drake & H. A. Mooney & F. di Castri & R. H. Groves & F. J. Kruger & M. Rejmanek & M. Williamson (Eds.), *Biological invasions: A global perspective* (Vol. 37, pp. 1 - 26): John Wiley & Sons.

Dobkowski, K., Gallegos, Y., Hoffman, J., & Mapa, A. (2001). *Fact Sheets on Management of Nine Coastal and Marine Protected Areas* (Internship report). Indonesia: University of San Francisco, School of Law (USF).

Drake, J. A., Mooney, H. A., & Castri, D. (Eds.). (1989). *Biological invasions : a global perspective* (Vol. 37).

Erasmus, D. J. (1988). *A Review of mechanical and chemical control of Chromolaena odorata in South Africa.* Paper presented at the First International Workshop on Biological Control of C. odorata, Bangkok, Thailand.

Goodall, J. M. (2000). *Managing Chromolaena odorata in sub-tropical grasslands in KwaZulu Natal.* Paper presented at the Fifth International Workshop on Biological Control of Chromolaena odorata, Durban, South Africa.

Groves, R. H. (1989). Ecological control of invasive terrestrial plants. In J. A. Drake & H. A. Mooney & di Castri F. & R. H. Groves & F. J. Kruger & M. Rejmanek & M. Williamson (Eds.), *Biological invasions: a global perspective* (Vol. **Scope 37**, pp. 437 - 457): John Wiley and Sons Ltd.

Hoevers, R., & M'Boob, S. S. (2000). *The Status of Chromolaena odorata (L.) R. M. King and H. Robinson in West and Central Africa.* Paper presented at the Fifth International Workshop on Biological Control and Management of C. odorata, Durban, South Africa.

Joshi, C. M. (2001). *Invasive Banmara, Chromolaena odorata, spatial detection and prediction.* Unpublished MSc, ITC, Enschede.

Kindie, F. A. (2003). *Land Use and Land Cover in Relation to Chromolaena odorata Distribution: Mapping and Change Detection in St. Lucia Wetland Area, South Africa.* Unpublished MSc, ITC, Enchede.

Levin, S. A. (1989). Analysis of Risk for Invasion and Control Programmes. In J. A. Drake & H. A. Mooney & F. di Castri & R. H. Groves & F. J. Kruger & M. Rejmanek & M. Williamson (Eds.), *Biological Invasions: A Global Perspective* (Vol. Scope 37, pp. 425 - 432): John Wiley & Sons.

Lillesand, T. M., & Kiefer, R. W. (2000). *Remote sensing and image interpretation* (Fourth edition ed.). New York etc: Wiley & Sons.

MacFadyen, R. C. (2000). *The ACIAR Project for the Biological Control of Chromolaena odorata, Future Developments.* Paper presented at the Fifth International Workshop on Biological Control of C. odorata, Durban, South Africa.

Mack, R. N. (1989). Biological invasions : a global perspective. In J. A. Drake & H. A. Mooney & F. di Castri & M. Rejmanek & M. Williamson (Eds.), *Biological Invasions: A Global Perspective* (Vol. **37**, pp. 155): John Wiley & Sons.

Majam, N. J. (2002). *Spatial Distribution of Invasive Alien Plants in the Futululu Forest Reserve, South Africa.* Unpublished MSc. Thesis, ITC, Enschede.

McFadyen, C., R.E. (1991). *The Ecology of Chromolaena odorata in the Neotropics.* Paper presented at the Second International Workshop on Biocontrol and Management of Chromolaena odorata, Bogor, Indonesia.

McNeely, J. (2000, 22 - 24 Feb). *Invasive Species: A Costly Catastrophe for Native Biodiversity.* Paper presented at the Best Management Practices for Preventing and Controlling Invasive Alien Species, Cape Town, S.A.

Mooney, H. A., & Drake, J. A. (1987). The ecology of biological invasions. *Environment, 29*(5), 10-15.

Moore, J. (2002, 24.10.2002). *Alien Invader Plants* [Internet]. Retrieved, from the World Wide Web: www.geocities.com/wessaaliens/current.htm

Muniappan, R., & Marutani, M. (2000). *Mechanical and Chemical Control of Chromolaena odorata.* Paper presented at the Fifth International Workshop on Biological Control of C. odorata, Durban, South Africa.

Nortje, D. (2001). *Eradication of C. odorata (Paraffien bos) in KwaZulu Natal*. Unpublished manuscript.

Plant Biosecurity. (2002, 7 August 2002). *Siam weed - fact sheet No. 56 - AFFA*. Department of Agriculture, Fisheries and Forestry, Australia. Retrieved, 5 February 2003, from the World Wide Web: http://www.affa.gov.au/content/output.cfm?ObjectID=D2C48F86-BA1A-11A1-A2200060B0A03977

Potvin, C., & Roff, D. A. (1993). "Distribution-Free and Robust statistical methods: viable alternatives to parametric statistics?" *Ecology*, ***74***(6), 1617 - 1628.

Qualifor Programme Associated Documents. (2001). *Forest Management Surveillance Report for Mondi Forests (Pty) Ltd* (Surveillance Number 01

Forest Management Certificate Number 0755/6326/0084 4). Number AD 72.

Richardson, D. M., Macdonald, I. A. W., Hoffman, J. H., & Henderson, I. (1997). Alien Plant Invasions. In R. M. Cowling & D. M. Richardson & S. M. Pierce (Eds.), *Vegetation of Southern Africa* (pp. 535 -570): Cambridge University Press.

SGS Forestry. (2000). *Main Assessment Report: Forest Certification, SAPPI Forests* (Public Summary Report Project Number: 6709ZA): SGS Forestry.

SGS Forestry. (2001). *Forest Management Surveillance Report for SAPPI Forests* (Surveillance Number 02 Forest Management Certificate Number SGS-FM-0442): SGS Forestry.

Stirton, C. H. (1979). *Taxonomic problems associated with invasive alien trees and shrubs in South Africa.* Paper presented at the 9th Plenary Meeting AETFAT, South Africa.

Taylor, R. H. (1982). St. Lucia Research Review.

Timbillah, J. A., & Braimah, H. (2000). *Establishment, Spread and Impact of P. pseudoinsulata (Lepidoptera:arctiid moth) an Exotic Predator of the Siam Weed, Chromolaena odorata (Astaraceae: Eupatoriae) in Ghana.* Paper presented at the Fifth International Workshop on Biological Control of C. odorata, Durban, South Africa.

Toa-Kwapong, D. (1984). *Chromolaena Odorata : a menace or a resource : the Acheampong plant in Ghana.* University of Ghana.

van Wilgen, B., Richardson, D., & Higgins, S. (2000). *Integrated control of invasive alien plants in terrestrial ecosystems.* Paper presented at the Best Management Practices for Preventing and controlling invasive species, Cape Town, South Africa.

Waterhouse, B. (2000). *Chromolaena odorata in Australia: Progress in Eradication of an Established Infestation.* Paper presented at the Fifth International Workshop on Biological Control of C. odorata, Durban, South Africa.

Witkowski, E. T. F., & Wilson, M. (2001). Changes in density, biomass, seed production and soil seed banks of the non-native invasive plant, Chromolaena odorata, along a 15 year chronosequence. *Plant Ecology, 152*(1), 13-27.

Wu Renrun, & Xu Xuejun. (2000). *Cultural control of Feijicao (Chromolaena odorata (L.) R. M. King and H. Robinson) by Planting Signal Grass (Bachiaria decumbens stapf) in Southern Yunnan, People's Republic of China.* Paper presented at the Fifth International Workshop on Biological Control of C. odorata.

Yadav, A. S., & Tripathi, R. S. (1999). Studies on the demography of Eupatorium odoratum in a secondary successional community. *Tropical Ecology, 40*(2), 269-273.

Zachariades, C., Strathie-Korrubel, & Kluge, R. L. (Eds.). (1999). *The South African Programme on the Biological control of C. odorata using insects.* (Vol. 1): Entomological Society of Southern Africa.

Zachariades, C., Strathie-Korrubel, & Kluge, R. L. (Eds.). (1999.). *The South African Programme on the Biological control of C. odorata using insects.* (Vol. Memoir No. 1, June 1999).

6. APPENDICES

Appendix 1: Releveé Sheet

Releveé sheet

Sample unit #:	Sample plot #:	Collector:	Date:
Easting		Northing	Altitude
Land ownership:		Aspect to nearest 1°	Slope to nearest 1°
Site Photographs: Roll		Photo description:	

Land cover %

	Tree	Shrub	Grass/Herb	Crop	Water	Bare soil	Buildings	Other
Species								
Cover								
Distribution								

***C. odorata* status**

Age of infestation					
	Seedlings	Etiolated shrubs	Bushy shrubs	Flowering	Seeding
Plant count					
Cover %					

***C. odorata* control methods indicators**

Plant stage targeted	Damaged leaves	Damaged stems	Dead plants	Other

Land use/disturbance

Plantation forest

Species		Age of trees	

Natural forest

Tree stumps count			Other disturbance		

Grazing signs		Fire signs		Other			

Distance to

Power lines (m)		Road (m)		Tracks (m)	

Notes

Appendix 2: Interview checklist

	Information required	**Notes**
1.	Name of organisation	
2.	Objectives/mandate	
3.	Activities	
4.	*C. odorata* management strategy	
	methods	
	timing of clearing(s)	
	plant stage targeted	
	abundance of follow-up	
	number of follow-ups	
	monitoring	
	information system	
	planning	
	coordination/partnerships	

Appendix 3: Classification criteria for *Chromolaena odorata* growth form/morphology

	Height	**Branching/ Habit**	**Reproduction**	**Other**
Seedling	≤50cm	1 – 3 stems	not reproductive	
Young	>50cm<100cm	3 or more stems	not reproductive	
Etiolated shrub	>100cm	tall thin stems, few branches, scrambling	possibly reproductive	dark green
Bushy shrub	>100 cm	numerous branching, thick short stems	possibly reproductive	pale green leaves woody
Resprout	Any	main stem visibly cut & resprouting	possibly reproductive	

Appendix 4: Classification criteria for land use types

Land use	**Land cover criteria**
Conservation	natural forest
Production forestry	eucalyptus trees
Commercial agriculture	unmixed sugarcane crop, bare soil within sugarcane crop area
Subsistence agriculture	expanse of short grassland; small areas of mixed crops
Urban area	built-up area mixed with or adjacent to areas of fragmented short mixed vegetation
Wetland	flooded area with emergent vegetation
Open water	flooded area without emergent vegetation

Appendix 5: Error matrix for land use map

Error matrix (a)

Preliminary classification

		Conservation	Production forest	Commercial agriculture	Subsistence agriculture	Urban	Wetland	Open water	Total	Accuracy
T	Conservation	85827	39732	1842	47	0	0	413	127861	0.671252
E	Production forest	31160	112769	3321	61	0	36567	0	183878	0.613282
S	Commercial agriculture	0	0	60114	0	99	3589	0	63802	0.942196
T	Subsistence agriculture	0	0	0	73799	17096	160	28	91083	0.810239
	Urban	43	295	100	15922	46671	35213	553	98797	0.472393
M	Wetland	0	9	50	292	6	37632	0	37989	0.990603
A	Open water	0	0	0	2145	0	0	6285	8430	0.745552
P	Total	117030	152805	65427	92266	63872	113161	7279	611840	0.7493595
1	Reliability	0.733376057	0.7379929	0.918794993	0.799850432	0.73069577	0.33255	0.86344278	0.7309579	0.6915158

Error matrix (b)

Post fieldwork classification

		Conservation	Production forest	Commercial agriculture	Subsistence agriculture	Urban	Wetland	Open water	**Total**	**Accuracy**
T										
E	Conservation	84158	35856	22	6	4	43	20	**120109**	**0.70068022**
S	Production forest	22494	117284	51	206	29	5729	58	**145851**	**0.80413573**
T	Commercial farming	6105	50	64773	7	17	307	0	**71259**	**0.90897992**
	Subsistence agriculture	14	93	0	94669	0	80	4	**94860**	**0.99798651**
M	Urban	10	25	0	7	59831	23	0	**59896**	**0.99891479**
A	Wetland	4554	444	202	116	43	107620	11	**112990**	**0.95247367**
P	Open water	4	95	0	17	0	3	6085	**6204**	**0.98081883**
2	**Total**	**117339**	**153847**	**65048**	**95028**	**59924**	**113805**	**6178**	**611169**	**0.906284236**
	Reliability	**0.717221043**	**0.762341807**	**0.995772353**	**0.99622217**	**0.998448034**	**0.94565**	**0.9849466**	**0.9143721**	**0.874422623**

Appendix 6: Field data summary

Stratum	**Area (ha)**	**Sample (Size)**
Conservation		
Futululu State Forest	3639.9486	79
NBAL blocks	(1,129.7368)	(49)
Non-NBAL	(2,510.2117)	(30)
Conservation areas within production forest area	220.3875	27
Conservation area within commercial agriculture area	96.3900	20
Production forestry	4,002.0000	98
Mondi	(1,793.1300)	(48)
SAPPI	(2,208.9000)	(50)
Commercial agriculture	2,201.8500	48
Subsistence agriculture	2,011.1525	59
Urban area	1,348.2900	25
Wetland	560.8600	not sampled
Open water	139.0050	not sampled
Total	13659.636	356

() included in statistics for the level above

Appendix 7: Data used in the study

Data	Date	Scale	Source	Derived data
ASTER image	8.6.2002	Digital	Internet	Land use, land cover maps
Map of NBAL blocks of WfW	09.2002	Digital	WfW	*C. odorata* density, stage, method of control
Topographic maps: South Africa 2832AC 2832 AD	1982	1:50,000	Chief Directorate, Surveys & Land Information, South Africa	Drainage map
SAPPI Stock map	Undated	1:20000		Forest blocks, conservation areas
SAPPI NBAL contracts map	23.08.2002	1:20000		Clearing locations, status of conservation areas
Cadastral map	Undated	Digital	Local Government (KZN)	Land ownership categories

Appendix 8: Sample of WfW information system data

Nbaldat

NBALID	SP_CODE	SIZECODE	PD	STAGE	METHOD	DENSCODE	NOTES	UPD	VERIFIED
W32H100142	48	a	10938.2	1	9	m	?	10938.	0
W32H100142	48	s	2734.55	4	7	s	?	2734.5	0
W32H100142	48	s	546.91	5	7	v	?	546.91	0
W32H100141	48	a	7518.2	1	9	m	?	7518.2	0

nbalfup

NBALID	FOLLUPREQ	PRIORITY
W32H100142	12	0
W32H100141	12	0
W32H100140	12	0
W32H100139	12	0

ta_stage

NBALID	TRAREAID	STAGE
W23D100056	W32H100200009	3
W23D100056	W32H100200033	5
W23D100072	W32H100699810	1
W23D100072	W32H100699810	2

Physdesc

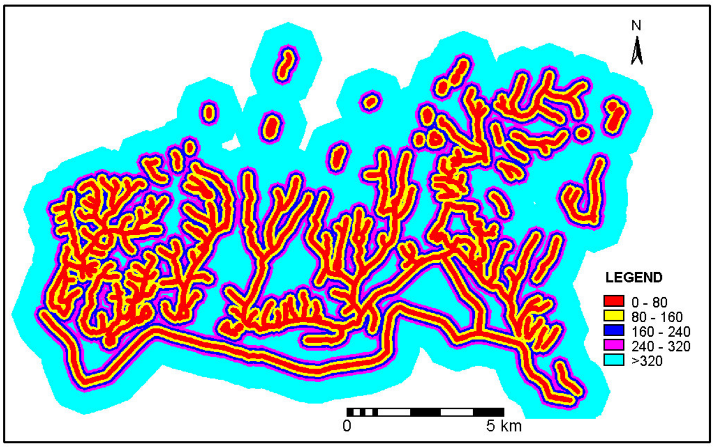
NBALID	OBS_TYPE	OBS_VAL
W23D100177	1	0.02ha
W23D100177	3	1,1,1
W23D100109	10	129.67ha
W23D100109	9	0

Appendix 9: Chemicals used in control of *Chromolaena odorata*

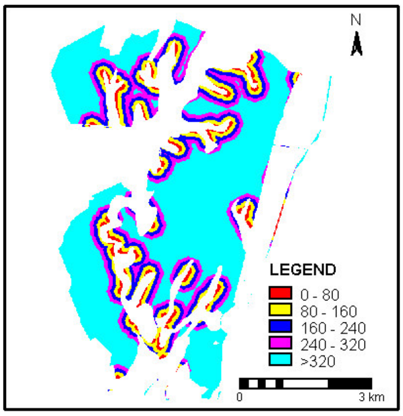
Common Name	**Trade name**	**Description**
Actipron	Actipron	Self-emulsifying adjuvant oil for use with post emergence application of certain crop protection products to improve reliability and effectiveness
Chopper®, Arsenal®, Contain®	Imazapyr	2-(4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl)-3-pyridinecarboxylic acid
MCPA	Acme MCPA Amine 4	2-methyl-4-chlorophenoxyacetic acid
Merlin (Balance)	Isoxaflutole	isoxaflutole [5-cyclopropyl-4-(2-methylsulfonyl-4-trifluoromethyl benzoyl) isoxazole]
MSMA	MSMA	Monosodium methanearsonate
Paraquat	Ortho Paraquat, Gramoxone (58)	1,1’-dimethyl-4,4’-bipyridinium ion
Roundup	Glycophosate,	Isopropylamine salt of N-(phosphonomethyl)glycine
Metribuzin	Sencor, Lexone	4-amino-6(1,1-dimethyl)-3-(methylthio)-1,2,4-triazin-5(4H)
Garlon 4	Triclopyr	[(3,5,6-trichloro-2-pyridinyl) Oxy]acetic acid
Hexazinone	Velpar	3-cyclohexyl-6-dimethylamino-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione

Source: Monzi Agri-chemicals, KZN; The Pesticide Management Education Program, Cornell University

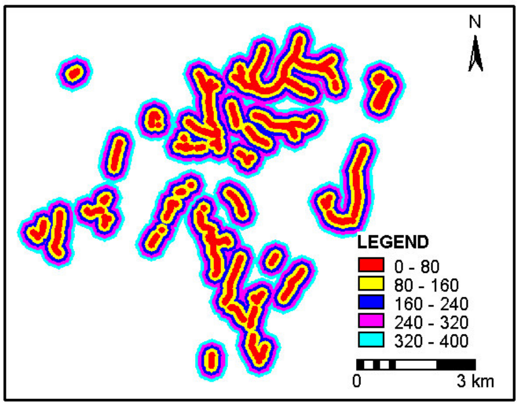
Appendix 10: Distance maps



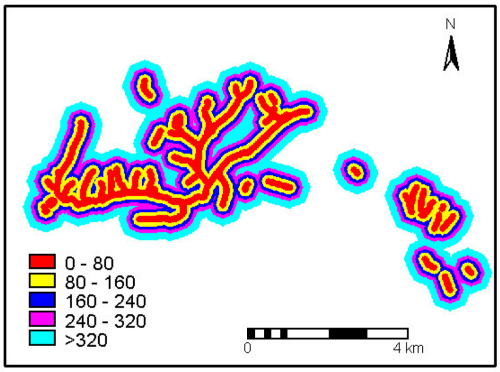
Distance to water classes map, entire study area



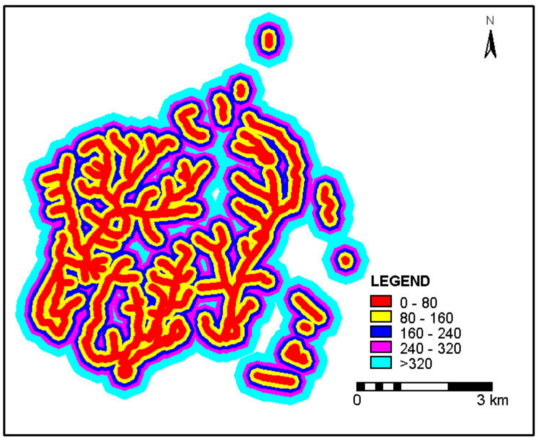
Distance to water NBAL - Futululu non-NBAL area



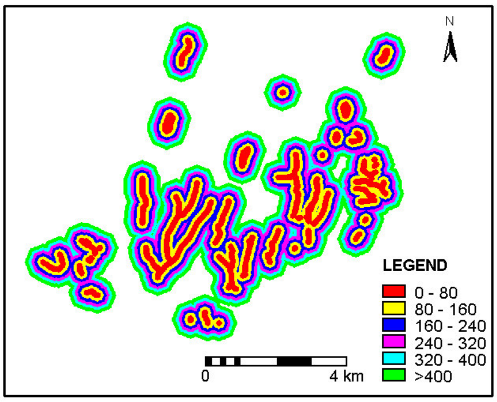
Distance to water classes – conservation areas



Distance to water classes – commercial agriculture area



Distance to water classes - Subsistence agriculture area



Distance to water classes - Production forestry area

Appendix 11. *Chromolaena odorata* picture album