Control of invasive *Chromoleana odorata* (L.) R.M. King and H. Robinson: an evaluation of its efficacy in Futululu State Forest, South Africa

Delfino Abeya, J.A.

March 2002

Control of invasive *Chromoleana odorata* (L.) R.M. King and H. Robinson: an evaluation of its efficacy in Futululu State forest, South Africa

Delfino Abeya, J.A.

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 Rural Land Ecology (RLE 2)

Degree Assessment Board

Chairman: Prof. Dr. Skidmore, Head, ACE Division, ITC.
External Examiner: Dr. D.M. Pegtel,: Laboratory of Plant Ecology, University of Gronigen
Internal Examiner: Mr. R.C. Albricht, MSc., Forest Science Division, ITC.
Primary Supervisor: Dr. H.A.M.J. van Gils, ACE Division, ITC.
Secondary Supervisor: Dr. I.C. van Duren, ACE Division, ITC.

AGRICULTURE, CONSERVATION AND ENVIRONMENT (ACE) DIVISION
INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION, ENSCHEDE, THE NETHERLANDS

Disclaimer

Acknowledgement

I sincere thanked the Netherland Government for offering me this scholership without which this Study would have been impossible.
Iam also owed my deepest appreciation and thanks to my supervisors Dr. H.A.M.J.van Gils and Dr.I.C. van Duren for their kind and timely support and advise during the term of this study.
It is also my honor to thank Mr. Denis Rugege, and for his full support during the data collection in the field and being available at all time whenever his help is needed and not forgetting his colleagues in the University. My acknowledgement alsogoes to Staff of WFW Ms Mkhwanazi the Project coordinator and Mr Myhill the GIS officer in the Futululu state Forest for their kind co-operation and provision of all the necessary data required for this study. My special thanks to the entire Field guides who took the bore the burden of collecting the data in the forest.
I'm also thankful to Dr Ayoub, the Dean, College of Natural Resources and Environmental Studies, University of Juba for his recommendation and releasing me for this study. I also thanked and appreciated all those who have provided me with the moral and material support in the course of my study. My special thanks to all the colleagues in the ACE division and particularly J. Kandeh and J.N. Majam for their good company.
Lastly I'm thankful to my family for their patience and courage during this long period of my absence.

To: My Mother, brothers and my Dear Vukeni

Abstract

Chromoleana odorata is one of the worse environmental weeds threatening both the natural and managed ecosystems. Introduced in 1940s in South Africa, this species has naturalized and invaded most of the tropical and Sub-tropical regions of the country. In the Province of KwaZulu and in particular the Greater St. Lucia, threatens biodiversity, eco-tourism, forestry, watershed management and sustainable farm management. Control programme has been initiated to reduce the impact of this species. However, little has been known about the efficacy of the control strategy being used.

The aim of this study was to assess and evaluate the efficacy of the control strategy. It was also intended to determine and analyze the factors affecting the control efficacy. To achieve the objectives of this study, a combination of field observations related to the cover of *C. odorata* and the related biophysical data and secondary data on the control of *C. odorata* were used.

The results showed that the current control strategy has significantly reduced the cover of C. odorata. Considering factors such as number of treatment and time lapse, the result indicated that C. odorata cover increases with both number of treatments and time lapse since last treatment. With the biophysical factors, the result showed that the most important factors affect the efficacy of the control are tree cover, grass cover, number of invasive alien plant species and consistency of treatment. However, the combination of these factors can explain only about 45% of the variability in the cover of C. odorata within the management blocks.

Therefore, based on the result, while number of treatments does not guarantee the efficacy of control of C. odorata, it is important that time lapse between follow-ups be kept as short as possible while treatments be done consistently. Furthermore, the result suggested that control of *C. odorata* requires maintaining dense forest cover and keeping high grass cover in case of tree less area.

1. Background

1.1. Invasive alien Species

Invasive alien species are major threat to biodiversity and human welfare. They influence and alter the functioning of ecosystem through their competitive, predative and parasitic nature leading to loss of the indigenous species, health risk (Adair, 1995; Richardson, Macdonal, Haffmann, & Henderson, 1997) and economic consequences (Myers, Simberloff, Kuris, & Carey, 2000; Simberloff, 1996). After habitat destruction and fragmentation, invasive species are the second important threat to biodiversity (Schmitz & Simberloff, 1997; Williamson, 1999). This growing worldwide habitats destruction is a product of human induced transfer of organisms either intentionally or accidentally through trade and colonization (Mack et al., 2000; WRI, 1999) disturbances to ecosystems (Turlings, 2000). By definition, "Invasive or alien species are species, subspecies or lower taxon occurring outside of their natural range and dispersal potential and includes any part or gametes of such species that might survive and subsequently reproduce" (Turlings, 2000)

Due to their serious environmental consequences, invasive alien species have become one of major conservation problem both at national levels in many countries and internationally (UNEP, CBD, & SBSTTA, 2001; WRI, 1999). As such several attempts to control and eradicate invasive species have been initiated (Groves, 1989; Muniappan & Marutani, 1996; Myers et al., 2000; Usher, 1989). While others have given successful results, some proved difficult to the present day. For instance the eradication of Purple loosetrife (*Lythrum salicaria*) in United States (Sharov & Leibhold, 1998) in 1970s and the case of boll weevil (*Anthonomus grandis*) in Southern USA (Myers et al., 2000) resulted in heavy financial cost yet eradication was unsuccessful. While eradication of Barberry (*Berberis vulgaris)* in Canada (Haber, 1998) New Zealand and European rabbits (*Oryctolagus cuniculus*) were successful (Myers et al., 2000) yet their impacts were considerable in both economic and environmental terms.

Based on these experiences, it has been recommended that the best and most economical measure is to keep alien species out by the use of quarantine (Foxcroft, 2001; Myers et al., 2000). However, according to (Simberloff, 1996) quarantines is not a sure method of protection against invasion of alien species. He argued that despite strict laws proliferation of new species are inevitable through smuggling. Furthermore, (Schmitz & Simberloff, 1997) disputed that quarantines are seriously imposed only when an invasive species has established and proven serious threat. He also pointed out that taxonomic screening of blacklisted species is controversial by itself. As such, monitoring, eradication and/or control of invasive species at early stage of establishment is yet the best way of avoiding unforeseen consequences (Myers et al., 2000). However, despite all the efforts, today around the world, many countries' biodiversity are under the threat of established invasive species, which require eradication or control programmes.

Different approaches of control have been in practice depending on which alien species are under consideration, their biology and size. Further more, the availability of fund and public perception influence which approach of control is more appropriate (Richardson et al., 1997). These control measures are as follows: -

- Physical or mechanical control: This involves the removal of all the individuals manually or some mechanized implements such as tractors (Muniappan & Marutani, 1996).

- Chemical control involves the use of chemicals (Herbicides) to kill the individuals. This method although more effective, its associated environmental impact may not be desirable (Myers et al., 2000).
- Biological control is a method where a pathogen or often pest is introduced that may either kill the invading population or retard their reproduction capacity below sustainable level. Although this approach proved economical, some of the introduced pest or pathogen may prove invasive themselves (van Wilgen, Richardson, & Higgins, 2000)
- Integrated control: This approach is a combination of mechanical, chemical and biological in a more economical manner (Foxcroft, 2001).

1.1.1. Alien plants in South Africa

In South Africa, introduction of alien plant species dated back to early European settlers for agricultural and forestry purposes. By 1940 over 400 alien species had already been well-established displacing 40% of the native species around KwaZulu-Natal (Richardson et al., 1997). Among others, *Pinus pinastar,Eucaliptus, Hakea*, *Melia azedarach, Jakaranda mimosifolia* among the woody species, *Opuntia spp* for the succulent and *Chromoleana odorata, Datura innoxia* and *Tagetes mimuta* among the non-woody species. `To date, there are over 750 trees, about 8000 shrubs and herbaceous alien species of which 161 have become invasive species claiming about 10% of the country's area. Of the above, currently 44 species are declared noxious by law amongst them is *Chromoleana odorata* (Richardson et al., 1997).

Chromoleana odorata (L) R. M. King & H. Robinson (Eupatorium odorata L) is native to tropical and Sub-Tropical Americas (South to central America and West Indies) and now is established in all tropical Africa and Asia (McFadyen, 1988). Normally, *C. odorata* strives under annual rainfall of 1000-2000mm but this species has proved to grow at rainfall as law as 600-500mm(Goodall, 2000; Timbilla, 1996). It belongs to the Family Asteraceae or Compositae, one of the largest plant families. There are about 129 species in the genus *Chromoleana*. Taxonomically, *C. odorata* can be recognized by its pinkish white terminal flowers. The leaves are light to yellowish green with three prominent veins from beneath. It has linear straw-colored bristle fruits about 5mm long with hairy, light seeds.

In South Africa, *C. odorata* has been introduced in 1940s accidentally in Durban where it spread and invaded Port Shepston and Stanger respectively in the North and South direction by the coast along the wind direction in 1960 (Blackmore, 1996). Thereafter, several parts of South Africa mainly along the coast started to experience extended invasion of *C. odorata* except in the frost free and the drier areas and far beyond into other neighbouring Southern African countries for instance Swaziland and Mozambique (Strathie-Korrubel, 2000)

Currently, *C. odorata* is one of the most serious invaders (Blackmore, 1996; Kluge & Caldwell, 1994) and is ranked among the top priority noxious species in South Africa. In other words, it is one of the top ten black listed noxious species. Like in many other countries, the impacts of this invasive alien species in South Africa has resulted in to transformation of ecosystem, riparian habitats and agricultural (Richardson et al., 1997). These ecological effects range from reduction of carrying capacity of grazing lands for livestock, alteration of catchments water yields by blocking stream flow or excessive water use and biodiversity loss. Furthermore, this species reduce the aesthetic values of conservation areas as they form close thicket along the corridor, placing constrain on the tourism (Blackmore, 1996). On the other hand, invasive alien plants especially, *C. odorata* is seen as fire hazards as they form dense thickets, increasing the total biomass which in turn increases the fire intensities. This results in damage to physical properties of the soil; increase soil erosion and directly killing all the associated plants.

1.1.2. Control Programmes

“Control or Eradication” according to (Myers et al., 2000) “is the removal of every potentially reproducing individual of a species or the reduction of their population density below sustainable levels”. In the face of the large number of invasive alien plants, South Africa has had a long battle dealing with management of invasive alien plants. The first problem of invasive species was felt since 1860 when *Xanthium spinosum* was spreading widely and proved invasive alien (Richardson et al., 1997). By 1945, the problem of woody alien plants on both native species suppression and water yielding capacity of catchments were explicitly recognized (van Wilgen et al., 1997). Although control attempts were initiated as early as 1941, the insufficiencies of funds and lack of coordination of the program made it difficult to achieve any progress (Richardson et al., 1997).

At the present, the control of invasive species run under the “Slogan” of “Working for Water”(WFW) which was initiated by the Department of Water Affairs and Forestry (DWAF) in 1995 especially in Greater St. Lucia has considerable achievement in this regards (CCWR, 1998). However, despite this effort the rate of spread of these species especially *C. odorata* is higher than the control rate (Foxcroft, 2001). As such, being one of the most serious invasive alien species, well established and fast expanding, the eradication of *C. odorata* is given special consideration (Foxcroft, 2001).

1.1.3. Methods of *C. odorata* control

A number of methods such as mechanical, cultural, chemical and biological are used to control *C. odorata*. In many countries cultural control is practiced for instance, in China, Cultural control using various legume ground covers in plantations and Signal grass in pastures showed effective results (Wu Renrun & Xu Xuejun, 1991). On the other hand, in West Africa, *C.odorata* plays an important role in crop fallow management (Akobundu & Ekeleme, 1994; de Rouw, 1994; Timbilla, Braimah, & Toa-Kwapong, 1994) as it improves soil fertility and suppresses other weeds e.g. *Imperata cylindrica*. Likewise, mulching has proved effective, although it is so tedious and insufficiency of the mulching material impedes its use (Muniappan & Marutani, 1996).

Like the cultural control, slashing and uprooting are a common method of control of *C. odorata*. Although this method is widely used, it is laborious, costly and the control is short lived (Erasmus, 1988; M'boob, 1991; Muniappan & Marutani, 1996). Mechanical control is a source of further disturbances to the ecosystem that may only result in further propagation of *C. odorata*. In his investigation (Goodall, 2000), recommended the use of prescribe fire as an effective control of *C. odorata* in the Savannas. He however acknowledged that the success of the method depends on continuous maintenance and monitoring.

Based on the weaknesses of the above two methods, several chemicals (herbicides) have evolved for control of *C. odorata* which proved much more promising especially on young dense cover (Erasmus, 1988). Although the control is more persistent, the use requires proper follow up and training of the labour force. The main disadvantages of this method are that, it is not effective on taller plants (two meters or more), is influenced by weather condition and may pose environmental pollution (M'boob, 1991; Nortje, 2001). Therefore, currently much attention is being focused on the biological control as the only long-term method of Control against *C. odorata* (Goodall, 2000; Nortje, 2001; Timbilla, 1996).

In South Africa, all the above-mentioned methods are being applied and met with the same advantages and disadvantages (Erasmus, 1988; Foxcroft, 2001; Goodall, 2000; Nortje, 2001). However the main methods adopted by the WFW is a combination of mechanical and chemical control being applied concurrently. The seedlings and young weed are hand pulled if the soil is moist and soft enough to uproot the weed. On a hard (dry) soils however, a dense seedling and young stand of the weed is sprayed with chemical. The adult plants are slashed (cut) at ground level and the stumps are treated with chemical. Although this method is labour intensive, it is the main strategy adopted. It serves a second objective of WFW of improving the socio-economic condition of the inhabitants specially the disadvantaged (CCWR, 1998). WFW employs

1.1.4. Problem Statement

The Greater St. Lucia is very rich in biological diversity and as such it is considered to be a hot spot in terms of biological diversity, which requires special attention. There are about 2180 flowering plants, 521 bird, 97 mammal, 52 dragonflies, 212 estuary fish, 55 fresh water fish, 115 amphipods and 41 terrestrial molluscs species respectively some of which are endemic to this area (CCWR, 1998). Neighboring the Park are State owned forest reserves one of which is Futululu State Forest.

This Forest is an important eco-tourism centre and is declared a World Heritage (Gowans, 1998) and is managed as water shed. In addition to this, the forest provides the communities with non-timber forest products that support their livelihood (Klopfer, 1999). Most importantly, it was observed that the Forest Reserve is used as a natural laboratory for educational purposes by (schools) educational institutions. Apart from these however, there are other land use types such as poor forest management, deforestation and overgrazing are depleting the neighboring Dukuduku forest at an alarming rate (http://www.hsf.org.za/Briefing_15/forest.htm,).

One of the major threat to the forest apart from the deforestation is that posed by the invasive alien species like Pine and Eucalyptus plantation and noxious weed such as *C. odarata,* *Psidium guajava, Pereskia aculeate* and *Melia azedarach* which are claiming the deforested area, invading the catchments and farmlands (CCWR, 1998). The threats of these species following the degradation of the forest is seen as a disaster to the general ecosystem of Greater St. Lucia and the welfare of the community especially those around the forest whose life is dependant on the forest directly or indirectly (http://www.hsf.org.za/Briefing_15/forest.htm,).

Among all, *C. odorata* is currently the worse threat in Greater St Lucia.

Despite some achievements in the control of *C. odorata* through the effort exerted by the "Working for Water program"(WFW) over the years, it is believed that the invasion is still expanding at the rate of about 5% annually (DWAF, 2000). This high rate of invasion requires not only much effort but also the most effective method of control, which can be achieved by effective monitoring. Remote sensing and high-speed computer processor GIS, has been used for decades in natural resources management (Lillesand & Kiefer, 2000). In South Africa, although GIS is applied in the mapping the distribution of Invasive species, little has been known about the use of RS (Multi spectral TM) in the control of *C. odorata*. Therefore, there is need to assess the efficacy of C. odorata of multi spectral image in assessing and monitoring control of *C. odorata* in Futululu State forest.

1.1.5. Problem Definition

In Greater St. Lucia Wetland Park *C. odorata* is regarded as one of the leading threat to the conservation of the wetland It is homogenizing productivities of farmlands, livestock, forestry and eco-tourism industries (Erasmus, 1988). Further more*, C. odorata* affects stream flow and is a fire hazard. In the view of these problems, the Department of Water Affairs and Forestry (DWAF) has initiated the control program under the WFW in KwaZulu Natal using different strategies such as mechanical and chemical. However although some progress has been made, the efficacy of these different methods remain disputable (Erasmus, 1988). Furthermore, it has been estimated that despite the current control effort, the invasion rate of *C. odorata* is higher than the control efforts. Therefore based on this, it is necessary to assess and monitor the efficiency of the control strategy currently being implemented in Futululu State forest. It is hoped that this research will help the planners in their future management strategies.

1.1.6. Research Objectives

- To assess the efficacy of the *C. odorata* control strategy being applied in Futululu state forest Reserve.
- To assess and analyse the influence of number of treatment and the time lapse between successive treatments on the efficacy of the control effort being applied
- To determine and analyse the biophysical factors influencing the efficacy of this control strategy

1.1.7. Research questions

To meet the above objectives, this research will address the below specific question

- Is control of *C. odorata* feasible? How effective is the control strategy being applied in Futululu forest?
- Is control efficacy dependant on number of treatments? If so what is the reasonable number?
- Does time lapse between successive treatments influence control efficacy?
- What are the biophysical factors influencing the performances of the control strategy?

1.1.8. Research hypothesis

A number of assumptions or hypothesis have been formulated to guide the research. These can be stipulated as follows:

- There is no difference in the cover of *C. odorata* in the treated and untreated areas verses there is difference in the of *C. odorata* cover in the treated and untreated areas. This can be written as;

  $Ho: \eta_1 = \eta_2$

  $H\alpha: \eta_1 \neq \eta_2$

  Where η_1= the median of *C. odorata* cover in the treated area and η_2= the median *C. odorata* cover in the untreated area

- There is no difference in the of the cover of *C. odorata* in the areas under the different number (level) of treatments verses there is difference in *C. odorata* cover in the areas under the different number (level) of treatments;

  $Ho: \eta_0 = \eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_6$

  $H\alpha: \eta_0 \neq \eta_1 \neq \eta_2 \neq \eta_3 \neq \eta_4 \neq \eta_6$

Where $\eta_0, \eta_1, \eta_2, \eta_3, \eta_4$ and η_6 are the *C. odorata* cover in areas with no, one, two, three, four and six treatments respectively

- There is no significant difference in the cover of *C. odorata* between different time intervals versus there is a significant difference in the *C. odorata* cover between the different time intervals.

$Ho: \eta_1 = \eta_2 = \eta_3$

$H\alpha: \eta_1 \neq \eta_2 \neq \eta_3$

Where η_1, η_2 and η_3 are the median cover of *C. odorata* after 1, 2 and 3 months respectively.

$Ho: \eta_1 = \eta_2 = \eta_3$

$H\alpha: \eta_1 \neq \eta_2 \neq \eta_3$

Where η_1, η_2 and η_3 are the median of *C. odorata* cover in the different distance classes to watercourses respectively.

- Land cover types (grassland, open forest and closed forest) do not influence *C. odorata* control strategy versus land cover types influence *C. odorata* control strategy

$Ho: \eta_1 = \eta_2 = \eta_3$

$H\alpha: \eta_1 \neq \eta_2 \neq \eta_3$

Where η_1, η_2 and η_3 are the median cover of *C. odorata* in grassland, open forest and closed forest respectively

- There is no correlation between the cover of *C. odorata* and the selected environmental factors such as tree canopy cover, grass cover, distance to watercourses, distance to road, slope, altitude, soil pH, percentage litter and bare soil in the treated blocks versus there is correlation in the cover of *C. odorata* and the selected environmental factors in the treated blocks.

$H_{0:}$ r = 0

$H_{a:}$ r ≠ 0

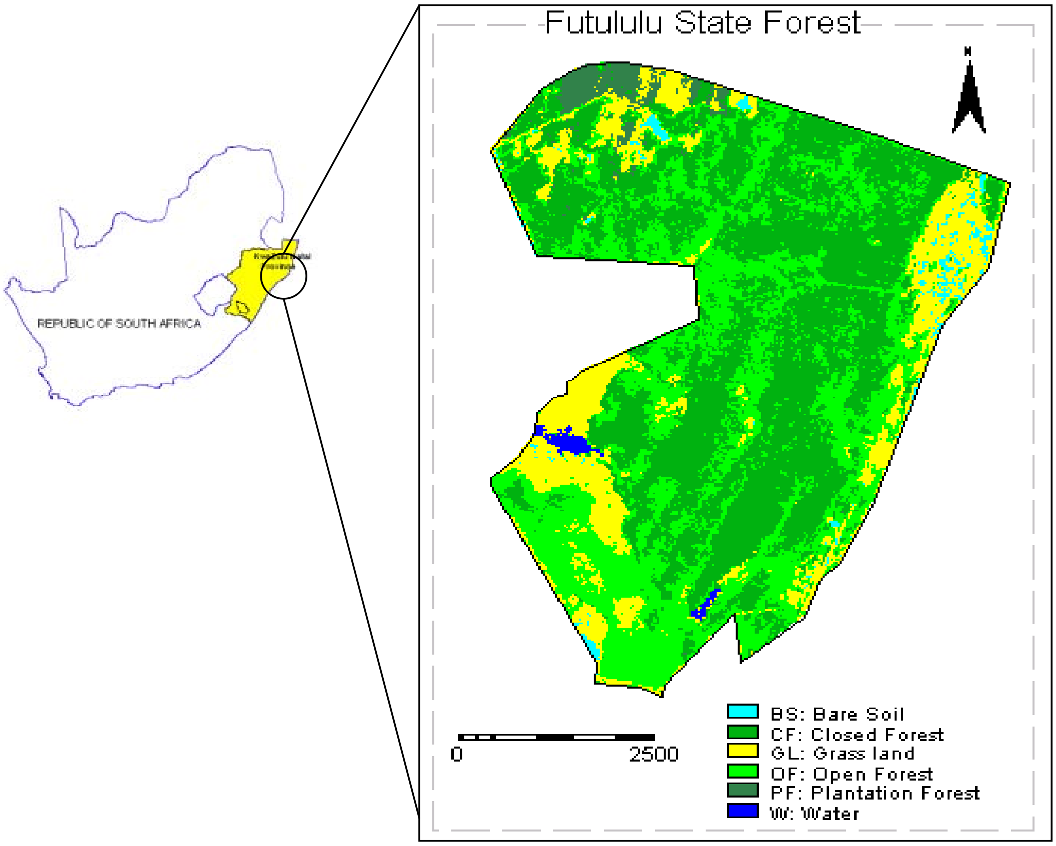
Where r is the correlation coefficient

2. Materials and Methods

This chapter gives an over view of the study area, the materials used for the study, methods applied for the data collection and the statistical methods used to analyse the data towards answering the above stipulated research questions and the formulated hypothesis.

2.1. The Study Area

This study was conducted in Futululu State Forest. It is part of the Greater St Lucia Wetland Park complex located between Latitude 28^0 $22^'$ to $28^0.27^'$S and Longitude 32^0 $15^'$ to 32^0 $22^'$ E. It borders the Umfolozi River to the South, covering Futululu Lake on the West, and separated in the North by St. Lucia-Umtubatuba road from Dukuduku North forest reserve and Dukuduku South Forest reserve in the East. The forest covers a total area of 36399486.0 square meters of which 11297368.9 mainly along watercourses are currently mapped (Nbal) and where *C. odorata* control operations are being carried out.



Map 1 : Location of the study area

2.1.1. Climate

In general term, the climate in the coastal areas of kwaZulu-Natal is subtropical. In summer, the temperatures often rise above 30°Celsius. Humidity is high, and precipitation is normally from October to April and particularly in the summer months of December to February but predominantly mid summer (Schulze, 1997). In South Africa the province of KwaZulu-Natal is receives the highest amount of rainfall (Schulze, 1997). The winters are mild to warm with temperatures on average over 20° C.

The St. Lucia area is situated in the Coastal lowland bio-climatic zone (Taylor, 1982) between latitudes 27°S to and 29°S and falling in Phytogeographic region of Tongaland-Pondoland (Cowling, Richardson, & Pierce, 1997) quoting White 1983). Its Proximity to the sea and a warm (ocean) Mozambique current influence the climate to a large extent.

2.1.2. Rainfall

The most important form of precipitation in the study area is rainfall. The warm Mozambique current plays an important role in causing high rainfall along the Zululand coast. The St Lucia coastline is the most easterly point in South Africa (Taylor, 1982). The surface air in contact with the warm current heats up comparatively quickly, causing instability and the formation of cumulus clouds along the coastline, which often bring abundant rainfall.

Available rainfall figures from 1927-1977 for the Dukuduku/Futululu area gives an average annual rainfall of 861mm (Taylor, 1982) while that for kwaZulu-Natal province gives an average of 845mm (Schulze, 1997).

2.1.3. Temperature

The mean annual temperature for the St Lucia area is about 21.5°C (Taylor, 1982) while that for the whole KwaZulu-Natal province is 18.1°C (Schulze, 1997). It becomes warmer in the months of January to March.

2.1.4. Relative Humidity

All the year round, the relative humidity in the Greater St Lucia area is high (Taylor, 1982) with a daily mean of 70% as compared to a daily mean of 66% for the province of kwaZulu-Natal (Schulze, 1997).

2.1.5. Topography

The topography of the Futululu is mainly undulated with several watercourses flowing into the Futululu Lake and others into the Umfolozi River. According to (Goodall, 2000) quoting Tinley (1985) the formation of this landform in the area has been a result of the glacial deposits influenced by the marine environment. The soil type is mainly regic sand with some silt and lomme along the valley.

2.1.6. Land tenure and land use

The Futululu forest is state owned and is jointly managed by the Department of Water affairs and Forestry, and the Natal Conservation Services. The latter organises its staff to patrol the area to prevent illegal activities in the forest. As state owned, one the last remnant natural forests and most of all important water shed area, the Futululu forest is conserved and managed under the Management Ordinance No. 15 of 1974. The main land use around the study area is sugarcane farming and plantation forestry accounting for 54% of the total area owned by commercial farmers, 39% by the Kwa-Zulu and 7% by the Natal Conservation Services (Taylor, 1982).

2.1.7. Pre-field work Image Processing

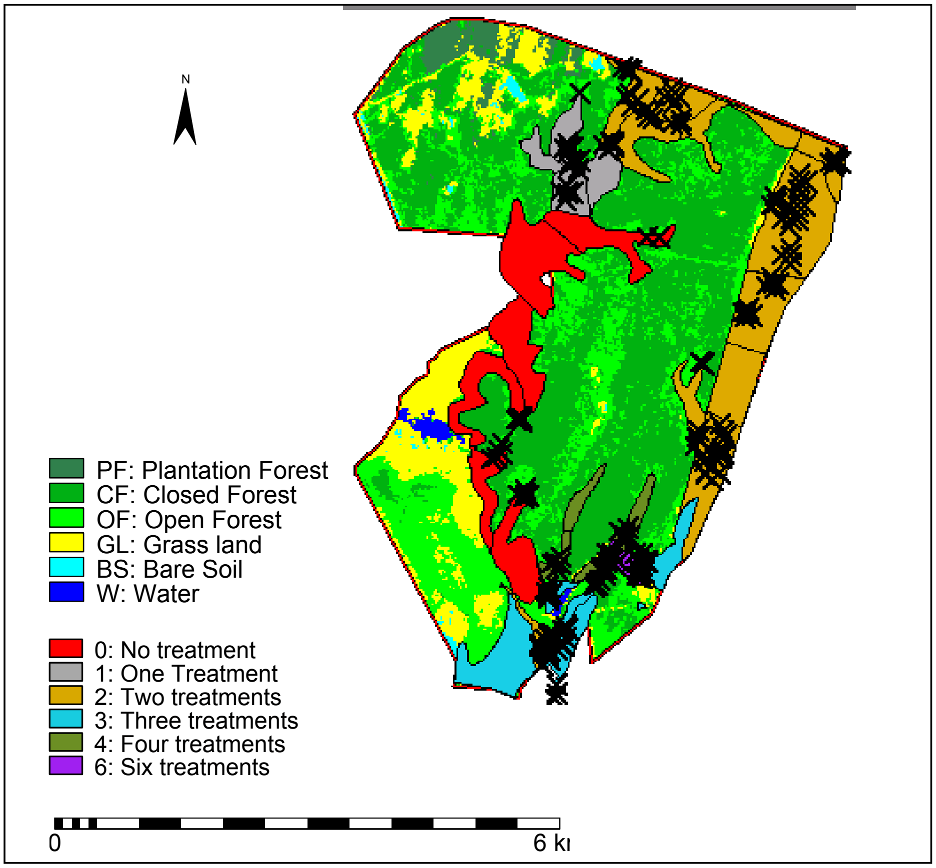
Prior to the fieldwork, multi spectral satellite image (October 1999) was goereferenced to the exiting topographic map of the study area. A total of 15 points were identified on the satellite image that correspond to remarkable points on the topographic map out of which one that contributed to high sigma value was deleted and a sigma value of 0.668 was obtained. Following the geometric correction, the image was classified in order to develop a land cover map of the study area needed for the sampling design. Based on spectral characteristics, Bands 4, 5 and 3 were selected.

Supervised classification was used. Prior to sampling, three bands (4, 5 and 3) were selected and displayed as False Colour Composite (FCC). Based on the spectral characteristics, six land cover classes namely; Plantation Forest, Closed Forest, Open Forest, Grass land, Bare Soil and Water were identified and sampled. Using the sample set, a maximum likelihood classification was done to generate a land cover map for the study area.

2.1.8. Sampling technique

Stratified clustered Random sampling method was used for field data generation. This is for the fact that, Stratified Simple Random Sampling offers better analysis with minimized sampling error (Goldsmith & Harrison, 1976). Random numbers within the boundary of the study area were generated in SPSS and imported into ILWIS as point map, which were then overlaid on the classified land cover map. Based on the land cover types total of 60 sampling points were selected for field observation.

In the field, a detail map of *C. odorata* management (control) was obtained from the WFW and was georeferenced. It was found that different management blocks (units) received different number of treatments or control operations ranging from 0(untreated) to maximum of 6(six). It was also realised that some of the initial randomly selected sampling points fall in Sugarcane plantation while others fall within reed in marshland, which couldn't be sampled. Therefore more points were randomly distributed into the management blocks based on their number of treatments with the aim that a group of management blocks should have a minimum of 15 sample points. Taking the undulating topography of the study area in to consideration, a cluster of 4(four) sample points were distributed around each of the randomly selected sampling units in North, South, East and West direction at a distance of 100 meters each (Fig.2). A sample point (plot) covers an area of 225 square meters. Concentric to each sample unit, a smaller plot of radius 2.75 meter was measured take observations on the variables such as the number of regenerating *C. odorata* and native species.



Map 2 : Sampling distribution in the study area

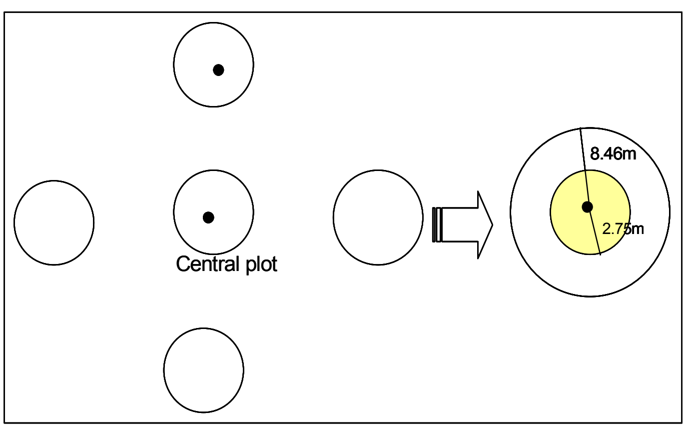


Figure 1 : A cluster of sample plots around a random sample unit and two concentric plots within a single sample plot

2.1.9. Field data generation

During the field observation, a number of biophysical data were recorded. The percentage cover and number of the regenerating *C. odorata* were mainly considered as the main response variables and taken as a measure of the control efficacy being applied. Different stages (adult, young, seedlings and mixed) of *C. odorata* were also identified and recorded. Other variable recorded includes percentage tree cover, grass cover, individual cover of other invasive alien plants, soil pH and texture, percentage litter and bare soil slope, altitude, stage of growth of *C. odorata* and present/absent of control measure (treatment).

The method of measurement adopted in measuring the percentage cover of *C. odorata,* tree canopy cover, shrub cover, grass cover, litter and bare soil was ocular estimate. Soil samples were taken with auger to a dept of 25 cm. The pH was tested using pH kit and the assessment of textural classes was determined based on 'Texture-by-feel analysis' method (Driessen, 1995).

GPS was used to navigate to each the selected sample points. While taking field observation, it was a common experience that the GPS' reading was obstructed in close forest canopy cover. As such the altitude readings like the slope and distance from watercourses were extracted from contour and streams maps digitised from the topographic map. Distance from road was generated from the Forest boundary map since the main accessibility to the forest is the boundary itself (Personal observation). Apart from these, historical data containing the treatment records was obtained from the WFW from which time lapse since the last treatment of each management unit (block) was extracted and added into the database for analysis.

To gain some rough idea about the attitude and the factors that they feel affect their work, some Rapid Rural Appraisal was done to two teams (group) of contractors.

2.1.10. Study Materials

To achieve the objective of the research, the following dataset and materials were used: -

- Topographic maps 2832AC,AD&BC St. Lucia Estuary at Scale 1:50,000 dated 1982 and 1979 respectively obtained from the Directorate of Survey and Land Information, Mowbray, South Africa.
- *Chromoleana odorata* management map (Nbal) at Scale 1:50,000 updated 2001 provided by the WFW Futululu State Forest
- Landsat 7 TM satellite image of October 1999 bands 453.
- Other material for field observations includes; GPS, Altimeter, Sunto Compass Slope meter, pH kit, soil texture chart, canvas bag, 50m measuring tape, marchet (Bush knife) canvas bag and sample bags.

2.2. Statistical Analysis

The field data and the secondary data were entered in to a database in MS Excel. Statistical softwares SPSS 10.0.5 (SPSS Inc.1999) and Minitab 13.1(Minitab Inc. 2000) were used for data analysis. To answer the fore stated research questions and addressing the specific research hypothesis, a number of explanatory statistics were used.

Prior to any statistical analysis, the nature of the distribution of the data was explored to test the assumption that the data distribution is normal versus the data distribution is not normal.

Kolmogorov-Smirnov normality test was used. Based on the result, several methods of data transformation were such as square root, logarithmic, reciprocal and reciprocal root were used to improve the normality.

To test for the efficacy of the control strategy being applied, the influence of treatment, the number of treatments, different time intervals and the categories of different environmental factors, as stated in the above hypothesis, box plots were used. Due to the non-normal nature of the data, further statistical analyses were done using Kruskal-Wallis ranked test. The significant differences between classes were tested by Mann-Whitney U tests.

According to the control (management) record, the time lapse since treatment to the dates of observation falls between 10 days to 90 days (0.3 –3 months). As such it was assumed that the distribution of the different stages of growth especially the presence of the adult stage shows how effective or consistent the treatments have been. Therefore an attempt was made to establish the relationship between the stages of growth and cover of *C. odorata.* Boxplot was used to compare the cover differences while the statistical significance was tested with both Kruskal-Wallis and Mann-Whitney U test.

The possible relationships between the efficacy of control measures (treatment), some management factors and environmental factors and the cover of *C. odorata* cover were determined by Spearmen's correlation analysis. Furthermore regression analysis was under taken to establish to what extend each of the continuous explanatory variables could explain the pattern of *C. odorata* cover in the management blocks despite the non-normal behaviour of the data.

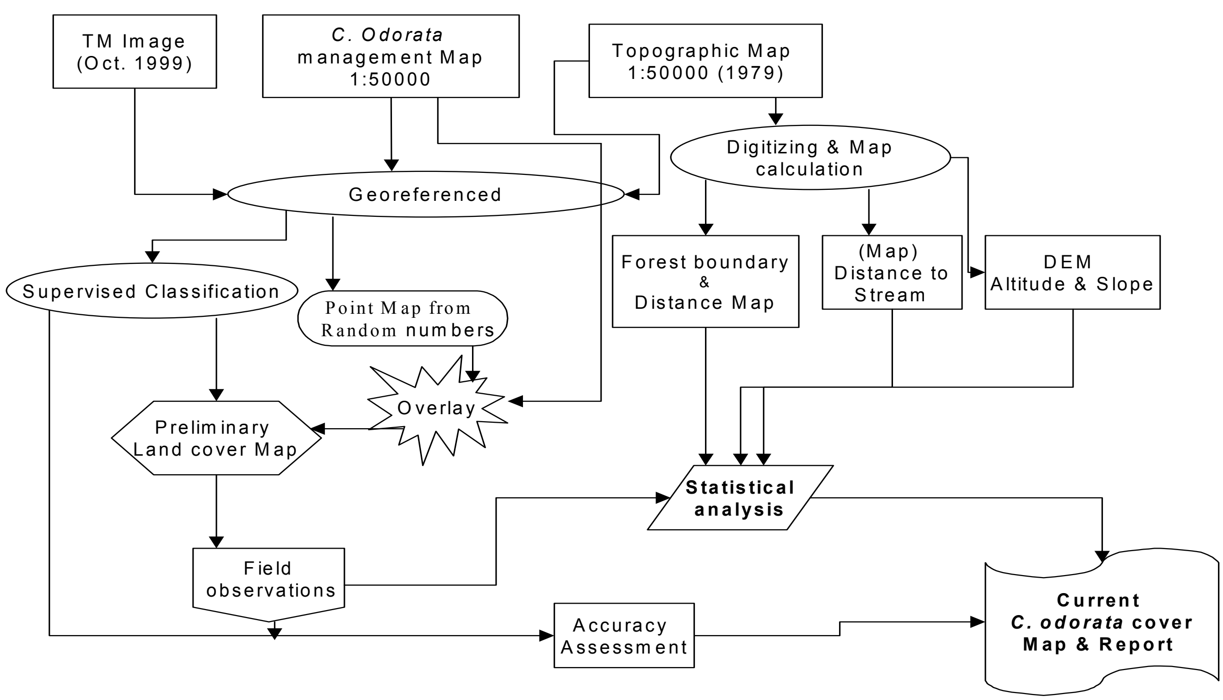


Figure 2: Summary of the Research methodology

3. Results

3.1. Exploratory analysis

The field observation (record) showed that *C. odorata* cover ranges from zero to 100 percent. A normality test result showed that the data were not normally distributed but right skewed (Figure 1a). Different methods of data transformation such as square root, logarithm and reciprocal root were attempted respectively but the results showed no improvement towards a normal distribution of the data. Further analysis with the Kolmogorov-Smirnov normality test showed the data were not normally distributed (P-value<0.01). Although the transformation failed to provide satisfactory improvement of the normality of the data, the square root transformed data was used for the analysis. The logarithmic transformed data could not be used because it removes all the observation with zero cover and changes those with cover less then 0.5 % into negative, which does not make sense since the cover of *C. odorata* can not be negative.

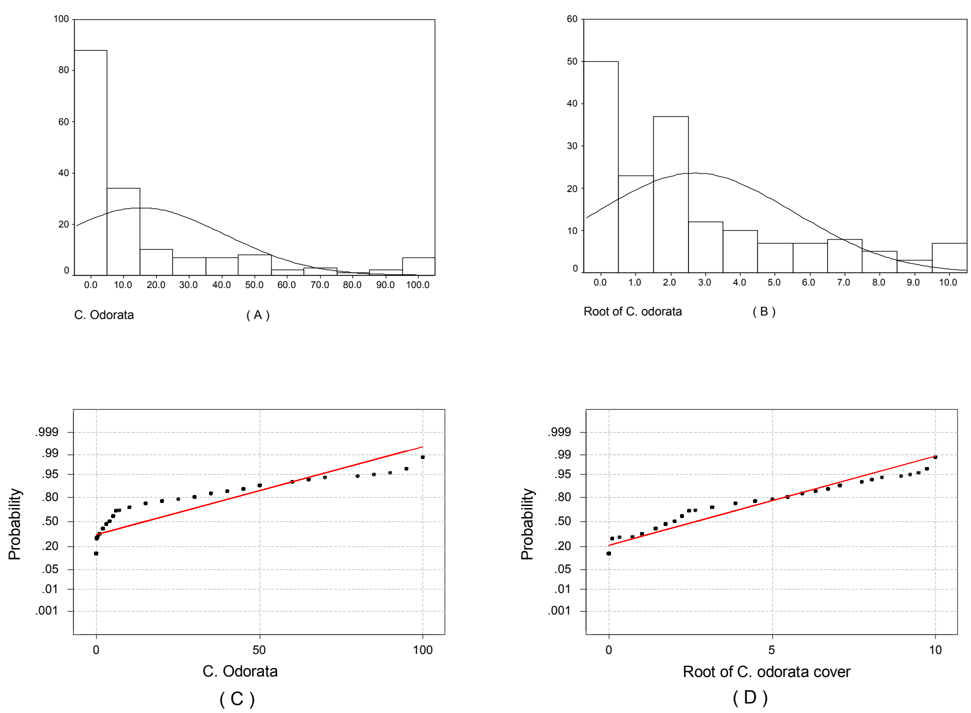


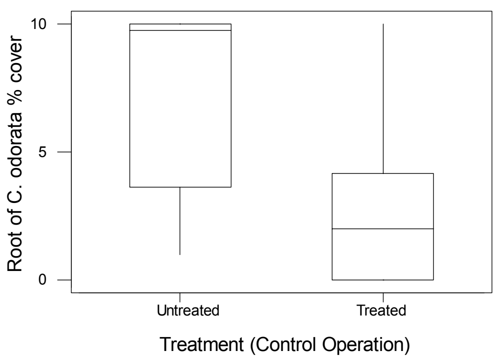
Figure 3: Normality test

(A) Histogram of the original data, (B) Root transformed data. Kolmogorov-Smirnov test of (C) original and (D) Root transformed data (P-value <0.01 N=169).

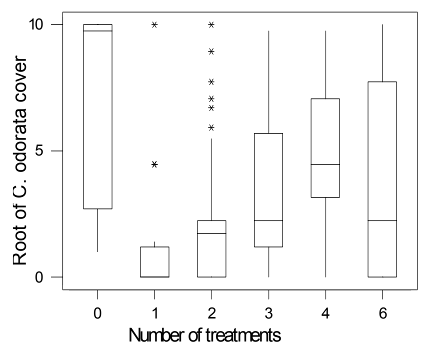
3.2. Descriptive statistics

3.2.1. *C. odorata* cover versus treated/untreated

Comparison of the cover of *C. odorata* in the treated and untreated management blocks showed that there was a significant difference in the median cover of *C. odorata* in the treated management blocks as compared to those untreated (fig. 5A). A statistical analysis with Mann-Whitney U test showed that the cover of *C. odorata* in the treated management blocks is significantly different from those untreated ones (P-value = 0.000, α = 0.05)



(A)



(B)

Figure 4: Box plot: Relationship between *C. odorata* cover vs Presence/absence of treatment and different the number of treatments respectively

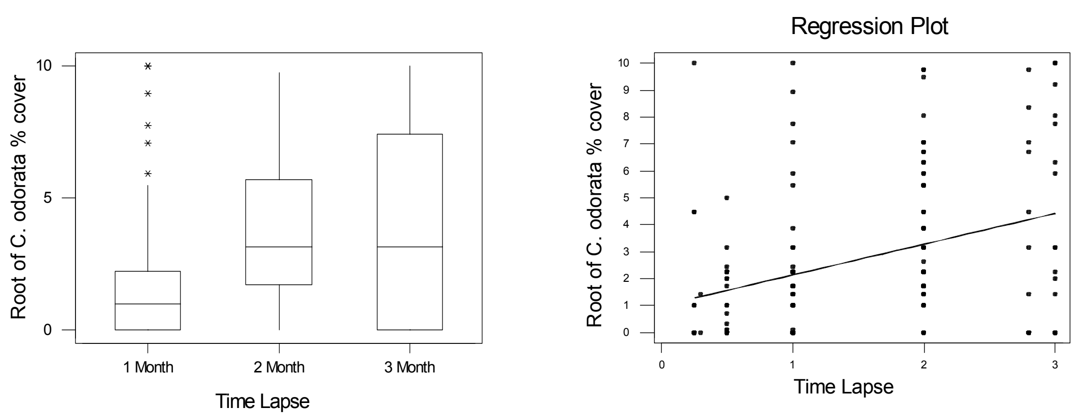
(A): Comparison of the cover of *C. odorata* in observations where treatement was present and absent within the treated areas only (N= 186, Mann-Whitney U test; P > 0.05). (B) Number of treatments vs *C. odorata* cover. (Kruskal-Wallis; $X^2 = 42.88$, df = 5, P < 0.001, N = 186)

3.2.2. Number of treatments

It was found that there was significant influence of the number of treatments on the covers of *C. odorata* (Fig. 5B). The median cover of *C. odorata* is highest in the untreated management blocks. Among the treated management blocks, *C. odorata* cover is lowest in the management blocks treated once and increases as the number of treatment increases to the fourth treatment. However, in the area that received six treatments, the median shows no difference to those management block treated three times. Statistical analysis (Kruskal-Wallis test) showed that the covers of *C. odorata* in the different management blocks of different number of treatments are significantly different (X^2 =42.88, df = 5,P-value =0.000, α = 0.05). Mann-Whitney U-test showed that the cover of *C. odorata* in the untreated management block is significantly different from all the different number of treatments except for the management block that received four treatments. Likewise, the result showed that the cover of *C. odorata* in the blocks treated once and twice are significantly different to all the other number of treatments except that treated six times. However, the management block that received three treatments showed no significance to those of fourth and six treatments (Table 2 C).

3.2.3. Time lapse between treatments

The time lapse between treatments had a direct influence on the efficacy of *C. odorata* control (Fig.5A). There is an increase of *C. odorata* with time. The statistical analysis with Kruskal-Wallis test showed that there was significant influence of time lapse on the cover of *C. odorata* in the management areas (X^2 =26.86, df = 2, P-value = 0.000, α = 0.05). As a support to the above test, Mann-Whitney U-test was taken and the results indicates that *C. odorata* cover in the areas treated within one month are significantly different from those treated two and three months ago. However, there was no significant difference between the cover in areas treated two and three months ago (Table 2 D).
Regression analysis showed that the cover of *C. odorata* had a positive linear correlation with the time lapse between successive treatments (Fig. 6B) R^2 = 12.5%, P-value = 0.000, α = 0.05. The cover of *C. odorata* increases with time.



(A) **(B)**

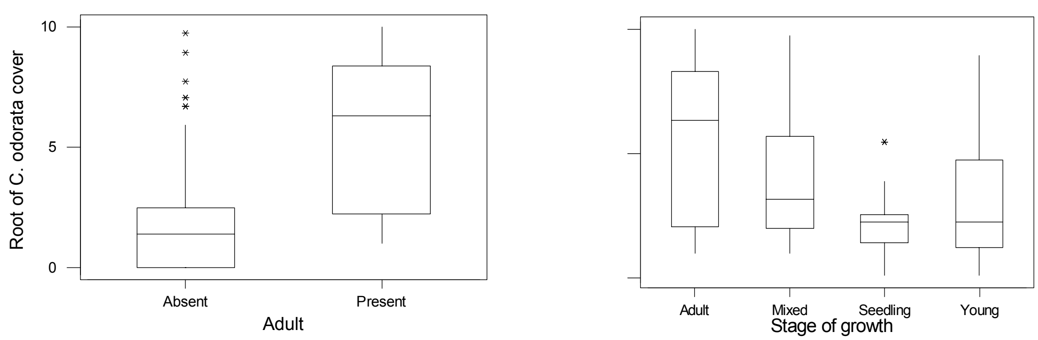
Figure 5: *C. odorata* cover vs time lapse

(A) Comparison of cover of *C. odorata* cover at three different time intervals after treatement (Kruskal-Wallis; X^2 = 26.86, df =2, P = 0.000, N = 169), (B) Regression *C. odorata* cover vs time lapse (R^2 = 12.5%, P-value = 0.000, α = 0.05)

3.2.4. Stages of growth and *C. odorata*

Comparison of the cover of *C. odorata* (Fig.6A) at different stages of growth (Adult, Young, Seedling and Mixed) showed that they are significantly different. The cover is highest in the adult stage followed by the Mixed stage (containing combination of the Adult, Young and/or Seedling), Seedling and Young stages. A statistical analysis with Kruskal-Wallis rank test

indicated that the cover of *C. odorata* at the different stages of growth (Adult, Young, Seedling and Mixed) was significantly different (X^2 = 25.91, df = 3, P-value = 0.000, α = 0.05). Further test using Mann-Whitney U-test to verify the above results indicated that the covers of adult *C. odorata* are significantly different from all the other stages except the Mixed stages. Likewise, the Young stage is significantly different from all the rest except to seedling stage (table 2 B).
Furthermore, the influence of the presence/absence of the adult stage on the cover of *C. odorata* of was investigated. The box plot (Fig. 7B) shows that the median cover of *C. odorata* is higher in the management blocks where the adult stages exist relative to those where they are absent. A Mann Whitney test (Table 2 G) revealed that the cover of *C. odorata* in the areas where adult stages occurred is significantly different from those with no adult stage (P-value = 0.000,α =0.05).



(A) **(B**

Figure 6: Relationship between *C.odorata* cover and Stages of growth.

A: Presence/absence of adult stage (N = 169), Mann-Whitney, P< 0.001. B: *C. odorata* cover vs different stage of growth (N = 123, all the zero values observations were removed). Kruskal Wallis; X^2 = 25.91, df = 3, P > 0.001

3.2.5. Proportion of the presence of adult stage per plot per number of treatment

Assessment of the proportion of the occurrence of adult stage *C. odorata* in the management blocks under different number of treatment was undertaken. The results suggests that in the management blocks treated more than three (3) times have higher proportions of the adult stage than in those treated three (3) times and/or less. This result shows that of all the different number of treatments, management block treated twice has the lowest proportion of the adult stage (Fig.7).

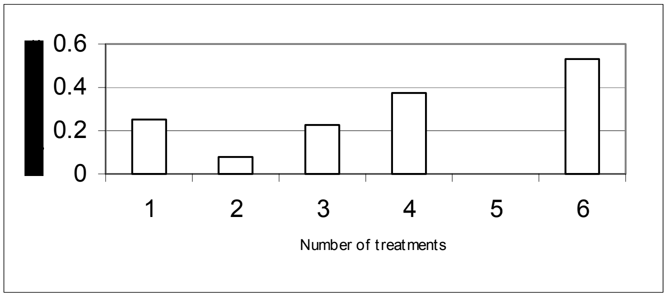


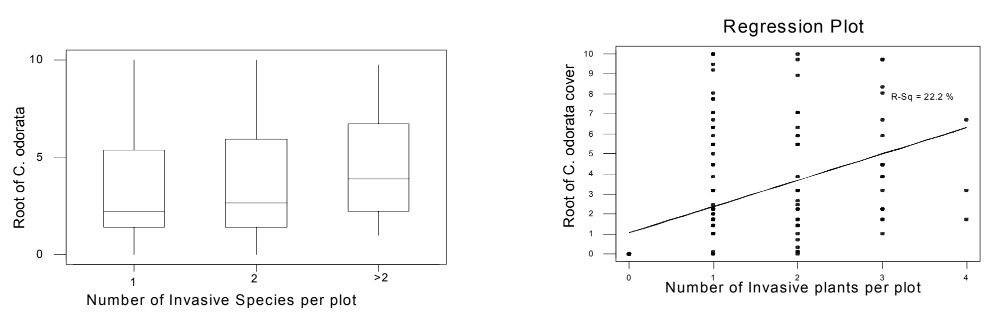
Figure 7: Proportion of the presence of Adult stage *C. odorata* number per plots in each given number of treatments

3.3. Environmental factors and the efficacy of *C. odorata* control

3.3.1. The cover *C. odorata* versus number of invasive alien plants per plot

Figure (8A) showed the influence of the number of invasive alien plant species on the cover of *C. odorata* in the management block. It shows that the median cover of *C. odorata* was higher in the plots where there were more than two invasive alien species per plot increases. However statistical analysis showed that there was no significant difference in the cover of *C. odorata* in different classes of number of invasive alien plants per plot (Kruskal Wallis test, X^2 =3.66, df = 2, P-value = 0.160, α = 0.05). Likewise, Mann-Whitney U test any significant difference between the cover of *C. odorata* in the different classes of number of invasive alien plants per plot (Table 2 E).

A regression analysis showed that there is a significant positive correlation between *C. odorata* cover and number of invasive alien plant species per plot (Fig. 8B) R^2 = 22.2% and P-value = 0.000, α = 0.05. This indicates that *C. odorata* cover increases as the numbers of invasive alien plants per plot increases.



(A) (B)

Figure 8: *C. odorata* cover vs number of invasive alien plants per plot

(A): Box plot; *C. odorata* cover vs classes of number of invasive alien plant species per plot, Kruskal Wallis; X^2 = 3.66, df = 2, P > 0.05. (B): Regression analysis, *C. odorata* cover vs number of invasive alien plant spcies per plot (R^2 = 22.2 %, P< 0.001).

3.3.2. *C. odorata* cover versus land cover types

The box plot (fig.9) showed that the cover of *C. odorata* in the different land cover types (Closed Forest, Open Forest and Grassland) was significantly different. It showed that *C. odorata* cover is low in the closed forest, high in the open forest with intermediate in the Grassland. Statistical analysis with Kruskal Wallis showed that the cover of *C. odorata* in the different land cover classes is significantly different (X^2 = 14.09, df = 2, P-value = 0.001, α = 0.05). Likewise, the Mann Whitney U test result (Table 2F) showed that the cover of *C. odorata* in the closed forest and grassland are both significantly different from that in the open forest. However, there is no significant difference between the *C. odorata* cover in the closed forest and the Grassland.

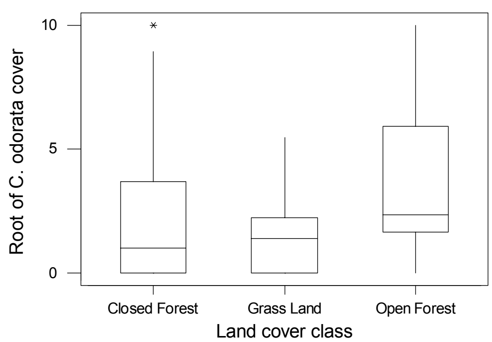


Figure 9: *C. odorata* cover vs land cover types

Kruskal Wallis; X^2 = 14.09, df = 2, P < 0.01)

3.3.3. *C. odorata* cover versus tree canopy cover and grass cover

C. odorata cover showed a polynomial relation with the canopy tree cover (R^2 = 10.1%, P-value = 0.000, α = 0.05). The cover of *C. odorata* is relatively low at the low and high tree cover but is high at intermediate tree cover. The investigation of the relation between the cover of *C. odorata* and grass cover shows that there is significant negative correlation between *C. odorata* and grass cover R^2 =13.3%, P-value = 0.000, α = 0.05 (fig. 10).

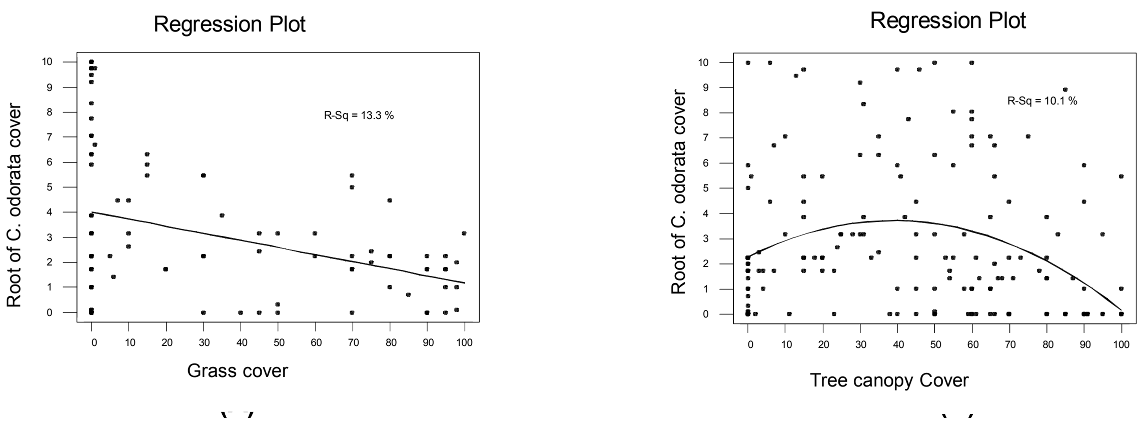
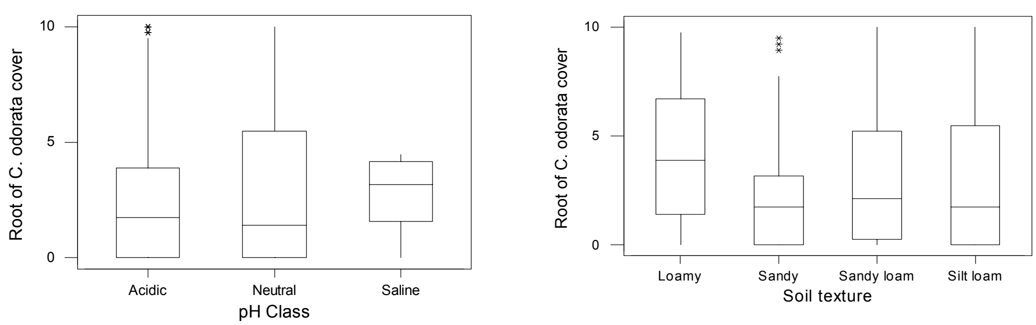


Figure 10: C. odorata cover vs grass cover and tree canopy cover
(A): Regression analysis *C. odorata* cover vs grass cover (R^2=13.3%, $P < 0.001$); (B): *C. odorata* cover vs tree canopy cover (R^2= 10.1%, $P < 0.001$

3.3.4. Soil pH

A comparison of the *C. odorata* cover in the different classes of pH (Acidic, Neutral and Saline) showed that there is no significant difference in the median cover *C. odorata* on Acidic and the Neutral soils. The two however, are significantly different from that on the Saline soils (Fig.11A). Detailed statistical analysis failed to test any significant difference in the cover of *C. odorata* on the different Soil pH classes (Kruskal Wallis test: X^2 = 0.17, df = 2, P-value = 0.922, α = 0.05). Regression analysis showed that there is no significant association between *C. odorata* cover in the management blocks.



(A) **(B)**

Figure 11: *C. odorata* cover vs pH and soil textural classes

(A) *C. odorata* cover vs pH classes (Kruskal-Wallis; (X^2 = 0.17, df = 2, $P > 0.05$). NB. Acidic soi = pH 4-6.5, Neutral = 6.5-7 and Saline > 7. (B) *C. odorata* vs soil texture (X^2 = 6.12, df = 3, $P > 0.05$).

3.3.5. Soil texture

Assessment of median cover of *C. odorata* on the different soil textural classes (Sandy, Sandy loam, Loam and Silt loam) showed that the median cover of *C. odorata* covers are low on both Sandy and Silt loam relative to Loamy and Sandy loam. Among all, the highest *C. odorata* median cover was observed on Loamy Soil while intermediate median occurred on Sandy loam (Fig. 11B). Kruskal Wallis test however showed that, Soil texture has no significant influence on the performance of treatments (X^2 = 6.12, df = 3, P-value = 0.106, α = 0.05).

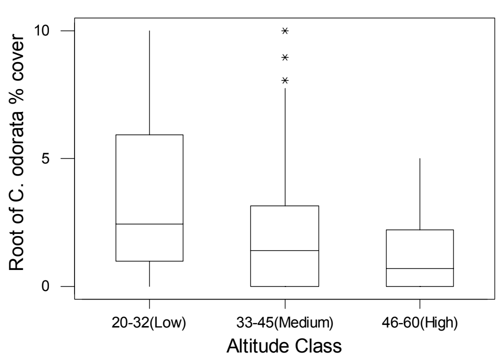
3.3.6. Ground cover

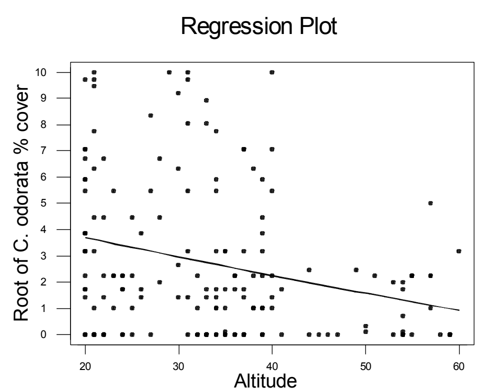
Result of regression analysis showed that there is no significant correlation between *C. odorata* and cover percentage cover of both bare soil and litter.

3.3.7. *C. odorata* cover versus altitude

According to the box plot (Fig.13A), the median covers of *C. odorata* high in the low altitude and declines with increase of altitude. Analysis with the Kruskal Wallis rank test however revealed that altitude has asignificant influence on the cover of *C. odorata* (X^2 = 11.29, df = 2, P-value = 0.004, α = 0.05). However*,* Mann Whitney U test (Table 2 J) showed that there was no significant difference between the cover of *C. odorata* in the different altitude classes.

Regression analysis (Fig.12B) showed that the cover of *C. odorata* has a significant negative linear correlation with altitude (R^2 = 8.0%, P-value = 0.001, α = 0.050). *Chromoleana* cover decreases as altitude increases.





(A) **(B)**

Figure 12: *C. odorata* cover vs Altitude

(A) C. odorata cover vs altitude class Kruskal-Wallis; X^2 =14.00 df = 2 P = 0.001 (B) Regression C. odorata cover vs altitude (R^2 = 8.0%, P > 0.001).

3.3.8. *C. odorata* cover versus slope

The box plot (Fig. 13) indicates that terrain characteristics are associated with the cover of *C. odorata.* The median cover of *C. odorata* in the valley bottom (Flat) is highest relative to valley slope, hill slope and flat (Non valley). However, statistical analysis indicated that there is no significant difference in the cover of *C. odorata* in the different slope classes (Kruskal-Walis $X^2 = 5.23$, df = 3, P-value = 0.155). Likewise, Mann-Whitney U tests showed that there is no significant difference in the cover of *C. odorata* in the different slope classes except between the valley bottom and flat (Table 4K)

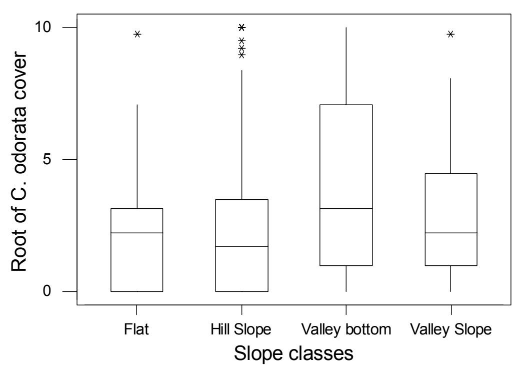


Figure 13: *C. odorata* cover vs slope

(Kruskal-Walis $X^2 = 5.23$, df = 3, $P > 0.05$)

3.3.9. *C. odorata* cover versus distance to streams

The result (Fig 14) showed that median cover of *C. odorata* cover closer to streams are relatively higher as compared to those medium and far distance from the streams. Statistical test (Kruskal Wallis test) showed no significant influence of distant classes on the cover of *C. odorata* in the management blocks ($X^2 = 3.12$, df = 2, P = 0.210, α = 0.05). Likewise, Mann Whitney U test failed to show any significant difference between the cover of *C. odorata* in the different distant classes (Table 4 I).

Regression analysis showed that there is no significant association between tree distance to streams and *C. odorata* cover within the management blocks.

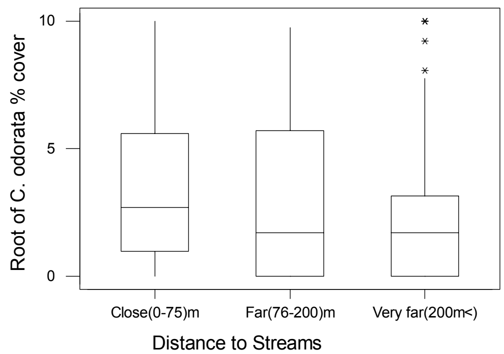


Figure 14: Relationship between *C. odorata* cover and distance from streams

(Kruskal Wallis $X^2 = 1.19$, df = 2, $P > 0.05$)

3.3.10. Relation between *C. odorata* cover and distance to road

The result (Fig. 16) shows that, the median cover of cover of *C. odorata* at a distance more than one kilometre from the road or forest boundary is significantly higher than those closer (less than a kilometre) from roads. Analysis with Kruskal Wallis showed that *C. odorata* covers in the different distance classes are significantly different ($X^2 = 7.86$, df = 2, P-value = 0.020, $\alpha = 0.05$). Further analysis with Mann-Whitney U test there is no significant difference between the cover of *C. odorata* in the different distance classes except between the medium distance (126-1000 m) and far (>1000 m) see table 5 M.

On the other hand, regression analysis showed that distance couldn't explain the cover of *C. odorata* in the management areas ($R^2 = 2.0\%$, P-value = 0.763, $\alpha = 0.05$).

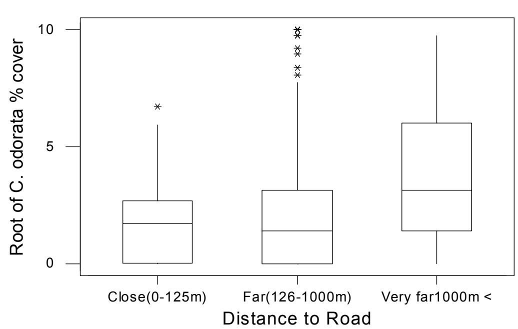


Figure 15: *C. odorata* cover vs distance to road

(Kruskal Wallis: $X^2 = 7.86$, df = 2, $P < 0.05$)

3.4. Regeneration of *C. odorata* and Native species

An attempt was made to assess the patterns of regeneration and distribution of both *C. odorata* and the native species within the management blocks. However the nature of the distribution of the data could not allow further sensible analysis.

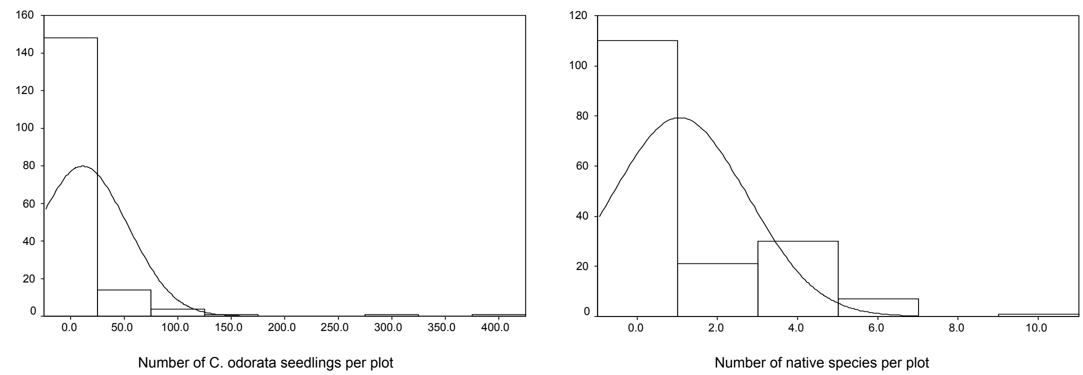


Figure 16: Normality test for the regeneration of *C. odorata* and native species

3.5. Multiple Regression Analysis

To establish combined effect of the group of independent variables on the response variable in this case the cover of *C. odorata*, a multiple linear regression analysis was applied. Four explanatory variables were selected through stepwise forward multiple regression analysis. The result (Table 1) shows that, the combination of tree canopy cover, grass cover, presence/absence of the adult *C. odorata* and the number of invasive alien plant species per plot can explain 45.15 % variability in the cover of the *C. odorata* within the management blocks under treatment at R^2 = 48.81%, P-value =0.000. The result of the probability plot of the residual (Fig 17) showed however that, the data does not fit the model so well although nearly 95 % of residuals fall with in the range of -2 to +2 of the standard deviation.

The model shows that (Table 3) the cover of *C. odorata* high regardless of the number of treatment where:

- Tree canopy cover in the management block was low or open forest
- Treatment was not consistently done that is; when pockets of adult *C. odorata* do escaped treatment.
- The number of invasive alien plant species in the management block was more than just *C. odorata* alone.
- The grass cover of the area of management block is low (in case of non closed forest area).

Table 1: Table 2: Stepwise regression analysis using four explanatory variables for *C. odorata* cover

N=169

	Step 1	Step 2	Step 3	Step 4
Constant	1.8842	0.6826	0.8607	1.9645
Presence/Absence	3.92	3.40	3.19	3.17
T-value	8.69	8.25	7.62	7.74
P-value	0.000	0.000	0.000	0.000
Number of Invasive alien plants		1.05	1.12	1.01
T-value		6.41	6.80	6.05
P-value		0.000	0.000	0.000
Grass cover			-0.0118	-0.0224
T-value			-2.27	-3.50
P-value			0.007	0.018
Tree canopy cover				-0.0177
T-value				-2.73
P-value				0.007
S	2.37	2.13	2.11	2.07
R-Sq	31.14	44.80	46.48	48.81
R-Sq. (adj)	30.73	44.13	45.50	47.56
C-P	55.6	13.8	10.5	5.0
PRESS	969.748	789.430	772.641	749.258
R-Sq (Pred)	**21.01**	**42.21**	**43.44**	**45.15**

Table 2: Analysis of variance

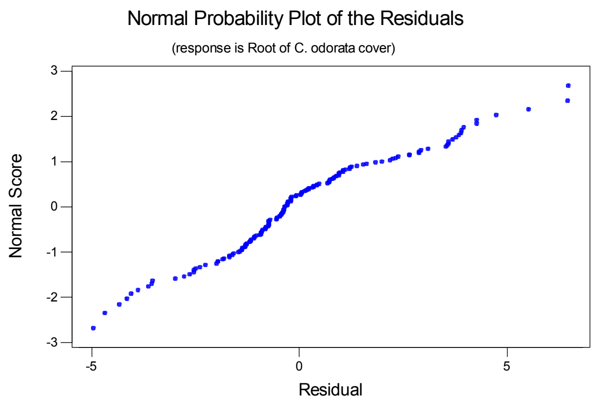
Source	DF	SS	MS	F	P
Regression	4	666.75	166.69	39.09	0.000
Residual Error	164	699.36	4.26		
Total	168	1366.11			

Table 3: Regression analysis of variance

Predictor	Coefficient	SE Coefficient	T	P
Constant	1.9645	0.4836	4.06	0.000
Tree canopy cover	-0.017689	0.006472	-2.73	0.007
Presence/Absence of Adult	3.1738	0.4103	7.74	0.000
Number of Invasive alien Plants	1.0114	0.1671	6.05	0.000
Grass cover	-0.022449	0.006412	-3.50	0.001

Root *C. odorata* cover = 1.96 - 0.0177* Tree canopy cover + 3.17* Presence/Absence of adult *C. odorata* + 1.01* Number of invasive species - 0.0224*Grass

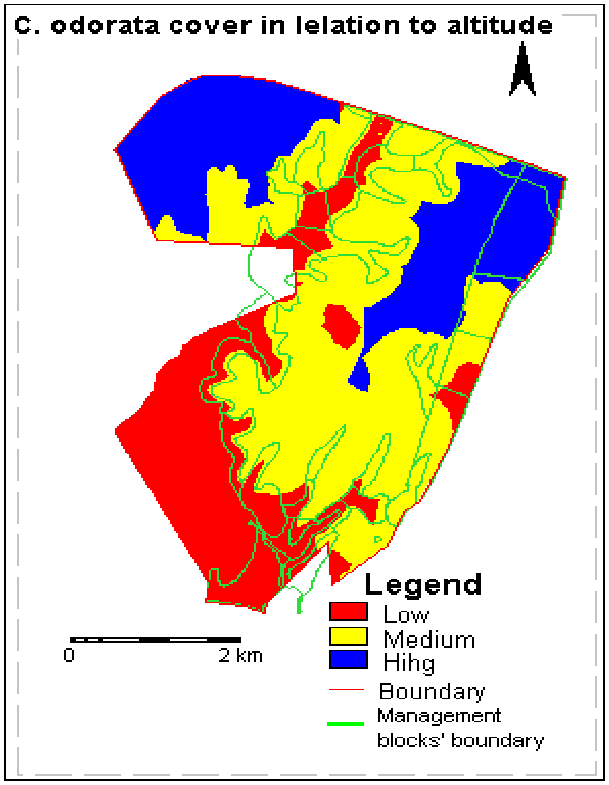
Figure 17: Normal probability plot of the residuals



3.5.1. Mapping

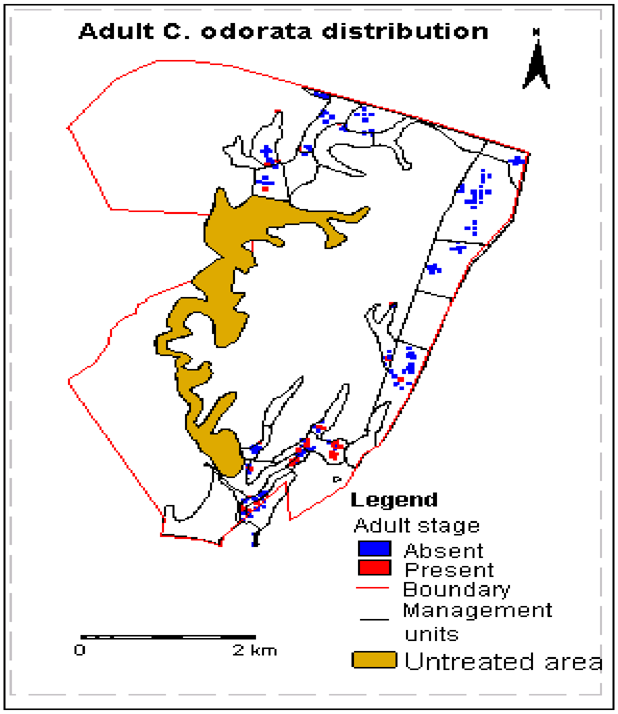
The result of the multiple regression analysis showed very weak relationship between the four selected predictors and the respond variable (the cover of *C. odorata*) in the management units under treatments. The predictors can only explain about 45% of the variability in the cover of *C. odorata*.

Based on the result of the residual plot, the model does not fit well despite fact that the data was re-expressed. Therefore, for spatial application, it is not possible to use the model for extrapolation over the entire area. As such *C. odorata* cover map and the explanatory maps were presented as point maps

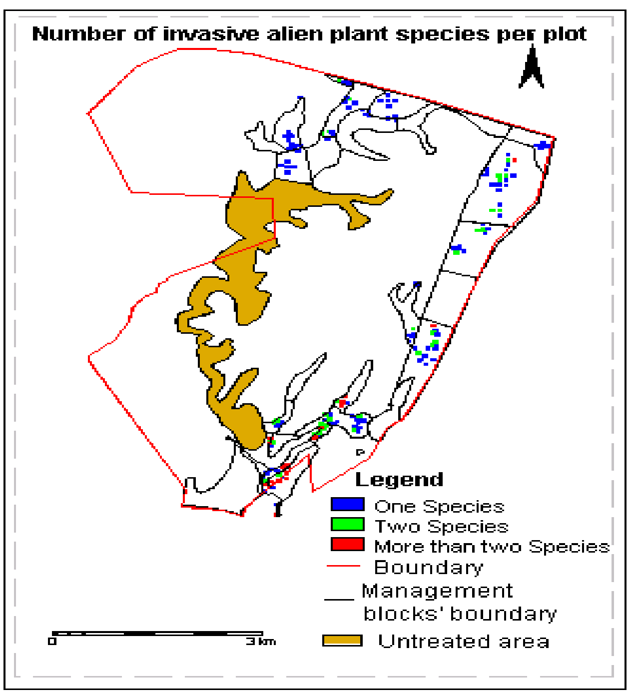


Map 3: Map showing the cover of *C. odorata* in relation to altitude

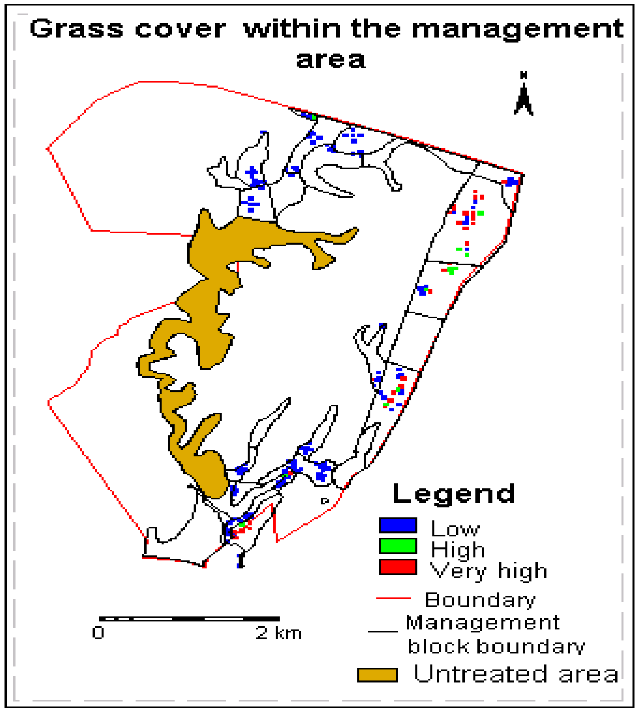
Areas indicated red means high *C. odorata* cove as compared to the rest of the areas



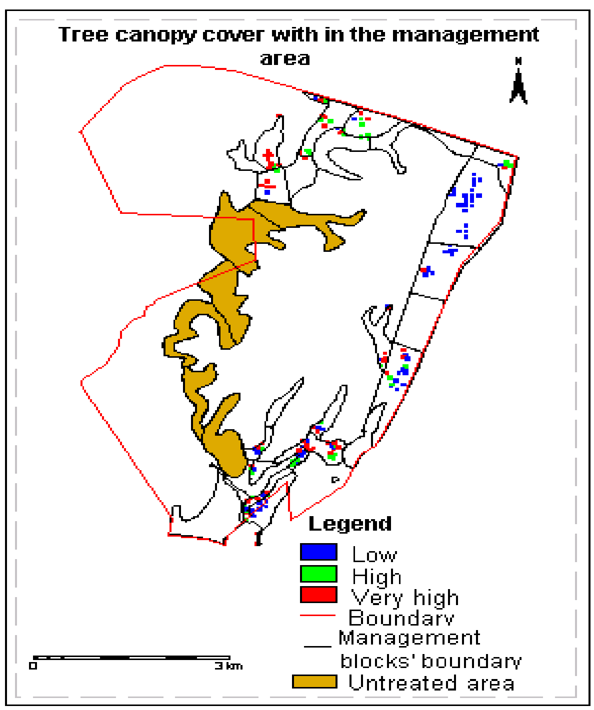
Map 4: Map showing the presence and absence of adult C. odorata



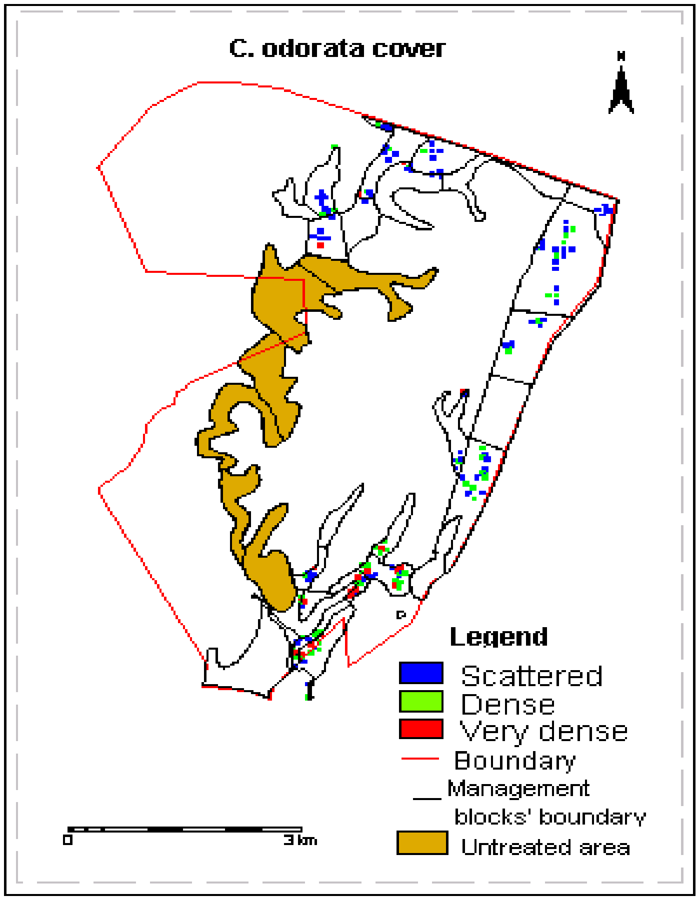
Map 5: Map showing the number of invasive alien plant species per plot



Map 6: Map showing the distribution of Grass cover in the management blocks



Map 7: Map showing the distribution of tree canopy cover in %



Map 8: Distribution of the cover of *C. odorata* in the management area

Map based on the four factors as determined by the above regression equation

4. Discussion

Chromoleana odorata forms one of the controversial ecosystem management problems. In the Futululu State Forest Reserve, it was observed that *C. odorata* could become a climber to the native woody vegetation and smother them or form monospecific impenetrable thickets. An appropriate weed management intervention could provide a useful remediation to this environmental degradation. The result of comparison of treated versus untreated revealed that; there is a significant difference between the two median covers (treated vs untreated), amongst the different number of treatments, there is a significant reduction in the cover of *C. odorata* (See Photo 1 in Apedix 4). This result is supported by the finding of (Nortje, 2001) in their experiments in Dukuduku plantation forest (near Futululu State Forest) that mechanical control of *C. odorata* with combination of chemical control could provide a useful method of *C. odorata* control. However, he acknowledged that, the success of the method dependant on the intensity of field supervision. He further argued that, ensuring consistent application of the chemical on the cut stamps might be difficult over a large area.

Success in invasive alien plant control is the result of proper consideration of combination of management and environmental factors in addition to the biology of the species in question (van Wilgen et al., 2000). In this study, *C. odorata* cover is positive correlation to the number of treatments, which suggests that, the cover of *C. odorata* increases as the number of treatments increases. It is an indication that the cover of *C. odorata* continues to remain high (if not increasing), despite the increase in the number of treatments. The finding suggests that the number of treatments alone does not determine the efficacy (success) of *C. odorata* controls. This finding contradicts that of (Nortje, 2001) which recommended that, up to four (4) treatments could ensure a complete control of *C. odorata*. Likewise, in the regression analysis, *C. odorata* cover showed significantly positive correlation with time lapse between treatments (Fig.9). The cover of *C. odorata* increases as time lapse between successive treatments increases. This finding supports that of (Tjitrosemito, 1994) which suggested that the biomass of *C. odorata* is proportional to the height, which itself is proportional to (time) age of the plant. *C. odorata* is a fast growing species and branches profusely as the age increases(Witkowski & Wilson, 2000) leading to a tangled mass or high cover. Based on these, it could be concluded that, success in the control of *C. odorata* requires that follow-ups be taken at shorter time intervals. Waterhouse (1996) suggested three month interval is appropriate to ensure that the plants that escaped treatment do not reach maturity and/or shed seeds before the next treatment.

Perhaps establishment of the relationship between *C. odorata* cover and different stages of growth could provide a good idea of planning a successful management strategy. Of the different stages of growth, this study showed that the adult *C. odorata* stage is the major contributor in the percentage cover of *C. odorata* relative to the other stages of growth. This shows that areas with high *C. odorata* cover have high concentrations of the adult stage. Despite the clearing efforts, the presence of adult stage are remarkably higher in the areas treated more than three (3) times. Although *C. odorata* is a fast growing, the longest time lapse since last treatment in the area was three months. Therefore, it can be argued that the existing adult *C. odorata* are results of inconsistent treatments. On the other hand, from the high proportion of the adults in the management blocks treated more than three times, one could argue that, at the beginning of the control program, treatments were relatively poor due to lack of experience and/or training and might have improved over time.

One of the most important aspects in successful control of *C. odorata* is the consideration of the seed dispersal (Blackmore, 1996). Weerakoon (1972) and Wilson (1995) as quoted by (Joshi, 2001), mentioned that *C. odorata* produces large quantities (93,000-1,600,000) of light wind dispersed seeds per plant. In Futululu State Forest observation showed that *C. odorata* occurs everywhere while the management blocks are distributed mainly along the watercourses. As such, the *C. odorata* occurring outside the management blocks and the surrounding area will remain untreated and serves as asource of re-invasion to the treated areas or management blocks (Blackmore, 1996). Therefore, the control of *C. odorata* will probably be impossible if the re-infestation risk remains.

On the other hand, the number of invasive alien plants species per plot showed significant positive correlation with the cover of *C. odorata* in the treatment areas. In the Futululy State Forest, the control operation of *C. odorata* is done on contract basis. A given contract is signed based on the result of the assessment of the existing status of invasion including the number and density of invasive alien plant species in the management unit. It could be argued that, sometimes the real field situation may prove that the actual number of the invasive alien plant species and density(ies) are more than was estimated. As such, the work on such a management unit will require more Mondays than was expected. To complete the contract in time, in such a situation, clearing or treatment may not be done properly and thus yielding poor results. This concept was supported by the response of the workers who mentioned the number of invasive alien plant species as one of the main factors affecting their timely completion of a given contract. However, detailed study is required to assess the socio-economic aspect of the control of *C. odorata* since there is no literature available on the subject.

One of the major factors behind the spread of invasive alien plants is the opening up of canopy and and/or ground cover naturally or through human activities. The mechanical control of invasive alien plants has been viewed as a direct opening up of the canopy and/or ground cover in the ecosystem under conservation (Erasmus, 1988; Goodall, 2000; M'boob, 1991; Muniappan & Marutani, 1996). In this study the cover of *C. odorata* showed significant negative correlation with grass cover an indication that the areas with high grass cover contain less cover of *C. odorara* as compared to the open forest or areas where there is less grass cover. With tree canopy cover, *C. odorata* showed low cover at both low and high tree canopy cover and higher in the intermediate where, low and high tree canopy cover indicate grass and closed forest respectively. Based on this result, it must be stressed that effective control of *C. odorata* requires maintaining a closed tree canopy cover or dense grass cover to suppress the regenerating seedlings. In Futululu State Forest, natural regeneration of the native species within the management units is very poor (Fig.16 which means rehabilitation of the treated areas by planting suitable species like grass (Campell, 2000) is required. However, in Futululu State Forest, the application of this method is not part of the control strategy being adopted.

On the other hand, successful mechanical and chemical control of *C. odorata* (95-98%) in Australia was a result of complete awareness, consistent funding and mass systematic eradication action programme (Waterhouse, 1996). However in Futululu State Forest, while the control of *C. odorata* was initiated in 1998, there was a shortage of the budget in 1999, which made it difficult to keep consistent follow–up in some management units (Mkhwanazi Personal Communication). It was also noticed that the clearing was not done systematically in that, the distribution of the management units according to their number of treatments are irregular (Fig.2). It can be argued that the untreated blocks will always act as a source of propagules to their neighbouring blocks. It must also be acknowledged that, the location of the boundaries between management units (Compartments) in the forest unlike on the map is rather fussy if not difficult (Personal observation). This could lead to pockets of untreated *C. odorata* in between management units. (Waterhouse, 1996) argued that an important aspect in the success of *C. odorata* control is the monitoring and identification of the distribution of the missed adult stage in the previous treated areas and the location of the new regenerations. In the Futululu State Forest, such monitoring is a difficult endeavour because of difficult accessibility in the forest (Personal observation).

It is also worth mentioning that the Futululu State Forest is surrounded by farmlands under sugarcane and/or commercial forest plantations. Most of these lands specially the forest plantations are infested by *C. odorata.* Although there are initiatives of controlling these infestations, it was observed that most of the plantations surrounding the Futululu State Forest are not being controlled. It can be argued that these infestations are immediate source re-invasion.

While the current strategy of *C. odorata* control remains the main method of control of this aggressive invasive alien plant, the associated costs, the short-lived control results and the large extend of the invaded area; there is much attention for biological control as it yields a long term control (Zachariades, Strathie-Korrubel, & Kluge, 1999). Based on the large quantities of seed *C. odorata* can produce and fast rate of growth that makes it attain its maturity so easily within a year, the effective and sustainable control of *C. odorata* requires mass clearing operation (Waterhouse, 1996). In South Africa, the rate of invasion by *C. odorata* and the area invaded is so vast that the mass clearing and chemical treatment is not achievable (Strathie-Korrubel, 2000). The use of natural enemy (insects and/or fungus) of the plant that retard the vegetative activities of the plant therefore is the only viable option.

5. Conclusion and Recommendation

5.1. Conclusion

This study was undertaken to assess the efficacy of *C. odorata* control in Futululu State Forest Reserve and the factors influencing its performance.

- The current *C. odorata* control strategy being applied in the Futululu State Forest has significantly reduced the cover of *C. odorata.* However, comparison of the cover of *C. odorata* in the different number of treatments showed that the first two treatments are the most effective but further subsequent treatments showed even increasing cover of *C. odorata.* This finding suggests that the number of treatments alone does not determine the efficacy (success) of *C. odorata* controls
- The cover of *C. odorata* showed positive correlation with time lapse. It showed that the cover of *C. odorata* becomes higher as time lapse between treatments are extended longer or as *C. odorata* grows from seedling stage to young and/or adult. Therefore, it could be concluded that, success in the control of *C. odorata* requires that follow-ups be taken at shorter time intervals.
- Comparison of the cover of *C. odorata* in the different stages of growth showed that the cover of *C. odorata* increases with age or the stage of growth (seedlings Young to adult). This study also showed that areas or management blocks that have higher proportion of adult *C. odorata* have higher *C. odorata* cover. Therefore since the time lapse since last treatment in this study ranges from about 10 days (0.3 month) to three month, the presence of the adult stage and subsequently high cover of *C. odorata* in those areas or management blocks were due to inconsistencies in the treatments.
- The result of the assessment of the cover of *C. odorata* in the different land cover classes (closed Forest, open forest and grass land) indicated that, the cover of *C. odorata* is low in both closed forest and grass land and high in open forest. This means that control of *C. odorata* is more efficient in the closed forest and grassland but rather difficult in the open forest.
- Apart from *C. odorata*, there exist other invasive alien plant species in the forest. The cover of *C. odorata* showed significant positive correlation with the number of invasive alien plant species per plot. It is an indication that, in management blocks or areas where many invasive alien plant species occur, control yields poor results.
- While most of he variables such as soil texture, pH, bare soil, litter, distance from streams and road (forest boundary) showed no significant correlation, with *C. odorata* cover, amongst the distance classes the cover of *C. odorata* is higher in the beyond 1 km from the roads. This may because of the difficult accessibility in the forest; supervising or monitoring may not be done properly. On the other hand, among the classes, the class closed to stream, low altitude and the slope class valley bottom all showed higher cover of *C. odorata* as compared to the other classes. These mean that in the valley or close to the streams control of *C. odorata* is relatively difficult.

5.2. Recommendation

The main objective of the WFW is to sustainably control invasive alien plants in the watershed areas. Based on the results of this study, it was concluded that the current *C. odorata* control strategy being applied in the Futululu State Forest has significantly reduced the cover of *C. odorata* but have not met the required standard of equal or less than 5%(2.2 transformed) in most of the management blocks specially those treated more than two times. Therefore, to meet their objective, the WFW may consider the following recommendations.

- Time lapse between successive treatments should be kept as short as possible to avoid those *C. odorata* that escaped previous treatment reach maturity and shed more seeds and/or reduce cost by following up a treated management unit before the weed forms closed thicket.
- Further re-invasion should be avoided as much as possible. This requires that treatments should be done consistently and the control should be extended beyond the boundary of the current management blocks since *C. odorata* occurs almost everywhere This may call for co-operation and co-ordination of the control programme with the private land owners specially the neighbouring forest companies whose lands hold enough stock of *C. odorata* which act as sources of re-invasion to the treated areas and/or the forest at large.
- Proper monitoring pre and after treatment is required to reduce the improper treatments that may result due to the excessive number of invasive alien plant species discovered during the treatment process. However further research is required to explore the socio-economic aspects influencing the efficacy of control of this aggressive weed.
- While the above factors may improve the efficacy of controlling *C. ododrata*, it is important that the WFW considers manipulation of the ecosystem itself. This can be done by improving the forest structure by planting more trees in the forest gaps and planting some suitable grass species in the cleared areas as a quick but long term remedy to this expensive environmental polluter since natural regeneration seems not forth coming.
- It is important that awareness campaign be considered equally important because it was observed that despite the fact that *C. odorata* is problem in the whole St. Lucia, the majority of the neighbouring residents (Kula and Dukuduku village) still use *C. odorata* snd *Lantana camara* as live fences around their homes (See Fig.--). Since these are the very people controlling *C. odorata* in the forest, it is likely that they may play role in further propagation of these invasive species.
- Due to the extent of the invasion and the results of the management blocks treated three times and more, it could be concluded that sustainable control of *C. odorata* in the forest may prove economically not viable, if not impossible. Therefore it is recommendable that the WFW looks more seriously into the option of biological control.
- In this study, most of the variables such as, the distance to road and streams, altitude and tree canopy cover did not explain the variability in the cover of C. odorata well. It could be that there are other variables such as season of treatment; accessibility and level of supervision may affect the efficacy of control strategy being applied. There-

fore, further detailed research is required at field level to investigate the effects of these factors.

References

Adair, R. J. (1995). The theat of environmental weeds to biodiversity in Australia: a search for solutions. *Conserving Biodiversity: Threats and solutions*, 184-201.

Akobundu, I. O., & Ekeleme, F. E. (1994). *Potentials for C. odorata (L.) R.M. King and H. Robinson in Fallow Management in West and Central Africa.* Paper presented at the Third International Workshop on Biological Control and Management of C. odorata, Cote d'Ivoire.

Blackmore, A. C. (1996). *Seed Dispersal of Chromolaena odorata Reconsidered.* Paper presented at the Proceedings:Fourth International Workshop on Biological Control and Management of C. odorata, Bangalore, India.

Campell, P. L. (2000). *Rehabilitation Recomendations after Alien Plant Control*. Pietermaritzburg, S. Africa.: Arrow Print.

CCWR. (1998, 1999). *St Lucia System South Africa*. South African Wetlands Conservation Programme. Available: http://www.ccwr.ac.za/wetlands/st_lucia_ris.htm [2001, June, 2001].

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

de Rouw, A. (1994). *Chromolaena odorata in the Farming Systems of Southwest Côte d'Ivoire.* Paper presented at the Third International Workshop on Biological Control and Management ofC. odorata, Cote d'Ivoire.

Driessen, P. M. (1995). *Lecture note on adequecy of soil data*.Unpublished manuscript, Wegenigen-Enschede.

DWAF. (2000, March, 2000). Clearing invading plants - making water for you. *Hack Day 2000,* pp. 8.

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

Foxcroft, L. (2001). *Management of Chromoleana odorata in Kruger National Park and surrounding Areas: regional management strategy for a shared problem* (Draft document for discussion). Letaba: Alien Biota Section.

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

Gowans, J. (1998). *The latest on Dukuduku*. Available: http://onafrica.net/jill/1998/19981128_dukuduku.html [2001, July, 2001].

Groves, R. H. (1989). Ecological Control of Invasive Terestrial Plants. 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 prospective SCOPE 37* (SCOPE ed., pp. 437-461). Chichester. New Yorek. Brisbane. Toronto. Singapore.: John Wiley & Sons.

Haber, E. (1998). *Impact of Invasive Plants on Species and Habitats at Risk in Canada*. National Botanical Services, Ottawa. Available: http://infoweb.magi.com/~ehaber/impact.html [2001, June, 2001].

http://www.hsf.org.za/Briefing_15/forest.htm. *Save the forest*. Available: http://www.hsf.org.za/Briefing_15/forest.htm [2001, July, 2001].

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

Klopfer, L. (1999). *Conflict in the Park*. Michigan Today. Available: http://www.umich.edu/~newsinfo/MT/99/Fal99/mt9f99.html [2001, July, 2001].

Kluge, R. L., & Caldwell, P. M. (1994). *Failure and Frustrations of Biocontrol of Chromolaena odorata in South Africa.* Paper presented at the Proceedings:Third International Workshop on Biological Control and Management of C. odorata, Cote d'Ivoire.

Lillesand, T. M., & Kiefer, R. W. (2000). *Remote Sensing and Image Interpretation* (4th ed.). New York, Chichester, Weinheim, Brisbane, Singapore, Toronto: Wiley & Sons Inc.

Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M., & Bazzaz, F. (2000). *Biotic Invasions: Causes, Epidemiology, Global Consequences and Control* (5). Issues in Ecology. Available: http://esa.sdsc.edu/issues5.htm [2001, June, 2001].

M'boob, S. S. (1991). *Preliminary Results of a Survey and Assessment of C. odorata (Siam Weed) in Africa*.

McFadyen, C. R. E. (1988). *History and distribution of Chromolaena odorata (L.) R.M. King and H. Robinson.* Paper presented at the Proceedings:First International Workshop on Biological Control of C. odorata, Bangkok, Thailand.

Muniappan, R., & Marutani, M. (1996). *Mechanical, Cultural and Chemical Control of Chromolaena odorata.* Paper presented at the Proceedings:Fourth International Workshop on Biological Control and Management of C. odorata, Bangalore, India.

Myers, J. H., Simberloff, D., Kuris, A. M., & Carey, J. R. (2000). Eradication revisited: Dealing with exotic species. *Trends in Ecology and Evolution, 15*(8), 316-320.

Nortje, D. (2001). *Eradication of C. odorata (Paraffien Bos) in Kwa-Zulu Natal*.Unpublished manuscript.

Richardson, D. M., Macdonal, I. A. W., Haffmann, J. H., & Henderson, L. (1997). Alien plant invations. In R. M. Cowling & D. M. Richardson & S. M. Pierce (Eds.), *Vegetation of Southern Africa* (pp. 535-567). Combridge: Combridge University Press.

Schmitz, D. C., & Simberloff, D. (1997). *Biological Invasions: A Growing Threat*. Available: http://www.nap.edu/issues/13.4/schmit.htm [2001, June, 2001].

Schulze, R. E. (1997). *South African Atlas of Agrohydrology and Climatology* (TT82/96.). Pretoria: Water Research Commission.

Sharov, A. A., & Leibhold, A. (1998). Model of Slowing The Spread of Gypsy Moth (Lepidoptera: Lymantriidae) With a Barrier Zone. *Ecological Applications, 8*(4), 1170-1179.

Simberloff, D. (1996). Impacts of Introduced species in United States. *Conesquences, 2*(2).

Strathie-Korrubel, L. W. (2000, Summer, 2000). The South African programme on the biological control fo Chromoleana odorata (Triffid Weed) and its Global signiture. *Plant Protection News:57,* pp. 4-7.

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

Timbilla, J. A. (1996). *Effect of Biological Control of Chromolaena odorata on Biodiversity: a Case Study in the Ashanti Region of Ghana.* Paper presented at the Proceedings: Fourth International Workshop on Biological Control and Management of C. odorata, Bangalore, India.

Timbilla, J. A., Braimah, H., & Toa-Kwapong, D. (1994). *The menacing effects of Chromolaena odorata: a case study in the Brong Ahafo Region of Ghana.* Paper presented at the Third International Workshop on Biological Control and Management ofC. odorata, Cote d'Ivoire.

Tjitrosemito, S. (1994). *The Management of Chromolaena odorata (L.) R.M. King and H. Robinson in Indonesia.* Paper presented at the Third International Workshop on Biological Control and Management of C. odorata, Cote d'Ivoire.

Turlings, L. (2000). *Invasive Plants and Animals: Is there way out?* Leiden: Netherlands Committee for IUCN.

UNEP, CBD, & SBSTTA. (2001, March, 2001). *Invasive alien species: a case studies and country comments on invase alien species*. Available: http://www.biodiv.org/doc/meetings/sbstta/sbstta-06/information/sbstta-06-inf-02-en.pdf [2001, June, 2001].

Usher, M. B. (1989). Ecological Effects of Controlling Invasive Terrestrial Vertebrates. 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 prospective SCOPE 37* (SCOPE ed., pp. 463-489). Chichester. New Yorek. Brisbane. Toronto. Singapore.: John Wiley & Sons.

van Wilgen, B. W., Little, P. R., Chapman, R. A., Gorgens, A. H. M., Willems, T., & Marais, C. (1997). The sustainable development of water resources: History, financial, and benefits of alien plant control programmes. *South African Journal of Science, 93*, 404-411.

van Wilgen, B. W., Richardson, D. M., & Higgins, S. (2000). *Intergrated control of invasive alien plants in terestrial ecosystems.* Paper presented at the Best management practices for preventing and controlling invasive alien species, Cape Town, South Africa.

Waterhouse, B. (1996). *Chromolaena odorata in Australia: Progress in Eradication of an Established Infestation.* Paper presented at the Fourth International Workshop on Biological Control and Management of C. odorata, Bangalore, India.

Williamson, M. (1999). Invasions. *Ecography, 22*(1), 5-12.

Witkowski, E. T. F., & Wilson, M. (2000). *Changes in density, biomass, seed production and soil seed banks of the non-native invasive plant, Chromoleana odorata, along 15 year chronosequence.* Paper presented at the 5th International workshop on biological control and management of Chromoleana odorata, Durban, South Africa.

WRI. (1999). *Mitigating the Impact of Alien/Invasive Species*. Available: http://www.wri.org/wri/biodiv/gbf/gbf13-02.htm [2001, June, 2001].

Wu Renrun, & Xu Xuejun. (1991). *Cultural Control of Feijicao [C. odorata (L.) R. M. King and H. Robinson] by Planting Signalgrass (Brachiaria decumbens Stapf) in Southern Yunnan, People's Republic of China.* Paper presented at the Second International Workshop on Biological Control and Management of C. odorata, Bogor, Indonesia.

Zachariades, C., Strathie-Korrubel, L. W., & Kluge, R. L. (1999). The South African programme on the biological control of Choromoleana odorata (L.) King & Robinson (Asteraceae) using insects. In T. Olcker & H. M.P. (Eds.), *Biological control of weeds in South Africa* (Vol. 1, pp. 89-102). Johannesburg: African Entomology Momoir.

Appendix 1

Table 5:Summary of Mann Whitney U test result

All the bold P-values indicate significance at α = 0.05.

(A): Treatment Status

	Treated
Treated	
Untreated	**0.000**

(B): Stage of growth

	Adult	Young	Seedling
Adult			
Young	**0.0001**		
Seedling	**0.0001**	0.2584	
Mixed	0.0522	**0.0068**	**0.0080**

(C): Number of treatment

	1	2	3	4	6
1					
2	**0.0182**				
3	**0.0019**	**0.0095**			
4	**0.0003**	**0.0000**	0.0801		
6	0.0615	0.2491	0.7200	0.1841	
0	**0.0001**	**0.0000**	**0.0044**	0.1131	**0.0134**

(D): Time lapse since last treatment

	One Month	Two Months
One Month		
Two Months	**0.0441**	
Three Months	**0.0044**	0.0507

(E): Number of invasive alien species

	One Spp	Two Spp
One Spp		
Two Spp	0.1478	
> Two Spp	0.0813	0.7977

(F): Land cover types

	Closed Forest	Open Forest
Closed Forest		
Open Forest	**0.0007**	
Grass	0.9876	**0.0029**

(G): Presence/absence of adult stage

	Absent
Absent	
Present	**0.000**

(H): Soil PH

	Acidic	Neutral
Acidic		
Neutral	0.9137	
Saline	0.6949	0.7596

(I): Soil Texture

	Sandy	Sandy loam	Loamy
Sandy			
Sandy loam	0.7405		
Loamy	0.1661	0.3907	
Silt loam	0.3924	0.7327	0.5810

(J): Altitude class

	Low	Medium
Low		
Medium	**0.0245**	
High	**0.0022**	0.2059

(K): Slope

	Flat	Hill slope	Valley bottom
Flat			
Hill slope	0.9923		
Valley bottom	**0.0371**	0.1002	
Valley slope	0.1800	0.2471	0.4334

(L): Distant to watercourses

	Close	Medium
Close		
Medium	0.3246	
Far	0.3802	0.6972

(M): Distance to road/forest boundary

	Close	Medium
Close		
Medium	0.6258	
Far	0.0610	**0.0061**

Appendix 2: Field observation sheet

Relevee No.________

Date: ----/----/ 2001		Observer's Name: ---------------		Cluster number: -----------------
Plot location UTM:	Easting		GPS	X:
	Norting			Y:
Terrain Altitude: ___________________ Slope: ___________________		**Land form** Flat: ___________ Valley: __________ Hills: ____________ Plateau: _____________ Land characteristics State owned:______Private:___ community:_____Leasehold____ others________		**Distance estimation from** Road:____________ Settlement:___________ River:_______________ Waterhole:____________
Soil Profile **Texture**: Sand (S), Loamy Sand (LS), Sandy Loam (Sl), Loam (L), Clay Loam (Cl), Clay (C)			pH	

Land Cover

	% Cover	**Dominant Species**
Tree layer > 5m		
Tree layer < 5m		
Non woody layer		

Human Activities

<table>
<tr><td rowspan="2">Grass cutting ________
Reforestation ________
Natural regeneration ___
Thinning ____________
Pruning ____________
Coppicing ___________
Looping _____________
Debarking ___________
Logging _____________
Firewood collection ____
Encroachment ________</td><td>Stump number: ______
Fire: Present/absent</td><td colspan="3">Control Operation</td></tr>
<tr><td>Tannin __________
Fruit _____________
Hunting __________
Charcoal _________
Tourism __________</td><td>Present
Treatment #
1
2
3
4
5</td><td>Past
Treatment #
1
2
3
4
5</td><td>Absent</td></tr>
</table>

Type of control (treatment): Mannual/ chemical / biological/ others_______________________

Vegetation discription

Dominant herbs ____
Shrub(s) ____
Trees ____
Forest type ____
Ground cover: Litter __________. Bare Soil ___________________

Observation	C. odorata	Other invasive alien species
% Cover		
No. of stems (regeneration only)		
No. of regeneration (native species)		

Further information:____

Other associated species

S/number	Associated woody species	% Cover	Individual	Remarks
1				
2				
3				
4				
5				
6				
7				

Appendix 3: List of plant species identified in the area.

No.	Scientific name	Family Name	Local name(Zulu)
1	Lantana camorra	Verbenaceae	
2	Melia azedarach	Meliaceae	
3	Chromolaeana odorata	Asteraceae	
4	Solanum mauritianum	Solanaceae	
5	Isoglossa woodii	Acanthaceae	
6	Celtis durandii	Ulmaceae	inDwandwazane
7	Albizia adiantifolia	Mimosaceae	iGowane
8	Combratum molle	Combretaceae	unBondwe
9	Cassine papilosa	Celastraceae	isiNama
10	Khaya spp	Meliaceae	
11	Rhus s	Anacardiaceae	
12	Ficus craterostoma	Moraceae	isihlamfane
13	Ficus abutifolia	Moraceae	imPayi
14	Ficus sycomorus	Moraceae	isiKhulchuboya
15	Ficus natalensis	Moraceae	isiHlamfane
16	Bauhinia galpini	Caesalpiniaceae	usololo
17	Acacia ataxicantha	Mimosaceae	
18	Acacia spp	Mimosaceae	uGagane
19	Carsa macrocarpa	Apocynaceae	umThungulu
20	Caparis fascicularis	Capparaceae	
21	Cussonia sphaerocephala	Araliaceae	UmSenge wehlathi
22	Antidesma venosum	Euphobiaceae	umHlabahlungulu
23	Celtis spp	Ulmaceae	
24	Rhus rehmaniana	Anacardiaceae	iNhlokoshiyane
25	Commiphora glandulosa	Burseraceae	isiNgankomo
26	Rhus guenzi	Anacardiaceae	umPhondo
27	Catha edulis	Celastraceae	unHlwazi
28	Cryptocaria myrtifolia	Lauraceae	umLahlankosi
29	Coddia rudis	Rubaceae	umGogwane
30	Stychnos madagascariensis	Loganiaceae	umNconjwe
31	Dichrostachys cineria	Mimosaceae	uMnukelambiba
32	Strychnos decusata	Loganiaceae	umLahlankosi
33	Stychnos mitis	Loganiaceae	umHlamahlala
34	Gardenia spp	Rubiaceae	
35	Rhus dentata	Anacardiaceae	umHlalamvubu
36	Dalbergia armata	Caesalpiniaceae	uThathawe
37	Commiphora	neglectaBurseraceae	isiNgankomo
38	Strychnos gerrardii	Loganiaceae	umGuluguhla
39	Sisal spp		

40	Rhoicissus tomentosa	Vitaceae	isiNwazi
41	Pinus spp		
42	Anona senegalensis	Anonaceae	umHlalajuba
43	Garcinia gerardii	Cluciaceae	isiKhwelafene
44	Grewia pendoensisi	Tiliciaceae	
45	Grewia flavescens	Tiliaceae	
46	Brachylaena uniflora	Asteraceae	umPhahlawenati
47	Maytenous senegalensis	Celastraceae	isiHlangwana
48	Syzigium gerrardii	Myrtaceae	umDunwana
49	Peltophorium africanum	Caesalpiniaceae	umSehle
50	Sideroxylon inerme	Sapotaceae	
51	Syzigium cordatum	Mytaceae	
52	Strelitzia nicolai	Strelitziaceae	
53	Dombeya cymosa	Sterculiaceae	
54	Rhus chirindensis	Anacardiaceae	
55	Maytenous pendicularis	Celastraceae	
56	Eucalyptus spp		
57	Ekebergia capensis	Meliaceae	
58	Chaetachme aristata	Ulmaceae	
59	Ziziphus spp	Zamiaceae	
60	Grewia flanagani	Anacardiaceae	
61	Canthium spinosum	Rubiaceae	
62	Brindelia micrantha	Euphobiaceae	
63	Phoenix rectinata	Arecacaeae	

Appendix 4: Photos of the study area

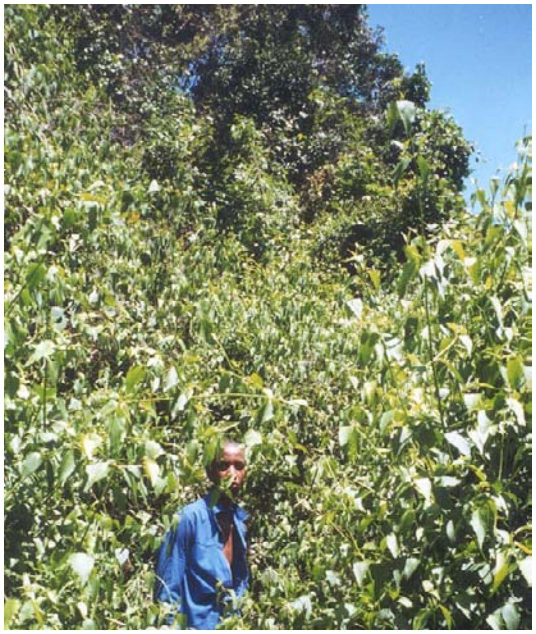



Photo 1: Picture showing the impact of control of C. odorata


Photo 2: Photo showing inconsistent treatment and regrowth of C. odorat

Photo 3: Cover of C. odorata in the same area within a difference of one month one month

Photo 4: C. odorata and L. Camara used as live fence

Figure 5: Dense regeneration of C. odorata on valley slope and open forest

Photo 6: Regeneration of C. odorata in grass free area and an area with dense grass cover

Photo 7: Grassland and watercourse with dense C. odotrata infestation.

Photo 8: C. odorata during fruiting season

Photo 9: C. odorata in plantation forest

Photo 10: A team of worker in the Forest

Photo 11: Signpost of DWAF