Regeneration of *Mimosa pigra* L following bush clearing and burning in Lochinvar National Park of the Kafue Flats of Zambia

by

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DECLARATION OF WORKS

This thesis report describes work undertaken as part of a programme of study at the University of Zambia. All views and opinions expressed in here remain the sole responsibility of the author, and do not necessarily represent those of the institution. I therefore, declare that the content of this thesis report is solely my original work and that it has not been submitted to this or any other university before.

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CERTIFICATE OF APPROVAL

This dissertation of Nkandu Brian has been approved as fulfilling part of the requirement for the award of the degree of Master of Science in Tropical Ecology and Biodiversity by the University of Zambia.

Signature of Examiners Date

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ABSTRACT

Mimosa pigra has been identified as a serious invasive alien plant that has invaded the floodplain of Lochinvar National Park in the Kafue flats. There has been a challenge in finding an effective method to successfully control *Mimosa pigra*. This is because when *Mimosa pigra* is cut, it regenerates rapidly either through seedling emergence or through saplings from severed parts of the plant.

The purpose of the study was to investigate the regeneration of *Mimosa pigra* following bush clearing and burning. The study was conducted in 2009 in Lochinvar National Park, in the southern part of Zambia. The study used a systematic random blocking design in which five transects were randomly established measuring 104 m long x 5 m wide with an inter transect distance of 30 m wide. Each transect consisted of 10 plots of 5 x 5 m sub divided in 1 x 1 m quadrats.

Results showed that there was a significant difference in the number of emerging seedlings per square metre among the treatments with $p = 0.0017$ and $F = 4.39$. Among all treatments applied on *Mimosa pigra* the combination of stem cutting, burning and uprooting had the lowest number of seedling emergence, stump resprouts and root resprouts. The treatment was successful in killing both the plant and seeds of *Mimosa pigra* in the soil seed bank. A comparison of the three modes of regeneration for all treatments investigated showed seedling emergence being the commonest mode of regeneration with a mean value of 604.08 emerging seedlings/m^2. The growth pattern of *Mimosa pigra* showed an exponential increase in length per week, while native plant species returned after the removal of *Mimosa pigra*. Plant succession after treatment showed appearance of grasses, creepers, herbs and native tree species.

The main conclusion of the study was that the method of combining stem cutting, burning and uprooting was most definitive in controlling *Mimosa pigra*. Although, it would be useful to expand the study in future, these results remain an important element in an effort to regulate the growth of this plant, particularly in areas where the species is in the stage of colonization. Since the plant is resilient and has several ways of regeneration, it is recommended that any control measure of *Mimosa pigra* should aim at killing the plant and reducing seeds in the soil seed bank.

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DEDICATION

To my Mother and Family

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ABBREVIATIONS & ACRONYMS

a.s. l.	Above Sea level
ANOVA	Analysis of Variance
ECZ	Environmental Council of Zambia
GEF	Global Environment Fund
GMP	Game Management Plan
GPS	Global Positioning System
IAP	Invasive Alien Plants
IAS	Invasive Alien Species
IBA	Important Bird Area
IUCN	International Union for the Conservation of Nature
JICA	Japanese International Corporation Agency
LNP	Lochinvar National Park
MEA	Multilateral Environmental Agreements
SABSP	Southern Africa Biodiversity Support Programme
TEB	Tropical Ecology and Biodiversity
UNEP	United Nations Environment Programme
UNZA	University of Zambia
WWF	World Wide Fund for Nature
ZAWA	Zambia Wildlife Authority
ZESCO	Zambia Electricity Supply Corporation
ZTB	Zambia Tourism Board

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CHAPTER 1.0 INTRODUCTION

1.0 Background

Mimosa pigra L. (Mimosaceae) is a semi aquatic shrub commonly known as giant sensitive plant (SABSP, 2004). It is an exotic and invasive plant, possibly introduced to Zambia from tropical America where it occurs in wide belts extending from Mexico through Central America to Northern Argentina (Walden *et al.,* 1999). Although, *Mimosa pigra* is native to tropical America, it has now spread throughout the world's tropical wetlands, spreading to Australia, Asia and Africa (Lonsdale, 1983).

While the plant occurs in limited quantities elsewhere in river valleys in Zambia, *Mimosa pigra* poses a major threat to the Kafue flats wetland especially in the Lochinvar National Park floodplains. Although it is not clear when this weed was introduced to Lochinvar National Park, records show that the plant became conspicuous in the 1980s (ECZ, 2004). *Mimosa pigra* is a notorious woody shrub that forms prickly, impenetrable mono-specific thickets, impassable to both humans and animals (Kampamba and Nyirenda, 2004). And if not controlled, *Mimosa pigra* would lead to loss of land important for agriculture and conservation (Braithwaite *et al*., 1989). In Lochinvar National Park, *Mimosa pigra* has invaded pasture land resulting in loss of grazing grounds for both wildlife and livestock. Furthermore, the presence of this weed has resulted in a loss of access to water and fishing grounds (Miller *et al*., 1981).

Efforts to control *Mimosa pigra* using physical or mechanical, chemical and biological have been tried elsewhere mostly in Australia and Vietnam (Triet *et al*., 2004), and results have remained inconclusive. Similarly, trials in Zambia for controlling *Mimosa* *pigra* manually were initiated in 2000 in which 16.6% (501 ha) of the invaded area (3000 ha) was cleared using physical control where the above ground growth was cut, using machetes, dried and burnt. Nevertheless, results of this effort have not been meaningful (ECZ, 2004). According to Paynter and Flanagan (2004), the removal of mature plants stimulates the germination of seeds from the seed bank resulting in emergence of hundreds of seedlings per square metre while young saplings regenerate from cut stems and roots. The ability of *Mimosa pigra* to regenerate rapidly after treatment has been a major problem in its control, and since the plant is aggressive and invasive, its spread remains a major challenge worldwide. This study, therefore, is significant as an ongoing effort to find ways of limiting the spread of this plant.

1.1 Statement of the problem

Mimosa pigra has been identified as a serious invasive alien plant that has invaded the floodplain of the Kafue Flats grassland causing fragmentation of the habitat (Genet, 2007). The main problem has been to find an effective method that would successfully control this plant. For the most part of the plant when cut, it regenerates rapidly either through seedling emergence or through the regeneration of saplings from cut parts of the plant. It has been observed that without understanding the recruitment and regeneration mechanisms of *Mimosa pigra* following treatment, the control efforts would not yield any meaningful results (Ayana and Gufu, 2008). Merely reducing the above ground biomass of *Mimosa pigra* would allow the plant to regenerate rapidly. Thus, an investigation into the regeneration of *Mimosa pigra* following treatment would generate new information and contribute to the finding of an effective method of controlling of this plant. This study was mooted in this regard.

1.2 Purpose and objective of study

The overall purpose and objective of the study was to investigate the regeneration of *Mimosa pigra* plant after treatment by bush clearing, burning and uprooting.

1.3 General Research Question

Mimosa pigra has been identified as a serious invasive alien plant. The main problem has been to find an effective method that would successfully control the plant. It regenerates rapidly either through seedling emergence or through the regeneration of saplings from cut parts of the plant. Therefore, the general research question is, does *Mimosa pigra* regenerate following bush clearing and burning?

1.4 Specific Research Questions;

In order to achieve the overall purpose of the study the following specific research questions will be answered:

(i) What is the effect of bush clearing and burning influence *Mimosa pigra* seedling emergence?

(ii) What is the effect of bush clearing and burning on *Mimosa pigra* resprouts from the remaining cut parts of stumps?

(iii) What effect does bush clearing and burning have on *Mimosa pigra* coppicing from the remaining cut parts of roots?

(iv) What is the effect of bush clearing and burning on *Mimosa pigra* seedling growth?

(v) What effect does the removal of *Mimosa pigra* has on plant species diversity return?

1.5 Hypotheses

The study tested the following hypotheses:

(i). Bush clearing and burning increases seedling emergence of *Mimosa pigra*.

(ii). Stem cutting of *Mimosa pigra* increases regeneration from the cut parts of the plant.

(iii). Uprooting of *Mimosa pigra* plants increases regeneration from the severed roots.

(iv). *Mimosa pigra* has an exponential growth pattern and a short juvenile phase.

(v). Bush clearing and burning of *Mimosa pigra* plant populations increases native flora diversity.

1.6 Significance of the Study

The study provided data of *Mimosa pigra* in response to;

(a) Seedling emergence after treatment through bush clearing the above ground biomass.

(b) Resprouting after treatment through bush clearing and burning of the plant.

(c) Growth pattern after treatment through bush clearing and burning.

(d) Diversity of plants after removal of *Mimosa pigra*.

The data derived from the study were used to indicate;

(i) The regeneration ability of *Mimosa pigra* after treatment.

(ii) The diversity return of plant species after the removal of *Mimosa pigra*.

(iii) The most effective treatment method of *Mimosa pigra* in Lochinvar National Park and provide recommendations on how to effectively control the plant. This information would be useful to Zambia Wildlife Authority (ZAWA), Environmental Council of Zambia, ZESCO Ltd and local communities surrounding Lochnivar National Park.

CHAPTER 2.0 LITERATURE REVIEW

2.0 Introduction

Literature review involved a desk study of available background information about the biology and infestation of *Mimosa pigra* in tropical America, Australia, Asia and Africa. On site field observations involved identification of impacts, estimation of extent of coverage was considered in this study.

2.1.1 Description of *Mimosa pigra* Plant

Mimosa is the common name of shrubs that constitute a subfamily of the legume family, *Fabaceae (Leguminoseae), subfamily Mimosideae.* When mature, *Mimosa pigra* is an erect, much branched prickly shrub and can grow up to 6.0 m (Lonsdale, 1992). When young, stems are greenish and later become brown and woody with randomly scattered slightly recurved prickles of 0.5 cm to 1.0 cm long (Figure 1.0). Leaves are bipinnate and consist of about 15 pairs of opposite primary segments of 5.0 cm long with sessile, narrowly lanceolate leaflets that fold together when touched or injured and at night (Lonsdale, 1992). The flowers are pink or mauve, small, regular and grouped into globular heads measuring 1.0 cm to 2.0 cm in diameter.

Figure 1.0: *Mimosa pigra* flowers of seedling plant (ECZ, 2004).

The fruit is a thick hairy, 20-25 seeded, flattened pod borne in groups in the leaf axils, each 6.5 cm to 7.5 cm long and 0.7 cm to 1.0 cm wide. The fruit turns brown when mature, breaking into one-seeded segments (Figure 2.0) The seeds are brown or olive green, oblong and flattened (Figure 2.0), 4.0 mm to 6.0 mm long, and 2.0 mm wide (Walden *et al*., 1999). It reproduces via buoyant seed pods that can be spread long distances in flood waters (Lonsdale, 1992).

Figure 2.0: *Mimosa pigra* drawing. (Ross, 1975), page 118. Parts 1 show - *Mimosa pigra* plant, 2 the seed pod and 3 the seed.

Mimosa pigra is an Invasive Alien Species (IAS) defined as an organism that when introduced to a new environment, establishes itself and spreads quickly, causing problems for native biodiversity and human livelihoods (Cook *et al*., 1996). Typical characteristics of an invasive alien species include those which originate from ‘outside’ a given area (ecosystem) and arrive without its native control – such as its own competitors, predators, parasites and pathogens that keep it in check. These ‘aliens’ can be plants, animals or micro organisms, introduced intentionally or unintentionally. Once established, they spread and cause problems and become invasive (Vitousek *et al.,* 1996). In this case, invasiveness means invading local ecosystems and habitats as well as adversely impacting on human development and infrastructure, for example, the invasion of *Mimosa pigra* in the early 1980s into one of Zambia’s Ramsar sites (Wetland of international importance as prescribed in the Ramsar Convention of 1971, Appendix IV).

Lochinvar and Blue Lagoon National Parks and the Kafue flats as a whole (Thomas, 2006) as reflected below.

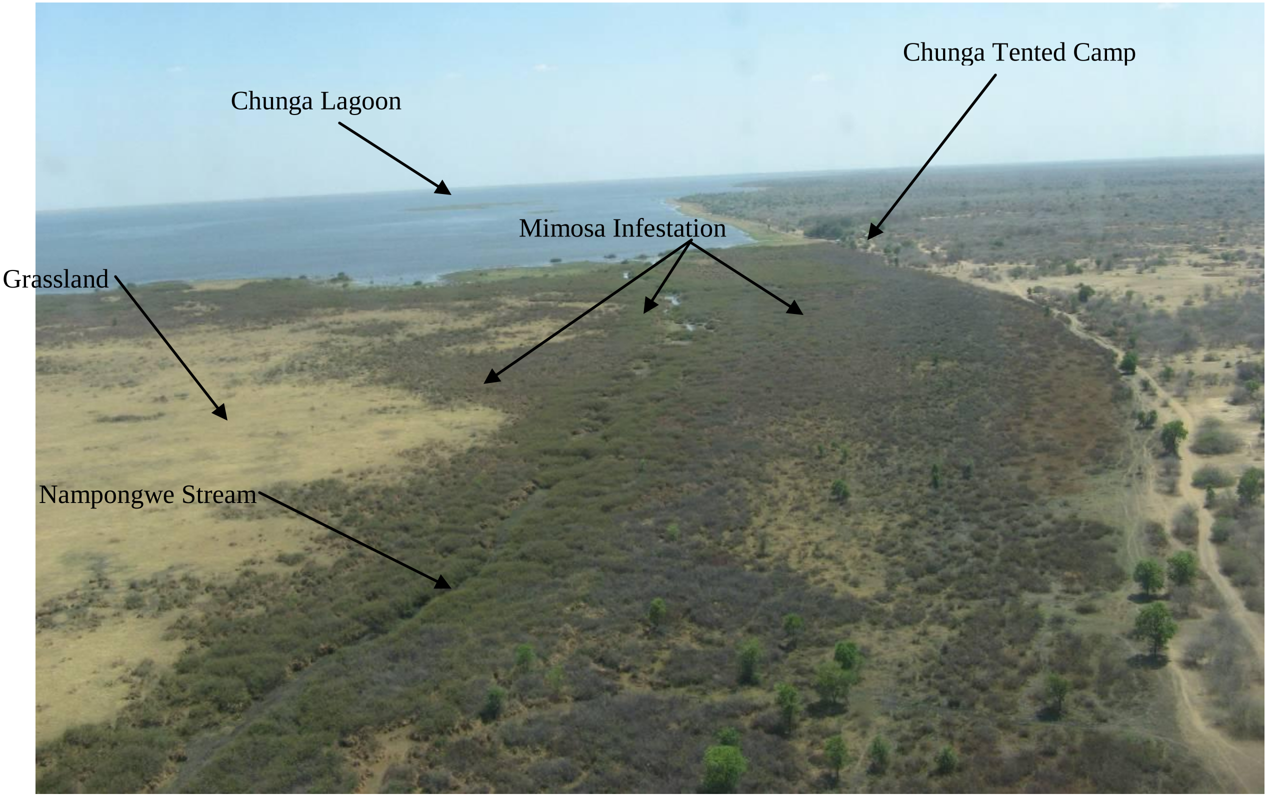

Figure 3.0: *Mimosa pigra* thickets along Nampongwe stream in Lochinvar National Park. (Thomas, 2006).

Mimosa pigra has short juvenile period and consistent seed reproduction. It produces a lot of seeds with small seed mass and has high initial germinability (Grime, 1983), shorter chilling period needed to overcome dormancy (Harper, 1977), and higher relative growth rate of seedlings (Forno, 1992). *Mimosa pigra* can grow and spread fast (Figure 5.0 shows dense, mono-specific, impenetrable thickets of *Mimosa pigra* in Lochinvar National Park). The plant grows so fast that before, there was only one small known infestation of approximately 2.0 ha (in 1980) at the head of Nampongwe stream (Mumba and Thompson, 2005). The plant then spread to 100 ha and 1000 ha in 1990 (Thompson, 1986). Invading areas previously dominated by grassland vegetation such as *Echinochloa* *stagina* and *Oryza longistamina* (Mumba and Thompson, 2005). Taking the rate of spread as an expression of $R = \sum [\Delta (A_2-A_1)/(T_2-T_1)]$, the exponential growth of *Mimosa pigra* was calculated to be 368 ha per year in Lochinvar National Park. (Where R is the rate of spread, and A_2-A_1 is the difference of mean for initial invaded area per year over time, T_2-T_1) based on Figure 4.0.

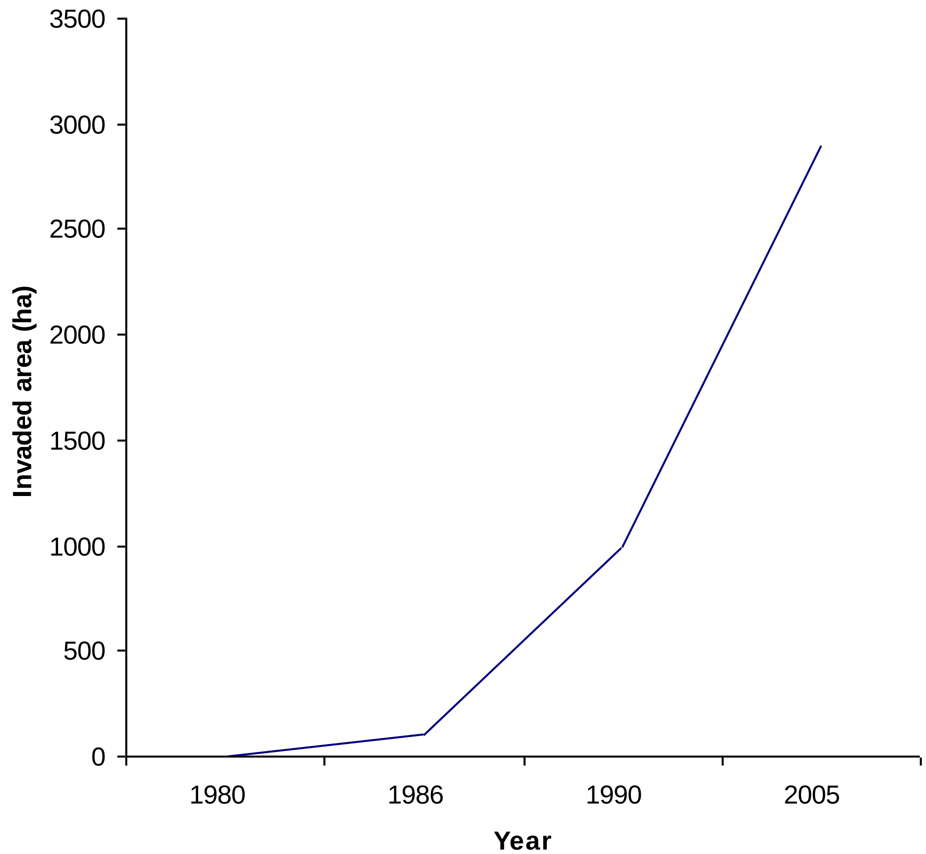

Figure 4.0: Exponential spread of *Mimosa pigra* in Lochinvar National Park (ECZ, 2004).

Mimosa pigra has invaded the lower Kafue Flats Wetlands, particularly the area around the Chunga Lagoon and its environs in Lochinvar National Park (Figure 3.0). Invaded areas on the Kafue flats have formed thick homogeneous stands, replacing the native vegetation of the wetland ecosystem.

Figure 5.0: *Mimosa pigra* thickets in Lochinvar National Park (ECZ, 2004).

The *Mimosa pigra* is highly intolerant to shade and requires sunlight to flower and fruit. The two principal ingredients for successful establishment are moist or wet soils and disturbance to the flooding regime. *Mimosa pigra* is a fierce competitor with low vegetation capable of succeeding in dense, tall grass swards (Figure 5.0 shows a mass of grass been eclipsed). It tolerates a wide variety of soil conditions, short-term flooding, seasonal drought, and grows at elevations from near sea level to 700 m (Janzen, 1983). Although it grows mixed with other vegetation in its native habitat, the species forms pure stands with little or no understorey in many of its exotic habitats (Pacific Island Ecosystems at Risk, 2002). The invasion of the floodplain of Lochinvar National Park has not only fragmented the habitat but also impinged on the existence of other plant and animal species such as the endangered bird species – the Wattled crane, *Grus carunculatus* (Kampamba and Nyirenda, 2004).

2.2 Challenges faced in controlling *Mimosa pigra*.

Mimosa pigra possesses a number of attributes that characterize it as a difficult plant to control and poses a challenge in controlling it. These attributes could be summed up as; (i) its ability to easily overcome geographical and environmental barriers (ii) its resilience to flooding and injury (iii) fire tolerance (iv) ability to regenerate (Rejmanek, 1989).

2.2.1 Overcoming geographical and environmental barriers.

Mimosa pigra grows quickly and it reproduces faster due to efficient seed dispersal. Lonsdale (1992) estimated that one plant could produce more than 9000 seeds annually. The seeds borne in clusters of bristly pods break up into segments containing a seed. The seeds remain dormant in the ground for a number of years before germinating (Roberts, 1972). This ability enables the plant to overcome various abiotic and biotic barriers as typified by this simple conceptualization of Invasive Alien Plants (IAP) below.

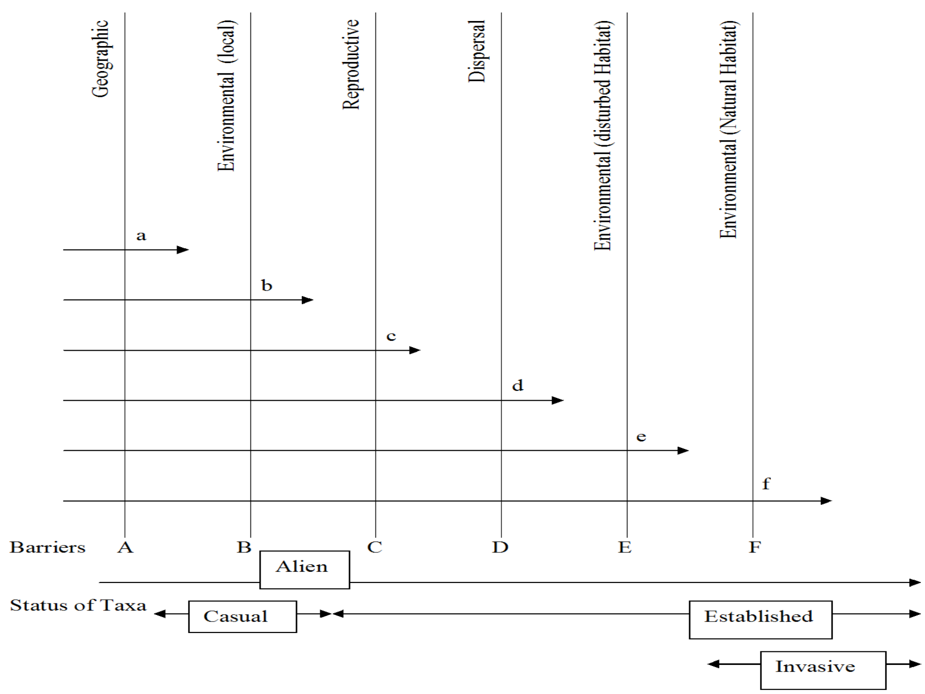

Figure 6.0: Invasion Process (Richardson *et al*., 2000).

Invasive plants (which includes *Mimosa pigra*) are usually, introduced through human aid over a major geographic barrier (A). Then establishment begins, by overcoming environmental barriers as they are able to survive both dry season and flooding in the wet season (Lonsdale, 1992). In the model highlighted in Figure 6.0, establishment begins when environmental barriers (B) and when various barriers to regular reproduction (C) are overcome. Then the taxon becomes established after overcoming barriers A, B and C. At this stage populations are sufficiently large that the probability of local extinction due to chance environmental events is low (Richardson *et al.,* 2000). This is followed by spreading of species into areas away from initial sites of introduction requires that the introduced species also overcome barriers to dispersal within the new region (D) and can cope with the abiotic environment and biota in the general area (E). Finally colonization of mature, successional and resistance posed by different category of factors (F).

2.2.2 Resilience to flooding and injury.

Mimosa pigra can withstand flooded conditions by sprouting adventitious roots near the surface where they can take up oxygenated water (Miller *et al.,* 1981). Lonsdale, (1985) observed that *Mimosa pigra* matures quickly could set long tap roots and seed in their first year of growth. In this way, infestation can double in one year (Walden *et al.,* 2004). If chopped down, *Mimosa pigra* easily resprouts from the stump (Wanichanatakul and Chinawong, 1979) and 90% of mature plants when cut regenerates from cut stems or roots. When burnt down, the foliage become desiccated and falls, but up to 50% of seedlings emerge from the seed bank (Miller, 1988).

2.2.3 Fire tolerance.

Because of the little grassy under storey in thickets of *Mimosa pigra*, it is difficult to burn and destroy *Mimosa pigra* plants, because the plant is fresh throughout the year, with very little litter, to provide fuel (Lonsdale and Miller, 1993). However, burning does not prevent resprouting of plants and kills only surface seeds, not buried ones. More than often fire stimulate seed germination by breaking the dormancy (induced due to low ambient humidity) resulting in the loss of the integrity of the testa which makes the seed permeable to water (Lonsdale, 1988).

2.2.4. Ability of *Mimosa pigra* to regenerate.

Mimosa pigra has a recovery phenomenon, where new plants are regenerated from a mass of fully differentiated cells and develop from dormant buds or seed, forming new parts, often as an induced response to injury or to profound changes in growing conditions (Zedler and Zammit, 1989). Thus, *Mimosa pigra* regenerates from vegetative tissue after severe injury from disturbances such as herbivory, fire or cutting (Wanichanatakul & Chinawong, 1979). This ability to resprout after disturbance overcomes barriers such as seed dispersal, predation, desiccation and seedling survival which are strong bottlenecks that impede recovery, as *Mimosa pigra* by passes the seed stage and have more vigorous shoots than seedlings (Walden *et al*., 1999). The removal of mature plants stimulates (through increased light or heat and some interaction with moisture) the germination of seeds from the seed bank resulting in hundreds of seedlings per square metre (Paynter and Flanagan, 2004). Mooney and Dunn, (1970) noted that regenerative mechanisms that allow plant populations to recover after fire were wide-spread in most plants. These mechanisms included, fire stimulated germination, resprouting from stumps, lignotubers, or burls (James, 1984). Fire has been proposed as a major selective force leading to the acquisition of this character associated with post-fire regeneration (Gill and Groves, 1981; Keeley, 1986). Whelan (1995) stated that it was important to know the ability of plant communities to regenerate after burning, as regeneration leads to the production of secondary trunks as induced response to injury or profound changes in growing conditions (Axelrod, 1986). This recovery phenomenon is typical of *Mimosa pigra* and has caused the control of *Mimosa pigra* to be difficult.

2.3 Control of *Mimosa pigra.*

In Sri Lanka, experiments to control *Mimosa pigra* were carried out using fire, physical or mechanical (using hand pulling and chaining), chemical (herbicides) and biological (Biocontrol agents). The results were not successful due to the ability of *Mimosa pigra* to regenerate vigorously (Miller and Siriworakul, 1992). This failure in controlling *Mimosa pigra* could be attributed to its main weedy attributes, which are, its vigorous growth rate, high fertility and production of durable seeds.

In Australia, *Neurostrota gunniella*, *Carmenta mimosa, Coelocephalapion pigrae* and *Chlamisus mimosae* as biological agents were released. However, the results showed that the stem boring moth *Neurostata gunniella* that had a measurable effect on the canopy growth and reduced plant size (Wilson and Martin, 1991), such that over 80% of biological control successes were said to have being achieved by this single agent (Myers, 1985). Nevertheless, it is always envisaged that a number of biological control agents working in combination would be required to control *Mimosa pigra* (Forno, 1992). Other methods to control *Mimosa pigra* conducted included aerial application of herbicide (Miller and Siriworakul, 1992), mechanical control (Siriworakul and Schultz, 1992) and fire (Lonsdale and Miller, 1993). Failures associated with these methods were observed, for example, mechanical control rarely killed *Mimosa pigra* plants (100%) as healthy *Mimosa pigra* plants were difficult to burn as plants often resprouted and buried seeds survived and became germinable (Lonsdale and Miller, 1992). For these reasons, Miller *et al.*, (1992) suggested that an integrated management program, combining all three methods (mechanical, chemical and biological) would provide effective control option of *Mimosa pigra*.

This study explored four different treatments in the regeneration ability of *Mimosa pigra* after treatment. The information obtained would therefore, contribute to finding the most effective control option of *Mimosa pigra.*

CHAPTER 3.0 DESCRIPTION OF THE STUDY AREA

The study was conducted near the Napongwe stream believed to be the first place where *Mimosa pigra* was cited between 1982 and 1984 (Turner, 1983). It's assumed that the period was long enough to allow the accumulation of seeds in the soil seed bank that would germinate and establish when subjected to treatment. Thus, the selection of the study area.

3.1 General location

Lochinvar National Park (LNP) is located on the Kafue flats in Southern Province of Zambia, between 15^0 43' and 16^0 01' S and $27^0$10' and $27^0$19' E. The Kafue flat is a large part of the Kafue basin, covered by protected area system of two national parks and a game management area (GMA). The surroundings are heavily settled with communities active in livestock and agriculture. The Kafue flats covers an area approximately 6,500 Km^2 (Figure 7.0) with an elevation of 975 – 982 m above sea level (asl) (Ellenbroek, 1987).

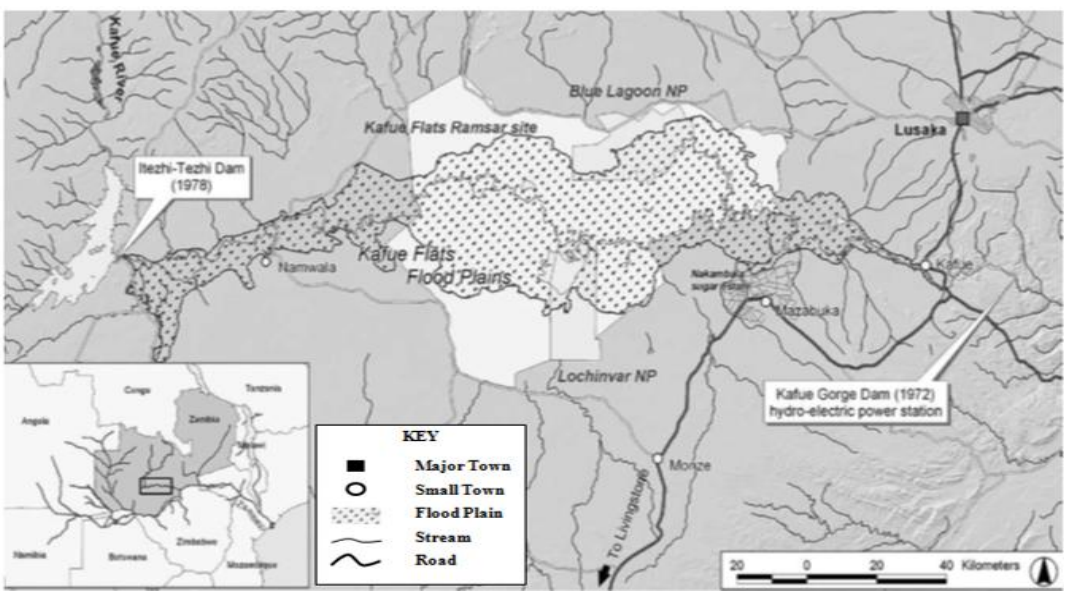

Figure 7.0: Location of Lochinvar National Park on the Kafue Flats (WWF Zambia, 2009).

The area of Lochinvar National Park (Figure 8.0) is 410 Km^2 and it's situated on the southern edge of the Kafue flats. The Kafue River forms the northern boundary while the floodplain occupies about two – fifths of the total area of Lochinvar National Park (Thomas, 2006). Originally operated as a private cattle ranch between 1933 and 1948 (Rees, 1978). Lochinvar National Park was established in 1972.

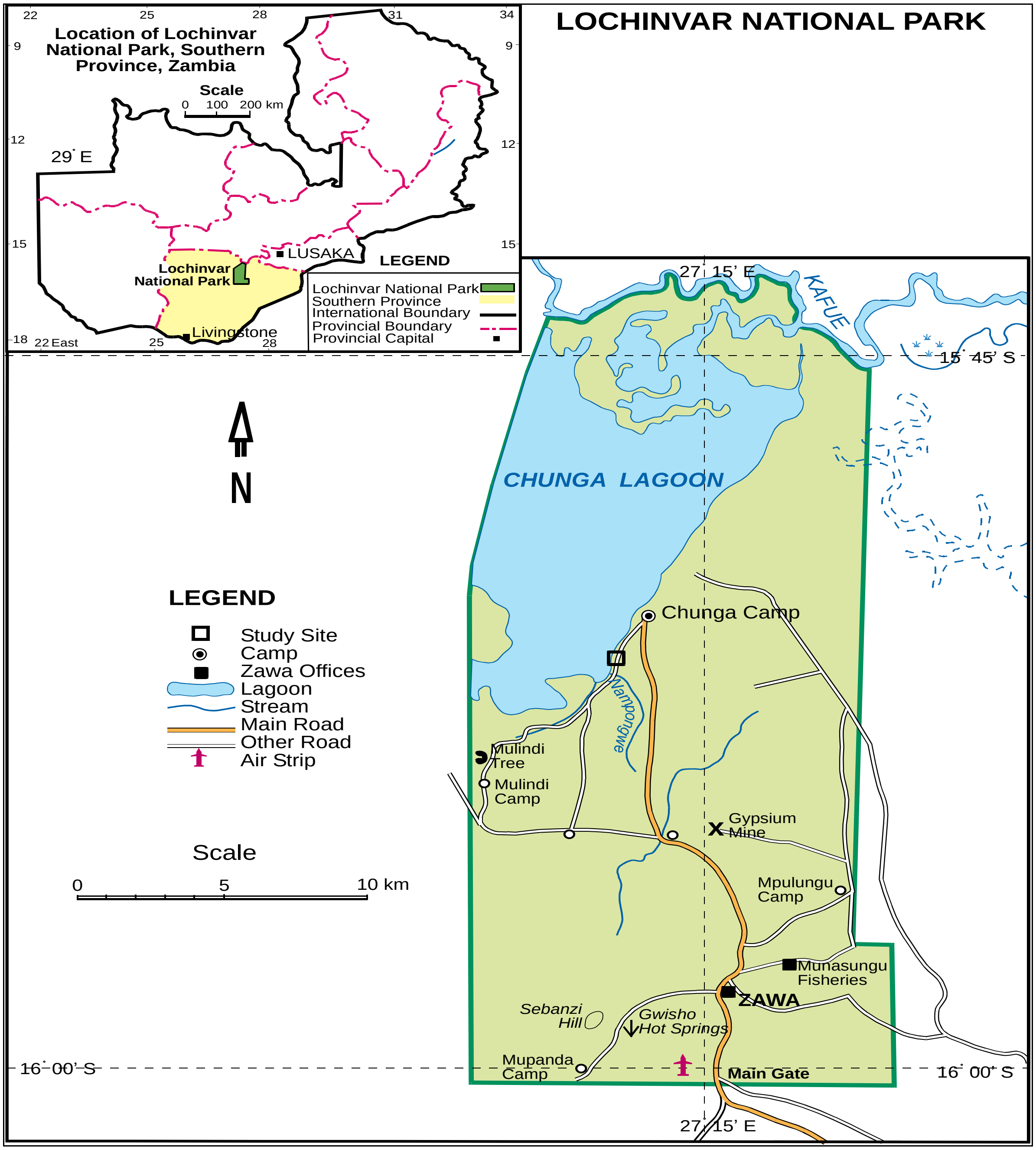

Figure 8.0: Location of the Study area in Lochinvar National Park (UNZA, 2010).

3.1.1 Location of experimental site

The exact location of the study site is at 15.85972^{o} S, 027.22458^{o} E and 15.85927 ^{o} S, 027.22372^{o} E and 15.85883^{o} S, 027.22518^{o} E, 15.85838^{o}S; 027.22429^{o} E near the tributary of Nampongwe stream (Figure 9.0) shown as sampling area, in the south west of Chunga camp.

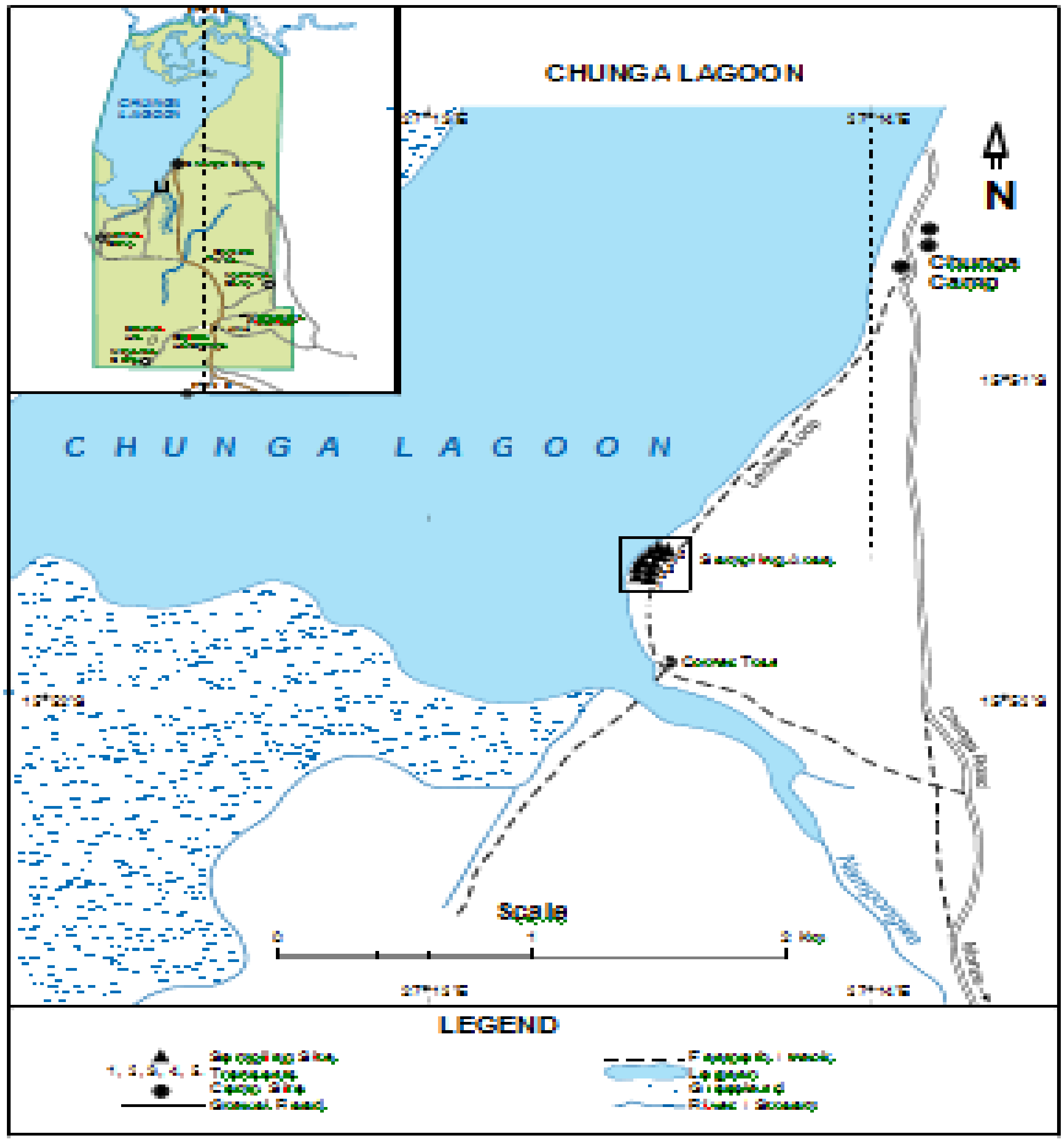

Figure 9.0: Location of experimental site in Lochinvar National Park (UNZA, 2010).

This area originally consisted of grassland and a swamp is now covered by *Mimosa pigra* plants.

Figure 10.0: *Mimosa pigra* infestation at the study site (ECZ, 2004).

The general vegetation of the experimental site is predominantly infested by *Mimosa pigra* with a few patches of grasses, sedges and herbs e.g. *Cynodon dactylon*, *Panicum repens*, *Ambrosia maritime, Heliotropium ovalufolia* and *Cyperus rotundus* (Figure 10.0). A few isolated *Faidherbia albida* trees are dotted among the vegetation. On the peripheral side of the termitaria zone (Area bordering the floodplain and the termite zone of Lochinvar National Park) the vegetation is predominantly woody species of *Dichrostachys cinerea* and *Acacia tortilis*.

Figure 11.0: *Dichrostachys cinerea* and *Acacia tortilis* bushes at the floodplain edge (ECZ, 2004).

3.2 Climate and Hydrology

Lochinvar National Park experiences two main seasons; the cool, dry season from May to September and the warm/hot, wet season from November to April. The temperature is generally warm, with mean minimum and maximum temperatures ranging from 22 to 30 ^{o} C in October and 14 to 24 ^{o} C in July with mean annual temperature of 20.6 ^{o} C (Ellenbroek, 1987). The rainfall trends have been on the decline in the last decades with average annual rainfall of between 700 mm and 800 mm recorded in Lochinvar National Park (ZAWA, 2004). However**,** extreme annual rainfall ranging from 380 mm to 1350 mm has been recorded before in LNP (Sheppe and Osborne, 1971).

The hydrology of Lochinvar National Park floodplains on the Kafue flats is by direct rainfall, inflow from tributary streams of the Kafue River and overflow from the Kafue River channel that inundates the floodplain and swampy areas each year (UNFAO, 1968; DHV, 1978). The water feeding Lochinvar National Park floodplains comes from the upper catchment of the river where rainfall is high. Normally, floods begin to rise by mid

– November and peak by April to June (DHV, 1978). The timing of the peak flooding does not coincide with the height of rains, because of a time lag of several weeks between rain fall in the upper catchment area and overflow of the Kafue River in Lochinvar National Park (Howard and Williams, 1982). Water levels begin to recede from late June reaching their lowest point in November when only lagoons and depressions continue to be inundated. However, the pattern varies from year to year depending on prevailing climatic conditions (Rees, 1978).

3.3 Soils

The detailed description of soils of the Kafue Flats is provided by UNFAO (1968). The soils are heavy, black, cracking vertisols, seasonally flooded which dry out forming crevices. The soils were developed from the Kafue Clay Alluvium that weathers to varying degrees at different localities (UNFAO, 1968). The vertisols soils at the study site consisted of black, margallitic clays which contain a high proportion of montmorillonite (Douthwaite and Van Lavieren, 1977). During dry conditions the soils are very hard and widely cracked. The crevices are partly filled with material breaking off the top layer and when the soils become wet, they start to expand (UNFAO, 1968). The expansion of the extra material in the crevices causes pressure that result in the formation of ridges and depressions. This phenomenon is known as gilgais, which gives way to a landscape of swells and depressions. Ridges may reach as high as 20 to 60 cm. The soils when wet are plastic and very sticky (Bingham, 1974).

It is believed that the gentle undulating geology formed over time through tectonic forces that led to a gradual uplift and subsidence, has had a larger influence on the soils formation in Lochinvar National Park. In the floodplains the soils are heavy, black, cracking clay vertisol soils, with lime concentrations in their lower layers (Kapungwe, 1993). They are capable of holding large quantities of water as they are impervious and poorly drained. The soils contain high proportions of organic matter (Turner, 1985).

3.4 Vegetation and Topography

The description of vegetation at the study area was based on Ellenbroek (1987).The vegetation of Lochinvar National Park is generally recognized by three vegetation zones: the woodland, termitaria and the floodplain. The floodplain is largely characterized by hydrophyte water meadows like, *Acroceras macrum* Stapf, *Panicum repens – Leersia* L. and *Paspalidium obstusifolium* (Del.) N. D. Simpson (UNFAO, 1968, Chabwela and Siwela, 1986; Ellenbroek, 1987). Other woody species of Acacia species such as *Faidherbia albida, Dichrostachys cinerea* and *Mimosa pigra* were also observed in the floodplain (own observation). The termitaria zone was characterized by the presence of several termite mounds with largely grassland and few wooded vegetation. The Southern area is mainly covered by woodlands dominated by Munga woodland, *Combretum* Loefl. and *Colophospermum mopane* (Kirk ex Benth). The dominant grass species in this zone are *Andropogon* spp. L. (Ellenbroek, 1987). However, vegetation in the study area was characterized by two vegetation types namely floodplain and termitaria zones.

3.4.1Floodplain

The floodplain is a flat area, with black clay soils, sloping almost imperceptibly towards the Chunga Lagoon (Mumba, 2007). The floodplain, with very little relief is subject to seasonal inundation for seven months of the year (Ellenbroek, 1987). Due to the low gradient and the generally impervious nature of soils, run-off from local rainfall (beginning November and December continuing through January, February and March) water slowly covers the floodplain and by the end of the rainy season in March and April, much of the area is submerged under flood waters (Thomas, 2006). Many aquatic and semi-aquatic plants grow well under these circumstances, because of adaptations (Rees, 1978). Plants posses air filled tissue (aerenchyma) in the stems, petioles, leaves and roots of many of the plants and they remain afloat. They are rooted in the submerged soil but grow faster enough to keep pace with the rising flood water to become emergent aquatic plants (Ellenbroek, 1987). The floodplain vegetation is largely grazed by the endemic Kafue Lechwe.

Figure 12.0: Kafue Lechwe grazing on land invaded by *Mimosa pigra* (Thomas, 2006).

Vegetation at the study site was predominantly grasses, sedges and herbs with other isolated tree species such as *Faidherbia albida*, palms (*Borassus aethiopum*) and large sparse of *Mimosa pigra* occur on the floodplains. Grasses included *Cynodon dactylon*, *Sporobolus pyramidalis*, *Sorghum verticilliforum*, *Acroceras macrum* and *Vetiveria nigritana.* Herbs included *Ambrosia maritima*, *Hibiscus trionum*, *Heliotropium baclei* and *Nidorella auriculata. All plant species* forms the most conspicuous elements of the vegetation (Douthwaite and Van Lavieren, 1977).

3.4.2.Termitaria

Bordering the floodplain of the study site is the termitaria zone. The termitaria are mainly grassy with trees restricted to large termite mounds built by *Odontotermes* termite species and can reach a height of approximately two metres. Small mounds, less than a metre high, are built by *Cubitermes* spp (Turner, 1983). Termitaria zones become waterlogged during rainy season due to local rains, local run off and the flatness of the terrain and poor drainage conditions. This area is not subject to prolonged flooding from the Kafue River but waterlogged and soaky (Ellenbroek, 1987). These conditions are not suitable for tree growth but termites are active here and are responsible for raising the great mounds that form part of the landscape (Douthwaite and Van Lavieren, 1977).The ground cover of termitaria zone is dominated by *Setaria sphacelata* (Schumach) Moss, *Panicum maximum* Jacq., *Digitaria milinjiana* (Rendle) Stapf, *Brachiaria regulosa* Stapf, and the overstorey by *Combretum ghasalensa* Engl. and Diels, *Philiostigma thonningii*, *Albizia anthelmintica* (A. Rich) Brongn. (Chabwela and Siwela, 1986; Ellenbroek, 1987). Several Acacia shrubs occur as pure stands in the grasslands of the termitaria zone which include species such as *Acacia seyal, A. polyacantha, A. tortilis, A. xanthophloea, A. nigrescens* and *Dichrostachys cinerea* (Turner, 1983).

CHAPTER 4.0 METHODOLOGY

In order to determine the regeneration of *Mimosa pigra* following bush clearing and burning (treatment) in Lochnivar National Park (LNP), a field survey was conducted. Five transects were established on one site. The first transect was randomly established and while the other four were systematically established, Thus, a systematic random blocking design was used in this study.

4.1 Experimental Design

The study site was located in a floodplain habitat, covering an area of 13,000 m^2 completely infested by *Mimosa pigra* mature plants. A total of five transects were established originating from higher ground to lower lying areas towards the lagoon. Transects were 104.0 m long x 5.0 m wide with an inter transect distance of 30 m wide. Each transect was further divided in to 10 plots of 5 m x 5 m with an inter quadrant distance of 6.0 m. All together the experiment employed 50 plots in five transects. Each of the ten (5.0 m x 5.0 m plots in each transect) were further sub divided into 25 quadrants of 1.0 m x 1.0 m established along each transect from which seedlings emergence were counted.

Figure 13.0: Quadrants used for Seedling emergence counts.

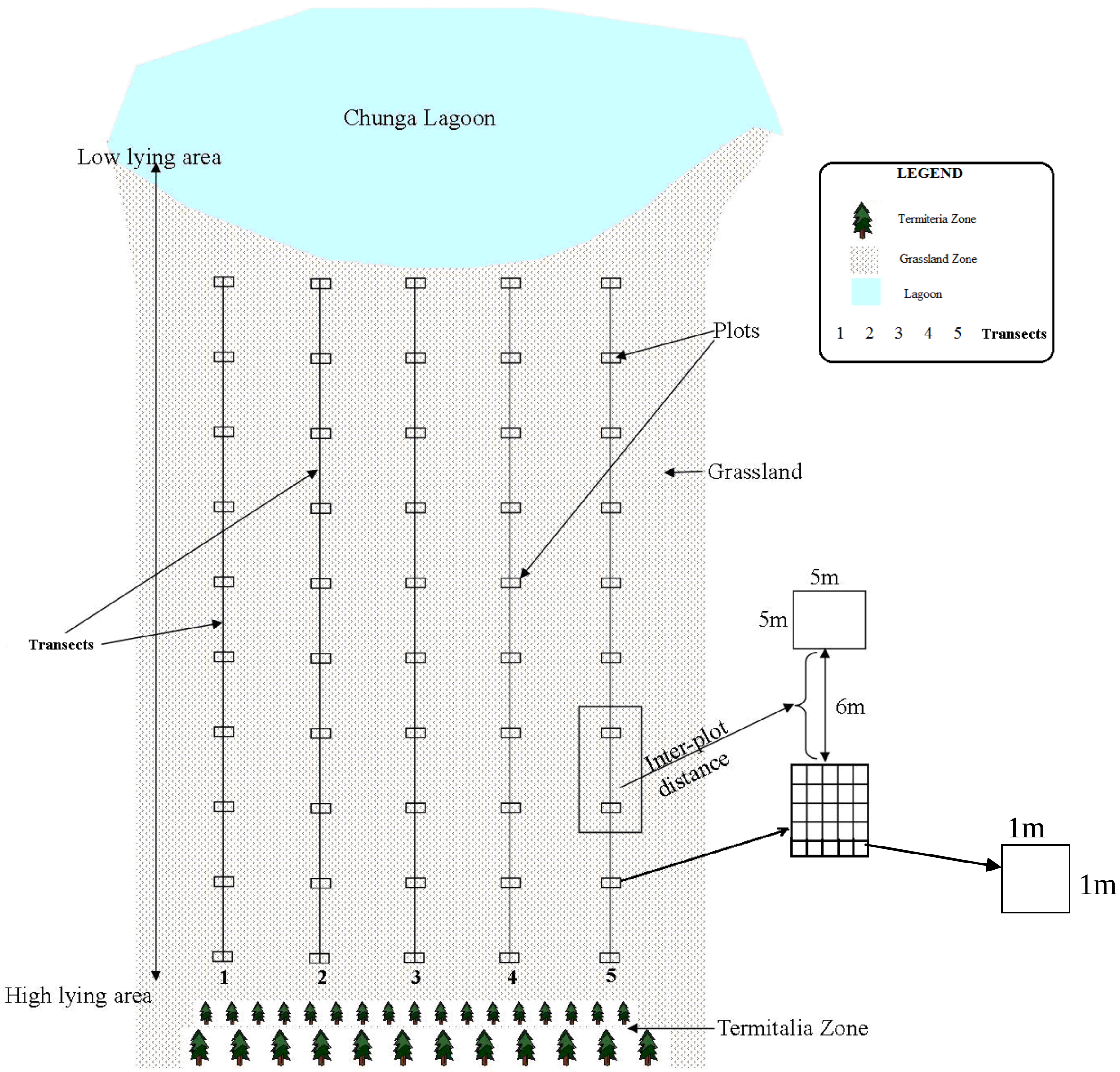

Figure 14.0: Schematic representation of transect layout at the study site.

The beginning and end point of each transect was geo-referenced using a Global Positioning System (GPS) and the coordinates were recorded as shown in Table 1.0.

Table 1.0: Records of GPS coordinates of transects position in the floodplain in Lochinvar National Park.

Transect #	Habitat type	Coordinates	
		Beginning of transect	End of transect
1	Floodplain	15.85972^o S 027.22458^{o}E	15.85927^{o}S 027.22372^{o}E
2	Floodplain	15.85947^{o}S 027.22466^{o}E	15.85903^{o}S 027.22380^{o}E
3	Floodplain	15.85294^{o}S 027.22485^{o}E	15.85882^{o}S 027.22396^{o}E
4	Floodplain	15.85904^{o}S 027.22500^{o}E	15.85857^{o}S 027.22410^{o}E
5	Floodplain	15.85883^{o}S 027.22518^{o}E	15.85838^{o}S 027.22429^{o}E

Data was collected from the 1 m^2 quadrats, in the third line in each of the subdivided plots. All five quadrants in the third line were considered when collecting data and emerged seedlings were counted in the third line of each 1 m x 1 m quadrats, uprooted (pulled out) to avoid, double counting (of the same emergent) and biasness in sampling. Only the stem length of *Mimosa pigra* was measured before the treatments and after treatments were applied, the following variables were measured; i) number of emerging seedlings ii) number of flowers iii) seedling height iv) number of resprouts from stumps v) number of resprouts from roots and vi) number of the native species which returned after treatments were applied. These variables were collected every week for a period of eleven weeks.

4.2 Sampling Treatments

The study explored four different treatments in the regeneration ability of *Mimosa pigra* after treatment as described below.

4.2.1 Description of Treatments.

The treatments used in the study were as follows;

Treatment 1 - Stem cutting

In this treatment the main stems of the plants were cut to 5 cm above the ground using a machete. The cut biomass was discarded leaving the 5 cm stumps in the soil.

Treatment 2 - Stem cutting and burning

In this treatment the main stems of the plants were cut to 5 cm above the ground. The parts of the plant which were cut off were layed over the 5 cm plant stumps and left to dry in open air for a period of 3 weeks. After drying the plots in which this treatment was done were subjected to burning using gasoline. The burning was done until all the biomass which was left to dry over the stumps was consumed by the fire.

Treatment 3 - Stem cutting and uprooting

In this treatment the main stems of the plants were cut to 5 cm above the ground with a machete. The cut biomass was discarded and the 5 cm stumps uprooted from the soil using a mattock.

Treatment 4 - Stem cutting, burning and uprooting.

In this treatment the main stems of the plants were cut to 5 cm above the ground. The parts of the plant which were cut off were layed over the 5 cm plant stumps and left to dry in open air for a period of 3 weeks. After drying, the plots were subjected to burning using gasoline. The burning was done until all the biomass which was left to dry over the stumps was consumed by the fire. After the burning process the stumps were uprooted using mattocks. The four treatments were tested together in a systematic random sampling design.

Treatment 5 – No treatment imposed.

All the plots in each transect were subjected to the same treatment. One transect was not subjected to any of the treatments and was considered as the control of the study. Care was also taken to clear all the *Mimosa pigra* vegetation which was between transects.

4.3 Sampling methods.

4.3.1 Determination of the effect of bush clearing and burning on seedling emergence of *Mimosa pigra*.

To determine the effect of bush clearing and burning on *Mimosa pigra* seedling emergence, the number of seedlings emerging from each of the five quadrants from each plot were counted and recorded every week for eleven weeks. The counted seedlings were uprooted from the quadrants and discarded, to prevent the likelihood of recounting the same seedlings.

ii. Determination of the effect of bush clearing and burning on *Mimosa pigra* resprouts from cut remaining parts of stumps.

To determine the response of bush clearing and burning on the regeneration of *Mimosa pigra* plants through resprouts from the stumps, the number of new resprouts from the stems were counted and recorded every week for a period of eleven weeks, all the counted resprouts were plucked out from the stems and discarded.

iii. Determination of the effect of bush clearing and burning on *Mimosa pigra* root resprouts from remaining parts of roots.

To determine the regeneration response of *Mimosa pigra* to bush clearing and burning through resprouting from the roots, the number of new resprouts from the roots were counted and recorded every week for a period of eleven weeks, all the counted resprouts were plucked out from the roots and discarded.

iv. Evaluation of the effect of bush clearing and burning on *Mimosa pigra* seedling growth.

Evaluation of *Mimosa pigra* seedling growth was done by taking stem measurements from the base of the seedling stem on the ground to the apex. The seedlings were marked and protected from being browsed by wild animals using thorny acacia plants for fencing around the plants. The measurements were done every week on the same seedlings.

v. Determination of the effect of *Mimosa pigra* on native plant species diversity.

Other plant species emerging in the plots were identified and recorded in order to describe the floristic composition of the blocks. Floristic composition was presented as species diversity, richness and evenness. Species richness refers to the total number of different plant species in a block per given treatment. The plants were counted and identified up to species level. This was done every week for eleven weeks.

4.4 Data Analysis.

Data analysis on the five variables from the quadrats were analyzed for significant differences in the mean number of emerging seedlings, resprouts and growth pattern of *Mimosa pigra* per square metre among the different treatments using ANOVA, in Statistix 9.0 software (Statistical, 2009). While the software PCORD (Statistical, 2009) was used to determine species richness, evenness and Shannon – Weiner diversity index.

CHAPTER 5.0 RESULTS

5.1 Effect of bush clearing and burning on *Mimosa pigra* seedling emergence.

The results of the effect of bush clearing and burning on *Mimosa pigra* seedling emergence are summarized in Table 2.0. Seedling emergence was highest in the control with a density of 952. 2 seedlings/ m^2. This was followed by stem cutting and uprooting (899.7), stem cutting (744.1), stem cutting and burning (373.9) and a combination of stem cutting, burning and uprooting with the lowest density of 50.5 seedlings/ m^2 (Table 2.0 and Figure 15.0). Appendix II outlines the details of data collected per week according to the treatments.

Table 2.0: *Mimosa pigra* seedling density of all treatments.

Treatments	Total seedling counts in ten plots per treatment	Seedling density/m^2
Control	9522	952.2
Stem cutting and uprooting	8,997	899.7
Stem cutting	7,441	744.1
Stem cutting and burning	3,739	373.9
Combination of stem cutting, burning and uprooting	505	50.5

Mean seedling densities per square metre emerging from plots of each treatment were captured as shown below.

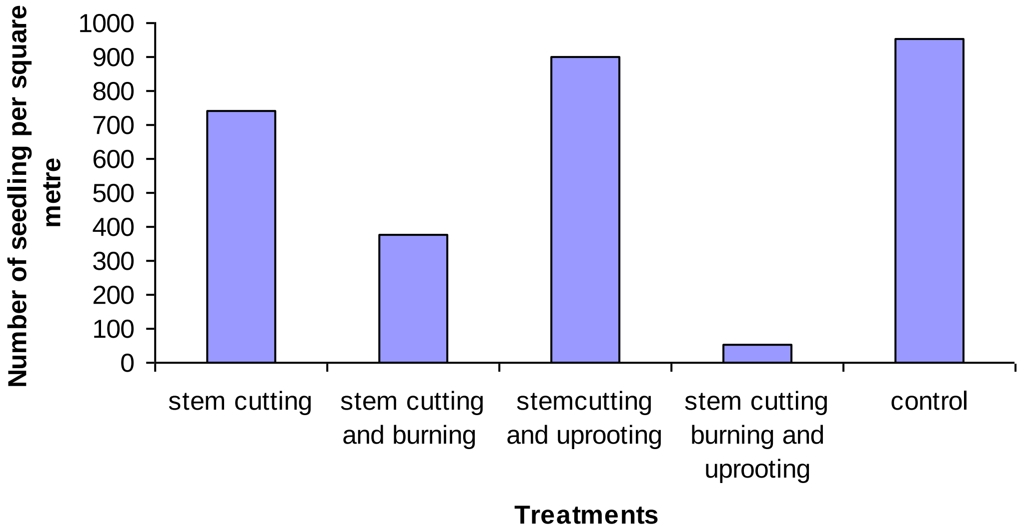

Figure 14.0: Mean seedling density/ m^2 emergent.

5.1.1 Variations in seedling density.

The differences among treatments using ANOVA showed that there was a significant difference in seedling density per square metre among the treatments (*F* = 4.37 and p= 0.0017 (Table 3.0) However, there was no significant difference in seedling density within plots of the same treatments (F = 1.58, p = 0.1189).

Table 3.0: Results of general ANOVA for seedling emergence at $\alpha = 0.05$ on the five treatments.

Source	**df**	**SS**	**MS**	**f**	**p**
Among treatments	4	529900	132475	4.37	0.0017
Within treatments	9	430313	47813	1.58	0.1189
Total df	13				
Total number of cases	548				

Further analysis using the Bonferroni all Pairwise comparison test showed that the mean number of seedlings was highest in the control plots which were not subjected to any treatment with 86.564 seedlings (Table 4.0). This was followed by stem cutting and uprooting with a mean number of 81.300, stem cutting (62.548), stem cutting and burning (31.609) and stem cutting, burning and uprooting with the lowest mean number of seedlings with a value of only 4.591. According to Bonferroni all pair wise comparison test, the variation among the treatment was due to the differences in the mean number of seedlings between the treatments. Therefore, stem cutting and uprooting and a combination of stem cutting, burning and uprooting had mean number of seedlings which were significantly different from each other.

Table 4.0: Bonferroni All-Pairwise Comparisons test results for seedling emergence.

Treatment	Mean number of seedlings	Mean Homogeneous Groups
control	86.564	A
stem cutting and uprooting	81.300	A
stem cutting	62.548	AB
Stem cutting and burning	31.609	AB
Stem cutting, burning and uprooting	4.591	B

5.2 Effect of bush clearing and burning on resprouts from stumps.

The results of the effect of bush clearing and burning on resprouts from stumps are summarized in Figure 16.0. Stem cutting had the highest number resprouts from the roots, with a value of 316 resprouts per square metre, followed by stem cutting and uprooting (211 resprouts), stem cutting and burning (7.01), a combination of stem cutting, burning and uprooting (2.05) and the control which had no resprouts with a value of 0.0.

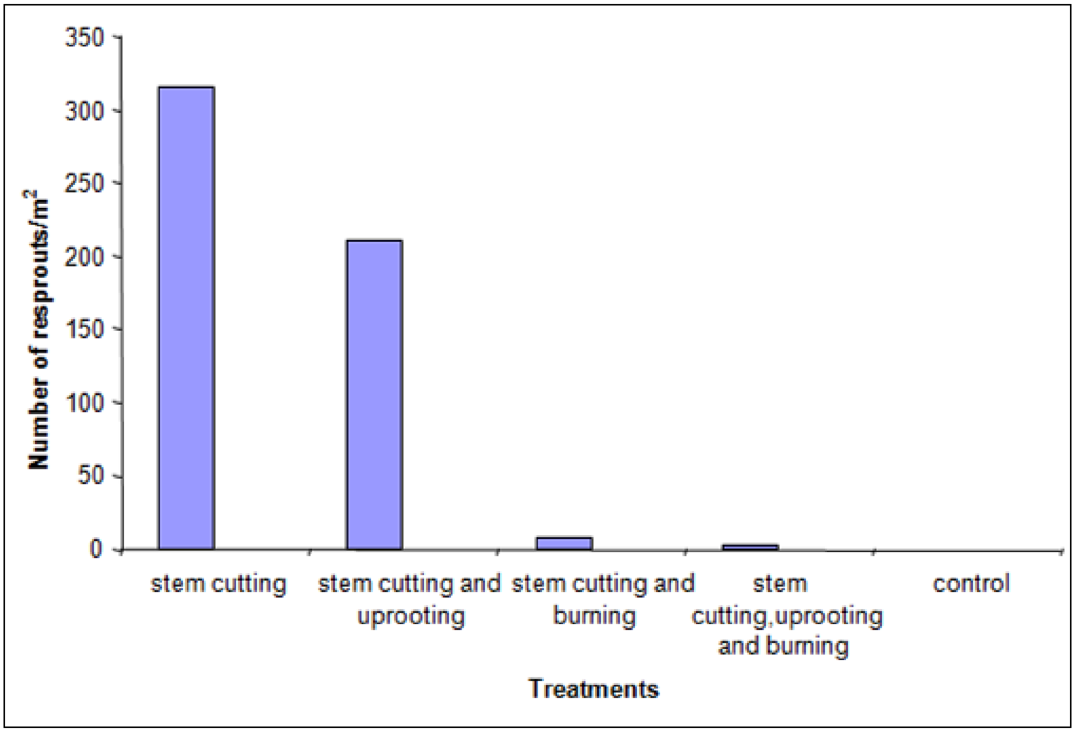

Figure 15.0: Mean number of stump resprouts for all treatments

5.3 Effect of bush clearing and burning on *Mimosa pigra* root resprouts.

The results recorded in the plots subjected to stem cutting and uprooting showed the highest mean number of root resprouts per square metre with a value of 9.05 resprouts per square metre. This was followed by plots subjected to stem cutting only, with a density of 3.6/m^2. The plots subjected to stem cutting and burning recorded a value of 0.5 resprouts /m^2 while, the plots subjected to all the treatments which were stem cutting, uprooting and burning recorded a value of 2.0 resprouts/m^2. The control plots had no resprouts from the roots and a mean value of 0.00.

5.3.1 Comparison of the three modes of regeneration of Mimosa pigra plants among treatments.

A comparison of the three modes of regeneration methods (seedling emergence, root resprouts and stump resprouts) showed that the most common and highest mode of regeneration of the plants was through seedling emergence, followed by stump resprouts and lastly root resprouts (Table 5.0 and Figure 17.0). The highest number of emerging seedlings was observed in the control plots (952.2 seedlings/m^2), whilst the highest number of stump resprout was observed in the plots which were subjected to stem cutting (316 stump resprouts/ m^2). The highest number of root resprouts was observed in the plots subjected to stem cutting and uprooting (9.05 root resprouts/m^2). The plots subjected to stem cutting, burning and uprooting showed the least number of emerging seedlings, root and stump resprouts.

Table 5.0: Mean number of seedling emergence, root and stump resprouts of each treatment.

Treatments	Mean number of seedlings/m^2	Mean number of stump resprouts/m^2	Mean number of root resprouts/m^2
Stem cutting	744.1	316	3.6
Stem cutting and burning	373.9	211	0.5
Stem cutting and uprooting	899.7	7.01	9.05
Stem cutting, burning and uprooting	50.5	2.05	2
Control	952.2	0	0
Mean number for all treatments /m2	604.08	107.212	3.03

The figure below shows mean number of seedlings, stump resprouts and root resprouts per square metre of each treatment.

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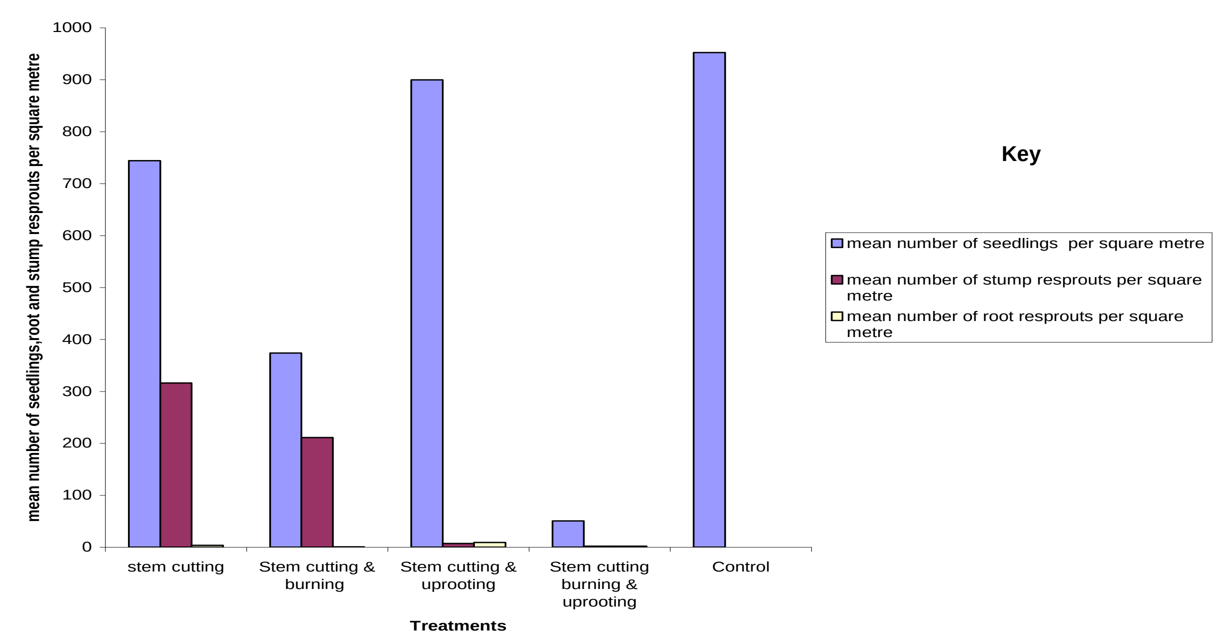


Figure 16.0: Mean number of seedlings, stump and root resprouts per square metre of each treatment.

Further, comparison of the three modes of regeneration of all treatments investigated in this study showed that seedling emergence was the most common mode of regeneration, with a mean value of 604.08 emerging seedlings/ m^2, followed by stump resprouts which had a value of 107.21 stump resprouts / m^2. Resprouts from roots only showed a value of 3.03 root resprouts/ m^2 for all treatment which was the least mode of regeneration observed as shown in Table 5.0 and Figure 17.0. Therefore, the contribution of the three modes of regeneration, is highest on seedling emergence (84.56%), while resprouts from stumps contributed 15.01% and resprouts from roots contributed only 0.42%.

5.4 The effect of bush clearing and burning on Mimosa pigra seedling growth.

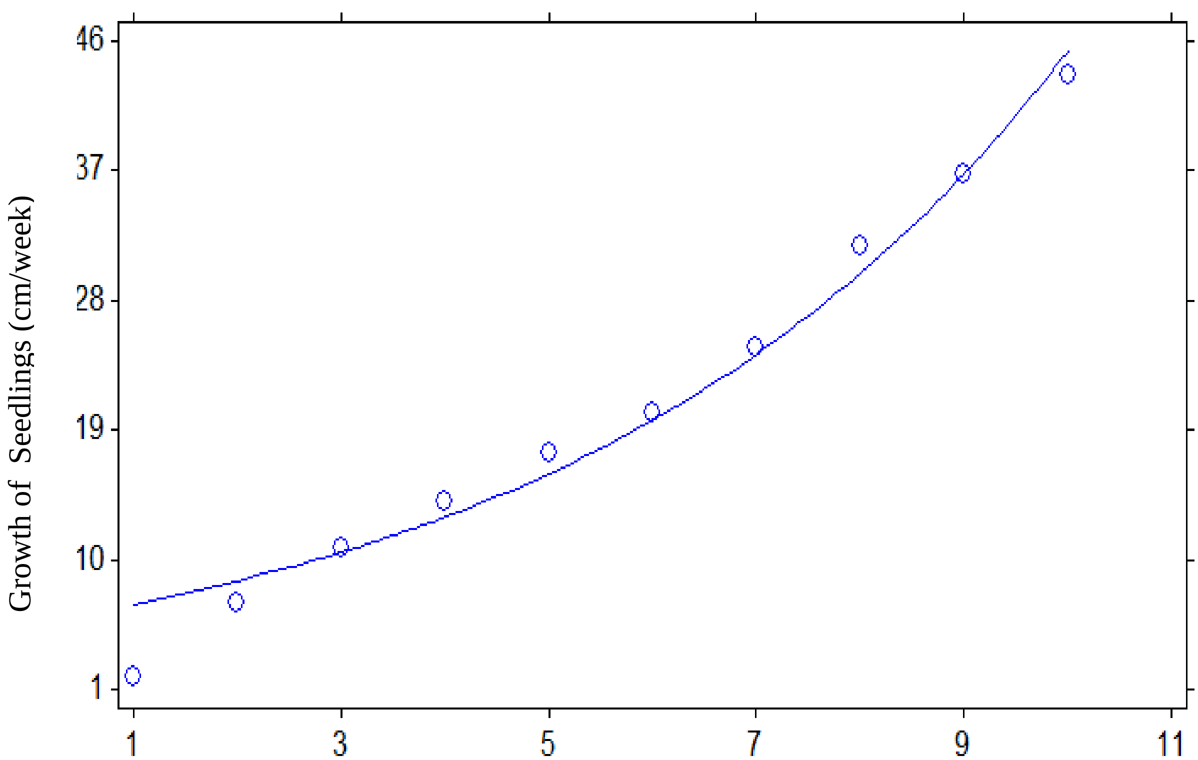
Table 6.0 shows the growth and growth rate of *Mimosa pigra* seedlings as measured in a period of eleven weeks. Figure 18.0 shows the trend in growth and the growth rate of *Mimosa pigra* seedlings. The average growth of the seedlings was calculated to be 23.87 in eleven weeks with an average growth rate of 0.75 cm/day. The growth rate as well as the increase in height of the seedlings showed an exponential trend in increase per week Table 6.0 shows the measured stem length per week and the growth rate calculated per week and per day. Figure 18.0 shows the non linear fitted regression curve for the growth rate of *Mimosa pigra* seedlings.

Table 6.0: Mean stem length measurements (cm) of seedlings eleven weeks after bush clearing.

Time in Weeks	Average stem length of seedlings	Growth rate/week	Growth rate/day
1	1.898	5.1763	0.7395
2	7.074	3.817	0.5453
3	10.891	3.112	0.4445
4	14.003	3.35	0.4786
5	17.353	2.788	0.3983
6	20.141	4.618	0.6597
7	24.759	7.085	1.0121
8	31.844	4.994	0.7134
9	36.838	6.8	0.9714
10	43.638	10.518	1.5026
11	54.156	-	-
Average	23.87227	5.22583	0.7465

- Growth rate/week = (stem length in week $_{i\,i\,-}$ stem length in week $_{i}$) /1 week.

Growth rate/day = (stem length in week $_{i\,i\,-}$ stem length in week $_{i}$) / 7 days.



Time in Weeks
Growth = 2.3198*Exp(0.1326*time)

Figure 17.0: The trend in growth of *Mimosa pigra* seedlings in eleven weeks.

Table 7.0 gives a summary of non linear regression statistics, which indicates growth of *Mimosa pigra* seedlings which increased by 5.6287 cm per week. When plotted, the fitted curve gives an equation of y = a*Exp(b*x) Figure 18.0 Where y = stem growth, a= constant(5.6287), b = constant (0.2086) and x = time in weeks. The fitted curve shows that *Mimosa pigra* seedling had an exponential growth pattern during the eleven weeks period showing a non linear relation between stem growth and time.

Table 7.0: Non linear regression analysis results for seedling growth.

Parameter	**Estimate**	**Std Error**	**Lower**	**Upper**
			95% C.L.	**95% C.L.**
a	5.6287	0.6677	4.0888	7.1685
b	0.2086	0.0140	0.1763	0.2409
Standard Deviation	2.1762	-	-	-
Pseudo R-Squared	0.9766	-	-	-

5.5 The effect of *Mimosa pigra* on plant species diversity.

Table 8.0 show results of species return in areas cleared of *Mimosa pigra*. There was a total of 30 species of plants belonging to 26 genera and 06 families recorded. The family of gramineae was the most diverse with 51.62 % of the recorded.

Table 8.0: Species return in areas cleared of *Mimosa pigra* in Lochinvar National Park

Family	Genera	# of species				Total
		Grasses	Creepers	Herbs	Tree	
Gramineae	Acroceras	1	0	0	0	1
	Brachiaria	1	0	0	0	1
	Cynodon	1	0	0	0	1
	Echinochloa	1	0	0	0	1
	Eleocharis	1	0	0	0	1
	Leersia	1	0	0	0	1
	Oryza	2	0	0	0	2
	Panicum	3	0	0	0	3
	Paspalidium	1	0	0	0	1
	Sacciolepsis	1	0	0	0	1
	Sporobolus	1	0	0	0	1
	Vetiveria	1	0	0	0	1
	Vossia	1	0	0	0	1
Fabaceae	Faidherbia	0	0	0	1	1
Oxalidaceae	Oxalis	0	0	1	0	1
Polygonaceae	Aeschynomene	0	0	1	0	1
	Ambrosia	0	0	1	0	1
	Heliotropium	0	0	1	0	1
	Hibiscus	0	0	1	0	1
	Nidorella	0	0	1	0	1
	Polygonum	0	0	1	0	1
	Vernonia	0	0	1	0	1
Convolvulaceae	Ipomoea	0	0	1	0	1
Onagraceae	Ludwigia	0	2	0	0	2
	Emilia	0	1	0	0	1
	Caperonia	0	1	0	0	1
Total 06	26	16	4	9	1	30

Figure 19.0 shows that 51.62 % were grass species and 29.03 % were herbaceous species, 16.12 % were creeper species and 3.23 % were tree species. Grasses were the most abundant.

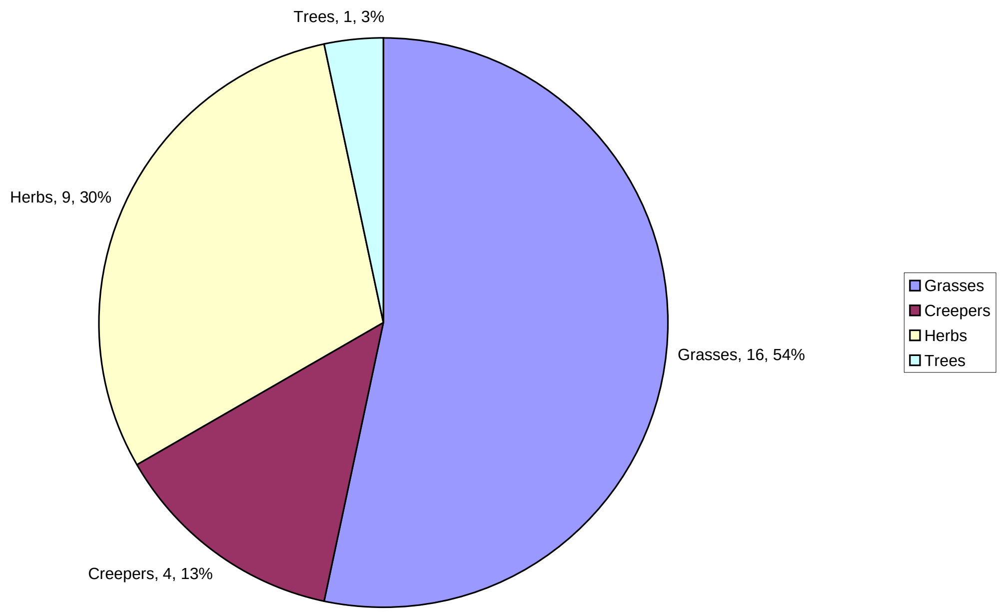


Figure 18.0: Percentage composition of each type of plants in treated plots.

The analysis of data using PCORD, that a combination of stem cutting, uprooting and burning had the highest diversity index of 2.81, highest species richness of 24 and highest species evenness of 0.88. This was followed by the control treatment which had a species richness of 23 diversity index of 2.28 and species evenness of 0.73. Stem cutting and uprooting had a diversity index of 2.17, species richness of 15.00 and species evenness of 0.80, while stem cutting had a diversity index of 1.99, species richness of 12.50 and species evenness of 0.76. The lowest diversity index was observed in stem cutting and burning which had a diversity index of 1.02, species evenness of 0.38 and species richness of 7.50 (Table 9.0).

Table 9.0: The Species diversity, richness and evenness in all four treatments.

Treatment	Diversity Index (H)	Species richness (S)	Species evenness (E)
Stem cutting	1.99	12.5	0.76
Stem cutting and uprooting	1.02	7.5	0.38
Stem cutting and burning	2.17	15	0,80
Stem cutting burning and uprooting	2.81	24	0.88
Control	2.28	23	0.73

Figure 20.0 shows that the combination of stem cutting, burning and uprooting had the highest average species richness at 24 species per plot and the highest species evenness at 0.88 per plot while stem cutting and uprooting had the lowest species richness at 7.50 per plot and the lowest species evenness of 0.38 per plot.

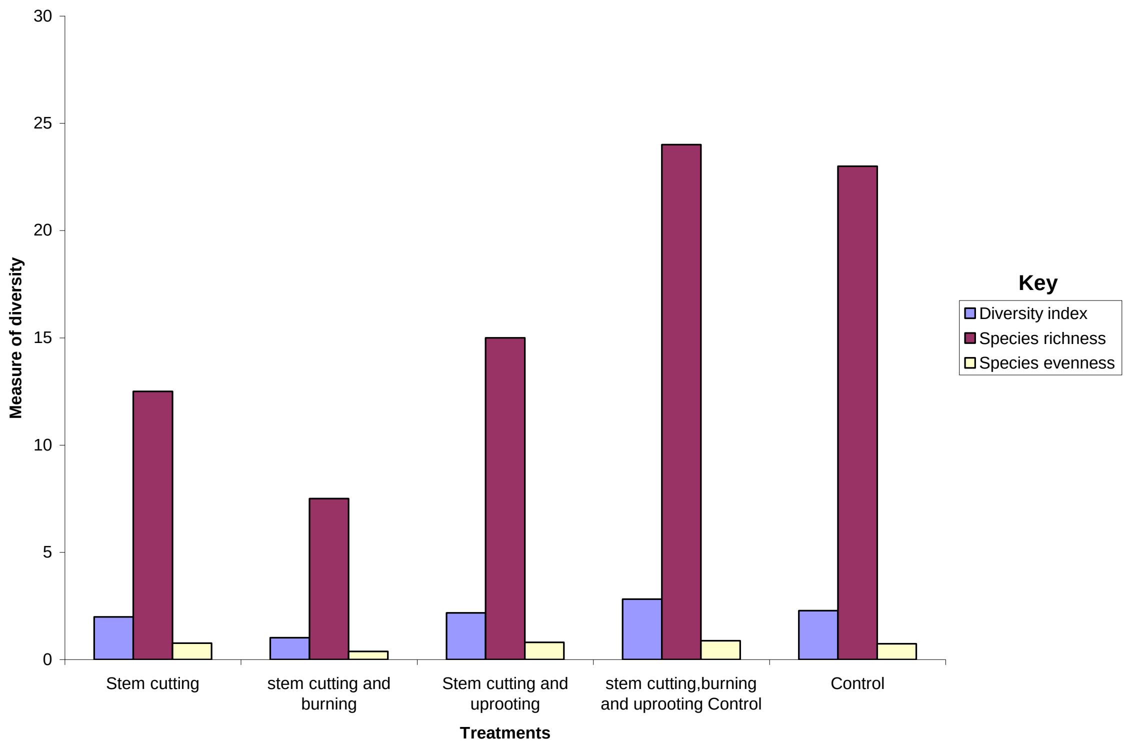


Figure 19.0: Group bar graph showing the diversity index, species evenness, and richness among the treatments.

CHAPTER 6.0 DISCUSSION

6.1 The effect of bush clearing and burning on *Mimosa pigra* seedling emergence.

Cutting of *Mimosa pigra* plants to the ground level using machetes and cut stems with foliage stacked, dried and burnt provided fuel for hot fires. Burning exposed the stumps and opened the areas (around stumps), for easy access. The stumps were then uprooted using mattocks, stacked to dry (the second time) for the period of 2 – 3 weeks and burnt. It's worthy to note that the initial burning of the cut stem (overlaid over transects) killed seeds on the soil surface up to six centimetres deep. The removal of *Mimosa pigra* plants facilitated the immediate surge of seedling emergence three weeks after treatment of *Mimosa pigra* in all four treatments. However, in the treatment combining stem cutting, burning and uprooting, results showed less emergence of *Mimosa pigra* seedlings with a mean seedling emergence of 50 seedlings/ m^2. This was attributed to the effectiveness of killing both *Mimosa pigra* mature plants and seeds in the soil seed bank. Miller (1988) reported that fire can increase the germination of the soil seed – bank by breaking seed dormancy. However, due to high temperatures, fire may also kill a proportion of seeds found on the soil surface. Therefore, in this study, the initial burning of transects, assisted to break dormancy of the seeds in the seed bank causing hundreds of seedlings to sprout after a few weeks of treatment (on average two weeks after removal and burning of *Mimosa pigra*), further depleting the seed bank. Therefore, heating and cooling of the soil surface temperature was crucial in causing the expansion and contraction of the hard seed coats of *Mimosa pigra* seeds, which eventually cracked and broke their dormancy making them to germinate and emerged as seedlings. This agrees with Lonsdale (1988) observation that the deeper in the soil a seed laid, the less extreme was the temperature range experienced and made it to survive and became viable in the subsequent years. The results obtained in the study support this view as shown in Australia where seeds buried deeper than 10 cm could not successfully germinate, unless those that were on the surface (James, 1984). The second burning and uprooting killed more seeds that were brought up to the surface from deep seated seeds in the soil seed bank (brought to the surface by the action of digging out during the uprooting of *Mimosa pigra* stumps, Witt. A., pers. com, 2009) hence, less number of seedlings emerged as high temperature from the second hot fires, caused direct damage to the plant tissue through combustion of stump remains and direct damage to physiological processes of seeds through radiant heating (Axelrod, 1986). Further analysis of results using ANOVA there were significant differences in seedling density per square among treatments (Table 3.0) $p = 0.0017$ confirming that the treatments of *Mimosa pigra* through, stem cutting only, stem cutting and uprooting, stem cutting and burning were not effective. This phenomenon of seedling emergence, which was the most common mode of regeneration in *Mimosa pigra* (shown in Table 5.0), makes it a resilient plant. It also explains that control measures that simply seek to merely remove adult *Mimosa pigra* plants would leave a horde of seeds in the soil seed bank, that once brought to the surface and germinated, could start a fresh infestation. Therefore, a combination of stem cutting, burning and uprooting was the most effective control method, among those tried. The results demonstrate that a combination of treatments was successful in killing both the plant and seeds of *Mimosa pigra*.

6.2 The effect of bush clearing and burning on *Mimosa pigra* stump/root resprouts.

Even though *Mimosa pigra* does not naturally reproduce vegetatively, evidence shows that it possesses epicormic buds that allow it to regenerate once the above ground parts have been cut or removed (Miller, 1988). Experiments conducted in Northern Territory of Australia showed that *Mimosa pigra* plants severed at ground level resprouted and reached a height of 2.5 m and covered an area of 6.3 m^2 within 12 weeks (Walden *et al*., 1999). In this study *Mimosa pigra* stems resprouted quickly after being cut with new young saplings regenerated from cut stems and roots in three treatments applied on *Mimosa pigra*. There was a significant difference in the mean number of stump resprouts per square metre among the treatments, with the combination of stem cutting, burning and uprooting having the least mean number of stump and root resprouts of 2.0 resprouts/ m^2. This explains why in treatment one (stem cutting) where *Mimosa pigra* plants were only cut without burning or uprooting had the highest number of stump and root resprouts. Treatment four (a combination of stem cutting, burning and uprooting), as proved by Bonferroni all pair wise comparison test, was very successful in killing the plant because burning destroyed the epicormic buds and killed the *Mimosa pigra* stumps and any root cut remains. Thus, stumps were not able to regenerate. This agrees with Schultz (2001) who found that cutting *Mimosa pigra* plants off at about 10 cm below ground level killed all *Mimosa pigra* plants. However, cutting plants off between ground level and 15 cm usually resulted in plants resprouting. A similar study by Schultz (2001) showed that *Mimosa pigra* plants cut off at 5 cm below ground level, burnt and roots removed were completely destroyed. Thus, cutting of *Mimosa pigra* plants off at 5 cm below ground was very effective in preventing the resprouting of *Mimosa pigra*. This study therefore proves the second and third hypotheses that stem cutting and uprooting of *Mimosa pigra* increases regeneration from cut stumps and roots. Such that merely reducing woody cover of *Mimosa pigra* stands would not be effective in killing the plant.

6.3 The effect of bush clearing and burning on *Mimosa pigra* seedling growth.

Mimosa pigra is promulgated by seeds born in segmented seed pods. The one seeded, hairy segment of *Mimosa pigra* is easily carried by water. Though, anecdotal evidence shows that humans and animals are also known to carry seeds, whose seed pods are buoyant and readily dispersed by water currents or floodwaters. The seeds have extremely hard, often impermeable seed coat and are able to germinate as soon as conditions permit (Lonsdale, 1985). In this study, it was observed that an average of 600 seedlings per square metre emerged in a short period of eleven weeks. The results are contrary to those of Lonsdale (1983) who counted more than 12,000 seedlings per square metre from a *Mimosa pigra* infested area in Northern Australia. The difference could be due to the difference in seed production per plant in Lochinvar National Park floodplains compared to *Mimosa pigra* seedlings growing in Lake Urema floodplains. However in the present study, it was observed that once established, seedlings grew rapidly and the first flowering occurred at an average of 20 to 30 cm of stem length eight weeks after treatment, at which time the average plant height was 23.87 cm. The average growth rate of the seedlings was calculated to be 0.75 cm per day. However, no poding and seed setting was observed in the same period. Though the results are contrary to those of Lonsdale (1989) who reported that under ideal conditions, *Mimosa pigra* seedlings would begin to flower within 6 – 8 months of emergence. The differences could be due to climatic variations of the present study compared with those reported by Lonsdale (1989). Lake Urema floodplains experience a monsoonal climate with average rainfall between 1300 and 1600 mm, while Lochnivar National Park experiences a tropical climate with average rainfall of between 700 and 800 mm.

It was also observed that the growth rate as well as the increase in height of the seedlings showed an exponential trend in increase per week, estimated at 5.6287 cm per week as shown in Table 7.0. These results differ again with Lonsdale (1992) who reported a slower but significant increase in *Mimosa pigra* seedlings at the rate of 1.1 cm per week after 12 weeks from germination in Thailand. However, the results indicate the importance of growth and development in *Mimosa pigra*, which supports the fourth hypothesis that *Mimosa pigra* has an exponential growth and shortened juvenile phase.

Furthermore, positive linear relationship between growth and time of 97.66% association indicates a predictive model showing a phenomenon of *Mimosa pigra* growing in an exponential pattern with an increase in time and would be useful in determining *Mimosa pigra* growth rate within a given time. This would be used as a predictive tool that could assist in planning when to undertake the control interventions (Rejmanek, 1989).

6.4 The effect of *Mimosa pigra* on native species diversity.

The return of native plant species after *Mimosa pigra* was cleared from the transects indicate that *Mimosa pigra* suppresses the growth of the native plants, due to shade cast by the canopy and plant competition for nutrients (Miller *et al*., 1988). In this study, the return of common plants after *Mimosa pigra* was cleared from the transects indicate that within the eleven weeks in which the study was conducted the plants that returned first included a range of grasses (Gramineae) followed by herbs (Polygonaceae) then creepers (Onagraceae) and finally the tree species of the Acacia family (Fabaceae) (Table 8.0). The appearance of *Cynodon dactylon, Panicum repens, Ambrosia maritime, Heliotropium ovalufolia* and *Cyperus rotundus* provided interesting findings. However, results for species evenness, richness and diversity index did not follow a trend. Whereas the control was supposed to have the lowest diversity index because *Mimosa pigra* suppresses the growth of native plants, due to many factors such as, shade cast by the canopy, competition, shortage of nutrients, soil toxicity and pathogens (Miller *et al*., 1988). This was attributed to the counting of plant species seedlings (recruited) that emerged at the start of the dry season (July – August) but never survived for long or got established, though, were counted as plant species emerged. This is contrary to the observation by Lonsdale (1993) that dense stands of *Mimosa pigra*, reduces the photosynthetic active photon flux density at ground level generally by 5% of the incidental light value falling to 1% allowing no other vegetation to grow under *Mimosa pigra* stands. This phenomenon could be further explained by observations made in Australia that seedlings emerged under canopy simply because of reduced fierce drying effect of the sun and wind without competing for moisture (Paynter and Flanagan, 2004). Furthermore, soils beneath *Mimosa pigra* stands provide a good growing medium hence the germination of *Mimosa pigra* seedlings (Lonsdale, 1983). Nevertheless despite high recruitment of seedlings understorey of *Mimosa pigra* no seedling establishment occurred. Thus, the removal of *Mimosa pigra* enhanced plant species diversity return as *Mimosa pigra* canopy forms a lush thicket and prevents 90% of incident light from reaching the ground and thus eclipsing native flora species (Lonsdale, 1993). This empirical evidence supports the fifth hypothesis of this study which states that native flora diversity increases following *Mimosa pigra* bush clearing and burning.

CHAPTER 7.0 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The study assessed regeneration responses of *Mimosa pigra* from seedling emergence and saplings from severed parts of the plant after being subjected to bush clearing and burning in Lochinvar National Park of Southern Zambia. It was shown that more and more seedlings emerged per square metre after clearing off *Mimosa pigra* plants, as observed in the findings of the study.

The principle finding of the study is that a combination of stem cutting, burning and uprooting was the most effective method of controlling *Mimosa pigra*, in that the plant regenerated less and less when treated to a combination of stem cutting, burning and uprooting. The treatment was successful in killing both the plant and seeds of *Mimosa pigra* in the soil seed bank. On the contrary, the study also showed that mere cutting and uprooting of *Mimosa pigra* would lead to rapid regeneration of *Mimosa pigra*. This proved true the fact that bush clearing and burning increases seedling emergence, saplings and would not be suitable method to control *Mimosa pigra* as the practice has being in Lochinvar National Park.

The study also demonstrates that the exponential growth pattern of *Mimosa pigra* increases plant length with time (per week) and encourages the plant to spread quickly if not checked. Its growth's versatility makes *Mimosa pigra* a resilient plant that regenerates rapidly, either through seedlings emergence or through saplings from cut parts of the plant and could establish itself within a short period of time. The study also shows that *Mimosa pigra* is an aggressive and competitive plant and has a short juvenile stage which allows it to establish quickly and become dominant over native flora in Lochinvar National Park.

Native plant species return after the removal of *Mimosa pigra* and allow the appearance of grasses, creepers, herbaceous and native tree species in the area. This confirms that the removal of *Mimosa pigra* plant populations stimulates the native flora to thrive and diversify. It was not possible to identify all seedlings to species level and therefore not all plant species were identified.

Therefore, the main conclusion of this study is that *Mimosa pigra* has very high survival rate which is attained by regeneration from seedling emergence and fragmented saplings arising from the mother plant. A combination of stem cutting, burning and uprooting significantly reduces plant regeneration from seedling emergence and from severed stems and root parts. It is therefore, recommended that any control measure should aim at killing the plant and reducing the number of seeds in the soil seed bank.

7.2 Recommendations

This study therefore recommends the following;

i. A combination of stem cutting, burning and uprooting should be adopted as the most effective method of controlling *Mimosa pigra*. However, the method is only suitable for eradicating small satellite infestations or nascent foci whose soil seed bank has not become fully established.

ii. There is need to explore an integrated management approach of controlling *Mimosa pigra* since it generally regenerates from either cut stumps/roots or seeds buried deep in the soil seed-bank.

iii. Mere cutting and uprooting of *Mimosa pigra* plant without killing the plant or seeds in the soil seed bank is not beneficial.

iv. Develop a model to predict what combination of management strategies are the most effective and what consequences of controlling one weed species would have on other weed populations, and how the other components of the ecosystem might respond.

v. Further studies are necessary to assess the *Mimosa pigra* soil seed-bank density within Lochinvar National Park. There is lack of information regarding the soil-seed-densities of *Mimosa pigra* in Lochinvar National Park.

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APPENDICES

APPENDIX I. Data recording sheet of Seedling emergence for the field work

THE UNIVERSITY OF ZAMBIA

SCHOOL OF NATURAL SCIENCES

Data collection sheet for field work

Thesis Title: Regeneration of *Mimosa pigra* – L following bush clearing and burning in Lochinvar National Park of the Kafue flats in Zambia.

Transect # -- Data Collector-------------------

Treatment type --

Area -------------------------------------- GPS coordinates -------------------------------

Week #	PLOT NUMBER									
	1	2	3	4	5	6	7	8	9	10
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
Total										

Note: plot counts are aggregates of five 1 m x 1 m quadrates in every third role in a plot.

APPENDIX II. Detailed data collection on the effect of treatment on *Mimosa pigra*.

Detailed data collected of the effect of treatment on *Mimosa pigra* showing seedling emergence per m^2 recorded per week postulated among the five treatments.

Date	Transect #	Week #	Treatment type	Total plot SE counts/week	Mean
19/09/09	T1	1	C	2,183	218.3
26/09/09	T1	2	C	1,528	152.8
3/10/2009	T1	3	C	949	94.9
9/10/2009	T1	4	C	132	13.2
16/10/09	T1	5	C	3	0.3
23/10/09	T1	6	C	0	0
30/10/09	T1	7	C	0	0
6/11/2009	T1	8	C	4	0.4
13/11/09	T1	9	C	74	7.4
20/11/09	T1	10	C	1,448	144.8
27/11/09	T1	11	C	1,120	112
Total				**7,441**	**744.1**
Date	Transect #	Week #	Treatment type	Total plot SE counts/week	Means
19/09/09	T2	1	C + U	2,976	297.6
26/09/09	T2	2	C + U	1,913	191.3
3/10/2009	T2	3	C + U	1,300	130
9/10/2009	T2	4	C + U	145	14.5
16/10/09	T2	5	C + U	37	3.7
23/10/09	T2	6	C + U	12	1.2
30/10/09	T2	7	C + U	3	0.3
6/11/2009	T2	8	C + U	3	0.3
13/11/09	T2	9	C + U	76	7.6
20/11/09	T2	10	C + U	1,054	105.4
27/11/09	T2	11	C + U	1,478	147.8
Total				**8,997**	**899.7**
Date	Transect #	Week #	Treatment type	Total plot SE counts/week	Means
19/09/09	T3	1	C + B	1,260	126
26/09/09	T3	2	C + B	533	53.3
3/10/2009	T3	3	C + B	587	58.7
9/10/2009	T3	4	C + B	141	14.1
16/10/09	T3	5	C + B	42	4.2
23/10/09	T3	6	C + B	14	1.4
30/10/09	T3	7	C + B	11	1.1
6/11/2009	T3	8	C + B	7	0.7
13/11/09	T3	9	C + B	27	2.7
20/11/09	T3	10	C + B	569	56.9
27/11/09	T3	11	C + B	548	54.8
Total				**3,739**	**373.9**
Date	Transect #	Week #	Treatment type	Total plot SE counts/week	Means
19/09/09	T4	1	C + B + U	134	13.4
26/09/09	T4	2	C + B + U	0	0
3/10/2009	T4	3	C + B + U	19	1.9
9/10/2009	T4	4	C + B + U	25	2.5
16/10/09	T4	5	C + B + U	17	1.7

23/10/09	T4	6	C + B + U	1	0.1
30/10/09	T4	7	C + B + U	3	0.3
6/11/2009	T4	8	C + B + U	0	0
13/11/09	T4	9	C + B + U	2	0.2
20/11/09	T4	10	C + B + U	131	13.1
27/11/09	T4	11	C + B + U	173	17.3
Total				**505**	**50.5**
Date	Transect #	Week #	Treatment type	Total plot SE counts/week	Means
19/09/09	T5	1	CA	5,441	544.1
26/09/09	T5	2	CA	3,654	365.4
3/10/2009	T5	3	CA	172	17.2
9/10/2009	T5	4	CA	255	25.5
16/10/09	T5	5	CA	0	0
23/10/09	T5	6	CA	0	0
30/10/09	T5	7	CA	0	0
6/11/2009	T5	8	CA	0	0
13/11/09	T5	9	CA	0	0
20/11/09	T5	10	CA	0	0
27/11/09	T5	11	CA	0	0
Total				**9,522**	**952.2**

APPENDIX III. Names of species recorded during the field work in all five transects.

Data on the names of species collected in plots.

Species name	Plant species collected from 10 plots									
	plot1	**plot2**	**plot3**	**plot4**	**plot5**	**plot6**	**plot7**	**plot8**	**plot9**	**plot10**
Ambrosia maritima (H)	93	60	50	100	130	90	28	30	6	24
Polygonum senegalense(H)	0	3	0	2	0	9	2	0	0	0
Heliotropium ovalifolium(H)	6	0	0	0	0	2	28	25	20	53
Ludwigia stolonifera(GC)	0	1	0	0	0	1	23	35	34	36
Vernonia glabra(G)	15	11	67	0	0	19	25	39	45	39
Echinochloa scabra(G)	33	15	21	0	0	14	35	25	31	45
Acroceras macrum(G)	81	3	106	70	90	70	32	19	26	64
Ludwigia leptocarpa(Gclipper)	0	0	0	0	2	1	32	29	43	5
Paspalidium obtusifolium (G)	1	1	0	0	0	1	26	43	51	51
Leersia denudata (likenga grass)	50	15	50	35	45	26	24	29	36	66
Oryza longistaminata(G)	1	26	0	0	0	6	3	4	10	4
Sacciolepis africana(G)	2	0	0	0	0	1	23	33	39	53
Hibiscus trionum(H)	0	0	3	0	0	1	28	22	29	47
Panicum repens(G)	78	13	6	9	20	43	22	34	38	46
Sporobolus pyramidalis(G)	3	3	7	12	36	30	49	46	52	50
Cynodon dactylon(G)	80	100	120	110	230	490	63	94	50	34
Oxalis corniculata(sH)	4	9	10	21	18	41	5	8	2	7
Aeschynomene fluitans(float matG)	0	0	8	3	1	14	3	7	0	3
Vossia cuspidata(G)	0	0	0	0	0	3	0	0	8	10
Brachiaria eruciformis(G)	1	10	5	13	4	0	9	8	0	7
Vetiveria nigritana(G)	0	9	0	0	0	9	0	4	5	0
Faidherbia albida (T)	1	0	0	0	0	0	0	0	0	1
Ipomoea aquatica (GCH)	0	0	0	0	0	0	3	1	0	2
Nidorella auriculata(H)	0	0	0	0	0	3	5	6	3	0
Caperonia serrata(flMaT)	0	0	0	0	0	0	5	3	13	6
Emilia protracta(GC)	0	0	1	0	24	4	0	23	0	1
Eleocharis dulcis	0	0	0	0	1	0	3	0	0	1

APPENDIX IV. The abridged Ramsar Convention

Ramsar Convention (1971)

The Convention on Wetlands (Ramsar, Iran, 1971) - called the "Ramsar Convention" is an intergovernmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance. The Convention provides a framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. Negotiated through the 1960s by countries and non-governmental organizations concerned about the increasing loss and degradation of wetland habitat for migratory waterbirds, the treaty was adopted in the Iranian city of Ramsar in 1971 and came into force in 1975.

The Convention uses a broad definition of the types of wetlands covered in its mission, including lakes and rivers, swamps and marshes, wet grasslands and peatlands, oases, estuaries, deltas and tidal flats, near-shore marine areas, mangroves and coral reefs, and human-made sites such as fish ponds, rice paddies, reservoirs, and salt pans.

At the centre of the Ramsar philosophy is the “wise use” concept. The wise use of wetlands is defined as “the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development”. “Wise use” therefore has at its heart the conservation and sustainable use of wetlands and their resources, for the benefit of humankind.

The Ramsar Contracting Parties, or Member States, have committed themselves to implementing the “three pillars” of the Convention: to designate suitable wetlands for the List of Wetlands of International Importance (“Ramsar List”) and ensure their effective management; to work towards the wise use of all their wetlands through national land-use planning, appropriate policies and legislation, management actions, and public education; and to cooperate internationally concerning transboundary wetlands, shared wetland systems, shared species, and development projects that may affect wetlands.

According to Article 9.2 of the Convention on Wetlands, “Any member of the United Nations or of one of the Specialized Agencies or of the International Atomic Energy Agency or Party to the Statute of the International Court of Justice can become a Party to the Convention”. (www.ramsar.org).

There are currently 159 Contracting Parties or member countries. There are 1888 Ramsar designated sites covering a total surface area of 185,272,001 of which Lochinvar National Park is one of such sites (www. Ramsar.org.)