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Dissertação
Mestrado em Ecologia e Gestão Ambiental

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Resumo

Mimosa pigra Linnaeus (mimosa) é uma das mais perigosas invasoras do mundo. Nativa da América do Sul, já invadiu outros continentes, como a Austrália, África e Ásia, diminuindo a flora e fauna nativa nos locais invadidos.

Uma planta jovem de mimosa apresenta-se na forma prostrada, enquanto as adultas formam arbustos que chegam a 3 a 6 metros. As folhas têm movimentos seismonásticos, ou seja, fecham-se quando tocadas, à noite ou quando está muito vento. A raiz consegue penetrar até 2 metros no solo e estender-se lateralmente até 3,5m, permitindo que mimosa avance à medida do recuo das águas. Consequentemente há um maior depósito de sedimentos, reduzindo o curso normal de água. As alterações do regime de inundação é vantajoso para mimosa, pois após um evento desse género resta um solo limpo e, portanto, sem competição pelo sol e nutrientes, dando a oportunidade a mimosa de excluir a restante vegetação e criar um coberto monoespecífico. Por consequência das alterações hidrológicas e vegetais foi registado uma diminuição da abundância e uma correlação negativa com a riqueza específica de espécies animais. Mimosa consegue duplicar a área de invasão num ano e tem uma rápida dispersão. Caracterizada por um crescimento agressivo, também tem uma persistência elevada aos métodos de controlo físicos, tornando mais difícil o sucesso do seu controlo. Após o corte consegue brotar facilmente, e após o fogo até 90% de mimosas adultas e 50% de mimosas juvenis sobrevivem.

Parque Nacional da Gorongosa (PNG) é conhecido pela sua riquíssima variedade de espécies e foi inclusive apelidado do Parque mais ecologicamente diverso do mundo pelo E.O. Wilson, com o Lago Urema sendo, figurativamente, e literalmente, o centro do Parque. No PNG a *Mimosa pigra* existe nas planícies aluviais crescendo em diferentes densidades entre as comunidades vegetais presentes. Esta invasora forma um anel em torno do Lago Urema e apresenta-se, geralmente, na forma rasteira.

Durante a guerra civil em Moçambique o número de animais diminuiu substancialmente no PNG e essa diminuição é tida como o impulso para *Mimosa pigra* se ter expandido, sendo argumentado que o pisoteio e herbivoria a controlava. Este argumento é discutível, visto que se reconhece que os animais herbívoros promovem as invasões de plantas. No caso específico de *Mimosa pigra* esta invadiu áreas continuas em 1980, na Austrália, apesar de ter sido altamente utilizada pelos búfalos (*Bubalis bubalis* Lydekker) como alimento. Crê-se inclusive que a presença de búfalo pode ter criado oportunidades para o aumento de *Mimosa pigra*,

visto que este removeu a maior parte da vegetação, que poderia competir com a mimosa retardando a sua invasão, deixando um solo nu que permitiu o estabelecimento das plântulas da mesma. Há indício que a remoção do búfalo permitiu a vegetação nativa volta-se a aumentar podendo competir com as plântulas de mimosa.

Neste estudo pretendeu-se perceber se existe alguma relação entre a abundância de *Mimosa pigra* e a abundância do restante coberto do solo, qual a influência da água nesta invasora e qual a localização e extensão da invasão de mimosa. Para perceber a relação da mimosa com o restante coberto realizaram-se parcelas de $625m^2$ em que se mediu a abundância das variáveis referidas, baseada na percentagem de cobertura do solo. Com esses dados realizou-se o teste de Spearman, no Statistic. Os resultados mostraram uma correlação negativa entre as plântulas *Mimosa pigra*, que são representadas como mimosa até 10 cm de altura, e a maioria das restantes plantas herbáceas não rasteiras e os arbustos lenhosos. Mimosa com altura entre 21 cm e 50 cm mostrou uma correlação negativa com a variável "lixo". Mimosa com altura compreendida entre 11 cm a 50 cm obteve-se uma correlação positiva para plantas herbáceas floridas.

As plântulas de *Mimosa pigra* não são tão competitivas quando há uma área densa de herbáceas, que são especialmente eficientes a suprimir o crescimento de mimosa e a controlar as plântulas, conseguido mesmo suprimir a sua germinação. Essa competição ou eficácia pode ser devido à sombra que se sabe ter um efeito de retardamento no crescimento e sobrevivência das plântulas de mimosa, o que também explica a correlação negativa com arbustos lenhosos, visto que estes apresentavam geralmente alturas mais altas, por volta dos 50 cm. A variável "lixo" é representada pelos detritos vegetais encontrados, como vegetação seca e morta. As herbáceas mortas são ditas como limitadoras da presença de espécies lenhosas, como a mimosa.

As coordenadas das parcelas estudadas foram registadas no GPS Garmin eTrex 10. Juntamente com coordenadas de estudo anteriores envolvendo a mimosa, criou-se um mapa das localizações de mimosa em que às parcelas registadas se atribuiu a definição de "Presente" ou "Ausente". Para uma parcela ser definida como "Presente" bastou existir um único individuo na parcela, e nas parcelas definidas como "Ausente" não se encontrou nenhum individuo de mimosa. Este mapa permite entender em que habitat é que a mimosa se encontra presente e qual é favorável para o seu crescimento e proliferação. Sabe-se, como resultado do mapa criado, que a mimosa só existe numa paisagem "Rift Valley Riverine and Floodplain". Esta paisagem é de grande importância para o Parque e para a vida selvagem que

o habita, visto que de todas as paisagens do Parque esta é a única a que foi atribuído “Bom” e “Muito bom” na análise da sua capacidade de carga.
Para entender a influência da água na invasora utilizou-se o mapa da cheia de 2008, a maior desde a co-gestão da Carr Foundation com o Governo Moçambique. Sobrepôs-se essa informação com a informação do mapa onde a mimosa se encontra presente. A diferença entre a altura e a percentagem de cobertura entre a zona inundada é bastante superior à área não inundada. Sabe-se que a mortalidade das plântulas de mimosa está altamente relacionada com a quantidade de água disponível.
Neste estudo definiu-se os níveis de infestação de mimosa baseados na percentagem de cobertura da mimosa, definindo de acordo com o nível da infestação a sua prioridade no plano de gestão, sendo que os com menor percentagem de cobertura serão os mais prioritários. Definiu-se então que: ausente (sem mimosa presente), raro (0% a 1% de cobertura), disperso (1% a 10% de cobertura), médio (11% a 50% de cobertura) e denso (51% a 100% de cobertura). Todos os mapas deste estudo foram criados no QGIS na projecção UTM 36S WGS84.

Parte da gestão preventiva inclui a prevenção de novas introduções de mimosa e também envolve o estudo e levantamento da identificação de plantas isoladas, tanto no terreno como usando meios aéreos, antes que essas se expandem para infestações maiores. Com os resultados obtidos neste estudo é possível entender quais as áreas onde investir mais tempo e recursos para um plano de gestão eficaz. Deve se estar preparado para manter os esforços de controlo e possível erradicação durante um longo período de tempo, devido às característica de mimosa, caso contrário o projecto de controlo torna-se um desperdício de tempo, dinheiro e recursos, e leva a que mimosa recupere das acções de controlo aplicadas no passado. Acções de reabilitação do habitat, como a revegetação, são métodos que contribuem para a retenção da expansão de mimosa. Na Austrália 4 agentes de controlo biológico mostraram impactos mesuráveis na mimosa. O agente mais eficaz é a *Carmenta mimosa*, sendo que foi considerada a sua libertação no Parque Nacional de Lochinvar, na Zâmbia e pode ser um agente promissor para o Parque Nacional da Gorongosa.

Palavras-chave: *Mimosa pigra*; espécie invasora; mapeamento; Parque Nacional da Gorongosa; plano de gestão

Abstract

Mimosa pigra, one of the world's 100 most invasive species, spreads very rapidly and can double its area of infestation in a year. In Gorongosa, Mozambique, this species (mainly the prostrate form) spreads in floodplains and waterways mixed with grassland vegetation.

This study examined the relationship between *Mimosa pigra* and rest of vegetation and soil coverage, the effect of water in the distribution and proliferation of the species. The extent of invasion was mapped to serve as the foundation for effective management. The study plots were located around Lake Urema and along waterways.

Mimosa pigra seems to only exist in the Riftvalley Riverine and Floodplain Landscape. The presence of water is important for the growth and proliferation of the species. Data from a major flood in 2008 and the height and percentage of coverage of mimosa showed that the presence of water led to much taller and denser mimosa stands.

bundance of mimosa and the other variables were measured based on the percentage of soil cover. Abundance of *Mimosa pigra* seedlings show a negative correlation with the abundance of non-creeping perennial grasses in general, and also with the abundance of woody shrubs. Abundance of mimosa plants in the height class 21-50cm was negatively correlated with litter abundance. Abundance of mimosa plants in the 11-50 cm height class was positively correlated with forbs abundance. This information contributes for determining which community or habitat is more susceptible to become invaded by mimosa, allowing the management of habitats so as to retrench the spread of the invasive species.

Effective management requires information on the location, extent, abundance and biological characteristics of mimosa to plan control and mitigation programs.

Keywords: *Mimosa pigra*; invasive species; mapping; Gorongosa National Park; management plan

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1. Introduction

1.1 Biological Invasions

Since pre-historic times humans have been responsible for moving species out of their native distribution ranges, with an unprecedented increase in recent decades towards a global redistribution of species (Didham, Tylianakis, Hutchison, Ewers, & Gemmell, 2005). Indeed, the introduction and spread of invasive alien species (IAS) has become a hot topic in ecology and conservation sciences, since these organisms are responsible for altering terrestrial and aquatic communities worldwide and considered to be one of the biggest environmental issues of public concern (Didham et al., 2005). IAS are a serious threat to biodiversity worldwide (Kumschick & Richardson, 2013), and with an increasing magnitude (Hulme, 2009). Accordingly to a recent review (Richardson, Pyšek, & Carlton, 2011), alien species are those whose presence in a region is due to human action that enable the species to overcome fundamental biogeographical barriers. Moreover, IAS are alien species that sustain self-replacing populations over several life cycles, produce reproductive offspring, often in large numbers at considerable distances from the parent and/or site of introduction, and have the potential to spread over long distances, possibly leading to adverse effects on invaded habitat (Richardson et al., 2000). The invasion process, can be considered a progression of events in which individuals of a species are introduced to a new location by overcoming, through human action, major geographical barrier (A); establish a self-sustaining population and become naturalized by overcoming environmental barriers (B) and reproduction barriers (C); spread across the landscape (D) and overcome environmental barriers in the general area (E) turning into an invasive. To invade mature and undisturbed communities it usually requires overcoming a different category of factors (F) (Diez et al., 2012; Richardson et al., 2000).

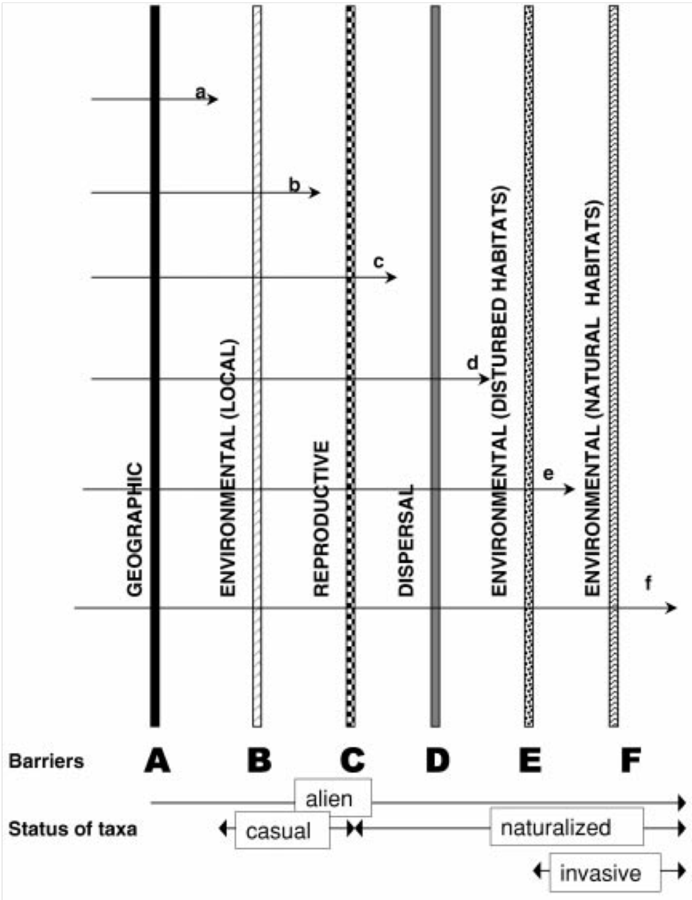

Figure 1 - The invasion process. Conceptualization of the various barriers that a plant must overcome to become alien, casual, natural or invasive in a new environment (Richardson et al., 2000)

The actual invasion of an environment by new species, and therefore the success of the invasive alien, is related to the features of the invaded community, geographical conditions, and a set of external factors, like the number of propagules entering the new environment (Richardson & Pyšek, 2006). A major factor driving invasion is disturbance (e.g. Carvalho, Antunes, Martins-Loução, & Klironomos, 2010). Disturbance, whether natural or anthropogenic, can influence the initial establishment of invasive, by favouring non-native over native species (Didham et al., 2005; Flory & Clay, 2010; Traveset & Richardson, 2011).
Climate change can be a cause of more frequent or pronounced events, like extreme floods, that cause disturbance in the ecosystem. Climate change and biological invasions are both threats to global biodiversity that may interact in the future, by the influence of climate change on one of the stages of the invasion process (Diez et al., 2012). This synergy between climate change and biological invasion can facilitate the homogenization of different world regions. Non-native invasive species generally present relatively strong dispersal abilities and

plasticity, and may respond more positively to climate change, likely having an advantage over native species (Staudinger et al., 2013).

Biological invasion are not only a threat to biodiversity, but it can also have serious impact on human health and economy development (Pyšek & Richardson, 2010). For example, the damages caused by IAS in U.S, U.K, Australia, S.A, India and Brazil totals more than US$ 336 billion per year (Pimentel et al., 2001). In South Africa the government has spent over US$657 million on the Working for Water, a programme that tackles the problems of invasive species, between its inception in 1995 and 2009 (Maitre, Lange, Richardson, Wise, & Wilgen, 2011).

Accordingly to the above, any efficient management of invasive species begins with the prevention of introduction of new potential IAS (Kumschick & Richardson, 2013). That is achievable by creating a first line of defence using regulatory measurements. A weak infrastructure and lack of regulatory measurements makes it harder to deal with IAS (Burgiel & Muir, 2010), making the global south vulnerable, specially due to the particularity that it is already an overstressed region due to the disproportionally rich biodiversity (Platnick, 1991). When prevention fails the management of IAS should follow by early detection, rapid response and possible eradication (Simberloff et al., 2013).

1.2 Invasive Alien Species in Protected Areas – case of *Mimosa pigra* in Gorongosa National Park

Some of the best-known examples of alien plant invasions come from protected areas (Foxcroft, Richardson, Pyšek, & Genovesi, 2013). Protected areas (PAs) are part of an approach to conserve biodiversity and slow its loss (Hansen et al. 2010) and the presence of IAS constitutes a substantial and growing threat to the ability of protected areas to provide this service (Foxcroft, et al., 2013).

Gorongosa National Park (GNP), located in Mozambique, is an example of a PA endangered by IAS. GNP is particularly special due to its singularity. It is home to spectacular wildlife and stunning landscape (Stalmans & Beilfuss, 2008) and has been called by E.O. Wilson "…ecologically, the most diverse park in the world" (Conneely, 2013). GNP biological richness defines it and assumes a great importance, making the Park a flag for national and global biodiversity protection.

The presence of *Mimosa pigra* Linnaeus (mimosa) in GNP puts in danger the work done so far in restoring and re-establishing the natural wildlife that the Park once had, before the civil war (Beilfuss, 2007; Brodin, 2010). This IAS is listed in the Global Invasive Species Database as one of the *One Hundred of the World's Worst Invasive Alien Species* (Lowe, Browne, Boudjelas, & De Poorter, 2000), and one of the most important invasive species in GNP (Stalmans & Beilfuss, 2008). Mimosa is now well established on the floodplains, pans and waterways of GNP. It occurs throughout the floodplain grasslands, forming a ring around Lake Urema (Beilfuss, 2007), growing in varying densities mixed with the native grassland communities.

Mimosa pigra is a plant native to tropical America, where it occurs as small clumps of multi-stemmed plants growing in seasonally flooded habitats, and favours a wet-dry tropical climate (W.M. Lonsdale et al., 1989). However, where it has been introduced, *M. pigra* is a serious weed of wetlands, invading ecosystems worldwide including Africa, Asia, Pacific Islands and Australia (Beilfuss, 2007; Chin, 2008; Marambe et al., 2004; Miller, Nemestothy, & Pickering, 1981; Samouth, 2004; Tjitrosoedirdjo, 1989; Triet, Kiet, Thi, Thi, & Dan, 2001; Triet, Man, & Nga, 1998).

Mimosa has been present in Africa for almost 200 years, but its spread and invasion have increased greatly in the last 20 years, mostly in response to hydrological changes, like the construction of dams (Economic Impacts of Invasive Alien Species: A Global Problem with Local Consequences>, 2004). In 2012 mimosa was present in 37 African countries (Heard, 2012).

Mimosa pigra is a prickly, perennial, woody shrub (Heard, 2012), found in moist open sites and growing on a wide range of soils (Waterhouse, 1994). Young mimosa plants grow a single prickly stem in a prostrate form, while mature mimosa forms branched shrubs reaching a height between 3 and 6 meters, with rose-like thorns (W.M. Lonsdale et al., 1989). In GNP the prostrate form, usually 10-20cm tall, is most common, with heights reaching 1,5m in drainage lines (Beilfuss, 2007). Mimosa distinctive feature are the bipinnate green leaves that have a thigmonastic response, meaning they are sensitive to a variety of stimuli, closing when touched, when it is very windy and at night (W.M. Lonsdale et al., 1989).

Figure 2 - *Mimosa pigra* in Gorongosa National Park. Top left - stand of mimosa in prostrate form. Top right - mimosa seedling. Bottom left - stands of adult mimosa. Bottom right - single adult mimosa plant

It typically germinates as floodwaters recede and the main period of growth is in the wet season. Flowering period is from February to April, but it can continue for as long as water is available (Lonsdale et al., 1989). The pink globular flowers produce an average of 7 densely bristly pods, each with 21 seeds (W.M. Lonsdale et al., 1989). This process, from flower bud to ripe seed, takes about 5 weeks, with germination occurring 3-6 weeks after flower bud is formed (W.M. Lonsdale et al., 1989).

Figure 3 - ***Mimosa pigra*** **in Gorongosa National Park, with flowers and seeds**

There are 7 key attributes that make *Mimosa pigra* a serious invasive weed:

1. It can withstand anaerobic conditions of inundation and flooded soils due to its root system (Miller et al., 1981). After a flood event most understory plants are dead leaving nothing but bare soil when water recedes. With plenty of soil, moisture, nutrition and sunlight, and no competition, mimosa gain the competitive edge and it becomes the ideal situation for domination.

2. *M. pigra* can easily re-sprout from the stump if cut down, and after burning up to 90% of mature *M. pigra* plants and 50% of seedlings can re-grow (Attard et al., 2006). This makes it harder to remove or to have physical control methods that are effective.

3. The seedpods are covered with bristles allowing it to easily disperse. It attaches to clothing and it's able to float on water for an extended period of time (Miller et al., 1981), it can be dispersed by soil and mud adhering to vehicles and other machinery, and also by animals that graze *M. pigra* and pass the seeds in their faeces (Attard et

al., 2006). *Mimosa pigra* has a rate of dispersal of 87.3 m per year (Pyšek & Hulme, 2005).

4. Seed lifespan varies with soil depth and soil type, and it is suggested that it might be up to 23 years in sandy soils (W.M. Lonsdale et al., 1989) and over a decade under grass cover (Lukitsch & Elliott, 2012).

5. It has an high seed production, with an average of between 9000 and 12 000 seeds per square metre per year in the Northern Territory in Australia (Lonsdale et al., 1988).

6. *M. pigra* displays very rapid growth – up to 1cm per day, and infestations can double in extent in one year (Attard et al., 2006; Weed Management Plan for Mimosa (Mimosa pigra), 2010). One-year-old plants with a stem diameter of 2,5 cm often attain a diameter of 7cm in the second year (W.M. Lonsdale et al., 1989). Maturity can be reached very quickly with a seed set in the first year (Walden, Finlayson, van Dam, & Storrs, 1999).

7. Can grow in a wide range of soil types, including nutrient-poor sandy soils (W.M. Lonsdale et al., 1989). Seed production, seedling density and plant longevity are higher on heavier soils, but seed longevity is greater in sandier soils (W.M. Lonsdale et al., 1988).

Mimosa is able to out compete native herbaceous layer vegetation for light, moisture and nutrients (Walden et al., 2004) turning floodplains into unproductive scrubland with monospecific thickets of *Mimosa pigra* with reduced levels of biodiversity (W.M. Lonsdale, Miller, & Forno, 1989) and lowering wildlife carrying capacity (Stalmans & Beilfuss, 2008). Mimosa may even modify water bodies reducing the natural water flows (Walden et al., 2004). Consequently, it causes effects on native fauna, by diminishing its abundance and species richness, due to the dramatic flora and hydrological changes (Shanungu, 2009; Walden et al., 2004).

It is thought that *M. pigra* has been present in GNP for decades, but due to heavy browsing and trampling it was not recognized as a major problematic species until recently (Beilfuss, 2007; Tinley, 1977). A contrasting view has also been advanced – heavily grazed locations remove the native vegetation creating the opportunity for mimosa to invade, and for the seed to be dispersed by animals (Attard, Chopping, Austin, Williams, & Pople, 2006). An example is the Water Buffalo (*Bubalis bulais Lydekker*) in the Northern Territory of Australia, by heavily grazing the native flora of the floodplains has created ideal opportunities for the increase of *Mimosa pigra* (Cook & Setterfield, 1996; W.M. Lonsdale, Harley, & Gillett, 1988). *Mimosa pigra* still developed a continuous stand in the 1980s, despite being heavily grazed by feral Water Buffalo, and after the Buffalo were culled the native vegetation resprouted (Paynter, 2004, 2005) competing with the mimosa seedlings (D'Antonio & Vitousek, 1992).

Mimosa pigra has attracted a great deal of attention with the expenditure of large sums of money and effort on control techniques (Finlayson & Mitchell 1981; Storrs & Finlayson 1998, Douglas et al 1998). It is calculated a staggering US$ 1.350/hectare or more to users of the floodplain, from farmers to conservation agencies, in Kafue Flats, Zambia (Leavold, Lloyd, & Lepetit, 2007). The example of this neighbouring country to Mozambique enables the extrapolation of the possible outcome of economic impacts mimosa can have in GNP.

1.3 Importance and aims of the study

This project aims to analyse the impact of flooding areas in the Gorongosa National Park in the distribution and dispersion of the invasive species *Mimosa pigra*, as well as to contribute to the management and control plans for *M. pigra* inside the natural Park.

Specific aims were to:

- Understand the relationship between *Mimosa pigra* and the native vegetation and soil coverage;
- Understand the impact of flooding in the distribution of *Mimosa pigra*;
- Use the present and past records of *Mimosa pigra* to produce maps that are useful for the environmental management, monitoring, and control plan;
- Suggest control actions in order to a better management and control of *M. pigra* in the GNP.

It is hypothesized that the existence of flooding areas has a great influence and impact on mimosa distribution and dispersion, expecting a greater abundance where flooded areas occur. Also, it is expected that the results show a negative impact in the native vegetation, in p

2. Materials and Methods

2.1 Study Area

2.1.1 Gorongosa National Park – Rift Valley

Gorongosa National Park (GNP) is located at the southern end of the Great African Rift Valley, in the district of Sofala, central Mozambique. The GNP has approximately 3,770 km^2 and is divided into four different regions: Gorongosa Mountain, Midlands, Cheringoma Plateau and the Rift Valley. The Rift Valley occupies the central position of the GNP and its buffer zone. The Cheringoma Plateau region is found to its east and the Midlands to its west. The Gorongosa Mountain region occupies the central part of the Midlands and is defined by the 600 m elevation contour.

The study area is located on the southern part of GNP, delimitated by Lake Urema on the north, Urema River on the west, Muscadizi River on the east and Pungue River on the south, covering in total 362km^2. The study area is within the Rift Valley Region, more specifically in the Rift Valley Riverine and Floodplain Landscape and the Rift Valley Alluvial Fan Landscape. The study area is characterized by a moist savanna biome, according to the existing habitats classification. Those landscapes are characterized by a mix of open to closed woodlands and dry forest and thickets, *Acacia*-*Combretum* open to closed and short to tall woodland, a mix of mostly open plant communities from pure grasslands to sparse palm veld and open *Acacia xanthophloea* and *Faidherbia albida* woodlands, mix of open to closed woodland.

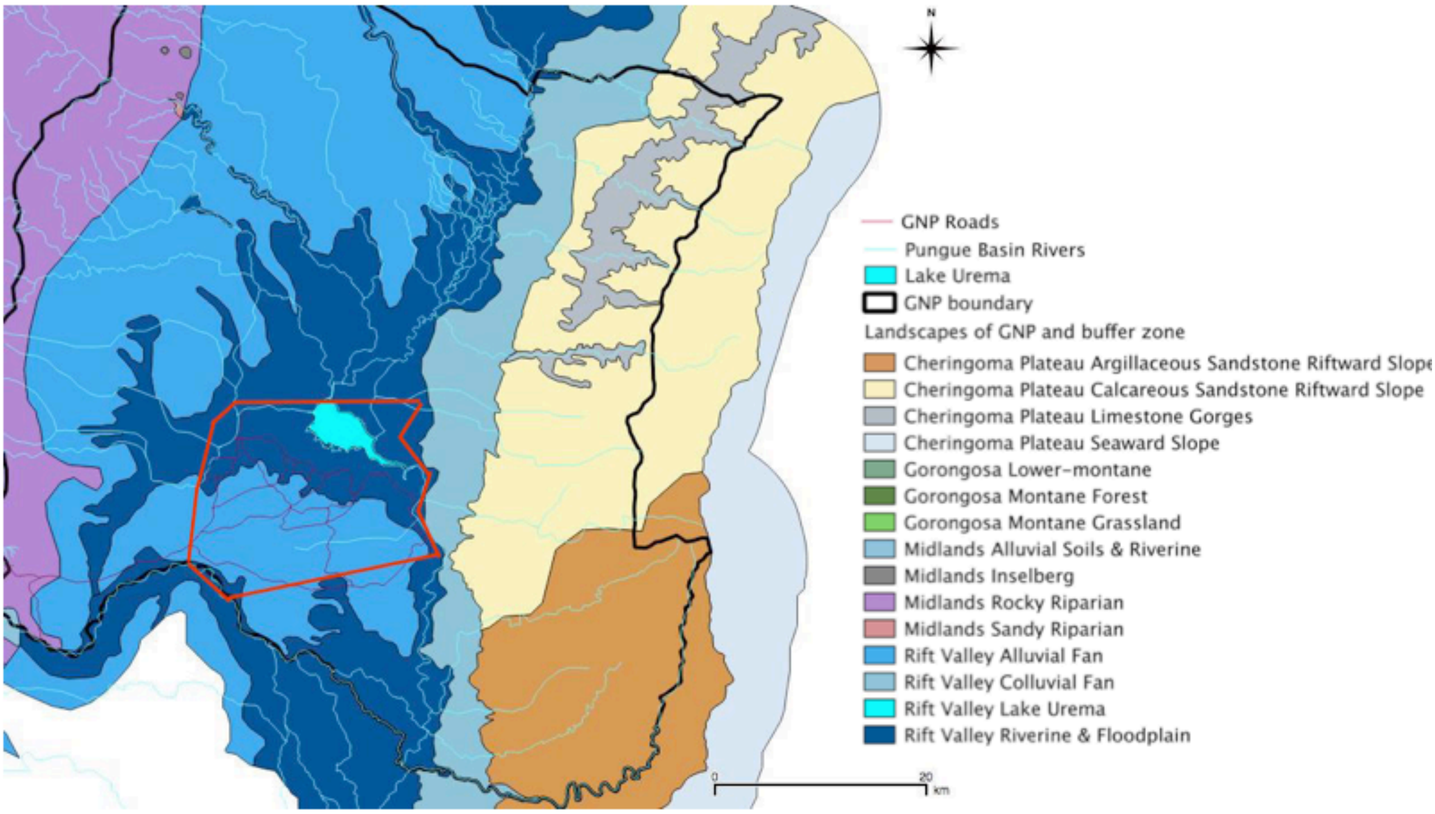

Figure 4 - Location of the study area, circumscribed in red, in the Gorongosa National Park, Mozambique

The climate of the study area is a tropical savanna climate, characterized by monthly mean temperatures above 18ºC in every month of the year and typically a pronounced dry season, with the driest month having a precipitation less than 60mm.

A weather station located in Gorongosa, provided the main climate variables information along the year (precipitation and temperature) aggregated during 30 years (from 1982 to 2012), that were expressed as monthly averages. According to the main climate classification for this region, we observed a strong precipitation period from November to May, and medium temperatures ranges from 20-25 C, during winter and 25-30 C during summer.

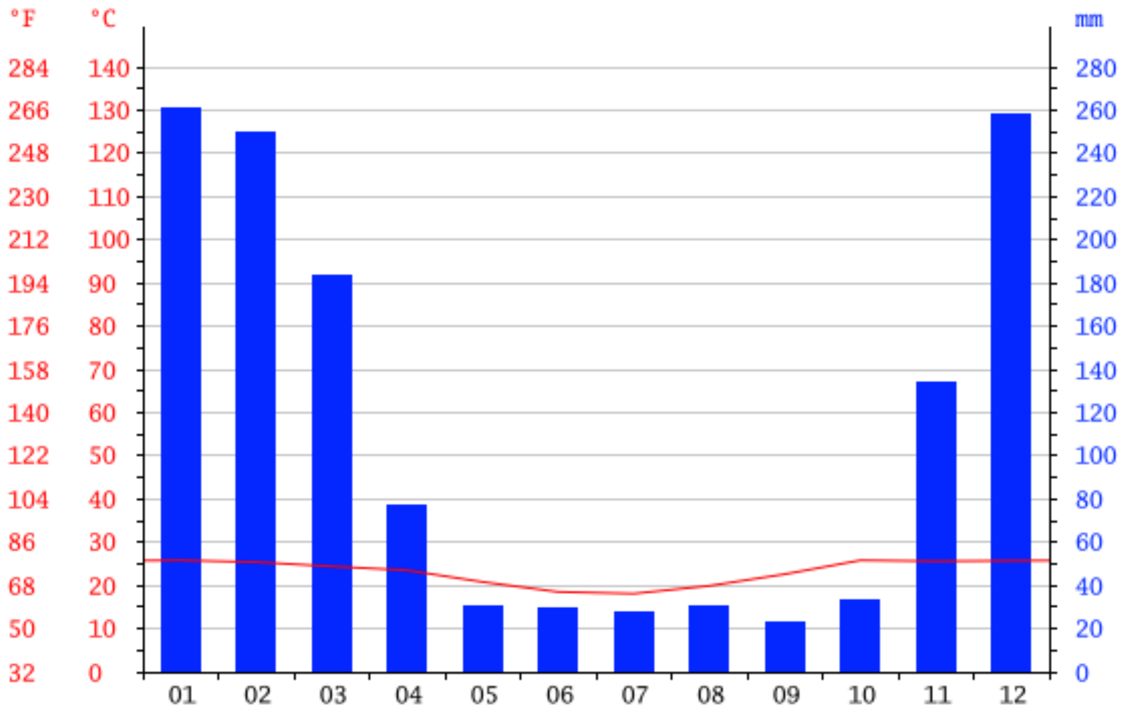

Figure 5 - Characterization of the climatic conditions in the study area. Climate variation along the year based in a weather station located in Gorongosa, displaying the medium temperature (red line) and medium rainfall precipitation (blue columns) per month (Source: http://pt.climate-data.org)

2.2 Sampling method

The data collection was performed during the dry season, between 17 June and 12 August 2013. The equipment used in the data collection included a GPS Garmin eTrex 10, a photographic camera, a roll metre tape and iron quadrants of 1x1m.

All the plots are located around Lake Urema, along Pungue River (south), Muscadizi River (east) and Urema River (west) (Fig.3). Distribution of the plots was established by 3 criteria: distance to the Lake Urema, distance to temporary and permanent rivers, distance to the road.

Figure 6 - Distribution of the plots inside the study area

Table 1 - Coordinates of the plots and respective information considering the presence or absence of Mimosa pigra in the plot, and its distance to the Lake, River or Road.

Plot	Latitude	Longitude	Presence/ Absence	Distance Lake Urema (m)	Distance Temporary River (m)	Distance Permanent River (m)	Distance Road (m)
M02A	-18,903194	34,480139	P	1034	-	-	-
M02B	-18,904889	34,479306	P	1241	-	-	-
M02C	-18,90675	34,4785	P	1449	-	-	-
M02D	-18,90374	34,481534	P	1072	-	-	-
M02E	-18,909294	34,477804	P	1735	-	-	-

M02F	-18,917189	34,476716	P	2613	-	-	75
M02G	-18,92433	34,479712	P	3328	-	-	-
M03A	-18,874636	34,380712	A	8276	-	-	-
M03B	-18,861204	34,393486	P	7117	-	-	-
M03C	-18,86101	34,412592	A	5123	-	-	-
M03D	-18,861312	34,418433	P	4389	-	-	-
M03E	-18,865272	34,429556	P	3149	-	-	-
M03F	-18,863208	34,434579	P	2658	-	-	-
M03G	-18,866075	34,452122	P	794	-	-	-
M03H	-18,865842	34,441546	P	1882	-	-	-
M05A	-18,929274	34,359469	A	-	65	-	-
M05B	-18,929826	34,359414	A	-	0	-	-
M05C	-18,93035	34,359451	A	-	55	-	-
M06A	-18,912865	34,484456	P	1970	-	-	55
M06B	-18,914394	34,488053	P	2113	-	-	194
M06C	-18,923406	34,49185	P	2427	-	-	83
M06D	-18,933202	34,4887	P	3533	-	-	4
M06E	-18,933481	34,489411	A	3510	-	-	48
M07A	-18,919234	34,514392	P	35	-	-	114
M07B	-18,921434	34,514802	P	222	-	-	105
M07C	-18,92204	34,514759	A	290	-	-	204
M08A	-18,951805	34,5406	P	-	-	13,3	3
M08B	-18,95186	34,540459	A	-	-	30	13
M09A	-18,955189	34,544043	A	-	-	16	117
M09B	-18,956385	34,542953	A	-	-	184	51
M09C	-18,956471	34,542479	A	-	-	231	97
M10A	-18,9877	34,568946	P	-	-	16	5
M11B	-18,855356	34,548842	A	5645	-	-	-
M11C	-18,863736	34,544257	A	4827	-	-	-
M11D	-18,871775	34,539541	A	3924	-	-	-
M11E	-18,87979	34,53461	P	2710	-	-	-
M11F	-18,880779	34,534019	P	2643	-	-	-
M11G	-18,884394	34,532024	P	2318	-	-	-
M12A	-18,922467	34,554667	P	-	-	372	-
M13A	-18,99475	34,3574	A	-	-	22	16
M13B	-18,997333	34,366194	A	-	-	13	58
M13C	-19,001222	34,373889	A	-	-	9	173

M13D	-19,017583	34,380722	A	-	-	5	-
M13E	-19,016694	34,382167	A	-	-	138	-
M13F	-19,015611	34,383083	A	-	-	238	-
M13G	-19,029583	34.392500	A	-	-	13	-
M14A	-18,91977778	34,50075	P	1636	-	-	454
M14B	-18,92275	34,5015	P	1903	-	-	142
M14C	-18,92511111	34,50172222	A	2154	-	-	55
M15A	-18,91394444	34,46119444	P	2946	-	-	21
M15B	-18,91411667	34,4608	P	2993	-	-	18
M16A	-18,88628333	34,43058333	P	3173	-	-	725
M16B	-18,88891667	34,42938889	P	3361	-	-	449
M16C	-18,894408	34,428262	P	3658	-	-	95

All the plots have a 625m^2 area (25x25m). Two methods, distributed in space and time, were used for sampling the plots. In 28 of 54 plots an intensive sampling was performed, where it was used sub-plots of 1x1m distributed inside the 25x25m plot, each separated by 5m from each other, resulting in 20 sub-plots of 1x1m inside the 25x25m plot. In the subplots the following data was collected: abundance of different height classes of mimosa, in order to represent the demographic structure of *Mimosa pigra*, defined by the percentage of foliar cover; abundance of the native vegetation measured by the percentage of foliar cover; abundance of different height classes of the perennial grasses; abundance of litter and bare soil measured by the percentage of cover of the soil surface. The height of mimosa and perennials grasses was measured from the ground to tallest end of the plant, using a measuring tape, and grouped forming different height classes. In 26 of 54 a faster method was used, were it was collected, for the entire 25x25m, the previous described data.

Figure 7 - Plots distribution in the study area with the different type of assessments

2.3 Statistical and spatial analysis

To perform the statistical analysis, the data in the intensive field assessment plots was modified to match the data collected with the fast field assessment plots. For each plot with intensive field assessment the previous described variables were estimated for the entire area of the plot (625m^2), using photographs and annotations taken in the field. It was statistically confirmed that the estimation could be used for the further statistical analysis of the study.

To evaluate the relation between *Mimosa pigra* and the rest of the vegetation the Spearman correlation test was performed using STATISTICA 12 *software*. To understand the relation between the distances to the Lake, to the road, and to the permanent and temporary rivers with the abundance of mimosa an analysis of the correlation was made using STATISTICA 12 *software*. The results were considered significant for a p-value ≤ 0,05000.

All the maps in this study were performed using QGIS 2.2 Valmiera *software*, and all data are in the UTM 36S WGS84 projection.

3. Results

3.1 Classification of the structural type of vegetation present

The vegetation structure was classified according to Edward (1983), using the data collected in the plots along with annotations and photographs. The herbland and grassland were the most abundant structural type, with grasses appearing in different densities and heights. The following table demonstrates the different vegetation structure and the number of plots where it was present, as well as the number of plots where mimosa was found and the corresponding percentage of plots with mimosa present.

Table 2 - Classification of the vegetation structure in the study area, according to Edward (1983)

Vegetation structure	Nº plots	Percentage of plots	Nº of plots with *Mimosa pigra*	Percentage of plots with *Mimosa pigra*
Low closed herbland	31	57,41	23	74,19354839
Short closed grassland	5	9,26	3	60
Low closed grassland	8	14,81	3	37,5
Low desert grassland	3	5,56	3	100
Tall closed grassland	3	5,56	0	0
Short open grassland	2	3,70	0	0
Low open shrubland	1	1,85	1	100
Tall closed woodland	1	1,85	0	0

A total of 21 plots were located in grassland type vegetation, with 31 in herbland vegetation, and 1 in a shrubland and 1 in woodland. The plots in this study capture a multiple different types of vegetation structure. Mimosa was not present in tall closed grassland, short open grassland, and tall closed woodland. The absence of mimosa in these structural types of vegetation can be due to the few numbers of plots assessed.

3.2 Relation of *Mimosa pigra* with the distance to the Lake, permanent and temporary rivers and to the road

In order to understand the effect of the distance to the lake, to the river and to the road and correlation analysis was performed. The correlation analysis was only significant for the distance to the permanent river and the percentage of foliar cover of *Mimosa pigra*.

Table 3 - Significant results of the correlation analysis

	Correlations (Excel_plot_ANOVA) Marked correlations are significant at p < ,05000 N=14 (Casewise deletion of missing data)
Variable	%mimosa (5)
Dist Perm River	,6431
	p=,013

	Correlations (Excel_plot_ANOVA) Marked correlations are significant at p < ,05000 N=14 (Casewise deletion of missing data)
Variable	%mimosa (10)
Dist Perm River	,6602
	p=,010

	Correlations (Excel_plot_ANOVA) Marked correlations are significant at p < ,05000 N=14 (Casewise deletion of missing data)
Variable	% mimosa (20)
Dist Perm River	,6757
	p=,008

	Correlations (Excel_plot_ANOVA) Marked correlations are significant at p < ,05000 N=14 (Casewise deletion of missing data)
Variable	%mimosa (50)
Dist Perm River	,6742
	p=,008

The results show a positive correlation between the distance to the permanent river and the percentage of foliar cover for mimosa with a height up to 50cm.

3.2 Relation of *Mimosa pigra* with the native vegetation

The relation of the vegetation and soil cover with mimosa can also be a factor in the distribution of this species.

Table 4 - Significant results of the Spearman correlation test

Pair of Variables	Valid N	**Spearman R**	t(N-2)	p-value
%p grass (>100) & %mimosa (5)	54	**-0,407170**	-3,21469	0,002246
%p grass (50) & %mimosa (5)	54	**-0,377423**	-2,93900	0,004901
%p grass (20) & %mimosa (5)	54	**-0,328985**	-2,51219	0,015140
%p grass (>100) & %mimosa (10)	54	**-0,310953**	-2,35927	0,022102
%p grass (100) & %mimosa (10)	54	**-0,271243**	-2,03215	0,047261
% litter & %mimosa (50)	54	**-0,334229**	-2,55722	0,013508
% woody shrub & %mimosa (5)	54	**-0,337067**	-2,58170	0,012689
% woody shrub & %mimosa (10)	54	**-0,270830**	-2,02880	0,047613
% forbs & %mimosa (20)	54	**0,468183**	3,820725	0,000357
% forbs & %mimosa (50)	54	**0,471759**	3,858220	0,000317

As these results show, mimosa seedlings, represented by "mimosa (5)" and "mimosa (10)", show a weak to moderate negative correlation with the general of the non-creeping perennial grasses. The strongest correlation is between "mimosa (5)" and "perennial grass (>100)". For "mimosa (5)" there is a negative correlation with smaller heights of perennial grasses than "mimosa (10)", that only shows a negative correlation with the taller perennial grasses. Grasses can be a serious competitor for water, nutrients and light. They have a greater impact in shade and nutrient competition with mimosa seedlings, explaining this negative correlation only with these mimosas classes, and not with adult mimosas. This may also explain why the creeping grasses do not appear in these results, because they do not compete, especially for light, with mimosa. Grasses can be effective in suppressing mimosa germination, by not providing habitat suitability.

The results show a weak negative correlation between litter and "mimosa (50)". The litter recorded is mostly grass litter, and was present in higher percentage in the beginning of the study, close to Lake Urema shore. In June a large amount of grass litter was recorded, due to the recent water levels receding. In the end of July and begging of August, when the majority of the work field took place, the amount of litter wasn't as remarkable. This different time frame could lead to a not so expressive result concerning the suppressive factor that litter could have on mimosa. The relation between litter and mimosa was expected to be more detrimental, especially with smaller mimosas.

The woody shrubs have a weak negative correlation with mimosa seedlings. The woody shrubs recorded were mainly of a height around 50cm, and like the perennial grasses, can be competitors for light, moisture, and nutrients, increasing the mortality of mimosa seedlings, and creating a not so suitable habitat.

The only positive result was the moderate positive correlation with forbs and *Mimosa pigra* with a high from 11cm to 50cm.

It is possible to hypothesize which locations are more susceptible to become invaded by mimosa. These results sustain what previous studies shown, that a location with taller, denser vegetation is less prone to mimosa growth and spread, since the seedlings don't have the ideal conditions to thrive. Acknowledgment of which habitats or community are more presumable at risk of establishment and spread of mimosa assists in deciding on which areas should be a priority in future monitoring, and also allows to manage habitats so as to curtail the spread.

3.3 Distribution and levels of infestations of *Mimosa pigra*

In the following map the coordinates of this and previous studies that registered the presence or absence of mimosa are displayed. The criterion for the "presence/absence" classification of the plots is if one or more individuals of mimosa are present inside the plot it is labelled as "Present". It allows to evaluate the occurrence of mimosa in the Park and also to understand the suitable habitat of this invasive species. The knowledge of the locations of mimosa invasion, and also where it is not invaded, is fundamental to an environmental management plan. A goal of this map is also to easily identify what are the main areas to continue to survey, and also the areas that are still pristine regarding mimosa and need to be in special attention to prevent further invasion.

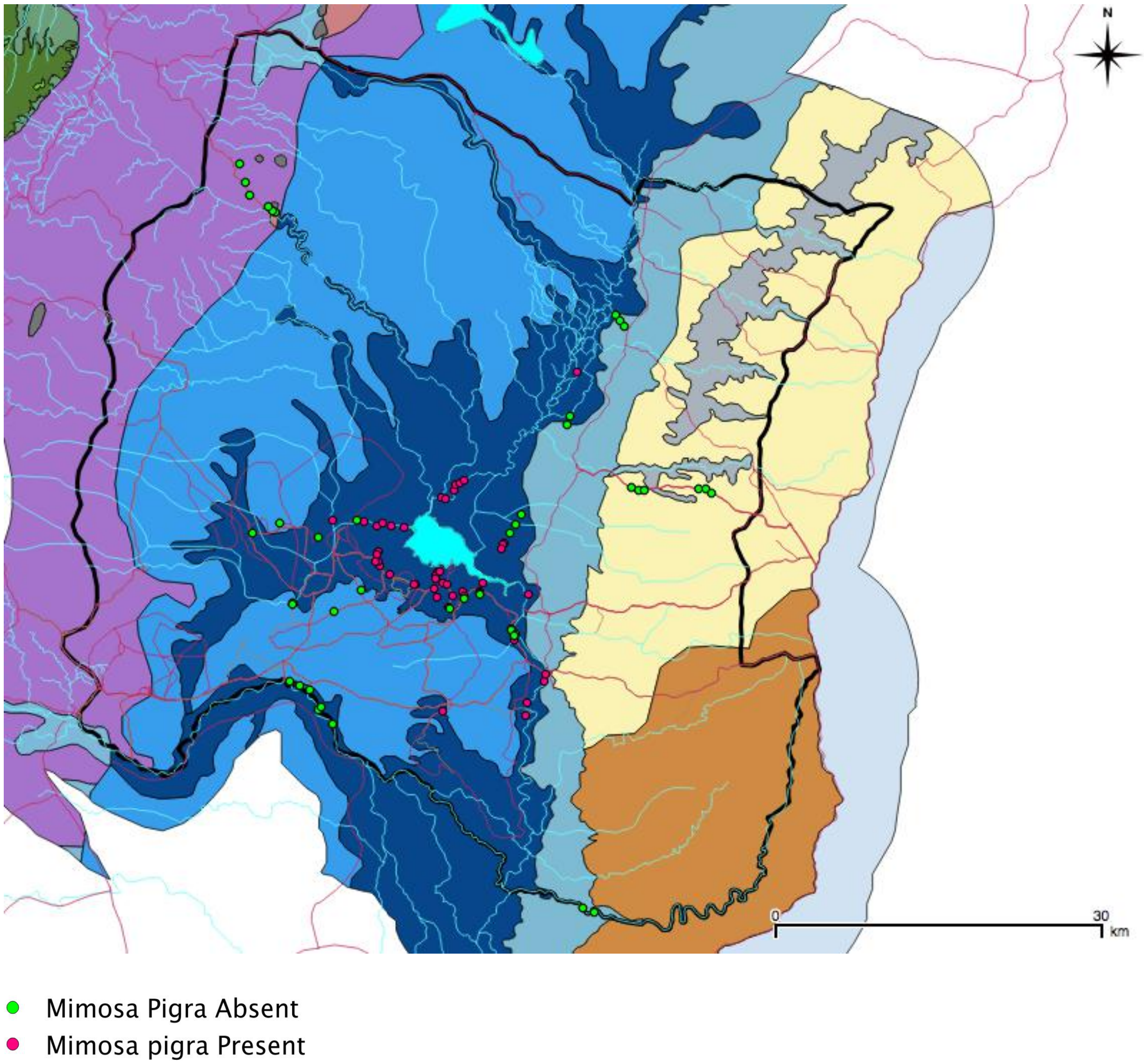

Figure 8 - Map with the display of the plots where *Mimosa pigra* is present or absent in Gorongosa National Park

The plots are located in five different landscapes and spread all over the park. Some areas are inaccessible, so, more scattered plots around the whole Park is, most of the time, practically impossible. As it is possible to see in this map, the concentration of efforts in future mimosa studies and control plans should be focused in the Rift Valley Riverine Floodplain Landscape, since that is the only landscape where mimosa is present. This is a helpful guideline in the next surveys. In the attempt to produce a more detailed map the plots should be located in the landscape is known to be its suitable habitat.

The entire Riftvalley Riverine and Floodplain Landscape has a good capacity for wildlife, classified in a previous study. A particular area of the Rift Valley Riverine and Floodplain Landscape has *Cynodon- Dactylon* short grasslands, a key resource to the herbivores, classified, by the same study, has a very good carrying capacity. No other landscape across the Park has such a high classification. This special feature referring to this particular landscape makes it even more crucial to actively control and management this weed. If the effort of mapping is kept, it is possible to later compare weed inventories and determine how fast mimosa is spreading and if the control methods are effective. The green dots, especially the ones between the red dots, although still considered non-invaded, they are at great risk. The green plots should be revisited to assure that they remain pristine and prevent further invasion. It is important to have in mind that the information provided by the distribution of the green dots can lead to misunderstanding, assuming that a bigger area is clear of mimosa. What sometimes happened is that within the 625m^2 plot there was no mimosa present, but the surroundings were invaded, and that does not translate in the results.

The levels of infestation of mimosa were defined by *Mimosa pigra* percentage of soil cover: absent (no mimosa present), rare (0% to 1% coverage), scattered (1% to 10% coverage), medium (11% to 50% coverage) and dense (51% to 100% coverage).

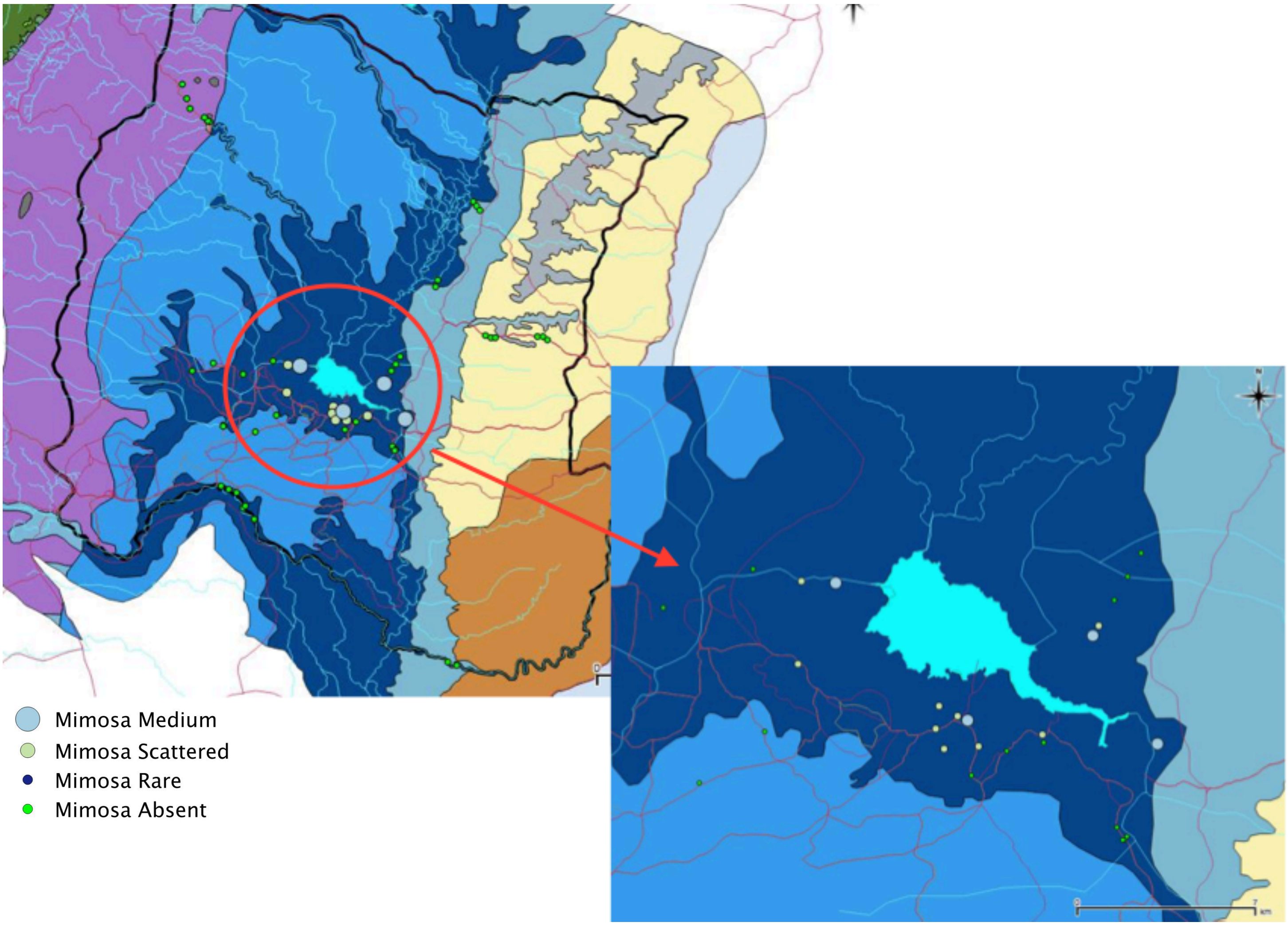

Figure 9 - Map showing the plots with the level of infestation of mimosa. The size of the dot is related to the size of the infestation. On the right panel a more detailed view of a section of the study area, where larger infestations are present

The size of the dots represents the density of mimosa in that particular plot, so that a highly infested plot will have a larger dot, and a plot with a very low density of mimosa will have a smaller dot. The size of infestation is crucial information for management purposes. According to the density of each plot there is a priority assigned and different methods to be used in order to control mimosa, with the lowest density areas having the highest priority. This is because if the initial area of a single large focus and the initial area of many small foci are equal, and all foci grow at the same constant rate, the small foci will collectively occupy space much faster than the single large focus, eventually exceeding the area occupied by the larger focus. Is very likely that the "medium" infestations located close to "scattered" infestations will combine into a denser infestation.

The control of satellite outbreaks of mimosa prevents large stands from developing. For this reason is important that a high proportion of the mapping budget should go into detecting and recording small infestations of mimosa, that can only be done by field assessments.

3.4 Relation of *Mimosa pigra* with water

Overlaying the map of *Mimosa pigra* locations and the flood level allows evaluating the importance of water as a facilitating element of invasion.

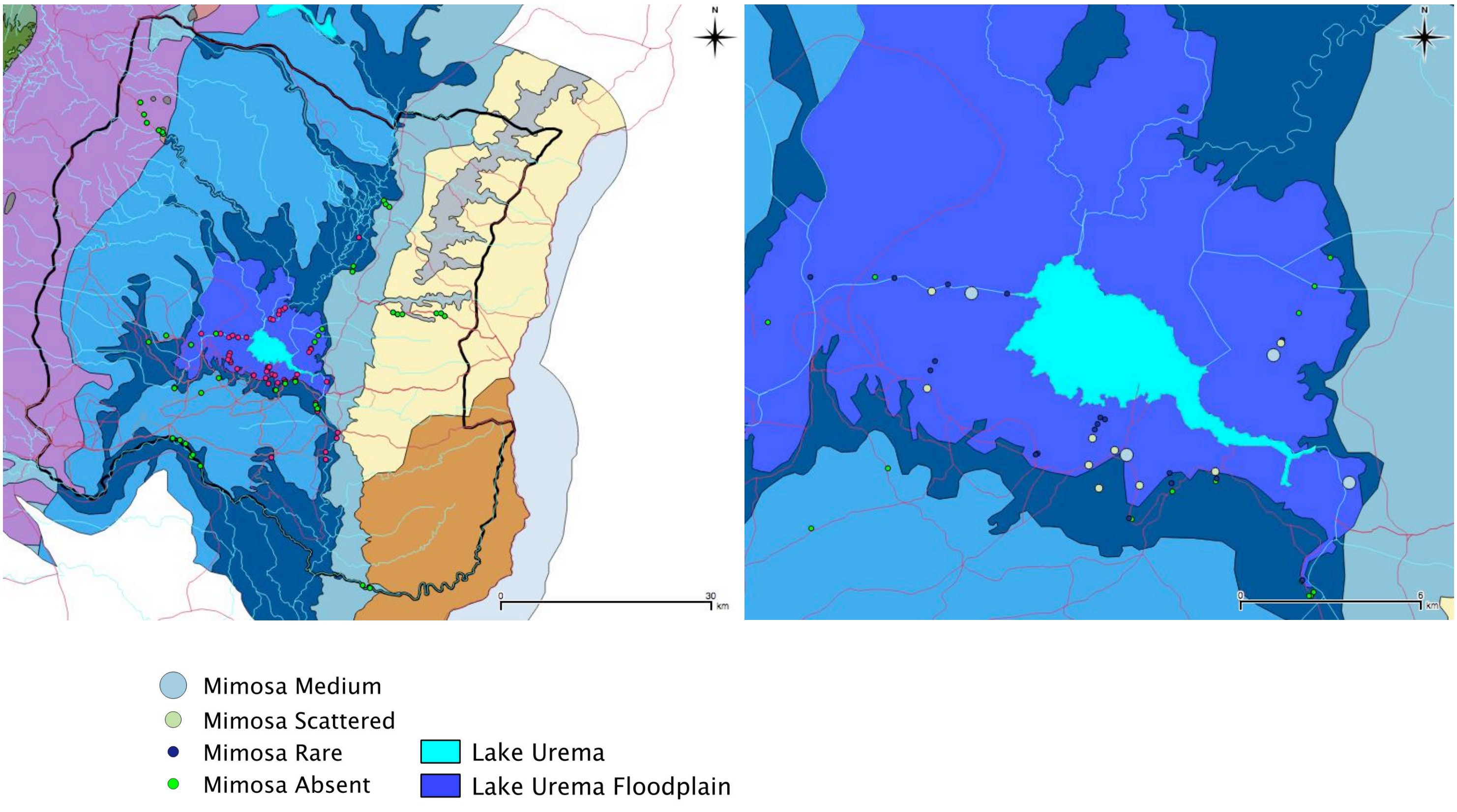

Figure 10 - Map with the overlay of Mimosa pigra locations (on the left panel) and levels of infestation (on the right panel) with an overlay of the map with the flood level of 2008

The analysis of the influence of flooding in *Mimosa pigra* was done using a map, provided by the scientific services of GNP, illustrating the 2008 flood levels. This flood had the most extreme flood levels since 1997, being the biggest flood since the co-management of the park between Carr foundation and the Mozambican Government. This map was overlaid with the map of *Mimosa pigra* location in GNP.
In these maps we can see, with the overlaying of the flood levels, how important water is for mimosa. The majority of mimosa's presence is in the "Lake Urema Floodplain", that represents the flood level of 2008. Analysing the levels of infestation is possible to see the larger dots, meaning the biggest infestations, present where the flooding occurred. In the non-flooded area, mimosa when present is in the smaller infestation classified as "rare". The locations more subject to drought are where mimosa is in less abundance, not being a suitable habitat for mimosa to survive and grow.

This map allows us to determine which plots were in the flooded and non-flooded area, thus designating the plots accordingly. For the flooded plots the percentage of coverage for each mimosa height class was summed. The same was done for the non-flooded plots. This information was combined in a graphic that represents the percentage of cover of each mimosa heights within each area – the flooded and the non-flooded. This allows understanding the relation between water and mimosa in abundance and also growth.

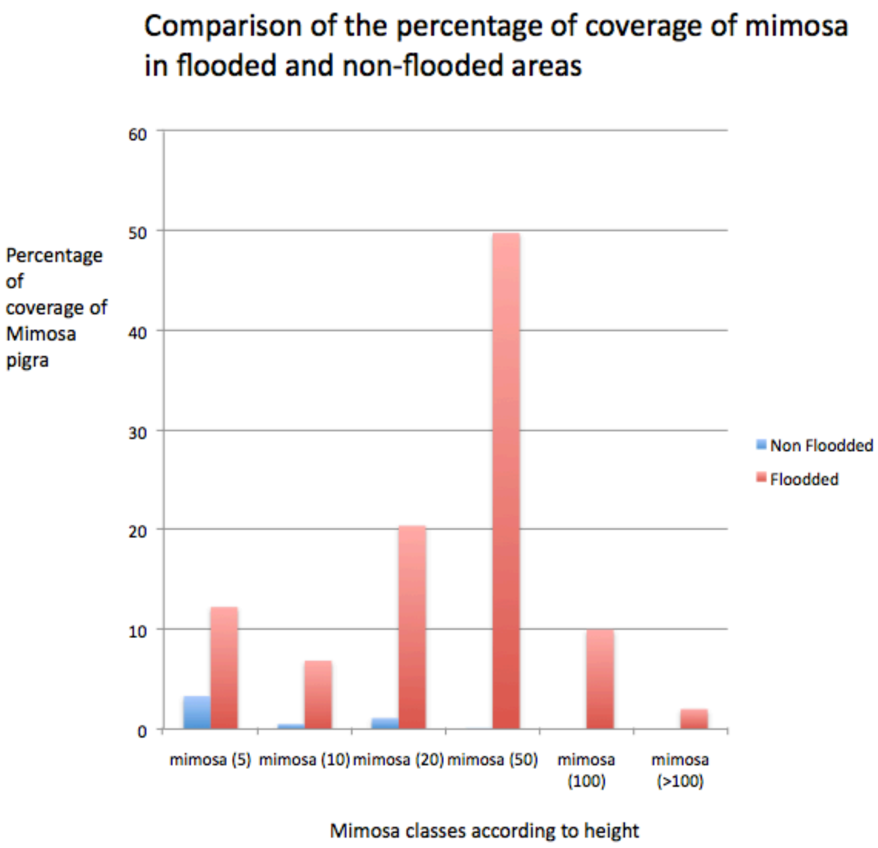

Figure 11 - A comparison between a flooded and a non-flooded area, considering the percentage of coverage of *Mimosa pigra*

This graphic clearly shows a higher percentage of coverage of *Mimosa pigra* in the flooded area than in the non-flooded area. In this graphic a total of 48 plots are represented, 27 plots in the flooded area and in the non-flooded area a total of 21.

In the non-flooded area only mimosas up to 20cm high were recorded. When compared in the flooded area the percentage of mimosas in that height range is much higher. The flooded area has a very significant percentage of mimosas taller than 50cm that represents older mimosas (considering that taller mimosas are older). The remarkable difference between the two areas is not due to any asymmetry in the distribution of the plots, since the difference of plots between the areas is rather small.

In 2008, when the major flood happened, the opportunity was created for mimosa to invade and thrive. When the water receded, the *Mimosa pigra* that germinated in the flooded area had more access to water than the mimosa in the non-flooded area, causing the second ones to die in bigger percentages due to the lack of water.

The mimosas in the flooded area kept growing, obtaining taller heights. The mimosas in the non-flooded area, probably, by the end of each rainy season, when the waters recedes, germinated, but due to the drought a lot of them died, thus having such a small percentage of coverage of mimosa in that area and a smaller height of mimosas. Water appears to be an important factor in the distribution, survival and growth of mimosa.

4. Discussion

4.1 Water as a facilitating element in the distribution and invasion by *Mimosa pigra*

The analysis of the data suggests that water is a facilitating element in mimosa invasion, with the locations that experience the high levels of the flood event in 2008, and thus are closer to the Lake Urema, having bigger abundances and heights of mimosa. It was expected that water would have an effect in the distribution of mimosa, since the seeds dispersal is mainly done by water. The results demonstrated that it also has a strong effect in the survival and growth of this species. Drought is a major cause of seedling mortality in mimosa, with survival being significantly enhanced when water is available (W M Lonsdale & Abrecht, 1989). When Tinley first recorded mimosa, in 1977, it was not considered a problem to the ecosystem of the GNP. Only in the last few years has mimosa expanded to the levels seen today, and that is probably due to the big flood event in 2008. In Australia, records indicate that in 1978, a year which was followed by a major expansion in the range of *Mimosa pigra*, there was an uncommonly high rainfall (Taylor & Tulloch, 1985 in W M Lonsdale & Abrecht, 1989).

The spread of mimosa, due to floodwaters, can be restricted by retaining vegetation cover, preventing seed movement (Weed Management Guide Mimosa - Mimosa pigra, n.d.). Although water is important for survival and growth of mimosa, it is only tolerant to flooding if some leaves remain above the water surface. If cut, the remaining stumps will die if totally immersed for more than 30 days (Thamasara 1985, in Walden et al., 2000); (Shibayama *et al*. 1983 in Paynter & Flanagan, 2004). This method has been successful in controlling mimosa in reservoirs in Thailand (Thamasar 1983, in Walden et al., 2000) and eliminated about 75% to 90% of mimosa plants in Vietnam (Thi, Thi, Triet, Storrs, & Ashley, n.d.). The combination of stem cutting and flooding was the most effective control method tested in Vietnam to control *Mimosa pigra* (Thi et al., n.d.).

4.2 Relation between *Mimosa pigra* and native vegetation – implication for invasiveness and distribution of mimosa

Considering the relation between mimosa and the vegetation, it was expected that the results would show a decrease in the density of the native vegetation in plots where mimosa was present. However, this was not the case. A possible reason for this is that mimosa was only recorded in high densities and taller heights in a small number of plots. The results showed that mimosa seedlings are quite susceptible to the type of native vegetation present and that it can provide an effective means to suppress mimosa's germination and growth, consequently controlling its expansion. Mimosa seedlings densities have a negative correlation with the density of tall perennial grasses and woody shrubs. This is due to competition for light, soil and nutrients (D'Antonio & Vitousek, 1992). Mimosa seedlings are less competitive in the presence of dense stands of grasses, and it has already been demonstrated that competitive vegetation, like grasses, suppress mimosa germination (Paynter, 2005). Rapidly growing grasses can reduce light incidence at the soil surface, reducing the photosynthetic ability of mimosa (D'Antonio & Vitousek, 1992). Grasses may be most effective as competitors against mimosa seedlings, rather than adults, since the root system of grasses and mimosa seedlings coexist at the same height. As mimosa grows, the root system becomes deeper and the competition for water and nutrients with the root of grasses that locate at an upper soil level diminishes (D'Antonio & Vitousek, 1992). The taller grasses provide shade that slows the growth of mimosa seedlings. A previous study (W M Lonsdale & Abrecht, 1989) demonstrated that no seedlings survive beyond 9 weeks in 77% of shade, nor beyond 5 weeks in 92% shade. The negative correlation, in this study, between the non-creeping perennial grasses density and mimosa seedlings density probably is not as strong as could be expected, because, as the previously mentioned study shows, with 60% of shade the seedlings continue to grow.

The use of certain vegetation types, like tall perennial grasses, seems a logical method in the control of mimosa and restoration of GNP. The goal of revegetation is not only to eliminate the disturbance of *Mimosa pigra* and return the ecosystem to its prior state, but also to avoid new invasions (Marambe et al., 2004). Although in some places, after the removal of *Mimosa pigra*, the natural revegetation was prolific, it may not be constituted by the perennial species that once inhabited that location or that exist in undisturbed floodplains (Paynter, 2004). *Panicum maximimum*, an existing grass in GNP, has showed successful results in controlling mimosa populations at younger stages and preventing the germination of mimosa seeds (Marambe et al., 2004).

4.3 Distribution of *Mimosa pigra*

From what was gathered during this study, it appears that the smaller infestations are located around Lake Urema and downstream. According to park staff, larger infestations occur upstream, in Vunduzi River, and probably other rivers where outflows occur in the rainy season. There should be an assessment of the accurate size of the Vunduzi River infestation and records of their exact locations should be elaborated, using GPS. Aerial survey by helicopter has proven the most effective method for detecting small clumps and mature mimosa plants, particularly in remote or inaccessible areas (Sanford-Readhead & Hosking, 2001). On a helicopter survey it was possible to identify larger, and therefore visible infestations, but it was not, unfortunately, possible to record the locations by GPS. The outermost extent of all these major infestations should be recorded with the use of a GPS (Attard et al., 2006).

Is considered particularly important to control mimosa upstream of uninfested areas, due to its dispersal mechanism trough the floodwaters (I. L. Miller, 2001; Walden et al., 2000), but it is also fundamental to clear the infested area upstream of Lake Urema. Although the Lake is already invaded by mimosa, without this measure, the effort of controlling mimosa around the Lake can be useless in the next rainy season, because of the dispersal of seeds from the infestation upstream, trough floodwaters.

To facilitate the control plan around Lake Urema is suggested to divide that area in sections, probably according to size of infestation and access. Working each section at a time, from clear to invaded areas, progressing towards the Lake Urema, will make the eradication of the weed more achievable.

4.4 Management plan Proposal

Is possible to eradicate small infestations of mimosa by physical or chemical means. Single plants or small outbreaks of mimosa can be removed by hand pulling or grubbing, ensuring that as much of the roots as possible are removed (Walden et al., 2000).

For larger infestations an Integrated Weed Management (IWM) is a more sustainable and effective approach (“Weed Management Guide Mimosa - Mimosa pigra,” 2003). IWM combines biological, cultural, physical and chemical methods to manage weeds, in a way that maximizes their effectiveness while minimizing economic, health and environmental risks (Paynter, Flanagan, Lonsdale, Schatz, & Steinbauer, 2000; Paynter & Flanagan, 2004). It is a successful method of ecosystem management because it accumulates the benefits of individual control techniques, and decreases the probability of mimosa developing resistance to a particular control technique (Walden et al., 2000).

The integrated approach to large, dense infestations of mimosa commences with, preferably, aerial application of foliar-applied herbicide, during the wet season, and timed to avoid periods of high temperatures and low humidity ("Weed Management Guide Mimosa - Mimosa pigra," 2003; Wingrave, n.d.). Paynter & Flanagan (2004) indicate that two aerial herbicide applications in consecutive years would greatly reduce mimosa infestation, allowing competing vegetation to rapidly regenerate.

The disadvantages in using chemical and mechanical controls are the relative costs involved, so that biological control often represents the only economically practical long-term management option (Paynter & Flanagan, 2004; "Weed Management Guide Mimosa - Mimosa pigra," 2003). Given their high initial costs, however, biological control programs are only undertaken for weeds that are a major problem over large areas (Mimosa Steering Committee 1996 in Walden et al., 2000). *Carmenta mimosa*, a biological agent released in Australia, is responsible for the most conspicuous impact on the plant, killing branches, and after several years of sustained attack they will even kill large mature plants (Flanagan & Julien, 2004). It is seen as the most promising long-term control techniques for mimosa (Paynter & Flanagan, 2002) and its release has been under consideration in Lochinvar National Park, where the Kafue Flats, a floodplain highly infested by mimosa, are located (Shanungu, 2009).

It is not adequate to rely solely upon technology to achieve effective management of mimosa. The participation by local communities has been recognized as a form of sustaining protected areas (Boer & Baquete, 1998) and, with community capacity-building, it is possible to achieve sustainable long-term control of mimosa (Ashley, Storrs, & Brown, 1995). The involvement of people in this management plan can be achieved through educational programs to raise community awareness of the ecological and economic impacts of mimosa on the park and the surrounding areas.

Mapping, planning and devoting enough resources to carry the control plan through are essential management tools. In the case of *Mimosa pigra* it can mean decades of monitoring even after the removal of adult plants, since the seeds can remain dormant in the soil for long periods of time (Lukitsch & Elliott, 2012), mechanical control rarely kills the plant, healthy mimosa is difficult to burn and plants often re-sprout (Miller and Lonsdale 1992 in Paynter & Flanagan, 2002). Many infestations were eradicated within 1 year, although 20% required sustained control for 7 years or more to prevent regeneration from the seed bank (Paynter & Flanagan, 2004). Interruptions in any control project wastes time, resources and funds, and allows *Mimosa pigra* to recover from previous treatments (Miller et al., 1992 in Walden et al., 2000). If monitoring and control actions are not sufficient to maintain the *status quo* in place at the end of the program, the entire program will have been a regrettable waste of resources (Walden et al., 2000). Annual monitoring is helpful to assess the efficiency of the control methods and to help improve weed management activities.

4.5 Final considerations

During this study an attempt was made to collect soil samples in order to count mimosa seed bank, but the soil around the Lake Urema is black clay soil. That type of soil is very hard to collect and it would be unfeasible to comply with the time available for the fieldwork. Knowledge on the seed bank of *Mimosa pigra* is helpful to understand the effort it will need to be made during the management plan, in order to keep *Mimosa pigra* from germinating in areas thought to be clear of the invasive.

An aerial survey was made during the study but it was not possible to record the location of the larger infestations. However, some interesting pictures were taken where it is possible to see a vast infestation of mimosa in this unknown area of the Park.

Also it was found that around the bigger mimosas there is a patch with no vegetation. This apparently has no relation with herbivory due to the uniformity and extension of the patch. Could this mean mimosa has allelopathy?

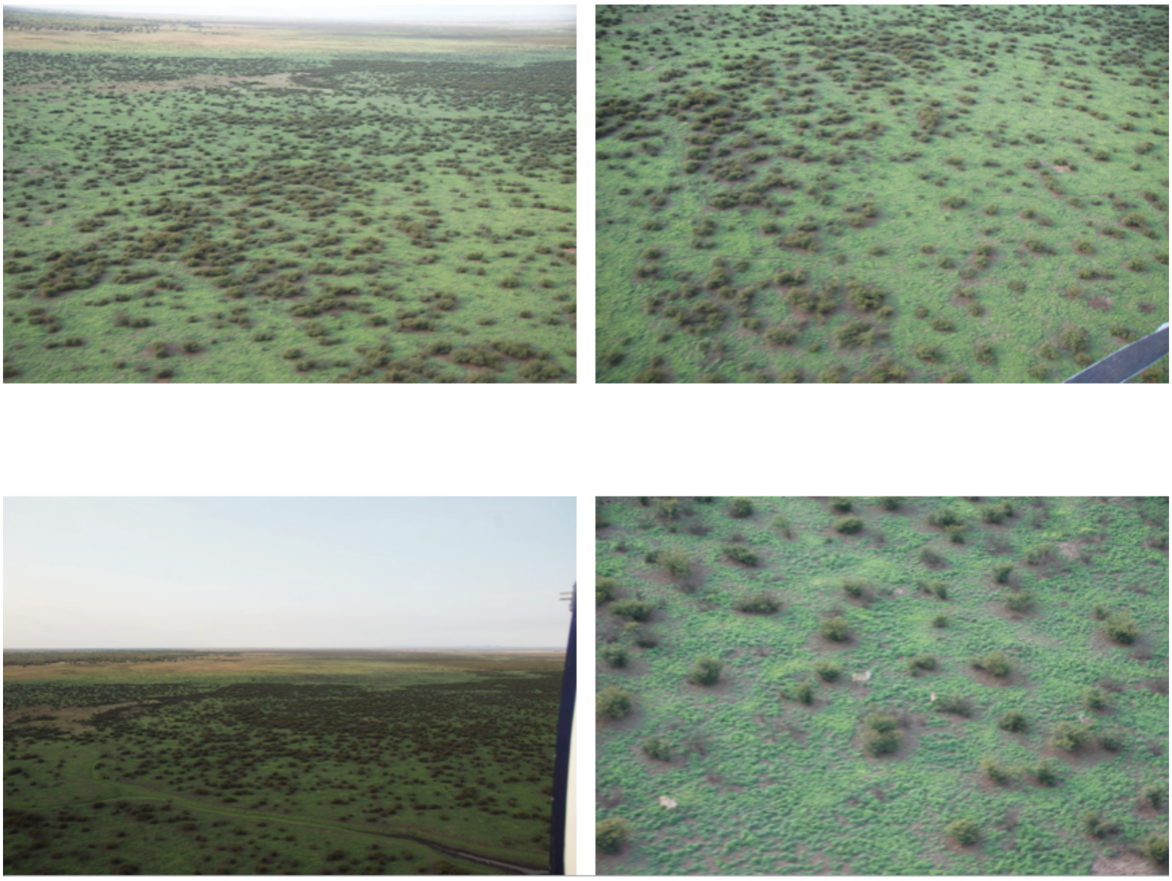

Figure 12 - Pictures taken during the aerial survey, showing the vast infestation of older, and therefore visible, mimosas and the patch with no vegetation around them (clearer on the bottom left)

The use of geostatistical methods should be attempted in order to predict the dispersion and invasion of mimosa. This data would be very useful in the context of the management plan, as it would allow for different degrees of monitoring effort to be attributed, thus avoiding human and financial efforts in areas that are not as likely to be invaded.

These considerations should be further investigated, since these particular questions are still not explored, or not sufficiently enough to provide a clear answer. Further results would provide support for the management and control plan of *Mimosa pigra* and contribute with new data for the scientific community.

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