Development of case studies on the economic impacts of invasive species in Africa

Mimosa pigra

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EXECUTIVE SUMMARY

This report details the results of an extensive desktop study to quantify the economic impacts of *Mimosa pigra* (Mimosa), an invasive weed species in Africa.

Mimosa is a thorny shrub which invades floodplains and wetlands and is established in the Kafue Flats region of Zambia. It forms thick, mono-specific stands and spreads rapidly, rendering productive land useless and impeding the movement of people and stock. Mimosa invasion of the Lochinvar National Park also has the potential to reduce tourism revenues.

This report examines the economic impact of these invasive weed species, including impacts on fishing yields, agricultural production and tourism. The impacts were valued using market prices (where available) and published data on yields and productivity.

Table 1-1: Annual economic cost of Mimosa invasion per hectare by land use in the Kafue Flats, Zambia ($US 2005)

Land use	Annual cost
Agriculture	
Cassava	$434
Maize (rain-fed)	$233
Maize (irrigated)	$649
Cattle grazing	$30
Fishing	$3 - $26
Tourism	$2.40

Mimosa is already present in many African countries, including Southern, Central and East Africa. A risk assessment was carried out for Mimosa, on the basis of both natural and structural (political) risks. This identified the Democratic Republic of Congo and Tanzania as being at significant risk of invasion by Mimosa, with further spread within Zambia noted as a significant risk.

A number of potential management methods are investigated, including chemical, mechanical and biological control. Cost-benefit analyses of management methods are presented. The effectiveness of management measures is expected to increase if a variety of methods are used in conjunction as part of an integrated weed management plan. Management costs per hectare for Mimosa varied from close to zero up to US$76. Management costs close to zero were based on the assumption that labour has a very low opportunity cost in regions where unemployment is high. However, this disguises the fact that labour availability for other domestic chores is reduced when labour is required for weed management activities.

Prevention measures to avoid weed infestation are examined, including legislative measures, quarantine controls, education and community participation, monitoring and early detection and contingency planning. Although little evidence of the cost and effectiveness of these measures was available in the literature, it was generally acknowledged that prevention of invasion was more cost effective than management of established weed populations. Annual prevention costs of less than US$2 per hectare are estimated for capital-intensive methods of monitoring and early detection to avoid establishment of weed infestations.

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1 INTRODUCTION

Invasive species are widespread in Africa and place a huge economic burden on African countries. Many different invasive species have become established in Africa, emanating both from other regions in Africa and from many locations around the world.

These invasive species have impacts on natural habitats, agricultural systems, social and cultural practices, human health, and economies.

This project focuses *Mimosa pigra,* a shrub which prefers seasonal wetlands (hereafter referred to as Mimosa). The aim of the study is to estimate the economic impact of current and potential infestations of Mimosa in Zambia. In addition, the study looks at the costs and benefits of management actions, prevention strategies and identifies countries in Africa that face similar threats.

The first two chapters present the methodology that will be used for assessment of the economic impacts and the cost benefit analysis of management actions.

The next chapter covers Mimosa, beginning with a review of its biology, moving on to assess its economic impact in the Kafue Flats, Zambia and then conducting a cost benefit analysis on potential management actions. A discussion of risk of invasion of neighbouring countries and regions is included, as well as an assessment of potential prevention measures.

2 METHODOLOGY FOR ASSESSMENT OF ECONOMIC IMPACTS

2.1 Introduction

The aim of assessing economic impacts is to determine the cost per hectare of an invasion by Mimosa in the Kafue Flats in Zambia.

The following steps are required in order to assess these impacts:

- The impact of the species on economic variables must be determined, and valued in the context of the Kafue Flats in Zambia; and
- The change in economic welfare resulting from these impacts must be estimated.

2.2 Determining the impact of Mimosa

2.2.1 Use of existing examples

There are very few studies that estimate quantitatively the impact of invasive species on production, consumption, health, transport and water access. Even fewer are based in Africa. Many studies note that much of the evidence that does exist is anecdotal (eg Mack *et al* 2000; Joffe and Cooke 1997). In addition, the studies that do exist have taken a 'top down' approach, by trying to value the costs of one or more invasive species in reference to countries, regions or globally.

This study is limited to using available data and studies. Given the dearth of African based case studies, examples from other continents have been used.

Similarly, given the lack of studies which focus on *Mimosa pigra*, the search for data was widened to include species which would be likely to have a similar effect. These species are set out in Table 2-1, and were selected for their comparable growth forms and habits (i.e. flood-plain or wetland shrub) in relation to the target species. However, aside from papers relating to the water hyacinth, no useful literature was found that related to the species in Table 2-1.

Table 2-1: Species which may have a comparable effect to the target species

Target species	Comparable species
Mimosa pigra	*Acacia spp, Albizia julibrissia, Melaleuca quinquenervia, Tamarix ramosissima*

The following steps have been taken to use the information uncovered in the literature search:

- Calculation of average values from the range of values that can be used; and
- Conversion of the impact data to a Zambian context using, where possible, local data on prices, average yields etc, where available. Where local data is not available, this is highlighted as an area where further research is needed.

There are some limitations to this approach:

- Assumptions on the business as usual case - many of the studies assess the impact on productivity by looking at the yield before and after an infestation (eg De Groot *et al* 2003). Using these figures to extrapolate to other areas means we are implicitly assuming that the business as usual rate of growth of yield would be zero, that is, that all of the change in yield found over the period of infestation can be attributed to the invasive weed. In practice, other factors are likely to be important;

- Difference in the interactions of species with ecosystems. For example, the effect of Mimosa in crowding out populations of native vegetation may be different to that of other invasive species; and
- Different baseline levels of productive efficiency in different countries mean that the impact of the invasive weeds will be different. For example, traditional low yield crops lose less to pests in absolute terms, but more in percentage terms. Even with these losses the high yield variety of crop may be more productive (Yudelman et al 1998).

Where each of these limitations is present in a valuation, they will be highlighted. The resulting values will be indicative, but can be used to gain a sense of the magnitude of the problem.

These impacts are particularly acute when offsite impacts are involved. For example, an infestation of Mimosa upstream might impact on local fish stocks downstream, if they rely on native plants for habitat or food, by reducing local floral riparian diversity. Any offsite impacts may vary greatly depending on natural and social conditions in the area.

In order to best use the case studies, comparisons of the areas where the studies were carried out to the areas where the information will be used are included, wherever the information is available.

2.3 Methodology for estimating the change in economic welfare

2.3.1 Focus on use values

Invasive species impact on both use and non-use values of natural resources:

- Use values include the values of the productivity of the natural resource. For example, rivers have a use value through the fish that can be caught in them and common land has a use value through the fuel that can be collected from it; and
- Non-use values include existence values (the value of knowing that something exists) and option values (the value of having the option to use a resource in the future). For example, biodiversity has an existence value (eg, somebody who will never see a black rhino may still take pleasure in the fact that it is not yet extinct) and option value (eg, there may be medicinal value in some plants that we do not yet know about).

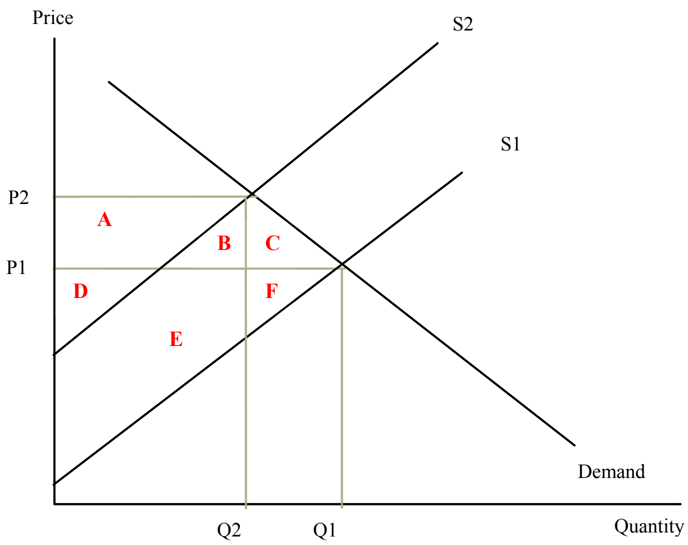
This study will focus on the impact invasive species have on the *use values* of ecosystems. Non-use values are notoriously hard to estimate. It is also argued that they are much smaller than use values in this context (De Groot *et al* 2003). An exception might be where large areas of forest are being cleared due to existing agricultural land being invaded - Wilson and McFayden (2000) noted a tendency for invaded land to be abandoned and primary forest to be cleared as a substitute.

Nevertheless, it should be borne in mind that the results of this study do not include the impact of Mimosa on non-use values and are therefore likely to be an underestimate of the total economic impact of the invasive species in question.

2.3.2 Estimation of the change in economic welfare

In order to estimate the economic impact of an infestation in a given area, the change in economic welfare should be estimated. This is valued by summing the change in producer surplus and the change in consumer surplus. To illustrate this concept, the impacts of an infestation on production and yields are illustrated in Figure 2-1.

Figure 2-1: Change in economic welfare



Before a given area is infested producers sell quantity Q1 at price P1. The amount that they are willing to supply at each price is illustrated by S1, the supply curve;

- Both the decrease in yield per hectare and the increase in the costs of production per hectare have the effect of decreasing the quantity of the product supplied at any given price, shifting the supply curve to the left (from S1 to S2);
- The new equilibrium price and quantity demanded are P2 and Q2;

- The change in consumer surplus is measured by the areas A + B + C; and
- The change in producer surplus is measured by the area E+ F –A.

In order to calculate these figures, knowledge of elasticities is required. Elasticities measure the response in demand or supply to a change in price and are the slopes of the demand and supply curves. They will vary for different commodities, for different populations, for different price levels and across time. It is therefore very difficult to obtain accurate data on elasticities of supply and demand, and for this reason no attempt is made in this study to quantify the change in producer and consumer surplus using this method. The alternative methodology adopted is described below.

2.3.3 Alternative valuation methodologies

Estimation of the changes in consumer and producer surpluses requires a substantial amount of data. Some of these data, such as estimates of demand and supply elasticity are very rare.

In practice, there is a trade off between methodological soundness and accuracy of data employed. Using the 'first best' method that is consistent with economic theory may require many assumptions to be made to cover data gaps. It will sometimes be better to use a 'second best' method which can be based on more reliable data, and to note whether this method is likely to over or underestimate the true value.

Due to the sparse nature of data available for this study, 'second best' methods have been adopted to ensure that the results are based on reliable data. Insufficient data is available to achieve a reliable result using the 'first best' method.

Table 2-2 sets out a number of methodologies and discusses their advantages and disadvantages, and when they are used in this study.

Table 2-2: Potential valuation methodologies

Methodology	Example	Comments	Should be used	Used
A. Estimate the change in producer surplus plus the change in consumer surplus	An infestation may increase the production costs and lower the yield of fish in a water body. This pushes up the price of fish increasing the cost to consumers and lowering the quantity of fish they can consume. Thus both consumers and producers are affected	'First best' valuation methodology Requires knowledge of demand and supply elasticities Accuracy will be lost if too many assumption have to be made to cover data gaps	Where enough data exists for a reasonably accurate assessment	Not used. Data regarding supply and demand elasticities required for accurate conclusion.
B. Estimate the direct cost increases incurred by producers or industries, along with the loss in revenue from reductions in the quantities produced	An infestation may increase the production costs and lower the yield of fish in a water body. This lowers the profit of producers but may not impact too heavily on consumers in an open economy, where the price is determined by imports or exports, or where the majority of the goods being produced is for export	Implicitly assumes that producers do not reduce the amount of effort they put into the activity in response to the increase in costs – that is supply falls due to a decrease in yield, but for no other reason This may not be accurate as producers may substitute effort into a different activity. Hence this method may overestimate the costs	Where exports and imports are important, and where there is not enough information for Methodology A	Used for the impacts on agriculture
C Estimate the change in production or economic activity resulting from an infestation	An infestation may lower the yield of fish in a water body. There may be few other opportunities for fishermen to use their capital and labour, hence the opportunity cost of these inputs are low, so any change in the effort they put into fishing does not have a large economic cost	May overestimate the impact on producers as it does not take into account any change in input costs. May underestimate the impact on consumers as the consumer surplus is not valued.	Where there is not enough information available to use methodology A or B, or it is likely that the opportunity costs of inputs to production are low	Used for the impacts on fishing, tourism and for the impacts of Mimosa on cattle grazing

Methodology	Example	Comments	Should be used	Used
D. Estimate the cost of replacing the ecosystem service from another source	An infestation may result in a reduction in households' access to water from common sources such as rivers. The amount of money spent on purchasing water from an alternative source is an indication of how much the free water was worth to the affected households	Ignores the fact that as well as paying more, consumers will use less of the resource that was previously free Thus this method may underestimate the costs	Where the species is impacting on a good that was previously collected from common resources such as water or fuel	Not used. Additional data required to quantify the impacts on water supply. Neither weed is likely to have an impact on fuel
E. Damage control costs	The amount of money it is decided to spend on clearing up an infestation is an indication of the value of the negative impacts it has on communities.	Public control expenditures are frequently politically influenced. In addition, they can be underestimated in the long run when fixed cost elements such as permanent salaries, training, research, etc are ignored (Joffe and Cooke 1997) The amount of time spent by individuals in clearing up infestation may be a better indication of the impact	Where data constraints do not allow use of the other methodologies	Used to estimate the impact of low density Mimosa infestations

2.4 Other methodological issues

2.4.1 Marginal versus average effects

This study seeks to value the impact of a hectare of infestation. However it is important to note that the marginal impact of a hectare of infestation is not constant. In fact, the marginal impact will depend on how many hectares are already infested. For example if one hectare of grazing land is affected by Mimosa this will have an impact on the production and profits of those producers directly affected, but would probably not have an effect on the price of animal products in the market. However, if there is substantial infestation across a whole region, the market price of the products is likely to be affected, and consumers as well as producers will thus be impacted.

Where a per hectare impact is referred to in this study, it refers to the average impact rather than the marginal impact.

2.4.2 Level of infestation

Mimosa has a pattern of invasion which builds steadily over time. Costs of impacts for Mimosa are given for both high and low levels of infestation. A low level of infestation is defined as an infestation in the early stages of establishment, which can still be controlled by hand, and a high density infestation is defined as one which has completely taken over the land and rendered it unavailable for other use. There were not enough data in available to distinguish any further between levels of infestation.

2.4.3 Shadow price of labour

Zambia has a very high unemployment rate of 50% (CIA, 2006). Because of the lack of opportunities for labour in Zambia, it is assumed that the shadow price of unskilled labour is close to zero. That is, the opportunity cost of their labour to society is close to zero as there is a large surplus of labour.

This follows Turpie (2004) who argues that the shadow price of labour in the Working for Weeds programme in South Africa should be close to zero, due to the high unemployment rates in that country and the fact that the programme targets unskilled, unemployed labour.

This implies that any impact that the weeds have on labour requirements does not have an economic cost to society.

However, it is clear that there is a financial cost to hiring labour – management agencies still have to find room in their budget to pay wages of unskilled workers. This cost is identified in the management section.

2.4.4 Discounting

Where it is necessary to take into account costs and benefits are occurring over time, a discount rate of 10% will be used.

3 METHODOLOGY FOR COST BENEFIT ANALYSIS OF MANAGEMENT AND PREVENTION ACTIONS

3.1 Introduction

The aim of the cost benefit analysis of management and prevention actions is to determine which actions can be employed most beneficially to clear land of Mimosa or to avoid invasion by this species.

In order to assess the costs and benefits, examples of cases where each management technique has been used in the past are examined. The costs of implementing these management techniques in the Kafue Flats for Mimosa are then estimated by using a schedule of costs developed for each area and applying these to the amount of inputs needed to manage the species as found from the case studies. Note that management techniques (i.e. clearing established infestation) and prevention measures (i.e. avoiding infestation) are considered separately in this report. It is likely that an effective land management plan will combine both of these approaches.

3.2 Costs and benefits to whom?

Costs to society

The aim of a cost-benefit analysis is usually to assess the costs and benefits to society (in practice usually the inhabitants of one country). There are several implications for this including:

- Costs should be presented net of taxes, as taxes are simply a transfer from one agent in the economy to another, rather than a real cost; and
- Shadow prices, representing the opportunity cost of the resource in that society, should be used. For example, as unemployment is extremely high in Zambia (particularly in rural areas), the shadow price of unskilled labour for weed control could be considered to be close to zero as it can be assumed that many of those employed in the weed management effort would otherwise not be engaged in any productive economic activity. However, it should be noted that labour spent on weed management efforts reduces the availability of labour to be spent on other tasks such as caring for children, collecting fuel, tending subsistence agricultural plots, fishing etc. Although these activities may not all be recognised for their economic value they are important tasks in the context of these communities.

In order to assess the societal costs and benefits, the costs and benefits to Zambia of managing a hectare of each weed will be examined using tax free prices and shadow prices.

Costs to agencies involved in management

The financial cost of management techniques to those who will be implementing them is also of interest. For example, even though the shadow price of labour might be close to zero, government agencies and NGOs still have to meet the actual cost of this labour out of their budgets.

Therefore, as well as a standard cost-benefit analysis, an analysis comparing the financial costs to the benefits will be presented.

3.2.1 Costs

Estimates of the costs of management and prevention actions are taken from other studies and converted to the context of the regions being examined in this paper through the use of data on costs specific to those regions.

The following are key methodological issues:

- Only studies relating to the specific weeds were used. For example, although Mimosa may have similar economic impacts to other invasive shrubs, the management regime may be very different. Studies relating to the management of other invasive shrubs are thus not relevant for costing purposes;
- Subsequent infestation by another weed. Management of one weed species can sometimes result in a later infestation by another weed. This was the case in Lake Naivasha in Kenya. After successful control of a floating aquatic weed, *Salvinia molesta*, through the introduction of Salvinia-specific biological control, the lake was subject to a water hyacinth infestation with even more severe consequences (ECZ 2004). While the risk of reinfestation by the target weed species needs to be recognised when a management decision is being made, the costs of subsequent infestation by another weed will not be incorporated into the cost-benefit analysis. This would require estimating the economic impacts of infestation by other weeds, which is beyond the scope of this study; and
- Environmental non-use costs of management actions have not been quantified; however they will be discussed qualitatively.

3.2.2 Benefits

The benefits of management and prevention are assumed to be equivalent to the avoided economic impacts of the weed, as identified in Section 5. Note that where there are benefits gained from the weed species, such as for compost, fire wood or charcoal production, this is not considered here.

The qualifications applied in Section 5 are relevant here also. In particular, it should be recalled that this assessment is only concerned with use values. Environmental non-use values have not been assessed. However, where these non-use values are likely to be important their presence will be noted.

Where a management action has only been temporarily effective, the benefits will be assumed to be zero. Some benefits may have been realised during the short period over which the infestation was cut back before reinfestation occurs. However, these benefits are likely to have been minimal.

Note that there is anecdotal evidence of weed removal contractors or employees deliberately carrying out their work ineffectively, to enhance the possibility of ongoing work. That is, weed control efforts are poorly executed by the contractor to ensure re-infestation occurs and further work becomes available. This analysis assumes that weed clearing efforts are carried out properly, and levels of effectiveness arising from private weed clearing efforts (where no such perverse incentives exist) are used.

3.3 Consideration of institutional capability

While integrated weed management is widely considered to be the first best method of weed control, some commentators say that biological control of weeds is the only method that is affordable and sustainable in resource poor developing countries (eg Wilson and MacFadyen 2000).This is due to the need for a particular degree of institutional capacity required to support the introduction and maintenance of any weed management measures (as well as capital resources and technology).

Institutional capability will be discussed qualitatively during the assessment, but will not be explicitly costed.

3.4 Crowding out of private sector activity

It has been noted that government provision of weed control can create a dependency among farmers and discourage them from managing the problems themselves (eg FAO 2001).

However, set against this problem is the fact that pest control is a public good – one individual’s refusal to invest in weed control will have consequences on neighbouring areas.

In addition, weed infestations frequently occur on common land (such as in nature reserves and national parks, on government controlled land (such as water catchment areas) or on land under the control of a local community leader rather than private individuals), requiring government efforts to control them.

While it is recognised that in some circumstances, government intervention will crowd out actions that individuals would have taken anyway, this effect only affects the incidence of the costs (i.e. who bears them), rather than their magnitude. Thus it will affect the financial cost to policy makers but not the overall cost to society.

In the financial assessment presented below it is implicitly assumed that complete crowding out occurs, so 100% of the management has to be undertaken by policy makers.

4 BIOLOGY OF MIMOSA PIGRA

4.1 Introduction

Mimosa is a large prickly shrub, which becomes woody as it ages. It is regarded as one of the worst weeds in the world because of its invasiveness, potential for spread, and economic and environmental impacts. It forms large impenetrable stands that prevent access to watering holes and grazing areas and reduce feed for stock. It prefers floodplains, waterways, seasonally inundated wetlands and other soils which are well watered. It is native to tropical America and has now become a significant weed in Africa, India, some Pacific islands and South-East Asia.

4.2 Taxonomy

The Taxonomy of Mimosa is presented in Table 4-1.

Table 4-1: Taxonomy of *Mimosa pigra*

Class:	Magnoliopsida
Order:	Fabales
Family:	Fabaceae
Genus:	*Mimosa*
Species:	*Mimosa pigra*
Common Name:	Mimosa
Other Common Name:	Giant Sensitive Plant

4.3 Description

Mimosa is a branched prickly shrub which can grow up to 6 metres tall (Figure 4-1). The bipinnate leaves fold up at night. The tree is covered in large thorns on the stem and smaller thorns on the branches. The shrubs have distinctive flowers (Figure 4-1) which mature to produce long seed pods, which break up and distribute large seeds. These seed pod fragments are hairy and float in water. They are easily distributed by floodwaters and by attaching to clothing and to animals' coats.

Figure 4-1: ***Mimosa pigra*** **(growth habit and flower heads)**

(credits: www.peterfaustdam.com/mimosapigra.asp; www.ecocrop.fao.org)

4.4 Natural distribution and habitat

The native range of Mimosa is from northern Mexico (25°N) to just south of Rio de Janeiro (23°S) in Brazil. The species prefers a tropical wet-dry (savannah) climate and rainfall of over 750mm but it has no preference for soil type. It has broad tolerances and will occur in many habitats, especially after natural or human disturbance.

Mimosa prefers wetlands, floodplains, riparian zones and watercourses but will invade agricultural areas, coastal zones, forest areas, and grasslands, particularly if the soils have been disturbed. Mimosa is particularly effective at colonising the bare flats left by floodwaters and at establishing virtually monospecific stands. Seasonal inundation, even at depth, stimulates the species to grow and flower.

4.5 Ecology

The Mimosa plant is a robust species with many characteristics that allow it to take advantage of a range of conditions. It has the potential to become weedy, even in its native range. For example, in Costa Rica, Mimosa is expanding into areas of rice cultivation, drainage channels and overgrazed areas.

The plants have many flowers and each flower results in many seeds. A mature infestation can produce 9000 seeds per square metre of Mimosa canopy cover. Large single or isolated Mimosa can produce even more seeds. Flowering can continue to occur as long as water is available and therefore seed production is enhanced in floodplain or seasonally inundated environments.

Seedlings can germinate long after adult plants are removed as seeds can be long lived (up to 2 years on clays and up to 25 years for seeds in sandy soils).

Furthermore, Mimosa seeds float in water and are easily transported along waterways and during floods. The hairy seeds adhere to hair, fur and clothes and can be transported easily. Seeds can be mixed with mud which can attach to vehicles and equipment and be further distributed by this means.

Mimosa plants also spread by suckers (new plants arising from underground rhizomes) and can consolidate and expand in areas where it is introduced. This leads to mono-specific stands out-competing other species.

Seedlings germinate in the dry season as floodwaters recede. Seedling survival is determined by the availability of soil moisture (Lonsdale & Abrecht 1989).

The rapid expansion of the weed during the 1970s in Australia was a result of the prolific seed production and unusually high recruitment during a very high rainfall period (Lonsdale & Abrecht 1989).

Outside of its native habitat in South America, Mimosa is not found growing in low densities. It very quickly takes over land, and no other vegetation can survive beneath it.

4.6 Environmental tolerances

Mimosa is a robust species with wide environmental tolerances enabling it to colonise a range of habitats and locations.

Mimosa stands are known to exist where salinities reach up to 18 ppt (about half that of seawater) but the plants growing in saline waters tend to be stunted.

The plants have broad temperature tolerances, as would be expected with a wide natural range, commonly withstanding minimum temperatures of 15°C – 24°C and maximum temperatures of 30°C – 36°C. Mimosa has withstood temperatures of 13°C in the Northern Territory, Australia.

4.7 Introduced Range

Mimosa has been distributed to almost 50 countries and to every continent since the 19th century. Its folding leaves make it a curiosity from an ornamental viewpoint. Seeds are also easily transported accidentally as they attach themselves to humans, animals and vehicles. In Australia, the invasion showed a classic pattern of introduced organisms - a 60 year lag phase was followed by a dramatic expansion in the 1970s.

The earliest reporting of the species outside it native range was 1829 in Egypt (Lonsdale *et al* 1989). Table 4-2 lists the countries and known dates of first introduction.

Table 4-2: Known introduced range of *Mimosa pigra* and earliest known dates of introduction

Africa	Asia Pacific	Americas
Angola	Australia	Dominican Republic
Benin	Cambodia	USA
Botswana	Fiji	
Burkina Faso	French Polynesia	
Burundi	India (1867)	
Cameroon	Indonesia	
Central African Republic	Malaysia	
Chad	New Caledonia	
Egypt (1829)	New Zealand	
Ethiopia	Papua New Guinea (before 1960)	
Gambia	Philipinnes	
Ghana (1925)	Sinagpore (1965)	
Guinea (1898)	Sri Lanka	
Guinea Bissau	Sumatra (1975)	
Ivory Coast	Thailand (1947)	

Africa	Asia Pacific	Americas
Kenya	Vietnam	
Liberia		
Madagascar		
Madagascar		
Malawi		
Mali		
Mauritania		
Mauritius		
Namibia		
Niger		
Nigeria (1822)		
Rwanda		
Senegal (1824)		
Sierra Leone (1891)		
Somalia		
South Africa		
Sudan		
Swaziland		
Tanzania		
Togo		
Uganda (1862)		
Zambia		
Zimbabwe		

4.8 Invasion pathways

One of the characteristics that makes Mimosa a successful invader is the fact that it can disperse it seeds in so many ways. Seeds are extremely numerous and long lived and are distributed by wind, water, people, animals, vehicles and machinery. The seeds are hairy and stick to clothes and fur and can also be transported via mud. They can survive passage through the alimentary canals of animals and can then be deposited in animal dung. Birds may also transport seeds though this has not been clearly demonstrated.

Botanical and garden escapees are also common due the curiosity factor of the sensitive leaves (which close on touch) and are often distributed and kept for this reason. A single plant can produce up to 220,000 seeds per year and these could be transported long distances from the source plant to begin distant populations.

Dispersal rates of Mimosa have been measured by Walden *et al*. (2004). If wind dispersal only was involved then estimated rates of dispersal would have been 18 metres per year, whereas the actual measured rate of dispersal was 76 metres per year in the Northern Territory floodplains (Lonsdale 1993). This indicates that waterborne dispersal must have been involved with flood waters rapidly and extensively distributing seed across the vast floodplains of northern Australia. In the early 1990s, Mimosa areas doubled within 1.2 to 1.4 years in prime areas for Mimosa whereas in marginal habitats it took approximately 6.7 years to double in area. On the Gunbalanya floodplains of Northern Territory, Mimosa expanded from 200ha in 1984 to 6000ha by 1991.

4.9 Current status in Africa

Mimosa is very widespread in Africa and has spread through almost all of the African countries with suitable habitat. It is specifically recorded in over 30 African countries (refer to Table 4-2 for details). While it was noted to be widely distributed in Africa by early explorers (Bentham 1975 in Lonsdale et. al. 1989) it is not believed to be native to Africa. The species in Africa is identical to the form of Mimosa that is present in the Americas, which confirms it is not native to Africa. Therefore the early widespread presence in Africa is inexplicable.

5 Economic impacts of Mimosa in the Kafue Flats, Zambia

5.1 Likely impacts

Direct impacts

The principal route by which Mimosa has a direct economic impact is through taking over, or threatening to take over, land and wetlands that could otherwise be used for agricultural production, fishing, or to support native biodiversity which attracts tourists. Land taken over by Mimosa can also impede access to waterways or block transport routes.

Mimosa may also increase the frequency and severity of fires, however no evidence was found where this has actually occurred.

Indirect impacts

Mimosa also affects the services provided by wetlands. Aside from being important for biodiversity, wetlands have the following functions through which Mimosa can indirectly affect economic activities (Seyam *et al* 2001):

- Nutrient retention and recycling;
- Groundwater recharge;
- Flood control;
- Sediment retention;
- Erosion control and
- Climate stabilisation.

These indirect impacts will not be quantified. In each case it would be very difficult both to isolate the contribution that Mimosa is making to the outcome, and to put a value on the outcome. For example, the impact Mimosa has on the incidence of floods and the cost of these floods when they occur will depend on a huge variety of factors specific to each locality.

However it should be noted that our estimates of the economic impact of Mimosa are incomplete, because they do not take account of these indirect effects.

5.1.1 Evidence of economic impacts

Evidence of the impacts of Mimosa are summarised in Table 5-1 and discussed in further detail below.

As can be seen from Table 5-1, quantitative evidence on the impacts of Mimosa is sparse. However, the following points can be made:

- National parks and grazing land are most vulnerable to Mimosa outbreaks;
- The heavier the land is grazed, the more vulnerable it is to Mimosa infestation as the animals churn up the ground creating ideal conditions for the weed to spread (John Thorpe, Australian Weeds Committee, pers. comm. 11/10/06.);
- Mimosa has not been a major problem on land used for crops, except in South East Asia. This is because farmers successfully apply weed control practices to manage Mimosa and other weeds, and therefore outbreaks can be kept from taking over farmland (Hong Son, N *et al* 2002). There is however a cost associated with these prevention and control activities.

The key point is that Mimosa is most successful on land that is not intensively managed, and is more likely to establish where land has been disturbed. National parks, and common land areas which are used for grazing, are most vulnerable to infestation. For example, wetland national parks are very seriously threatened by the weed (Hong Son *et al* 2002), while large scale commercial cropping farms such as those near infested land in the Northern Territory, Australia have not been impacted (John Thorpe, Australian Weeds Committee, pers. comm. 11/10/06). (Note however that the availability of resources to control weed invasion in the Australian context will be very different to the African context.)

Table 5-1: Evidence of economic impacts of Mimosa

Economic activity	Zambia – Kafue Flats	Australia –Northern Territory and Queensland	Cambodia
Tourism	Harder to catch poachers, as well as impeding tourists' access and views in the park (ECZ 2004)	On average US $1.3m per year was spent on the protection of Kakadu from Mimosa in the Northern Territory from 1996-2002 (Sinden *et al* 2004)	No evidence found
Livestock	Reducing the rangeland available for cattle herding, inhibiting access to watering points and other grazing lands (ECZ 2004)	Mimosa takes over grazing area (Walden *et al* 2004)	No evidence found
Crops	Perception of reduced productivity and increased effort (ECZ 2004)	Mimosa is not known to be impacting on any crops in Australia at present (Dave Walden, Environmental Research Institute of the Supervising Scientist, NT, Australia pers. comm.11/10/06, John Thorpe, Australian Weeds Committee, pers. comm. 11/10/06)	Increase in farm input costs of about 5-10% due to clearing effort before rice is planted. No impact on yield once Mimosa has been cleared. (Chamroeun *et al* 2002) Increase in time and money spent preparing agricultural land (Sanmouth 2002).
Fishing	Perception of reduced catch and increased effort among locals (ECZ 2004)	No information on impacts available	Decline in proportion of fish species without scales in annual catch in Kandal Province. No decline in fish catch overall (Chamroeun *et al* 2002). Declines in fish catch, difficulties in accessing wetlands for fishing and disappearance of several species of white fish (Sanmouth 2002)
Water supply and water quality	No significant impact observed (ECZ 2004)	No information on impacts available	
Fire	No evidence found	No evidence found	No evidence found

Evidence of economic impacts in the Kafue Flats

In 2004, a survey was carried out on 28 individuals living in the Lochinvar Park area. These included representatives of the Zambian Wildlife Authority, the Fisheries Department, fishermen, pastoralists, tour operators and staff (ECZ 2004).

The survey found that Mimosa has impacted on the following areas:

- Tourism – by causing accessibility difficulties for law enforcers charged with controlling poaching activities, as well as leaving reduced rangeland for wildlife and obstructing game viewing for tourists;
- Livestock - by reducing the rangeland available for cattle herding, inhibiting access to watering points and other grazing lands;
- Fishing – reduced catches or increased catch effort and reduced access to fishing areas and entanglement of boats in Mimosa;
- Crops – reducing the crop harvest or increasing the work effort; and
- Water quality and quantity - the survey did not find that there was an impact on either water quality or quantity, though it is noted that this could have been because of difficulties in respondents' comprehension of the technical questions on water. However, respondents did observe that water channels had been claimed by Mimosa.

The most important impacts identified by respondents were to do with accessibility for themselves and their livestock. Reductions in fish harvests and crop harvests were identified by a smaller number of respondents.

Evidence of economic impacts in Australia

Invasions of Mimosa have occurred in both the Northern Territory, where 800ha is covered, and more recently in Proserpine in Queensland, where Mimosa is spreading around a dam:

- Tourism – In the Northern Territory the plant risks affecting tourism to areas like Kakadu, and the Whitsundays in Queensland. On average AUS$1.5m (approximately US $1.3m per year from 1996-2002 was spent on the protection of Kakadu from Mimosa in the Northern Territory (Sinden *et al* 2004);
- Livestock – Mimosa has been reducing the area available for grazing(Walden *et al* 2004);
- Cropping – Mimosa has not had an impact on crops in Australia yet. Cropping tends to be large scale in the Northern Territory and intensive weeding is carried out to protect against all weeds. Thus it is difficult for Mimosa to get a foothold (Dave Walden, Environmental Research Institute of the Supervising Scientist, NT, Australia pers. comm. 11/10/06). However, there is a worry that sugar cane might be particularly vulnerable to Mimosa invasion. (John Thorpe, National Weed Management Facilitator with the Australian Weeds Committee, pers. comm. 11/10/06)
- Water supply - There is little or no quantitative information available on whether Mimosa impacts on water supply or water quality in Australia. However, due to its large biomass compared to grassland, it is likely that it increases evapotranspiration. In addition, it has a tap root that goes to two metres so it does withdraw from water tables. (Dave Walden, Environmental Research Institute of the Supervising Scientist, NT, Australia pers. comm.. 11/10/06)

Evidence of economic impacts in South East Asia

Two surveys were carried out in Kandal province, Cambodia in 2001-2 to collect primary data on Mimosa's impact on rice farming and fisheries (Chamroeun *et al* 2002).

The results of this survey show the following:

- Crops - overall, the farmers ranked Mimosa as the most significant problem affecting rice farming, ahead of pests, rodents, and drought problems. Farmers with Mimosa on their rice land incur labour costs to remove it prior to rice planting. On an average, these costs represented about 5-10% of the total farming input costs. The relationship between land that had been cleared of Mimosa and rice yield was tested but no relationship was found;
- Fishing - fishermen said that the proportion of fish species without scales has declined in the annual catch. However, there was no decline in fish catch overall. However, in Kompong Cham in Cambodia, Sanmouth (2002) spoke to locals who said that their overall catch had declined, they were having difficulties accessing the water, and several fish species had disappeared; and
- Water supply - about 40% of the households surveyed reported that Mimosa pigra caused problems to irrigation canals. Where the density of Mimosa pigra in canals was high, it reduced the flow of water to rice paddies. Further, the dense stands of Mimosa pigra drew considerable water from the canals, resulting in shallower canals and less water overall for rice paddies.

The impact of Mimosa on tourism and livestock were not discussed.

In addition, Sanmouth (2002) discussed with stakeholders what the impact had been in some areas in Cambodia. Stakeholders there had experienced declines in fish catch, difficulties in accessing wetlands for fishing and disappearance of several species of white fish as well as increased amount of time spent working on agricultural land.

5.2 The Kafue Flats floodplain system

5.2.1 Introduction

The Kafue Flats region is located in southern Zambia on the Kafue River, one of the main tributaries of the Zambezi River. The Flats are a floodplain that covers an area of more than 6,500 km^2 (Cabwela and Mumba 1996). Two national parks are located here, the Lochinvar National Park and the Blue Lagoon National Park. An area of 83,000ha covering parts of both parks has been designated as a wetland of international importance and has Ramsar status (Mumba 2005).

The parks are surrounded by Game Management Areas (GMAs) – buffer zones in which small scale agriculture and fishing are allowed. The GMAs are quite heavily populated; approximately 200,000 people live in the Blue Lagoon GMA alone (Mulenga Bwalya 2003). Overall, around 1.3 million people live in the Kafue Flats (Mumba 2005).

Figure 5-1: Map of the Kafue Flats

Source: WWF (http://assets.panda.org/img/original/kafuemap.gif)

5.3 History of introduction of Mimosa to the Kafue Flats

The Kafue Flats sit between two dams which have completely changed the hydrological regime of the river system. The Kafue Gorge dam was completed in 1971 and the Itezhi-tezhi dam was completed in 1978 (Mumba and Thompson 2005). Since probably the 1970s the Flats have been subject to the invasion of Mimosa (ECZ 2004). Mimosa was recognised in the 1980s as a weed that might require management in this area (Mumba and Thompson 2005).

As with many weed invasions, disturbance of the local environment and processes (such as the building of dams) are important factors which have encouraged the spread of Mimosa (Mumba 2005). Slowing down the flow of water generally promotes weed growth (Chabwela and Mumba 1996). The dams have meant there is less natural flooding of the river system. This has meant that numbers of palatable plants such as *Echionchloa sp*, *Vossia cuspidate* and *Acroceras macrum* have declined. Instead woody plants such as *Mimosa pigra* and *Dischrostachys cinerea* are invading (Mumba 2005).

Mimosa thrives mainly in the areas of the Kafue Flats which are now permanently inundated with water due to year-round water release from the Itezhi-tezhi dam and the flooding behind the Kafue Gorge dam. Other native species which cannot withstand prolonged flooding are being taken over by Mimosa (Mumba and Thompson 2005).

5.4 Socio–economic context

The most important economic activities in the Kafue Flats floodplain are as follows:

- Small scale agriculture – most of those living in the floodplain engage in small scale agriculture, growing groundnuts, maize and cassava (Mumba 2005, Chabwela and Mumba 1996); Cash crops of cotton are also grown on a small scale (Mulenga Bwalya 2003);
- Cattle grazing- 10-20% of the floodplain are used for cattle grazing (Mumba 2005). During the dry season pastoralists graze their animals on the wetlands (Mulenga Bwalya 2003);
- Fishing- Small scale fishing is carried out both within and outside the two National Parks (Mulenga Bwalya 2003). Commercial fishing is important elsewhere in the Flats;
- Tourism – though underdeveloped in the floodplain, it is still arguably the most important industry in the area, at least in its potential to employ and generate income (Mulenga Bwalya 2003);
- Hydroelectric power generation - there are two dams for hydroelectric generation, one at the Kafue Gorge and another at Itezhitezhi; and
- Water supply - nearly all of the water in nearby Lusaka is sourced from the flats and the area is also an important supplier to commercial agriculture and industry.

No wage rates were found that were specific to the Kafue Flats area. Table 5-2 shows the official minimum wage in Zambia. Where a Mimosa infestation causes additional labour costs to be incurred, for example in clearing, it is assumed that this minimum wage would apply. With unemployment currently at around 50% (CIA, 2006), the shadow price, or opportunity cost of labour is probably around zero.

Table 5-2: Wage rates (US$ 2004)

	Estimate	Source
Unskilled labour	$16.50 per month (83,200 kwacha) $0.69 per day	Minimum wage -US Department of State (2006)

5.5 Mimosa in the Kafue Flats floodplain system

Mimosa began to invade Lochinvar National park in the 1980s and is now covering an area of more than 2,600 hectares of the Park. The Blue Lagoon park is not yet infested (ECZ 2004, Mumba 2005).

5.6 Estimating the economic impact of Mimosa at different levels of density

A typical stand of Mimosa comprises one plant per square metre (Chopping 2002), but densities can be as high as two to eight plants per square metre (Hong Son *et al* 2002).

While there is little quantitative information on the impacts of Mimosa invasions at different levels of density, a distinction can be made between low density and high density infestations:

- Low density infestations involve young plants only. They can be kept in check through regular manual or chemical weeding; and
- High density – a high density infestation results where plants have been allowed to reach maturity and have completely taken over the land or wetland, excluding native plants, impeding access and preventing the use of land for other purposes.

Low density infestations are likely to occur on land that is used intensively – in practice this will usually be agricultural land. High density infestations will occur on land that is managed less intensively, such as common land used for grazing, common fishing resources and national parks.

Given the lack of quantitative evidence of the impacts of low density invasions of Mimosa on economic activity, it is proposed that the costs of manual management of the infestations (see Methodology D, Table 2-2, page 14) are used as a proxy for the damage costs of Mimosa at low levels of infestation. The resulting costs are set out in Table 5-3.

High density infestations are assumed to completely take over the land or water resource and remove any productive capability of that resource. Thus the impacts of high density infestations are valued as the lost productive capacity of the land.

Table 5-3: Costs of managing low density invasion of Mimosa

	Days	Wage cost in the Kafue Flats	Opportunity cost
Low density-seasonally inundated wetland	46 Value for maintenance of paddy fields Hong Son *et al* 2002)	US$32 per ha	Close to 0
Low density– rain fed land	10 Assumed that given the Mimosa is less invasive on drier land less labour is needed to keep it clear	US$7 per ha	Close to 0
Low density-irrigated land -	23 Assumed that given the Mimosa is less invasive on drier land, maintenance would only need to be carried out at half the levels of that in seasonally inundated paddy fields.	US$16 per ha	Close to 0

5.7 Mimosa and agriculture

Mimosa invasion has the potential to reduce yields and increase inputs to production for a range of agricultural products and can interfere with agricultural production in a number ways:

- Taking over land that could otherwise be used for production;
- Interfering with machinery used in cultivation and harvesting (although most subsistence farming is reliant on manual labour only);
- Hindering and/or preventing access to productive land;
- Competing for water and nutrients; and
- Reducing the efficiency of irrigation.

This section focuses on the economic impacts of Mimosa invasion on agricultural production, particularly decreasing productivity, increasing labour inputs to production, and declining area of land available for production.

5.7.1 Evidence of the impacts of Mimosa on agriculture

There is some evidence of the impact of Mimosa infestation on the production of rice (e.g. Chamroeun *et al* 2002) and there are fears that it may impact on sugar cane in Australia (John Thorpe, Australian Weeds Committee, pers. comm. 11/10/06).

There is also evidence that Mimosa has taken over land that could otherwise be used for production. In the Mekong River Delta thousands of hectares of alluvial land formerly used for agriculture is now occupied by the weed. (Hong Son *et al* 2002)

However, there is no evidence in the literature that Mimosa impacts on either maize or cassava, (the two most significant crops in the Kafue Flats region).There is thus uncertainty about whether Mimosa impacts on these crops at all.

A summary of evidence found in the literature is provided in Table 5-4 below.

Table 5-4: Evidence of the impacts of Mimosa on agricultural production

Study	Crop	Infestation	Estimated degree of negative impact	Country	Notes
Chamroeun *et al* 2002	Paddy rice	Young plants invading paddy fields	Production inputs increased (weed-clearing) by 5% - 10% to ensure no decline in yield	Cambodia	Labour to control Mimosa was equivalent to 20 days annually per hectare, based on survey results - average of TonleSap and Mekong deltas (range 15.5 to 25 days).
Hong Son *et al* 2002	Paddy Rice	Young plants invading paddy fields	Production inputs increased (weed-clearing) to ensure no decline in yield - 46 days per hectare per year	Viet Nam	Labour to control Mimosa was equivalent to 46 days annually per hectare, based on experimental data. Range 30 days/ha for low density infestation to 60 days/ha for dense infestation).

Due to the absence of any quantitative evidence regarding the impact of Mimosa infestation on cassava and maize yields, the impacts of infestation on rice yields are used as an indicator of the potential impact on maize and cassava. It should be noted however that the effects of infestation may vary due to the differing water requirements for the crops being considered. Given Mimosa's preference for wetland, the high water requirements of rice suggest that the impact of infestation may be greater than for maize, and considerably greater than for cassava. Cassava is drought resistant and is commonly not irrigated.

Mimosa infestations occurring in Australia do not currently have an impact on agricultural production (John Thorpe, Australian Weeds Committee, pers. comm. 11/10/06). This may be due to the fact that agricultural land in Australia is cultivated commercially and with high capital intensity and is usually well maintained.

The required effort shown above to control Mimosa infestation in Asia is likely to be higher than in Zambia. The inundated rice paddy environment is more conducive to establishing and thriving Mimosa populations than the dry-land agricultural regions of Zambia. Therefore, infestation is expected to be less aggressive and more easily controlled in Zambia.

5.7.2 Agricultural production in the Kafue Flats in Zambia

In the Kafue Flats region, a large part of the population is dependent on agriculture for their livelihood. Most agriculture takes place on a subsistence, small or medium scale, with many households growing maize and cassava for their own consumption – although 22% of the maize harvest is sold (Bwalya, 2003).

Cattle grazing for subsistence and sale also takes place, with reliance on the waters and pastures of the Kafue Wetlands for livestock maintenance during the dry season. Because the impacts on cattle grazing are very different, these will be dealt with separately in Section 5.8 below.

Yields

Cassava is grown in the Kafue Flats on a small scale for local consumption (Chabwela and Mumba 1996). Maize is the other crop most commonly grown for consumption – maize is commonly rain-fed although irrigated crops also exist. Data taken from the literature regarding the yields for both of these crops is stated in Table 5-5 below. Considerable variation in yields stated is possible, depending on factors such as soil type, fertiliser use and variety selected, as well as seasonal variations according to meteorological conditions and other factors (such as increased incidence of pests and diseases).

Table 5-5: Typical crop yields in Zambia (tonnes/ha)

Crop	Yield (tonnes per ha)	Source	Note
Cassava	12 - 15	Haggblade and Zulu, 2003.	Potential yield at small scale with new varieties. Commercial yield up to 30 t/ha.
Cassava	7.5	Haggblade and Zulu, 2003.	Yield in 2002 – improved varieties yet to penetrate. Average area 1.43 hectares
Cassava	5.8	Alabi *et al*, 2001	
Maize	1.5	Haggblade and Zulu, 2003.	Rain-fed, figures for 2002
Maize	1.3	http://www.cfa-international.org. Commonwealth Foresters Association	Rain-fed, Figures for 1998
Maize	0.75	http://www.lifenets.org/zambia/9-19-05.htm	Rain-fed, subsistence farming
Maize	1.75	FAOSTAT	Rain-fed, subsistence farming
Maize	1.2	Siegel and Alwang, 2005.	Rain-fed, 1990s, low technology inputs
Maize	2.5	Haggblade and Zulu, 2003	Rainfed, high yielding variety, small scale farming
Maize	5.3	FAOSTAT	Irrigated, small-scale farming
Maize	5 - 6	http://www.lifenets.org/zambia/9-19-05.htm	Commercial farming (irrigated)

Price

Most cassava and maize crops are produced for household consumption rather than sale (89% of the total area under cassava production is comprised of plantations less then one hectare) (Haggblade and Zulu, 2003). However, commodity prices apply to those who sell any excess or surplus production, or to those who need to supplement their own harvest. Evidence from the literature on the value of small-scale cassava and maize production follows in Table 5-6 and Table 5-7. Due to the perishable nature of fresh cassava, cassava is commonly traded as chips (dried cassava) with dry weight approximately 30% of the fresh weight.

Table 5-6: Commodity prices in Zambia- Cassava chips

Price (ZMK / tonne)	Price ($US 2005 / tonne)	Source	Note
843,000 (2006)	$205	Zambia AMIC Bulletin no 6, 15-31 March 2006	Based on an average over 6 regions and 2 weeks, March 2006. Range 417,000 – 1,844,000ZMK. Exchange rate 4000 ZMK : $1US. Dry weight of cassava chips approx. 30% of fresh weight
-	$250	http://www.new-agri.co.uk/06-2/newsbr.html	Nigerian cassava chips for export to USA

Table 5-7: Commodity prices in Zambia- Maize

Price (ZMK)	Price ($US 2005)	Source	Note
38,000 ZMK / 50 kg	$190 / tonne	Zambia AMIC Bulletin no 11, 1-15 June 2006	
720,000 – 900,000 ZMK/tonne	$US150 - $US190 /tonne	http://www.fews.net FEWSNet, May 2005	FEWSNet – Famine Early Warning Systems network
600,000 ZKM / tonne	$US 150 /tonne	http://www.fews.net FEWSNet, July 2003	Sales to FRA – Food Reserve Agency.
-	US$120-140 per	http://www.fews.net FEWSNet, July 2003	
300,000 per tonne (2003)	$80 / tonne	FEWSNet, July 2003	Small-farmer maize prices are half the government floor price.

It is noted that that the price of grain varies considerably over time as well as between localities.

5.7.3 Estimating the impacts of Mimosa on agriculture in the Kafue Flats

Mimosa infestations are most commonly established in wetlands, floodplains and channels, where seasonal inundation allows the species to thrive. Mimosa is also found in agricultural land. However, land which is cultivated and tended often is generally not susceptible to severe infestation due to the continued control of Mimosa infestation at low densities. There is no evidence in the literature of established Mimosa invasions on cultivated agricultural land in Zambia, and it is noted that Mimosa in the Kafue Flats region is currently confined to the national parks (Mr. Brian Nkandu, Environmental Council of Zambia, pers. comm.).

Prevention of invasion through regular maintenance and weeding of agricultural plots is less labour-intensive than removal of established Mimosa populations. It is therefore assumed that regular weeding is undertaken to prevent infestation.

Chamroeun (2002) found no correlation between the yield of a rice paddy and the effort required to maintain the paddy free of Mimosa - therefore, it can be reasonably assumed that yields of well-maintained subsistence (or small-scale) crops, including cassava and maize, are not affected by Mimosa infestation. However, the inputs to production (particularly labour in the form of weed-clearing effort) are increased with the threat of Mimosa infestation.

In the case of heavy infestations, it is assumed that the land becomes entirely unproductive (i.e. land is abandoned and is no longer used for production) rather than suffering a loss in productivity.

Chamroeun (2002) estimated 5% - 10% of total production effort for rice cultivation was required specifically for Mimosa control prior to planting. However, rice is a labour intensive crop, with 40% - 60% of the total productive effort for rice production generally being attributed to weed abatement. Cassava production in Zambia is often selected for its low labour intensity (particularly in households affected by HIV / AIDS) - weeding is generally required only twice in the first year and not at all in the second (Haggblade and Zulu, 2003). Therefore relative proportions of effort required to control Mimosa invasion in rice paddies may underestimate the proportional increase in effort required for a cassava crop.

A better estimate may be the amount of labour required to control Mimosa, assumed to be between 10 and 20 days annually per hectare for cassava and rain-fed maize production, equivalent to $US7 - $US13 per hectare (based on the minimum wage of $US 16.50 per month, assuming 24 working days per month). It is assumed that more intensive weed control (20-40 days per hectare) would be required for irrigated maize. This is based on a range of 30-60 days per hectare per year for rice cultivation found by Hong Son *et al* (2002), allowing for the increased aggression of Mimosa invasion in the rice paddy environment. The estimates from Hong Son are used which are the results of controlled experiment, rather than those found in Chamroeun *et al* (2002), which are the results of a survey and may be more subject to error and bias.

A summary of the cost of threatened Mimosa infestation is shown in Table 5-8 below. The following assumptions apply to these figures:

- It is assumed that agricultural land used for cropping is tended often and therefore the establishment of Mimosa populations is prevented.
- At low levels of infestation, and during the establishment phase of infestation, Mimosa is assumed to increase the inputs required for production (especially in respect of weeding effort) but not the output. Therefore the cost incurred is in the opportunity cost of labour to control Mimosa rather than the value of reduced production.

Table 5-8: -Value of increased inputs to production with threatened Mimosa invasion

Crop	Increased Labour Requirement	Financial cost of additional inputs	Opportunity cost of additional inputs
Cassava (rain-fed)	10-20 days/ha/year	$7 - $13US per ha	Close to $0
Maize (rain-fed) (combination of local and high yielding varieties)	10-20 days/ha/year	$7 - $13 US per ha	Close to $0
Maize (irrigated)	20-40 days/ha/year	$13 - $27 US per ha	Close to $0

The critical period for weed interference in cassava plantations occurs between 2 and 4 months after planting. (Alabi *et al*, 2001). Weed control efforts at this time are therefore expected to deliver the greatest relative benefit. Usually weed control is best done either pre-germination or just after germination.

If a Mimosa invasion occurs which is not controlled, the potential exists for Mimosa to become well established and to prevent the further use of the land for agriculture. If this is the case, the yield is assumed to fall to zero (with production inputs also falling to zero). Estimated losses in the case of established Mimosa invasion are set out in Table 5-9 below. Yields and crop values are based on averages of the figures set out in Table 5-5 to Table 5-7 above.

Table 5-9: Cost per hectare of established Mimosa infestation to cassava and maize production

Crop	Average Yield (tonnes per hectare)	Estimated Average Crop Value ($US 2005)	Input costs ($US 2005 / ha)	Harvest Value ($US 2005 / ha)	Net Losses ($US 2005 / ha)
Cassava	7	$62	$0	$434	$434
Maize (rain-fed)	2	$170	$107	$340	$233
Maize (irrigated)	5	$170	$201	$850	$649

The following assumptions apply:

- Cassava production inputs are limited to labour only, as cassava reproduces vegetatively and there is no requirement for seeds to be purchased for annual harvest.
- Labour required for cassava production per hectare is estimated to be 157 days per year. Labour required for maize production per hectare is estimated to be 175 days per year (Haggblade and Zulu, 2003). The opportunity cost of this labour is assumed to be zero.
- Irrigation costs for maize, assuming manual powered treadle pumps, estimated to be $94 per hectare (FAO). This assumes an opportunity cost of labour required to operate the system of zero.
- Other input costs for maize estimated to be $107/ha (Haggblade and Zulu, 2003)

5.7.4 Results

The results are summarised in Table 5-10.

A threatened or low-density Mimosa invasion increases the effort required (inputs to production) for cultivation of crops, including cassava and maize in the Kafue Flats regions. No reduction in yield occurs but a cost is incurred to prevent Mimosa infestations becoming established in agricultural land. Using Methodology E (Table 2-2, page 14), this abatement cost can be used as a rough estimation of the economic impact of low density Mimosa infestations.

If a Mimosa invasion is allowed to become established (or a high-density Mimosa invasion is present), it is assumed that the land can no longer be used for agricultural production. Using Methodology B (Table 2-2, page 10), the losses arising from the Mimosa invasion are assumed to be equal to the margin for production.

Table 5-10: Annual cost per hectare of Mimosa infestation to cassava and maize production

Crop	Low density infestation	High density infestation
Cassava production	Close to zero	$434
Rain-fed maize production	Close to zero	$233
Irrigated maize production	Close to zero	$649

The key qualification attached to these results is that they are based on the assumption that Mimosa will invade land used for cassava and maize production. Given the lack of evidence regarding the extent of the occurrence of Mimosa on land used for these purposes, there is uncertainty as to whether these costs would actually be incurred.

There is also substantial uncertainty around the data. It should be noted that significant variations to important parameters in these calculations, including input costs, yields and commodity prices are possible over both the short and long term. However the figures stated above give an indication of the potential magnitude.

5.8 Mimosa and cattle-rearing

Mimosa can impact on cattle rearing in a number of ways:

- Taking over land that could otherwise be used for grazing; and
- Lowering productivity by impeding stock access to pasture and water.

5.8.1 Evidence of the Impacts of Mimosa on cattle rearing

There is much anecdotal evidence that Mimosa is impacting on cattle rearing (e.g. ECZ 2004 and Walden *et al* 2004). However no quantitative evidence was found.

5.8.2 Cattle rearing the Kafue Flats

In the Kafue Flats, cattle are often grazed on common land rather than in privately owned sections.

The wetlands are a public good - open access to the pasture results in no regular weed clearing or maintenance, thus allowing invasive Mimosa populations to become established. The associated loss in productivity is considered to be primarily due to Mimosa infestations preventing access to, and use of, the land. The following assumptions have been made;

- Pastures used for seasonal grazing within the Kafue Flats are not maintained, due to common resource ownership. No regular weed-clearing activities occur.
- The absence of weed-clearing activities allow invading Mimosa populations to become established.
- The extent of Mimosa invasion increases steadily. Mimosa is an aggressive invader, with the initial Kafue Flats infestation of 2ha (pre-1980) increasing to 100 ha by 1986 and 2500 ha by 2003 (Mumba and Thompson 2005).
- At high levels of infestation, Mimosa is assumed to reduce the productivity to zero by entirely preventing access to, and use of, the affected land. In this case, the cost of Mimosa invasion is considered to be the value of lost productivity.

5.8.3 Estimating the impact of Mimosa on cattle rearing

Seasonal livestock grazing in the Kafue Flats takes place, with over 250,000 head of cattle being grazed on the flats in 1982 (Bungham 1982, cited in Seyam *et al*, 2001). No data was available in the literature regarding the current utilisation of the Kafue Flats region for grazing, and it is known that significant population changes have occurred since 1982, as well as significant changes to the Zambian livestock sector (including the incidence of disease among cattle).

Therefore, the value of the wetland use for cattle grazing is based upon the theoretical carrying capacity of the wetland, rather than its actual use value. The carrying capacity was estimated to be 2.5 head per hectare, based on the assumptions set out in Table 5-11.

Table 5-11: Estimated carrying capacity of Kafue Flats wetland

Parameter	Assumed Value	Note
Predominant cattle breed	Zebu (Boran)	Common breed across east, southern and central Africa
Adult Weight	500 kg	Range; 320kg for cows to 680 kg for bulls.
Nutritional requirements	7 kg/day dry matter	Average requirement, ranging from 4.5 kg/day for young animals (1 year) to 10.25 kg/day for mature animals (5 years), assuming animals not used for draught
Nutritional requirements	2550 kg/year	
Vegetative productivity of wetland	6500 kg/ha/year	Range for seasonally inundated wetland 6000 – 7000 kg/ha/year
Carrying capacity	2.5 head/ha	

With an average price of $US100 per head, capacity 2.5 head per hectare and an average livestock age of 5 years, the annual potential value of livestock production is $US50 per hectare per year. Assuming that 60% of grazing benefit is obtained from this wetland (as other areas are used for grazing during the wet season), the resultant average value of seasonal grazing in the wetland is $US30/ha/year.

This represents the average potential value of the wetlands used for grazing, not the actual value of its use. As grazing use in the wetland intensifies, the marginal benefit of grazing is expected to decline. It is also noted that higher grazing pressure in the wetland will increase the susceptibility of the area to Mimosa invasion (i.e. invasions will be more aggressive in heavily grazed areas).

Mimosa is assumed to prevent the use of invaded areas for grazing, due to its habit of forming thick and impenetrable monospecific stands. Therefore, the value of lost production per hectare can be estimated by the average value per hectare (Methodology C, Table 2-2, page 10). The result is set out in Table 5-12 below.

Table 5-12: Estimated cost per hectare of high density Mimosa invasion on grazing land ($US 2005)

	Cost per Hectare ($US 2005)
Value of lost production	$30

Qualifications:

- As noted above, this is based on the average value lost if large areas were infested, rather than the marginal value of an additional hectare of infestation;
- The economic impact has been estimated as the value of lost production. This implicitly assumes that input costs are close to zero. Given the low capital intensity of cattle rearing and low opportunity cost of labour this is likely to be a reasonable assumption; and

- The lost value of production is only an estimate of the change in economic welfare. The change in consumer surplus has not been estimated here, thus the results are likely to be a slight underestimate.

5.9 Mimosa and tourism

5.9.1 Impacts of Mimosa on tourism

The current and potential use of the Kafue Flats for tourism is being threatened by the Mimosa infestation.

Mimosa impacts on tourism in a number of ways:

- Replacement of native vegetation and habitat for animals by large stands of Mimosa may make the area less attractive to tourists, who come to national parks in order to see native biodiversity (both flora and fauna);
- Since Mimosa can grow to heights of many metres, views may be impeded; and
- Mimosa may threaten wildlife indirectly; it is thought that poachers can hide in Mimosa stands and snare animals as they approach the water sources. Thus Mimosa may result in increased levels of poaching of wildlife (ECZ 2004).

5.9.2 Evidence that Mimosa may impact on tourism

There is evidence that Mimosa has threatened tourism in the Northern Territory (see Table 5-1, page 27). One indication of how seriously the threat of Mimosa to tourism is taken is the millions of dollars that have been spent on its control in Kakadu National Park, Australia (Sinden *et al* 2004).

In the Kafue Flats, Mimosa is thought to be affecting both the habitat of the Kafue lechwe, which is now being forced to feed outside the park, and the levels of poaching in the park (ECZ 2004). Since the chance to view the lechwe and other wildlife is one of the primary selling points of the park, this threat to its habitat may have severe consequences.

No quantitative information is available on how Mimosa impacts on tourism. Even if surveys were carried out in the field, it would be hard to isolate the impact of Mimosa from the many other factors that impact on people's choices to visit a particular area. However, given the mono-specific nature of Mimosa stands, it is likely that tourists would be put off visiting an area where dense infestations exist.

It is clear that national parks are vulnerable to high density and rapidly spreading Mimosa invasions (e.g. Hong Son 2002), as they tend to be less intensively managed than agricultural land.

5.9.3 Tourism the Kafue Flats

Tourism in Zambia

Tourism has exhibited very strong growth in the last few years in Zambia, partly due to displacement of visitors from Zimbabwe due to the current political situation there. A total of 650,000 foreign visitors travelled to Zambia in 2005. Many of these come to the Victoria Falls and Livingstone, which are not far from the Kafue Flats (Independent Online 2006).

Table 5-13 presents key data on tourism in Zambia. These figures show that tourism is an important industry for Zambia, and one which is growing steadily.

Table 5-13: Available information on tourism in Zambia

	Estimate	Cited in
Economic activity generated by travel and tourism 2006	US$765.4m	World Travel and Tourism Council 2006A
Percentage employment generated by travel and tourism	3.4%	World Travel and Tourism Council 2006A
Number of foreign visitors to Zambia 2005	650,000	Independent Online 2006
Real predicted growth rate in travel and tourism demand per annum (2007-2016)	3.9%	World Travel and Tourism Council 2006A
Economic activity generated per tourist	US$1178	Total economic activity (World Travel and Tourism Council 2006A) divided by total tourist numbers (Independent Online 2006)
Economic activity generated per tourist per day	US$168	Assuming average length of stay is 7 days

Tourism in the Kafue Flats

There are two national parks in the Kafue Flats floodplain system: Lochinvar National Park, and the smaller and less developed Blue Lagoon National Park. These both contain wetlands of international importance and an area of 83,000ha spanning both parks has been granted Ramsar status (Mumba 2005). Both national parks are promoted as being areas of exceptional beauty and as places where Lechwe and a wide variety of birds can be viewed (Zambia National Tourist Board 2006).

Data on tourism in the Kafue flats are rare. However, it seems tourism in the two national parks is currently quite limited. A very small amount of accommodation exists in each park – four chalets and a camping ground in the Blue Lagoon and a campground and a lodge in Lochinvar. Moreover, Blue Lagoon National Park is described as "untouched" and "an undiscovered gem" by the Zambia National Tourist Board (2006).

However, there is potential for these parks to develop further. They are well located for tourists travelling through Southern Africa, as they lie between Lusaka and the popular tourist destination of Livingstone. The threat of Mimosa could thus be seen in terms of lost potential for tourism rather than for any losses over current levels.

Table 5-14 sets out available information on tourism in the Kafue Flats.

Table 5-14: Available information on tourism in the Kafue Flats

	Estimate	Cited in
Daily admission to Lochinvar national park	US$15	Lonely Planet 2003
Cost of luxury accommodation per night in Lechwe Plains tented camp- located by Chunga Lagoon – including activities in the park.	US$300-$400	Star of Africa 2006
Maximum capacity in Lechwe Plains tented camp	12	Star of Africa 2006
Cost of camping accommodation in Lochinvar National Park	US$5	Lonely Planet 2003
Area of Ramsar wetland	83,000ha	Mumba 2005

5.9.4 Estimating the impacts on tourism

Costs of a high density infestation

In the absence of reliable information, a number of assumptions are required in order to calculate the cost of a Mimosa infestation on tourism. Annually 400 people visit the Blue Lagoon and Lochinvar National Parks (Sonile Mtine, Zambia National Tourist Board, pers. comm.). The following additional points were assumed:

- A trip to the Lochinvar National Park and/or the Blue Lagoon National Park adds an additional day to a trip to Zambia, for each visitor to the park. That is, each visit to the park generates one additional day's worth of economic activity;
- Days spent at Lochinvar and Blue Lagoon National Parks are not displaced from tourist attractions elsewhere in Zambia. This is based on the assumption that those planning trips to Zambia decide how long to stay by considering all of the available attractions, rather than choosing attractions to fill a given amount of time to spend in Zambia. Given that people often visit Zambia as part of a tour through Southern Africa, this seems like a reasonable assumption;
- Given the fact that luxury tourism is important in these parks, due to the existence of the Lechwe Plains tented camp, it is assumed that the average tourist to this area generates $193 of economic activity a day. This is more that the average figure of $168 set out in Table 5-13, (page 44) and is based on the assumption that 50% of tourists stay at the Tented Camp spending $350 per day, and the other 50% are budget travellers, spending $20 a day including accommodation (Lonely Planet 2003) plus $15 entrance to the park;
- In the absence of further infestation by Mimosa, visits to the park would grow by 3.9% which is the average growth rate for tourism in Zambia (see Table 5-13);
- It is assumed that the real daily spend will increase by 2.5% per year in line with likely annual real GDP growth in the home countries of the tourists;
- 35% of the daily spend goes on imported goods and services (estimated proportion of tourist spend on imported goods and services in Senegal – data for Zambia unavailable); and ,
- An infestation across 50% of the wetland which spans the two parks would eliminate tourism in the area.

These assumptions are summarised in Table 5-15.

Table 5-15: Summary of assumptions necessary to estimate the impact of Mimosa on tourism in the Kafue Flats

	Assumption
Annual daily visitor numbers to Lochinvar National Park and/or Blue Lagoon National Park	400 (2006) 827 (2025)
Visitors' daily spend, less proportion which goes on imports	$125 (2006) $205 (2025)
Level of infestation at which tourists no longer wish to come to the parks	50% of the Ramsar wetlands 41,500ha

The total cost of infestation was calculated as follows using Methodology C from Table 2-2, page 14). This involved multiplying the tourist daily spending money (less the proportion which goes on imports) by the annual daily visitor numbers. Infestation cost per hectare was then calculated by dividing this total figure by the area of 50% of the wetlands.

Costs of infestation

The costs of both a low and high density infestation are measured using the figures set out in Table 5-3 (page 32). The figure for wetlands and seasonally inundated land is used here, as these are the conditions that prevail in the park. It is assumed that low density infestation is managed with manual removal (labour intensive) and that high density invasion incurs only the cost of foregone tourist revenue (as attempts to clear established infestation are abandoned)

5.9.5 Results and qualifications

The results are set out in Table 5-16:

Table 5-16: Annual cost per hectare of Mimosa infestation on tourism (US$, 2005)

	Annual cost per hectare – high density (foregone tourism revenue) $US2005	Annual financial cost per hectare - low density (weed management) $US2005	Annual cost to society per hectare- low density $US2005
2006	$2.40	$32	$0
2025	$6.20	$61	$0

A number of points can be made in relation to Table 5-16:

- The annual financial cost of a low density invasion is more than the annual cost of a high density invasion. This is because it costs more to manage the infestation than is delivered through benefits from tourism. If non-use values such as existence and option values were included in this costs the results would be likely to be different;
- Growth in visitor numbers to the park exceeding the assumed 3.9% p.a. is possible, and would result in an annual cost of high-density infestation greater than the costs stated for 2025;
- Mimosa invasion currently occupies between 5% and 7% of the total park area (Mr. Brian Nkandu, Environmental Council of Zambia, pers. comm.). The level of infestation at

which tourists stop using the park may be more or less than 50%. A level less than 50% would increase the per-hectare cost of infestation. Tolerance of Mimosa invasion exceeding 50% would reduce the cost of high density infestation; and

- The annual cost per hectare of Mimosa infestation on tourism is much lower than the cost of Mimosa in other sectors (such as fishing or agriculture. This is primarily because there are so few tourists per hectare of potentially infested wetland in the Kafue Flats. In this analysis the cost per hectare depends on the utilisation of the park, not on the nature of ecological impacts of the weed, as it is assumed that large scale infestation by Mimosa would drive tourists away from any location.

Though it gives an indication of the degree of magnitude of the cost per hectare, the estimates set out in Table 5-16 should be treated with a degree of caution due to the number of assumptions that were required to be made in their estimation. The following qualifications are particularly important:

- This is an average cost rather than a marginal cost. That is, it is based on infestation occurring across the park to reach a level that would stop tourists, coming to the park. Infestation of an additional hectare once tourists have stopped coming would not have an impact. The cost per hectare is very sensitive to this assumption; and
- It is implicitly assumed that the opportunity cost of all of the inputs to tourism (aside from the 35% purchased from abroad) are close to zero. This may not be accurate as goods that tourists spent their money on such as food and transport would have an opportunity cost. Hence the figures presented in Table 5-16 are likely to be overestimated.
- The value of land use for tourism is based on real growth in tourism revenue of approximately 6.5% per year (including 3.9% increase in tourist numbers and 2.5% increase in real average spend). Due to the very low base from which this growth commences, and the significant potential for further development of the Zambian tourism sector, it is possible that land use values greatly in excess of those stated could be realised

5.10 Mimosa and fishing

5.10.1 Introduction

Mimosa could impact on fishing through the following means:

- Reducing fishes habitats, by reducing the levels of food available and taking over breeding grounds (Chamroeun *et al* 2002);
- Impeding access to waterways; and
- Damaging boats and nets.

5.10.2 Evidence of the impact of Mimosa on fishing

There is very little evidence of the impact of Mimosa on fishing, but a number of points can be made:

- It is often perceived that fish stock is declining due to Mimosa- surveys and discussions with stakeholders in Cambodia and in the Kafue Flats in Zambia found that locals perceived that there had been an overall reduction in fish stocks (ECZ 2004, Sanmouth 2002); However Chamroeun *et al* (2002) surveyed fish lot owners in Cambodia and found that respondents were not able to isolate any impact of Mimosa on overall catch levels, though they had noticed a decline in the proportion of fish without scales; and
- Again, in Cambodia and in the Kafue Flat, locals said that it had become harder to access water due to the Mimosa, and, that nets and boats can become entangled in the plants.

Given the lack of quantitative and consistent evidence on the impact of Mimosa on fishing, this is an area where further field work may be warranted.

5.10.3 Fishing in the Kafue Flats

Fishing in the Kafue flats is a very important activity, for both subsistence and trade. Although fish has always been an important part of the diet of the local people, its significance has increased due to livestock loss and a decline in maize production in the last decades. In the drought year 2002/3, fish was traded more often than cattle (WorldFish Center 2006). Catches in the swamp and floodplain areas comprise mostly tilapia and *Alestes* spp (FAO 2000). Fishermen use mainly gill nets and canoes.

There is much anecdotal evidence that productivity has been declining (e.g. WorldFish Center 2006). Among the reasons given are:

- Overfishing - between 1980 and 2004, the price for fish has increased nearly twice as much as the price for maize, due to increased demand for fish in the urban and industrialized centres. Some local agro-pastoralists have switched into fishing in response (WorldFish Center 2006);
- Construction of the Kafue Gorge Dam – the construction of the Kafue Gorge Dam altered the natural flooding regime and affected the catch (FAO 2000); and
- Invasive weeds: both Mimosa and a water hyacinth infestation along the Kafue are said to have reduced catch (ECZ 2004, FAO 2000).

Data on catch and yield are set out in Table 5-17. As shown in this table, data on price and yield vary considerably according to the estimates, and thus their reliability could be questioned.

Data is collected by the Zambian Fisheries Department, and further studies could use their data. However, collecting these data in this desk based study was not possible.

Table 5-17: Fishing in the Kafue Flats: price and yields

Source	Years	Area of wetland	Catch in the Kafue Flats	Yield in the Kafue Flats	Price
Dugan 2003	1982	4754ha	7, 400 tonnes	15.6 kg/ha/year	
Seyam *et al* 2001	1971-1982	Assumed that 40% of total Flats area (6,500km^2) was important for fisheries (2,600 km^2)	11,200 tonnes	43 kg/ha/year	US$1830/tonne
Gréboval 1994	1990		7,335 tonnes		US$350/tonne (Average across Zambia)
Jamu and Brummett 2001	2001				US$830/tonne (farmed tilapias in Zambia- could be higher quality than average fish caught in the Kafue Flats)
FAO 2000				2 tonnes/fisherman per year	

5.10.4 Estimating the impact of Mimosa on fishing

In the absence of reliable information on the impact of Mimosa on fishing the following assumptions are made:

- Where Mimosa takes over an area of wetland, it is assumed that this has an impact on the function of that area of wetland as a breeding ground for fish, and that fishing in the area reduces by 10%, 50% or 100%. These are arbitrary assumptions as no information is available in the literature on the quantitative impact on fishing of Mimosa, and are intended to illustrate the range of potential impacts at different levels of infestation;
- As the wetlands of the Kafue Flats are important for the supply of both the local market and the market in nearby cities, the impact of Mimosa may be felt in the price as well as in the quantity of fish supplied, and the impact will be similar to that shown in Figure 2-1 (page 12). In order to best estimate the change in economic welfare, elasticities of supply and demand must therefore be known. However, we do not know what these elasticities are.

The next best methodology to roughly estimate the change in economic welfare would be to assume that economic welfare is approximated by the change in the value of production, less the costs of production. This can be estimated as follows.

$$\Delta W = \text{Change in value of production less costs of production}$$

$$\Delta W = (P-C1)*Q1-(P-C2)*Q2$$

Where P is the price of fish C1 is the cost of production before the infestation and C2 is the cost after the infestation. Q1 is the quantity before the infestation and Q2 is the quantity after the infestation.

We do not know what the production costs are for fisheries in the area. However, the opportunity cost of these can be assumed to be close to zero, given the high unemployment rate in Zambia, the low capital intensity of the fishing and the lack of alternative uses for this capital in the event of an infestation.

It is also assumed that if Mimosa makes it more difficult to access waterways, fishermen will compensate by dedicating more effort to fishing. Due to the lack of alternative economic opportunities in the area, the cost of this additional effort has a shadow price close to zero.

The equation then becomes simply (Methodology C, Table 2-2, page 14):

$$\Delta W = P * \Delta Q$$

Estimates needed for the calculation of the change in welfare are shown in Table 5-18. Price data are taken from Jamu and Brummet (2001) as this is the most recent figure, and relates to tilapias (a fish species farmed in Zambia). Yield is taken from Greboval 1994 as these are the most recent data found;

Table 5-18: Assumptions for estimating the impact on fishing

	Estimate	Source
Price before infestation	US$910	Jamu and Brummet 2001, inflated to 2005 price levels
Annual quantity before infestation	7,335 tonnes	Gréboval 1994
% change in quantity	10%, 50% or 100%	Assumption
Assumed area of infestation	260,000ha (40% of the Kafue Flats)	Seyam *et al* 2001

5.10.5 Results and qualifications

The results are set out in Table 5-19

Table 5-19: Annual cost per hectare of Mimosa infestation ($US 2005)

	Assuming 10% reduction in catch	Assuming 50% reduction in catch	Assuming 100% reduction in catch
Annual cost	$3	$13	$26

Given the lack of data on the impact that Mimosa has on fishing, and the unreliability of the data on catch and yields, these estimates should be treated with caution, and this is an area where further field work is needed.

It is also noted that the lack of data on elasticities means that the change in consumer surplus that would follow from a reduction in fish production and the corresponding rise in price has not been estimated. This means that the change in economic welfare may be slightly underestimated.

5.11 Other economic impacts of Mimosa in the Kafue Flats

5.11.1 Mimosa and water use

Mimosa could interact with water use through the following means:

- Mimosa may increase evapotranspiration, leaving less water for other uses;
- Access to water may be impeded; and
- Water may decline in quality.

Evidence of the interaction of Mimosa with water is sparse, though the results of surveys and discussions with stakeholders reveal the following points:

- Farmers living along the La Nga River expressed concern about the pollution, due to the Mimosa leaves falling into water sources used for drinking (Hon Song *et al* 2002);
- ECZ (2004) found that respondents to the survey did not detect any change in the smell, colour, taste and viscosity of the water. They could not comment on how Mimosa was affecting water availability;
- No evidence on the impacts of Mimosa on water supply and quality in Australia was found.

Given the lack of evidence, it was not possible to estimate the impact of Mimosa on water quality or quantity.

To give a sense of the value of water in Zambia, it is common for households in some areas of Zambia to pay between K50 and K100 (US$0.13 to $0.25) per 20 litre container of water from a communal tap (Chitonge 2006).

5.11.2 Mimosa and Hydroelectricity generation

Mimosa could interact with hydroelectric generation if it decreases flows in the river, or if it interferes with the workings of the dam.

The Kafue River hosts the Kafue Gorge Hydroelectric Power Station, which generates about 60% of Zambia's electricity requirement (ECZ 2004). Any impact on this dam could have severe economic consequences. The power station is downstream of the Kafue Flats region, and is therefore downstream of the existing Mimosa infestation.

There is evidence that Mimosa can invade hydroelectric systems - In Tri An hydro-electric lake, Mimosa covers 800 ha of 32,400 ha of total lake area. (Hong Son *et al* 2002). While it might be assumed that Mimosa debris may block intakes, or that Mimosa stands may impede water availability or flow of water during floods, none of the literature reviewed indicated how or to what extent Mimosa might impact on power generation.

This is an area where further field work will be necessary.

5.11.3 Mimosa and accessibility

There is evidence that Mimosa impacts on accessibility to areas.

A survey in the Kafue Flats found that the stiff thorns from Mimosa bruise people and cause other injury, and that both humans and animals have difficulties in traversing the Mimosa thickets (ECZ 2004). Other injuries caused by Mimosa are expected to include laceration.

Quantifying the impact of Mimosa on accessibility was not be possible. However it is likely that this has more of a social impact than an economic one, as the shadow price of any additional effort needed to access areas is likely to be close to zero.

5.11.4 Benefits of Mimosa

Due to its nature as an invasive species, it is not suggested that attempts to cultivate Mimosa are carried out. However, there is discussion in the literature of what uses could be made of it once the infestation is already present (Miller 2004):

- Mimosa was purposely introduced to Thailand from Indonesia in 1947 as a green manure and cover crop in tobacco plantations;
- It fixes nitrogen, increases soil fertility and redistributes nutrients from the lower soil profile to the surface. This may be beneficial for establishing vegetation after clearing Mimosa;
- It can be used as fencing, though is not used in construction as it rots quickly;
- It is heavily grazed by native animals in Nigeria and has been observed to be browsed by horses, buffalo, cattle and goats elsewhere.
- Mimosa has been used successfully as goat fodder in Vietnam. It may also be used as a substrate for the cultivation of mushrooms (Triet, undated). These uses have both been developed as part of the control effort for Mimosa and is not the first-choice source of livestock fodder or substrate for mushroom production.

However, most of the evidence suggests that benefits are minor and not widely perceived:

- Chamroeun *et al* (2002) asked villagers in Cambodia to identify any benefits they received from Mimosa pigra. Little evidence was found. 25% of the households occasionally used Mimosa pigra as fuel wood, but they indicated that it was poor quality fuel. The households also noted that cattle would not eat Mimosa, so it did not have value as fodder; and
- The survey reported in ECZ (2004) found that there are no uses to which the plant is put to enhance the socio–economic welfare of the local communities.

Any beneficial uses of Mimosa may be realised to offset the cost of management, however, cultivation of Mimosa is not recommended as this will perpetuate invasion and hamper control efforts.

6 MANAGEMENT OF MIMOSA

6.1 Management of Mimosa

This section evaluates the major management and control approaches for Mimosa, including:

- Manual or physical removal;
- Mechanical removal;
- Chemical control (herbicides);
- Biological control;
- Fire control;
- Revegetation and habitat improvement; and
- Integrated pest management.

In addition, a search was carried out in order to assess the effectiveness of genetic modifications in the management of Mimosa. However, no genetic modifications for Mimosa, either existing or proposed, were found in the literature.

Mimosa is a very intractable weed species; the adults and seedlings are very hardy, with tap roots capable of re-sprouting if the above ground plant dies. Mimosa seeds are long lived and easily transported, meaning infestations frequently recur once control measures have been implemented.

Generally, integrated control measures are most effective, but the effectiveness of the control measures depends partly upon the nature of the infestations. Biological control measures are showing some promise with many options now available. However, biological control can be slow and sometimes variable in effectiveness.

Control of Mimosa is a long term project - monitoring and vigilant follow-up control are required to contain Mimosa where it has occurred in the previous 25 years or so. Valuing the benefits of management of Mimosa

6.1.1 Uncertainty over effectiveness

There is very little quantitative information on the effectiveness of the management techniques for Mimosa, particularly for management techniques applied in isolation. This is because a number of management techniques are often used in combination to tackle Mimosa.

Because of this, it is difficult in many cases to conduct a cost benefit analysis on the effectiveness of management techniques.

Where this is the case, the costs of the management technique will be estimated, and the level of effectiveness required to justify this cost will be set out. This should help inform decisions on whether or not to use these management techniques.

6.1.2 The benefits of managing Mimosa

The benefits of management are assumed to be the avoided damage costs of the weed as identified in Section 5. The benefits of managing a hectare of high density Mimosa infestation are presented in Table 6-1

All of the qualifications set out in Section 5 above apply here also.

Table 6-1: Benefits of managing Mimosa, per hectare, by land use in Zambia (US$, 2005)

Land use	Annual benefit – low density	Annual benefit – high density	Net present value over 25 years (discount rate of 10%) – high density
Agriculture			
Cassava	Close to zero	$434	$3,939
Maize (rain-fed)	Close to zero	$233	$2,115
Maize (irrigated)	Close to zero	$649	$5,891
Cattle grazing	N/A	$30	$272
Fishing	Close to zero	$3 - $26	$27-$236
Tourism	N/A	$2.40	

6.1.3 Costs: Schedule of rates

Table 6-2 sets out the schedule of rates which will be used to calculate the costs of each management technique. Note that these costs indicated assume that the required infrastructure and skills exist in the economy, e.g. biological control costs do not include the cost of training staff or building quarantine and laboratory facilities.

Table 6-2: Management of Mimosa - schedule of rates

Item	Cost Estimate	Shadow price/opportunity cost	Source
Labour			
Unskilled labour	US$16.50 per month (83,200 kwacha)	$0, assumed due to high unemployment in rural Zambia. Note that labour directed to weed management reduces the labour available for other activities.	Minimum wage -US Department of State (2006)
Semiskilled labour (machine operators)	US$100 per month	US$100 per month	Assumed
Man hour – scientist/ supervisor	US$2500 per month	US$2500 per month	Assumed
Inputs			
Biological control agents and materials for establishing colony	US$3750	$3750	Pers. comm.- Steve Wingrave, Northern Territory Weeds Management Branch, Department of Natural Resources, Environment and the Arts
Cages for Mimosa agent	$2625	$2625	Pers. comm.- Steve Wingrave, Northern Territory Weeds Management Branch, Department of Natural Resources, Environment and the Arts
Diesel per litre	$0.98	$0.57 (International benchmark level for non subsidised transport policy)	Metschies 2005
Airplane per hour, including fuel	$100-$200	$100-$200	http://www.bushair.co.za/hire.htm

6.2 Manual control

6.2.1 Effectiveness

Manual and physical removal is not regarded as very effective method of controlling Mimosa, as cutting is labour intensive and expensive, and even if done at ground level, leads to extensive re-sprouting. In addition, the shrubs are not easily knocked over using broad scale techniques.

However, manual techniques are useful in the following cases:

- Short term clearance of smaller infestations. Small Mimosa plants can be killed by hand pulling or grubbing them out with a mattock, hoe or shovel and ensuring to leave the roots clear of the soil (Miller and Lonsdale, 1992);
- Ongoing maintenance of agricultural land (Hong Son *et al,* 2002); and
- Part of integrated programs.

6.2.2 Evidence of costs and effectiveness

Evidence of the effectiveness of manual control is presented in Table 6-3.

Table 6-3: Mechanical and manual management of Mimosa– evidence of costs and effectiveness

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Chamroeun *et al* 2002	Medium to severe infestations	Local farmers clearing Mimosa each year prior to developing rice fields Infestation in rice fields and fish ponds. Manual removal of Mimosa. No machinery indicated	Maintained rice paddy fields clear for cultivation	Severe infestation (Mekong River) 20-30 days work per ha Medium infestation (Tonle Sap River) 13-18 days work	Cambodia 2000
Hong Son *et al* 2002	Not specified	Stem cutting To enable sowing of the next rice crop, farmers have to cut older Mimosa plants before seasonal flooding. Roots of the first year plants die during the seasonal flooding while roots of older plants can survive. Experimental sites and farmers experience.	In farmers experience this is sometimes effective for maintenance. Regrowth occurred after 7 days in the stem cutting experiments, when the ground was not flooded. When the ground was flooded, slightly less regrowth occurred.	Average of 46 days labour per ha The cost of labour for cutting depended on the age of plants and level of plant cover. From around 30 days/ha for low density and newly invaded sites, to 60 days/ha for high density sites.	Nam Cat Tien National Park Vietnam 1995-2002

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Hong Son *et al* 2002	Seedlings	Pulling Experimental sites	Manual pulling completely controlled Mimosa. However, it was found to be only feasible with seedlings at an early stage. It must be repeated annually due to the new germination of Mimosa from seed.	Plants younger than two months and less than 100 cm high took 69 days per ha to clear, while the control of older plants may require more than 92 days[1]	Nam Cat Tien National Park Vietnam 1995-2002
Sanmouth 2002		Stem cutting,	Ineffective - the cut stems grew quickly after the first rain.	None cited	Boeung Thom, Cambodia 1985-2000

[1] Calculation of days required assumes that cost of labour is the same as that for stem control.

6.2.3 Cost-benefit analysis of mechanical or manual management

The costs of manual management of Mimosa were used as an estimate of the value of the economic impacts of a low density infestation in Section 5 (following Methodology E as described in Table 2-2, page 14).Hence it is not meaningful to do a cost benefit analysis, as the benefits of clearing (approximated by the cost of management) are necessarily the same as the costs.

In addition, it is assumed that manual clearing can be undertaken using unskilled labour. Hence the shadow cost of this management technique is close to zero.

However, to illustrate the potential cost to management agencies, the financial costs of manual management of low density Mimosa infestations are set out in Table 6-4. Estimates are taken from Hong Son *et al* (2002). The lower bound of cost are adjusted down by 66% to reflect the fact that managing Mimosa on dry agricultural land, expected to be less conducive to Mimosa growth than rice paddy fields, may take less labour.

Table 6-4: Annual financial costs of mechanical or manual Mimosa management per hectare (US$ 2005)

Method	Days required	Low estimate	High estimate	Opportunity cost
Pulling	23-92	$16	$63	Close to zero
Stem cutting	10-60	$7	$41	Close to zero

6.3 Biological management

6.3.1 Introduction

Biological control has been underway in various countries since 1983 and has involved insect and fungal agents. Forty five potential biological control agents have been formally assessed and others may have been informally assessed and rejected during field work (Heard and Segura, undated).

6.3.2 Agents

At least nine insect species are established in Australia (from 13 species released) which control Mimosa to some extent. These are:

- *Acanthascelides puniceus* and *Acanthascelides quadridentatus* – flower and seed eating beetles
- *Coelocephalapion pigrae* – flower feeding weevil
- *Neurostrota gunniella* – stem mining moth
- *Carmenta mimosa* – stem boring moth
- *Chlamisus mimosae* – leaf-feeding beetle
- *Malacorhinus irregularis* – Mexican beetle (attacks many parts of the plant)
- *Macaria pallidata* a leaf-eating moth

Other species are still being assessed, each with potential to provide some control of Mimosa:

- *Syphrea bibiana* – leaf beetle
- *Sibinia species* (2) – a weevil
- *Leuciris sp.* – flower feeding moth
- *Pselaphorhynchites* - a tip eating weevil
- *Risbecoma pigrae* – a seed-eating wasp

Flower and seed eating insects take a while to become established due to the seasonal nature of flowering and are not entirely effective at controlling Mimosa seed production. The two stem attacking moths are particularly effective at reducing seed production and seedbanks (presumably by reducing seed set). The leaf-eating Mexican beetle larvae are effective at destroying germinating seeds and seedlings and have the potential with the moth species at significant control of Mimosa.

The leaf defoliating moth, *Macaria pallidata*, was shown in trials to be very effective in suppressing Mimosa growth after just one week of herbivory in a 6 week experiment, indicating this species has much potential (Wirf, 2006).

Two fungal biological control agents have been released in Australia (and elsewhere) which severely debilitate Mimosa in Mexico. These are *Phloeosporella sp*. and a rust *Diabole cubensis*. *Phloeosporella sp*. affects the leaves, branches, main stems and seed pods leading to die-back and death. *Diabole cubensis* causes chlorosis (loss of the green pigment in leaves) to stems and leaves resulting in leaf fall and plant death (Lonsdale *et al*, 1989).

Control of Mimosa using larger herbivores has been suggested (e.g. ECZ, 2004). Mimosa is commonly fed on by native animals such as elephants and buffalo in Nigeria (Miller, 2004). However, despite heavy feeding, Mimosa perseveres and reinvades during the wet season when floods prevent animals from accessing it. An additional negative aspect of control using native herbivores is that viable seed is excreted in the manure, thus facilitating further spread. (Miller, 2004)

Community management of Mimosa using biological controls has proven to be difficult in the Northern Territory, Australia. Significant input is needed from a technician to help set up the colonies of agents and to provide ongoing guidance in the biological control programmes for Mimosa. Mimosa agents require daily tending (watering plants, adding new plants if necessary). In addition, collecting and releasing pupae and cross breed adults and setting up new cages takes several days each month. There has been very little success with community rearing of Mimosa agents so far in the Northern Territory, Australia. While community members have been enthusiastic, a lack of technical expertise and suitable conditions has proven to be a problem (Steve Wingrave, pers. comm.). As a result, the cost-benefit analysis of biological control for Mimosa which follows (refer section 6.3.3) assumes suitably skilled paid labour is used, rather than relying on community efforts.

Evidence on the effectiveness of biological control is set out in Table 6-5.

Table 6-5: Evidence of the costs and effectiveness of biological management

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Australian National Heritage Trust 2004	Variety of infestations around the Northern Territory	Biological control 11 species of insects and 2 fungi	Tip and stem borers have been the most effective because they do not require flowers or seed for survival so can therefore feed on Mimosa during the dry season. The combined effect of these biological agents is to reduce seed production and seedling survival. However, there is a long lag between inoculation and effects – it has taken 14 years for some of them to have an effect.	Not stated	Northern Territory, Australia (1990-2004)
Hong Son *et al*	Not stated	The mimosa stem borer, *Carmenta mimosa* and the seed bruchid, *Acanthoscelides quadridentatus* were released in 10 locations.	*C. mimosa* established at the release sites, infected 50–80% of the Mimosa stems and spread 2 km after four years. However, *C. mimosa* killed only new shoots and young plants. The seed bruchid was released in 1997. It has established but has had no impact on seed production.	Not stated	Vietnam (1995-1997)

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year)
Hong Son *et al*	Tested in greenhouse	A strain of the fungus, *Phloeospora mimosae-pigrae Evans & Carrion* was imported from Australia	Disease index (the level of infection) increased with higher temperatures At 21°C disease incidence (the percentage of the plant diseased) was 94% and disease index (the level of infection) was 38% At 31°C disease incidence was 64% and disease index (the level of infection) was 78%	Not stated	1998
Paynter and Flanagan 2004	128ha	Biological Neurostrota gunniella	Reduced fecundity by 58–78% and stunted growth of both mature plants and seedlings (Lonsdale & Farrell, 1998; Paynter & Hennecke, 2001).		Australia 2004

6.3.3 Cost-benefit analysis of biological management

Not enough information on the effectiveness of biological control is available to do a full cost-benefit analysis. However, an analysis can be carried out to show at what level of effectiveness the benefits of biological control outweigh the costs.

The costs of biological control are first estimated. These are based on the following assumptions:

- Set up costs are the same as they are in the Northern Territory, Australia;
- Two months of employment by scientists will be required to get the biological control established and two full time unskilled labourers for one year thereafter;
- The biological agent covers an area of 200ha;

These assumptions are summarised in Table 6-6. Note that these costs assume that the infrastructure and skilled labour required to facilitate this management approach is available in the Zambian economy (i.e. it does not include the cost of construction of laboratory facilities or training skilled workers). Note also that legislative changes, host specificity testing and quarantine processes may be required before any biological control agent is introduced. These costs are not accounted for here.

Table 6-6: Cost estimation of biological control

	Assumption (costs in $US 2005)
Set up costs	$3750
Labour	$2000 (opportunity cost) $2396 (financial cost)
Area	200ha
Estimated cost per ha	$29/ha (opportunity cost) $31/ha (financial cost)

In order to estimate the level of effectiveness necessary to justify these costs, an assumption needs to be made on the time lag that there would be between release of the biological agent and its impact. The information in Table 6-5 suggests that this time lag could be anywhere between 4 and 14 years. An average lag of nine years is assumed for this assessment. Once the agents become effective, it is assumed that effectiveness at the level prevails for the subsequent ten years.

Table 6-7 sets out the effectiveness of biological control that would be necessary to justify the costs for each land use in the Kafue Flats, given the costs calculated above, the costs imposed by a Mimosa infestation on each land use and the assumption of a nine year lag between application and effectiveness.

The results show that even with a 9 year time lag between release and effectiveness, biological control of Mimosa may be cost-effective on agriculture land. However, it is noted that these percentages relate to the amount of land made available for agricultural use after biological control. That is, 18% of land currently infested by Mimosa would have to be cleared of Mimosa in order to justify the use of biological control. If the stand of Mimosa is simply damaged, and no additional land is cleared and made available for agricultural production, this value is not realised.

Note that for land uses where biological control of Mimosa is considered not to be cost effective (based on the assumptions stated above), its use should be reconsidered if the assumptions are demonstrated to be unreasonable. For example, if a weevil population could effectively colonise an area greater than 200 hectares, or if the marginal labour requirement to establish weevil colonies in adjacent areas (where conditions are similar) are less than those stated above, biological control may be a cost effective approach.

Table 6-7: Biological control of Mimosa – levels of effectiveness necessary to justify the costs

Land use	Degree of effectiveness necessary for biological control to be justified on high density Mimosa infestations (opportunity cost)	Degree of effectiveness necessary for biological control to be justified on high density Mimosa infestations (financial cost)
Agriculture		
Cassava	18%	18%
Maize (rain-fed)	31%	31%
Maize (irrigated)	12%	12%
Cattle grazing	Not cost effective	Not cost effective
Fishing	Not cost effective	Not cost effective
Tourism	Not cost effective	Not cost effective

Note that information provided in Table 6-7 above has been determined using production data for various land uses in the Kafue Flats region (or in Zambia generally where no specific data was available) (refer section 5). In areas where the benefits of land use are higher than in the Kafue Flats (for example, in different national parks where higher entry fees and/or higher tourist numbers result in greater loss per hectare of Mimosa invasion), biological control may indeed be cost effective despite being noted above as not being cost effective in the Kafue Flats.

6.4 Chemical management

Chemical control methods are commonly applied but with variable results. Various herbicides (using foliar, soil-applied and basal bark application methods) have been used previously which can be expensive, especially for large areas. About 19 different chemicals have been used on Mimosa. The strategic use of herbicides was important in controlling the outbreaks of Mimosa in Australia.

Single treatments are generally not effective on established Mimosa stands as the initial treatment only kills part of the population and seeds are often stimulated to germinate after cover is removed and therefore multiple spraying is required. Up to five years of spraying may be required for some infestations.

Lane *et al* (1997) showed that even at twice the recommended rate to control adult Mimosa, the herbicide tebuthiuron only kill 57% of seedlings but it was relatively selective for Mimosa.

Early morning application of the herbicide is most effective because of higher humidity at this time of day which allows better delivery of the herbicide to the plants and better uptake by the leaves. In addition, the temperature should not be over 35^{o}C during application (ECZ, 2004).

Costs for chemical control of high-density Mimosa infestation, assuming aerial application of herbicide, are as follows:

Table 6-8: Cost estimates for chemical management (aerial spraying) of Mimosa in Zambia

Cost component	Total financial cost per ha (US$ 2005)	Total cost to society per ha (US$ 2005)	Note
Aerial application – airplane and fuel	$3.30	$3.30	Assumes large area. Aircraft and spray hire $US200 / hour, flying at 100 km/s per hour with spray span 12 m. Sprays for 50% of airborne time, therefore spray rate approx. 60 hectares per hour.
Chemical cost - metsulfuron methyl	$9	$9	Based on US$45 for 300 grams, application rate 60 grams per ha
Pilot	$0.26	$0.26	Assumes $2500US per month for skilled labour, 20 working days and spray rate 60 hectares per hour
Total Cost	$12.56	$12.56	

Alternative chemical controls are available at greater cost, including fluroxypyr ester, with a cost of $US20 per litre and application rate 3 litres per hectare, resulting in a total chemical cost of $US60 per hectare. This would significantly increase the total cost of chemical control. Metsulfuron methyl is not suitable for use on corn (maize) crops (Extension Toxicology Network, Cornell University), therefore alternative chemical herbicide, or alternative control methods, should be selected for management of Mimosa invasion in maize crops.

Economies of scale are important in achieving low per-hectare treatment costs for aerial spraying. As the fixed costs (including aircraft hire) are high, the cost per hectare will increase dramatically for treatment of small infestations. Cost estimates for alternative chemical control methods for small infestations are presented below:

Table 6-9: Cost estimates for chemical management (manual spraying) of Mimosa in Zambia

Cost component	Total financial cost per ha (US$ 2005)	Total cost to society per ha (US$ 2005)	Note
Manual spray unit (back-pack style)	0.08	0.08	Assuming spray unit costs $US50, lasts for one year, used 6 days a week to spray 2 ha per day.
Labour	0.35	0	Assuming unskilled workers can spray 2 ha per day
Chemical cost - metsulfuron methyl	$9	$9	Based on US$45 for 300 grams, application rate 60 grams per ha
Total Cost	$9.43	$9.08	

Table 6-10: Cost estimates for chemical management (mechanised spraying) of Mimosa in Zambia

Cost component	Total financial cost per ha (US$ 2005)	Total cost to society per ha (US$ 2005)	Note
Mechanised spray unit	0.08	0.08	Assumes unit cost $AUD8000 ($US6000), unit lifetime 5 years, 310 operating days per year and spray rate 50 ha per day.
Labour	0.03	0	Assumes two operators can spray 50 ha per day, at the minimum wage of $US16.50 per month.
Fuel & transport	0.06	0.06	Assumes 5 litres of diesel per day for transport and operation of the unit
Chemical cost - metsulfuron methyl	$9	$9	Based on US$45 for 300 grams, application rate 60 grams per ha
Total Cost	$9.17	$9.14	

Note that the chemical costs are a major component of the total cost. Manual methods of herbicide application have variable, and potentially low, efficiencies of application. Therefore the actual chemical costs incurred may be higher than those stated above. Given the uncertainty in these estimates, regarding both the cost rates and quantities involved, the following total costs for chemical control of Mimosa were adopted:

Table 6-11: Cost summary for chemical management with various application methods of Mimosa in Zambia

Application Method	Chemical Cost ($US/ha)	Application Cost ($US/ha)	Total Cost ($US/ha)
Aerial spraying	$9	~ $4	$13
Manual spraying - mechanised spray unit	$9	~ $1	$10
Manual spraying – back-pack style unit	$9	~ $1	$10

The choice of spray application method will depend on the size of the area to be sprayed. Large areas are required in order to achieve the economies of scale assumed in the cost estimate above for aerial spraying. Manual spray methods would be selected with regard to the area requiring treatment and also the relative availability of capital or labour.

A number of references were found in the literature to the control of Mimosa using chemical means. A summary of these is provided in Table 6-12 below.

Table 6-12: Evidence from literature - chemical management of Mimosa

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year) Context
CRC Weed management, 2003	"Heavy infestation"	Control difficult and costly Aerial spraying	Up to five years of spraying may be required due to regrowth of germinated seeds	?	Australia, 2003
Marambe B. *et al* (2002) Symposium		Glyphosate at 1.44kg active ingredient /ha applied in 3 times at 4 months interval	Good results plants younger than 6 months	Manual application – no quantitative information	Sri Lanka, 2002
Hong Son et al 2002		Experiments were conducted with two non-selective herbicides, paraquat and glyphosate, and two selective chemicals for broadleaf weeds, metsulfuron methyl and triclopyr butoxyethyl ester. All were used at 1.5 times the standard dosage.	Leaf-drop occurred 7–15 days after treatment. Plants treated with paraquat quickly recovered 15 days after treatment while the other herbicides remained active for up to three months. After three months, new regrowth occurred The highest efficacy was achieved when glyphosate was applied at a rate of 600 L/ha with a hand knapsack sprayer or at 10 L/ha with a ULVA sprayer. The ULVA sprayer was equal in efficacy to the hand knapsack sprayer and also significantly reduced costs.	No cost cited	1995, 2002

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year) Context
Searle, 2006	10,000ha	Four-wheel drive vehicles, four-wheel utility vehicles (quad-bikes), motorbikes and horses, which are used for hand-spraying Mimosa regrowth and patrolling boundaries Vehicle-mounted spray units and backpack spray units etc. are used for herbicide application Prototype planting machines are used for distributing pasture seeds and planting pasture runners Three helicopters for aerial spraying		AUD$250,000 per year	Northern Territory, Australia 2006

Based on the evidence above, chemical control is not expected to be successful in isolation for well-established Mimosa populations and must be combined with other control methods, including removal of dead trees and follow-up spraying. The establishment of other vegetation on the land, and follow-up spraying (for up to 5 years, although potentially with reduced chemical application rates) will assist in preventing re-invasion.

Chaining, using two bulldozers to remove the dead timber, is estimated to cost $52 per hectare, and is required to clear the affected area to allow beneficial use of the land to resume. This cost is based on the following assumptions;

- Hire costs of $US50 per day per bulldozer; and
- Two semi-skilled operators being able to clear 2 hectares per day.

The net present cost over 25 years for treatment of a large infestation (including aerial spraying, clearing and follow-up manual spraying annually for five years, assumed to remain effective for 25 years) at a discount rate of 10% is therefore approximately $93 per hectare. The benefit-cost ratios for a combination of chemical and mechanical control to manage high-density Mimosa infestations for various land use methods are stated in Table 6-7 below.

Table 6-13: Chemical and mechanical control of high density Mimosa infestation – benefit-cost ratio of various land uses

Land use	NPV Mechanical and Chemical Control Costs ($US 2005)	NPV Productivity of Land (25 years) ($US 2005)	Benefit-Cost Ratio
Agriculture			
Cassava	93	$3,939	42.4
Maize (rain-fed)	93	$2,115	22.8
Maize (irrigated)	93	$5,891	63.4
Cattle grazing	93	$272	2.9
Fishing	93	$117	1.3
Tourism	93	$19	0.2

The benefit-cost ratios stated above assume a real increase in the value of tourism to the Kafue Flats region, and the Blue Lagoon and Lochinvar National Parks specifically, by 2.5% per tourist per year (the expected Gross Domestic Product growth in the home countries of foreign visitors), with tourist numbers increasing by 3.9% per year. This assumption is made as a result of current capacity for development in the Zambian tourist sector. For all other land use types, the real value is assumed to be unchanged over the 25-year Net Present Value period. Some increases in real value are possible, for example, as a result of development and adoption of high yielding crop varieties, selective cattle breeding programs and improved agricultural and fishing methods. These would result in increasing benefit cost ratios of combined chemical and mechanical control methods.

6.5 Fire control

6.5.1 Introduction

Fire control on its own is generally not an effective way to control Mimosa. It can in fact reduce competition from other species allowing more Mimosa to germinate. In addition, though it may kill seeds found on the soil surface, fire can increase the germination of the soil seed-bank by breaking seed dormancy (Marambe, 2002).

Mechanical crushing is useful in assisting fire control by ensuring a hotter fire which kills more Mimosa seedlings and seeds. However, follow-up control with a variety of methods is required to allow native plants to re-establishment. Fuel in the form of gelled petrol (gasoline) can be applied by aircraft and then completely burnt at a temperature high enough to destroy seeds and seedbanks.

Table 6-14 presents information on the costs and effectiveness of fire control of Mimosa.

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Table 6-14: Management of Mimosa using fire

Study	Infestation	Description	Estimated effectiveness	Cost	Country (year) Context
Lonsdale & Miller, 1993	$160m^2$	In this field experiment, gelled gasoline was applied to thickets of Mimosa from a helicopter and then lit. The fire produced was intense when the fuel was applied in a spiral pattern and cleared the infestation.	When applied correctly the application of fire killed all the adult Mimosa and killed all the seeds but only down to 5cm within the soil	None cited, but several staff were required, plus the use of a helicopter and fuel	Australia (1988)
Marambe B. *et al,* 2002	Upland conditions	Burning Agronomic (Panicum maximum) at 16 plants $/m^2$	Profuse regenerative branching of plants and increased seed germination of the soil seed-bank was observed two to three months after burning	None cited	Sri Lanka
Sanmouth, 2002	Not cited	Fire and combined cutting and fire	Communities noticed that fire triggered the germination of Mimosa seed	None cited	Cambodia 1985-2000

6.5.2 Cost benefit analysis of fire control

Because fire control is not effective, a full cost benefit analysis cannot be carried out. However, since it may be used as an element of an integrated management strategy, the indicative values of the costs are given in Table 6-15.

Table 6-15: Costs of fire control of Mimosa

Cost per hectare (US$)	**Source**
$63-$76	California Department of Forestry and Fire Protection (2004)

These costs relate to fire control in California in 2004 and relate to the spraying of gelled gasoline from a helicopter. Although the cost of this is likely to be less competitive in Zambia, these can be considered to be a lower bound to the costs that would be involved in fire control.

7 RISK ASSESSMENT – MIMOSA INVASION

A risk assessment has been carried out to identify likely propagation pathways of Mimosa to neighbouring countries and to other regions within Zambia. This assessment was based on examination of the habitat and ecology of Mimosa, the occurrence of suitable habitats in neighbouring regions and countries, and the likely pathways for invasion.

7.1 Risk Assessment Methodology

The following risk elements formed part of the assessment. Note that they are divided into natural risk (suitability of climate and habitat to support Mimosa populations) and structural risk (capability of government and communities to prevent or control Mimosa infestation)

Natural Risk:

- Introduction pathway – waterways: assessment of the existence and inter-connection of waterways that may act as dispersal vectors for Mimosa;
- Introduction pathway – potential for mechanical dispersal: given the risk associated with the mechanical dispersal of Mimosa seeds (eg. attached to boats, in mud that can adhere to vehicles), the presence of mechanical vectors was assessed;
- Survival likelihood – flow regimes: critical to Mimosa, flow regimes (and particularly flood events) were assessed for two major risk factors: (i) the absence of prolonged dry periods that may impact on the survival of the plants and (ii) the occurrence of floods, that disperse Mimosa seeds and best guarantee the survival and establishment of Mimosa seedlings
- Survival likelihood – climate: the assessment of climate with respect to survival focused on investigating the extreme climatic conditions (dry periods and extreme temperatures) that may eliminate Mimosa;
- Establishment risk – climate match: the assessment of climate with respect to longer term establishment of Mimosa. Average temperatures and precipitations were investigated – suitable conditions are defined in Section 4.6.
- Establishment risk – habitat match: habitat match was defined as the existence of suitable habitat conditions for the long term establishment of Mimosa: floodplains, non-agricultural land, nature reserves, etc.; and
- Establishment risk – proximity to existing infestation: Efforts were made to try to locate recognised infestation areas - the proximity of new areas to be infested was subsequently assessed. Finding precise information on the location of Mimosa infestation at a local level proved to be challenging. When this proved to be impractical, a general risk level was assumed for the country or region on the basis of comments and references to Mimosa in the literature.

Structural Risk:

- Control possibilities – organisational resources: the assessment focused on determining the existence and activities of governmental and parastatal organisations for each country or region that may have interest and/or responsibilities in the management of natural resources and water. International and regional organisations were also recorded;
- Control possibilities – political stability: the assessment of political stability was performed without any judgement of political orientation using the Political Stability Index developed by Kaufman *et al* in 2002[2]. Investigations focused on events affecting political stability which have

[2] The authors draw 194 different measures from 17 different sources of subjective governance data constructed by 15 different organizations. These sources include international organizations, political and business risk rating agencies, think tanks, and non-governmental organizations. The Political Stability index measures perceptions of the likelihood that the government in power will be destabilized or overthrown by possibly unconstitutional and/or violent means, including terrorism. This index captures the idea that the quality of governance in a country is compromised by the likelihood of wrenching changes in government, which not only has a direct effect on the continuity of policies, but also at a deeper level undermines the ability of all citizens to peacefully select and replace those in power. For more information : (http://humandevelopment.bu.edu/dev_indicators/show_info.cfm?index_id=117&data_type=1)

occurred since 2002. Information sources accessed were provided by third party bodies meaning that information arising from the country itself was considered but not recorded.

Each risk element is considered to have equal importance when assessing the total risk of invasion.

The risk of invasion was assessed for each of the following countries:

- Angola (excluding northern region);
- Angola (northern region);
- Botswana;
- Democratic Republic of Congo (DRC);
- Malawi;
- Namibia;
- Mozambique;
- Tanzania;
- Zambia; and
- Zimbabwe;

These countries were selected for their proximity to the known Mimosa infestation in Zambia and for subsequent their potential to suffer from Mimosa infestation in the future.

Each of the risk factors was assessed and scored according to the following scale:

- Negligible risk of infestation – 0;
- Very limited risk - infestation is unlikely under current conditions – 1;
- Limited risk - infestation is possible – 2;
- Medium risk - infestation is likely under current conditions – 3;
- High risk - infestation highly probable if no control/management in place – 4; and
- Extremely high risk - infestation most probable if no control/management in place – 5.

While the best efforts were exercised in the risk assessment for Mimosa, the level of information available and the scope of the project make it impossible to guarantee that all existing documents have been reviewed. There may be a number of documents that have not been included, especially documents published in languages other than English or French (which were used in the present study).

7.2 Risk Assessment Results

Detailed results of the risk assessment are provided in Appendix B. A summary of results in provided in Table 7-1 below.

Table 7-1 Relative risk of Mimosa Invasion

Country or Region	Natural risk score (max 35)	Structural risk score (max 10)	Risk score (max. 45)
Angola (ex. northern region)	24	9	33
Angola (northern region)	31	9	40
Botswana	23	3	26
Democratic Republic of Congo (DRC)	33	8	41
Malawi	26	6	32
Mozambique	23	5	28
Namibia	16	2	18
Tanzania	30	4	34
Zambia	31	4	35
Zimbabwe	23	7	30

Figure 7-1 Relative risk of Mimosa infestation

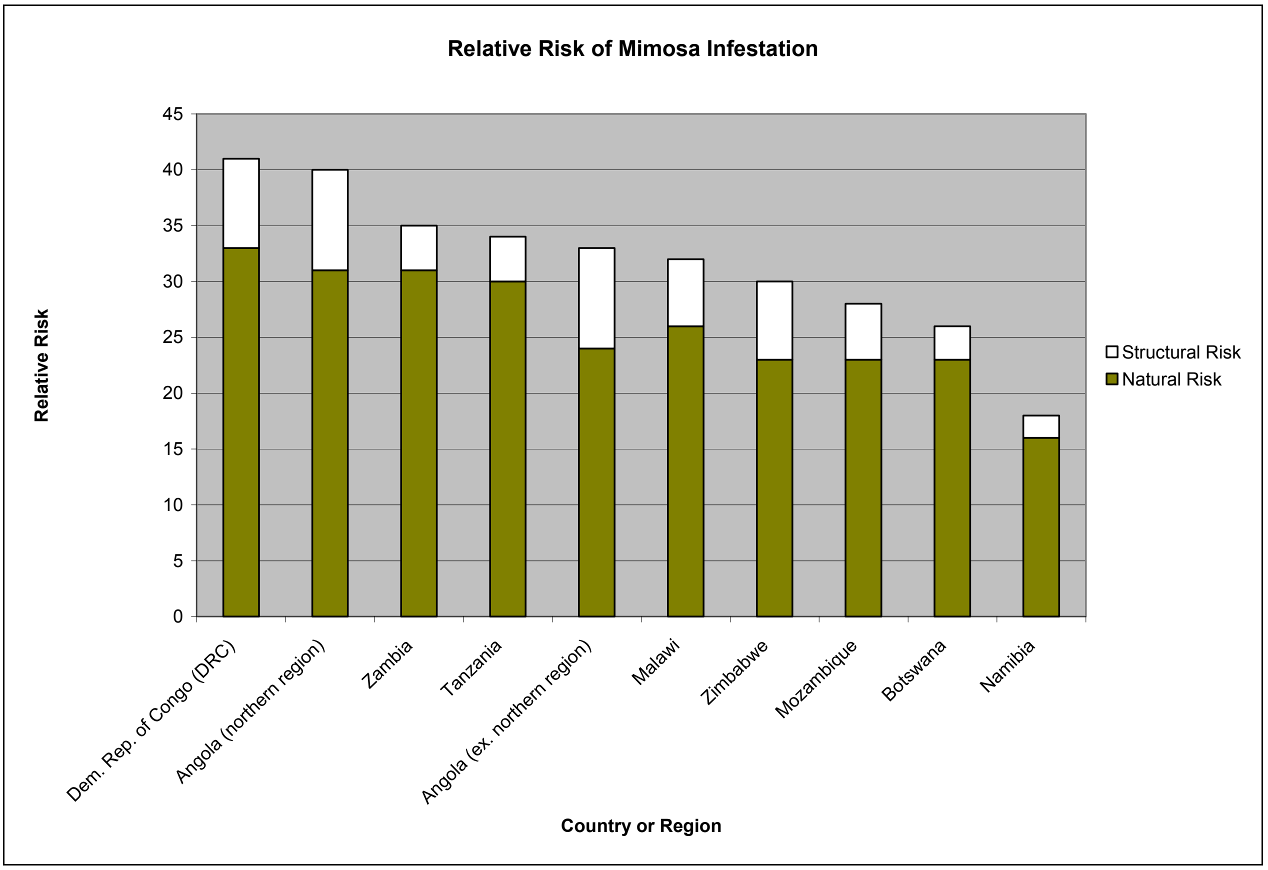


Figure 7-1 indicates that the greatest risk of Mimosa infestation in the region includes the Democratic Republic of Congo, the northern region of Angola, further infestation throughout Zambia, and invasion of Tanzania, Angola and Malawi. Note that all of the countries and regions considered in this assessment have been found to be at risk of Mimosa invasion or expansion of existing Mimosa infestation.

The expected ultimate size of invasion (that is the area of invasion in the very long term, in the absence of any control or prevention measures), has been estimated according Table 7-2 below. This includes consideration of the total susceptible area (area of suitable habitat) adjusted for the relative risk of invasion. Suitable habitat for Mimosa was considered to comprise the floodplain area (estimated to be 1000m wide) of major river systems, and wetlands, lakes and deltas which are seasonally inundated. As there is no evidence in the literature of Mimosa invasions becoming established in cultivated agricultural land, this land does not form part of the expected ultimate invasion size.

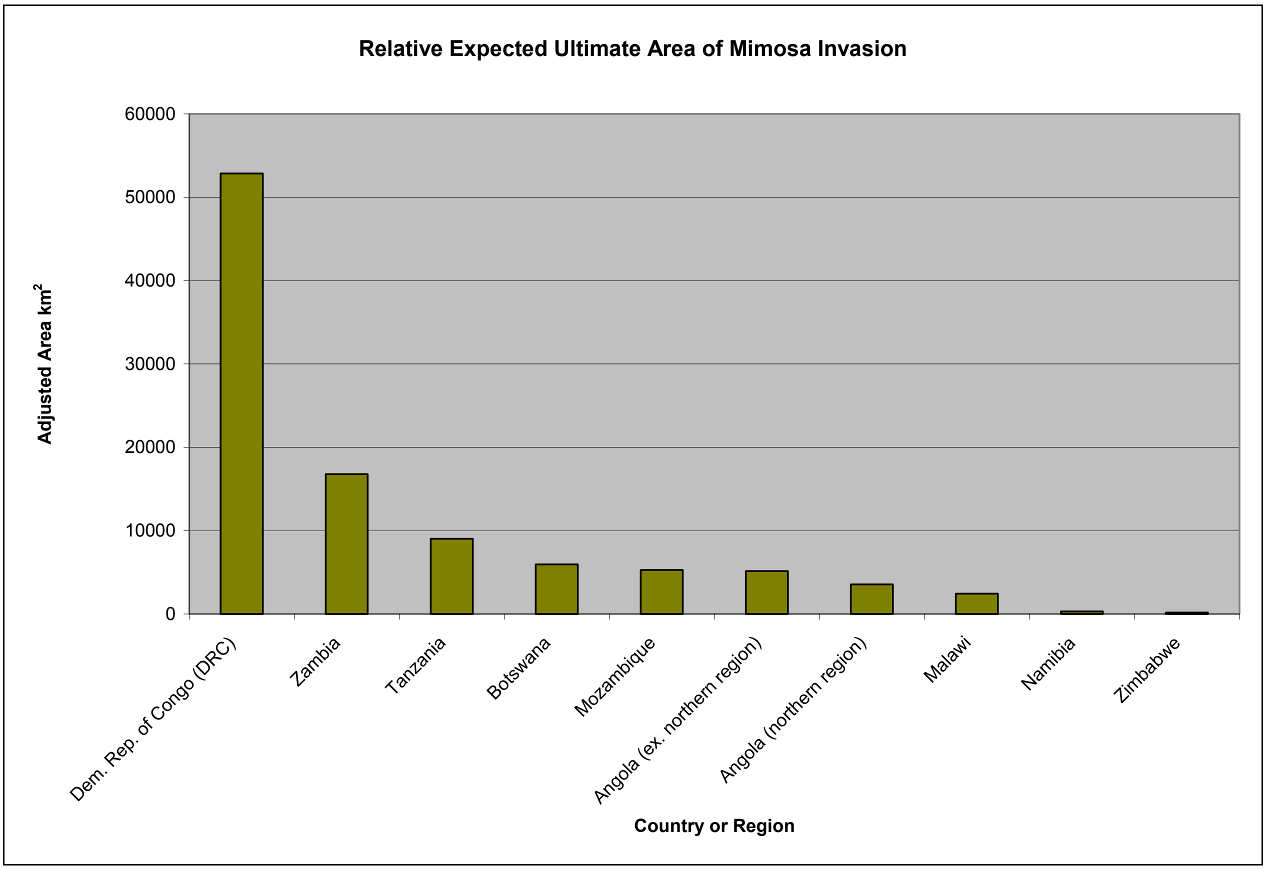
Note that this assessment does not include small waterways which are not documented in the literature available, and therefore is likely to underestimate the true area of potential invasion. However, the analysis allows for comparison of infestation risk between countries and regions.

Table 7-2: Expected size of ultimate invasion, if no preventative or control measures are applied

Country or region	Risk score (max. 45)	Susceptible area km^2	Adjusted area of ultimate infestation (km^2)
Dem. Rep. of Congo (DRC)	41	58000	52844
Zambia	40	4000	16761
Tanzania	35	21550	9029
Botswana	34	11950	5951
Mozambique	33	7000	5258
Angola (ex. northern region)	32	3420	5133
Angola (northern region)	30	250	3556
Malawi	28	8450	2432
Namibia	26	10300	296
Zimbabwe	18	740	167

The adjusted ultimate area of Mimosa infestation in the region (by country) is indicated in Figure 7-2 below. This clearly indicates that the Democratic Republic of Congo is most at risk (on the basis of area of suitable habitat and risk of invasion by Mimosa) followed by further infestation within Zambia. The adjusted area of habitat susceptible to Mimosa infestation in Namibia and Zimbabwe is quite small.

Figure 7-2 Adjusted ultimate area of Mimosa invasion



8 PREVENTION STRATEGIES FOR MIMOSA INVASION

Potential strategies to prevent the invasion of Mimosa in Africa are highlighted within this section. This section specifically examines:

- Similar invasive species;
- Invasion pathways; and
- Prevention strategies.

8.1 Similar Invasive Species

Unfortunately several species of plants exist which have similar characteristics to *Mimosa pigra* and which display a relatively high level of invasiveness in Africa and elsewhere in the world. The following species are similar to *Mimosa pigra*, including several of its congeners:

- *Mimosa* spp. (Sensitive Plants);
- *Acacia* spp. (Wattles);
- *Albizia julibrissin* (Persian Silk Tree) (together with 150 or so other species of the same genus);
- *Melaleuca quinquenervia* (Broad-leaved Paperbark);
- *Tamarix ramosissima* (Tamarisk Tree), *Tamarix aphylla* (Athel Tree, Salt Cedar), and many other species of this genus.

These small trees and large shrubs have similar habits to Mimosa. They invade using similar pathways, such as the production of large numbers of seeds, and are extremely hardy. The *Melaleuca* and other *Mimosa* species will invade wetter areas but all species can thrive in floodplains which are only inundated intermittently.

8.2 Invasion Pathways

Species become invasive following a series of processes after being transported to a new location. A subset of these organisms is actually introduced and some of these become established, before the populations grow and spread. It is usually at this stage they impact significantly upon human and natural values and are then recognised as invasive weeds (see Figure 8-1, Schooler *et al* 2005). Risk assessment procedures (see Champion & Clayton 2000) allow the identification of the species which are likely to become invasive.

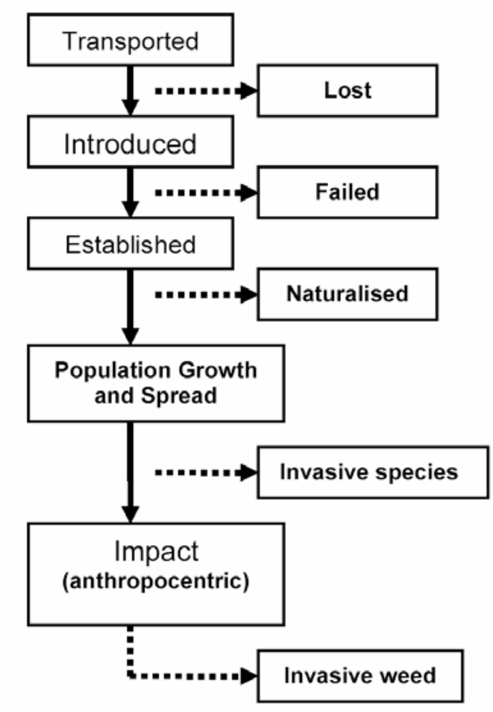


Figure 8-1. Steps in the process of invasion leading to anthropocentric impacts (from Schooler et al 2005).

Invasion pathways have been clearly documented in New Zealand which has extremely high level and effective weed control and quarantine procedures (Champion & Clayton 2000). While these controls are unlikely to be replicated in Africa in the near future, the pathways of invasion which have been recognised are likely to be similar. These include:

- **Natural spread** consists of wind-blown or water-borne seed or propagules which arrive in a new country or new location and become established.
- **Ship ballast** sometimes contains soil which can harbour weed seeds or propagules. If ballast is then discharged into a suitable receiving environment for the particular weed species carried, invasive species can become established.
- **Forage plants** are introduced to feed grazing animals and can then become established and invasive.
- **Industrial purposes** include species which might be used for wastewater treatment (e.g. reeds) or other purposes such as biofuels.
- **Research purposes** account for specific species which may be legally imported for research or teaching purposes but then escape to become established in the wider environment due to poor internal controls.
- **Culinary and medicinal purposes** is known as an invasion pathway for invasive species. Alligator weed has been used and cultivated in New Zealand and Australia in the mistaken belief that it is another species which is a traditional vegetable. Other species, such as water lettuce (*Pistia stratiodes*), are used for medicinal purposes and escape from cultivation to become invasive.
- **Incorrectly identified imports** occurs when the lack of taxonomic knowledge by border control authorities allow species to enter a country without recognition of its invasive potential. Small samples or young specimens can be very difficult to identify, even for trained staff.

- **Contaminated products** such as imported machinery, crates and packaging can transport invasive species. While this is less likely for aquatic species, plants like Mimosa have a good ability to be transported by this method.
- **Mail order plants** are dispatched world-wide. This is potentially a growing problem in Africa as many African nations become more prosperous, with businesses and private individuals accessing these services.
- **Pocket plants** are those species which accidentally (or carelessly, or deliberately) find their way into traveller's pockets or luggage and are not detected by quarantine authorities.

Mechanisms of spread for Mimosa are described earlier in the report (refer section 4.8). This includes the production of numerous seeds and propagules that can adhere to clothing and animal coats, allowing dispersal. The seeds may be transported long distances by wind or by water, and are long-lived. They are also frequently distributed in mud on vehicles and survive digestion by animals to be dispersed in manure. Botanical escapes also contribute to the establishment of invasive Mimosa populations.

8.3 Potential Invasion Prevention Strategies

A range of prevention strategies are required to prevent invasive plants including Mimosa, from colonising further habitats in Africa.

These include:

- Legislation;
- Education and community involvement;
- Quarantine and controls on movement, spread and use of the species;
- Monitoring & early detection; and
- Contingency planning.

8.3.1 Legislation

Legislation is required to prevent transport from one country to another and the prevention of in-country spread. The costs of controlling and managing outbreaks of either species are generally much larger than the costs of preventing it entering a country or being distributed within a country. The types of legislation which have served some countries well, in recent times, includes:

- Prohibiting the entry of identified weeds into the country;
- Mandating quarantine procedures of all people, parcels and other imported items;
- Prohibition of the keeping of invasive plants;
- Mandatory risk assessment of applications to import species; and,
- Mandatory risk assessment of applications to translocate species within countries.

The most powerful argument for this type of legislation is the disastrous results from unfettered importation of exotic species into Australia and Africa in past times without such legislation. Obviously legislation is only one of the tools required but is a useful first step and links closely with other prevention strategies, such as education.

Many African countries do not currently have legislation covering weeds. The Organisation for African Unity has established the Pan-African Phytosanitary Council, but this has not been effective in developing lists of prohibited species to date (Martin Hill, pers comm.)

Cost-Benefit analysis for legislation

No data has been found in the literature regarding the cost or quantified effectiveness of invasive species control by legislation. Prevention of invasive species establishment using legislation development would generally be expected to involve an entire country (not individual infestations). Therefore costs must be estimated at the national level and compared with the total area at risk of invasion in each country.

Due to the many variables which influence both the cost and effectiveness of this prevention technique, and the difficulty in estimating the required inputs to legislation development, no attempt can be made to estimate the associated benefit-cost ratio. The associated costs would include the development of legislation, which is expected to be a complex and drawn out process in most countries and may require lengthy revision and approval processes. Stakeholder consultation would also be required to ensure legislation developed is appropriate. A program of monitoring and enforcement will then be required indefinitely to ensure compliance with the law.

Where institutional capability is poor or the required resources for development and enforcement of legal requirements are not present, this method is unlikely to be successful.

Case Study	Prevention Strategy	Description	Estimated effectiveness	Cost	Cost US$ 2005	Country (year)
Jacot Guillarmod (1979)	Legislation	The Republic of South Africa (1964) and other African countries have weed control Acts. These acts make it illegal to keep or distribute weed species. The Act requires land holders to also control these weeds.	Many issues exist with the enforcement of this legislation which include: ▪ Too few weed inspectors ▪ General public ignorant of the laws or the dangers the weeds pose and how to identify these weeds ▪ Some countries don't have proclaimed weeds ▪ Provisions within the Acts are too general ▪ Ownership of water bodies at dispute ▪ Some rivers pass from one Country to another making control even more difficult Without remedy, such legislation is ineffective in controlling weed spread, and alone it is also ineffective. This case study indicates that legislation needs to be backed up by: ▪ Compliance measures and funds expended on weed inspectors ▪ Education programs to inform the general public of the: ○ laws themselves ○ impacts of the weeds ○ weed identification ▪ Risk assessment to identify weed species ▪ Specific provisions and actions within the Acts ▪ Ownership of water bodies to be clarified and responsibilities assigned ▪ Inter-country agreements on weed control			South Africa (1964)

8.3.2 Education and community involvement

Education and community involvement is required to enable stakeholders:

- to understand the potential impacts of Mimosa invasion;
- to identify this species and similar potential invasive species;
- to use alternative species (natives and non-invasive species);
- to learn what actions individuals can undertake to prevent or control infestation; and,
- to learn which actions communities can support governments to undertake in the prevention and control of Mimosa.

The education to assist local communities to identify Mimosa and other invasive plants will allow these communities to understand the extent of the infestations and develop appropriate strategies to control outbreaks.

Most countries in Africa have been ad hoc in their approach to education and community actions to date (Martin Hill, pers comm.). As a result, no case studies could be found in the literature describing the implementation, cost or effectiveness of education and community involvement in the prevention of weed invasions.

Cost-Benefit analysis for education and community involvement

No data was found in the literature of the cost or quantified effectiveness of the prevention of invasive species by education and community involvement.

8.3.3 Quarantine and controls on movement, spread and use of the species

Controls on the movement, spread and use of invasive species is critically important in terms of managing these species. Quarantine procedures will control these species from local movements and between countries. These controls need to be supported by legislation, regulations and enforcement. Not only would they set out quarantine procedures to prohibit importation of identified noxious species into a country, but would prohibit use of these species in aquariums, public gardens or private garden ponds. Prohibition of use is equally as important as limiting importation of these species.

Weed control legislation should ensure landholders are required by law to control Mimosa and other invasive species when it occurs on their property.

Controls on stock movement will also prevent distribution of Mimosa, as the seeds will stick to animals' coats and viable seeds are found in stock droppings. Therefore, fencing and control of stock movement may be necessary and useful in preventing Mimosa from colonising new territory. Fencing programs allow better control of stock and could limit the spread of invasive species.

Quarantine controls are generally not very effective in Africa, as most of the introductions of plants (which subsequently become weeds) are intentional imports for some reason or other (Martin Hill, pers. comm.).

Cost-Benefit analysis for quarantine measures.

No data was found in the literature regarding the cost or quantified effectiveness of invasive species control by quarantine. Prevention of invasive species establishment using quarantine controls and restrictions on movement of invasive species would generally be expected to involve an entire country (not individual infestations). Therefore costs must be estimated at the national level and compared with the total area at risk of invasion in each country to establish a cost per hectare of prevention measures.

Due to the many variables which influence both the cost and effectiveness of this prevention technique, and the difficulty in estimating the required inputs to developing and maintaining quarantine controls, no attempt can be made to estimate the associated benefit-cost ratio.

The associated costs would include the development of quarantine control processes and protocols (including stakeholder consultation and potentially complex government review and approval processes), as well as significant capital and labour requirements for enforcement. This would include inspection and administrative facilities at all ports, airports and border crossings, as well as prevention of border-crossing away from designated points.

Where institutional capability is poor or the required resources for development and enforcement of quarantine regulations are not present, this method is unlikely to be successful.

Case Study	Prevention Strategy	Description	Estimated effectiveness	Cost	Cost US$ 2005	Country (year)
Wingrave (2006)	Quarantine and Control Measures	Local quarantine measures have been introduced to control the spread of a weed, Cabomba, in Australia. Part of the Darwin River in Northern Territory in Australia has been made off limits to fishing, swimming and boating with fines up to $50,000 AUD.	▪ These have been effective in restricting the local spread of this weed ▪ It would be difficult to implement in many countries as enforcement of the financial penalties may not viable and subsistence farmers need access to all available resources			Australia (2006)

8.3.4 Monitoring & early detection

Monitoring and early detection are beneficial measures to identify and control outbreaks of invasive species (Howard and Harley 1998; Bowcher and Lee 2003; Bloosey 1999).

Small outbreaks are always easier and less costly to control than established populations (Howard-Williams and Thompson 1985; Howard and Harley 1998; Bloosey 1999, Bowcher and Lee 2003; Mumba 2005). Early identification and intervention have been found to be key factors in a successful weed management program, particularly in developing countries where resources and expertise are not generally available (Triet et al. undated).

Monitoring programs offer the opportunity of involving communities, providing education and building the community's capacity to identify and address outbreaks before infestations become established and difficult to control due to their sheer size.

In practice monitoring and early detection is poorly done, even in the most stable and advanced countries in Africa. While this approach has great potential to reduce the impact of invasive species, it is generally not realised (Martin Hill, pers. Comm.).

It is expected that this prevention measure would have low capital requirements in populated areas, and could be executed primarily using unpaid labour (that is, member of the community would carry out much of the monitoring and early detection work). However, in the case of community monitoring, there would be a need for program administration and co-ordination (including at the local and regional level) which would incur cost. Note also that this method only identifies the need for weed control measures – additional cost would be incurred for the control of the invasive species once it is identified.

The effectiveness of this approach would depend on the willingness of community members to remain vigilant and to co-operate by reporting presence of the weed species and addressing any invasion appropriately.

Cost-Benefit Analysis for monitoring and early detection

Some evidence of the cost and efficiency of monitoring, early detection and control efforts of potential Mimosa infestations in Australia was found in the literature. At a cost of approximately US$1.50 per hectare annually, Mimosa invasion has been avoided in the Kakadu national park. This information is of limited value in determining the cost of Mimosa prevention in Africa, due to the capital intensive nature of the approach (may not be possible in many countries noted as being at risk of Mimosa infestation, due to higher priorities for scarce capital). However, a cost-benefit analysis is performed using this information as an indicator of the order of magnitude of the cost of monitoring and early detection.

Table 8-1: Estimated cost of monitoring and early detection for prevention of Mimosa invasion

Cost component	Cost per hectare $US 2005	Source	Note
Monitoring and early detection	$1.50 per year	Department of Environment and Heritage, 2006	Includes monitoring and detection only, not control
Chemical control	< $0.50 per year	Section 6.1.3	Based on cost of US$10 per hectare for manual spraying , assuming that infestation density is less than 5% of total area with regular monitoring
Total Cost	$2.00 per year		

The net present value of ongoing monitoring and detection activities determined over 25 years, assuming a discount rate of 10% and inflation rate of 2.5%, has been calculated to be US$22.30 per hectare. The benefit-cost ratio of this activity is provided for various land uses (taken from section 5), assuming that it avoids a dense infestation of Mimosa which would eliminate the possibility of productive use of the land.

Table 8-2: Benefit-cost ratio of monitoring and early detection for prevention of Mimosa invasion for various land uses in the Kafue Flats. Net present value over 25 years (real discount rate 7.5%)

Land use	Value of use or production per hectare ($US 2005)	Prevention cost per hectare ($US 2005)	Benefit-cost ratio
Agriculture			
Cassava	$3,939	$22.30	177
Maize (rain-fed)	$2,115	$22.30	95
Maize (irrigated)	$5,891	$22.30	264
Cattle grazing	$272	$22.30	12.2
Fishing	$27-$236	$22.30	1.2 – 10.6
Tourism	$19	$22.30	0.85

For all land uses (except tourism), the benefit-cost ratio of monitoring and early detection is positive. Note however that the tourism industry in Zambia is not highly developed and there is potential for land use values in excess of those stated to be realised.

For many land uses, the benefit of Mimosa prevention using this method is many times greater than the cost of its implementation. Note that the estimated cost of prevention measures given here is based on an Australian case study which involves capital-intensive methods of monitoring remote areas. The cost and availability of capital (quad bikes, air boats, four wheel drives) in Africa may be a constraint to the use of this approach. However, given the relative abundance and low cost of labour in Africa compared to Australia, combined with the significant benefits of early detection measures, it is expected that early detection and monitoring activities for prevention of Mimosa infestation will deliver net benefits.

9 SUMMARY OF RESULTS

9.1 Economic impact of Mimosa

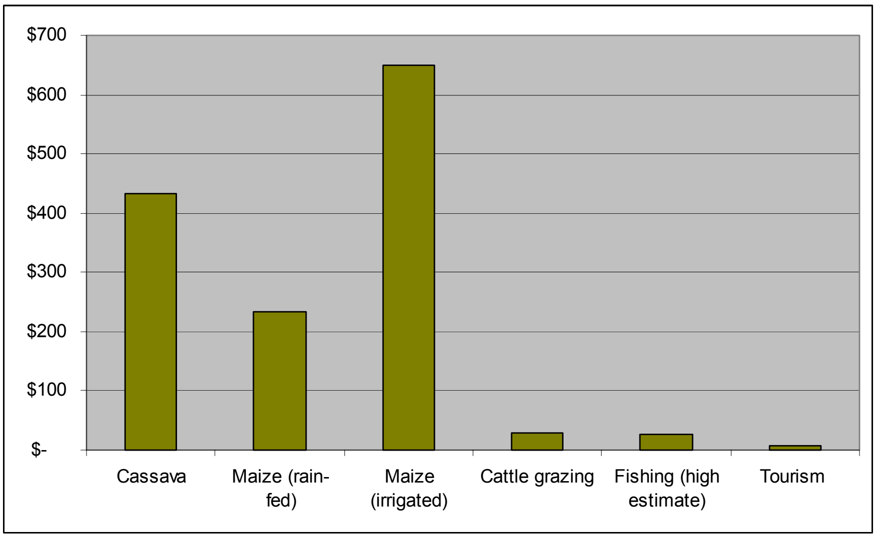
For Mimosa, the impacts of invasion on cassava production, maize production, cattle grazing, fishing and tourism were estimated. These are presented in Table 9-1 and Figure 9-1.

These figures are presented for high density infestations of Mimosa only – it is assumed that low density infestations can be managed with manual labour, which has a shadow price of close to zero.

Table 9-1: Annual economic cost of Mimosa invasion per hectare by land use in the Kafue Flats ($US 2005)

Land use	Annual cost – low density	Annual cost – high density	Net present value over 25 years (discount rate of 10%) – high density
Agriculture			
Cassava	Close to zero	$434	$3,939
Maize (rain-fed)	Close to zero	$233	$2,115
Maize (irrigated)	Close to zero	$649	$5,891
Cattle grazing	N/A	$30	$272
Fishing	Close to zero	$3 - $26	$27-$236
Tourism	N/A	$2.40	$19

Figure 9-1: Annual economic cost of Mimosa per hectare by land use in the Kafue Flats ($US 2005)



While there is substantial uncertainty around these figures, they do indicate the approximate economic impact of Mimosa on different land uses.

Because Mimosa completely takes over land and leaves it unavailable for production, the cost of its impact is significant.

The impact on tourism here is very low, due to the low numbers of visitors to Lochinvar National Park. Further consideration of the likely tourist numbers in the future may be warranted due to the potential for considerable growth in the Zambian tourism sector.

No evidence was found in the literature of Mimosa invasion of agricultural land, including land used for maize and cassava cultivation, in the Kafue Flats region. Attempts to contact farmer federations and herbicide companies throughout Southern Africa did not provide any evidence of Mimosa affecting agricultural production. Anecdotal evidence indicates that there are no known cases of Mimosa infestations affecting cultivated land (Mr. Brian Nkandu, Zambian Environmental Council, pers. comm.).

9.2 Management of Mimosa

Management of Mimosa is a long term strategy, which may add to the difficulties in areas where institutions are not stable or well funded, as may be the case in Zambia. No single simple and effective control measure is available, thus an integrated weed management approach is required.

The costs per hectare of various management techniques are presented in Table 9-2 along with recommendations on where they may be most suitably used.

Table 9-2: Management of Mimosa - summary

	Cost per hectare in Zambia	Most suitable to use
Manual		
Pulling	$16-$63 (financial) $0 (opportunity cost)	To maintain land for agricultural use, or to control young and small infestations
Stem cutting	$7-$41 (financial) $0 (opportunity cost)	To maintain land for agricultural use, or to control young and small infestations
Chemical		
Aerial spraying	$13	Dense infestations covering large areas As part of an integrated management strategy
Manual spraying - mechanised spray unit	$10	Small areas – more capital and less labour intensive than back pack As part of an integrated management strategy
Manual spraying – back-pack style unit	$10	Small areas - less capital and more labour intensive than mechanised spray unit As part of an integrated management strategy
Biological	$31/ha (financial cost) $29/ha (opportunity cost)	As part of an integrated management strategy
Fire control	$63-$76	As part of an integrated management strategy
Integrated weed management	A combination of the above costs	Best method, where institutions are set up in a way that allows a long term approach

9.3 Further field work on Mimosa

There is little evidence available in the literature on some of the impacts of Mimosa. Given the expected difficulties of managing Mimosa invasion, further research is warranted into the impacts of these invasions. The following areas in particular would benefit from further research:

- Mimosa and invasion of agricultural land (including maize and cassava);
- Mimosa and water use;
- Mimosa and fishing;

- Mimosa and hydroelectricity generation; and
- Mimosa and accessibility.

No attempt has been made to quantify the social impacts of Mimosa invasion, nor the impact of invasion on non-use values of invaded areas.

9.4 Risk of further Mimosa invasion

A risk assessment carried out using a combination of natural risks and structural risks (relating to the institutional capability of a government and community to manage threatened invasion) for neighbouring countries and other regions of Zambia suggests than invasion of Mimosa is most likely to affect the Democratic Republic of Congo, Tanzania and Zambia. Adjusting for the area of susceptible habitat in each of the countries or regions considered, the greatest risks lie in the same three countries, although the Democratic Republic of Congo has a susceptible area several times greater than either Tanzania or Zambia.

9.5 Prevention of Mimosa infestation

A number or prevention methods were considered, including legislative measures, development of quarantine processes, eduction and community involvement, monitoring and early detection of invasion, and contingency planning.

Very little quantifiable evidence was found in the literature regarding the cost and effectiveness of these measures. However, it was noted in the literature that prevention of Mimosa invasion using monitoring and early detection measures in the Kakadu National Park in Australia has delivered an excellent result. Assuming the necessary capital required to monitor the large areas involved is made available in areas where Mimosa infestation is most likely, the benefits of this measure outweigh the costs by factor ranging from 1.2 to 264 (for land uses ranging from small-scale fishing to irrigated production of maize.

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11 APPENDIX A. RISK ASSESSMENT – MIMOSA PIGRA

Psi-Delta Risk Assessment Matrix

Risk Scale

0 No risk identified - cannot induce infestation
1 Very Limited risk - inducing infestation is unlikely under current conditions
2 Limited risk - leading to infestation is possible
3 Medium risk - inducing infestation is likely under current conditions
4 High risk - inducing infestation highly probable if no control/management in place
5 Extremely high risk - infestation most probable if no control/management in place

	Zambia	Zimbabwe	Botswana	Malawi	Angola (except Northern region)
Risk element Introduction pathways waterways	5 There are a number of suitable waterways that could contribute to the dispersion of Mimosa. The 5 most important ones are : The upper main Zambezi River system is joined by the Luangwa and Kafue tributaries in Zambia. The upper Zambezi originates in Angola and flows to Mozambique after forming the border with Zimbabwe. The Kafue River system has two important dams, the Itezhi-Tezhi dam and the Kafue Gorge dam The Luangwa River drains most of the central parts of the country and empties into the Zambezi. The Chambeshi River and the Luapula River are associated with lakes Mweru and Mweru-Wantipa and drain their water into the Congo River system. The small Tanganyika drainage system is also part of the large Congo River system. http://www.africa.upenn.edu/CIA_Maps/Zambia_19892.gif	4 There are a number of waterways in Zimbabwe that may be vectors of seed dispersal. The most important one is the Zambezi that flows for approximately 850km and forms the north border of Zimbabwe. Most of the country is part of the Zambezi basin while the southern part of the country drains into the Limpopo river flowing to Mozambique. http://www.africa.upenn.edu/CIA_Maps/Zimbabwe_19893.gif	5 Waterways in Botswana can fluctuate significantly in time but there are a number of infestation pathways that need to be considered, especially i regards to the relatively long survival period of Mimosa seeds: The Okavango, flowing from Angola, soon after flowing through the Caprivi corridor turns into a large delta of endoreic wetlands. In wet years, the Okavango overflows into the Zambesi Basin through the Selinda gutter and the Linyati river and in the depression of Mababé into the Khwai river. The Mababé depression can also be flooded by the Zambesi through the Savuti river. http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.3	3 The Shire and Bua Rivers are the only significant waterways besides the lakes to offer a possible infestation pathway to Mimosa. http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.19 http://www.africa-expedition.com/images/ct/malawi-map.jpg A number of lakes have significantly varying water levels that would provide with suitable conditions: Lake Malombe Lake Chilwa Lake Chiuta	5 There are numerous rivers in Angola representing as many introduction pathways to Mimosa: Zaire Basin: including the Kasai and Kwango rivers Zambesi Basin: including the upper Zambesi and tributaries: Lungue and Cuando Okavango Basin with the Cuito and Cubango rivers http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.1
potential for mechanical dispersal	4 Potential for mechanical dispersal is high given the number of vectors of dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)	4 Potential for mechanical dispersal is high given the number of vectors of dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)	4 Potential for mechanical dispersal is high given the number of vectors of dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)	4 Potential for mechanical dispersal is high given the number of vectors of dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)	4 Potential for mechanical dispersal is high given the number of vectors of dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)
Survival likelihood flow regimes	4 Zambia has a number of dams that regulate flows in the region (eg. Itezhi-Tezhi dam and the Kafue Gorge dam). As a result, natural floods do not occur as regularly as previously but water levels still vary significantly providing particularly suitable conditions for Mimosa. http://www.fao.org/ag/agl/aglw/aquastat/countries/zambia/index.stm	4 Along the Zambezi river, flow regimes are controlled by dams such as the Kariba dam that create on a regular basis floods forming suitabel conditions for the survival of Mimosa	4 Flow regimes in Botswana are typically variable, unreliable and driven by rainfall. Floods occur on a regularly basis but inter-annual variation can be significant. http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.3	4 While flood control dams are currently in use in Malawi, flood events still occur at regular interval and form large areas of wetlands and marshes (eg. Elephant marshes). The variability of the levels offers particularly suitable conditions to Mimosa.	5 There is a limited number of dams in Angola, meaning that the heavy rainfall events that occur translate into regular flooding of variable magnitude. Especially in the Okavango and Zambesi basins http://www.africa.upenn.edu/CIA_Maps/Angola_19838.gif http://visibleearth.nasa.gov/view_rec.php?id=6925
climate	4 The lowest rainfall in the country reach 750mm in the south which is the minimum requirement for Mimosa that can grow in any wet-dry tropical climate. Therefore climat is suitable throughout the country. Mean annual rainfall for the country is 1000mm/yr. Despite the high altitude of the country and the sub-tropic temperature conditions, mean temperature are between 16 and 21 degrees throughout the year making the surviv of Mimosa likely, especially in warmer river valleys. http://www.fao.org/ag/agl/aglw/aquastat/countries/zambia/index.stm	3 Rainfall only allow for the survival of Mimosa in the northeastern part of the country (Highlands) where precipitation exceeds 750mm on average. It is expected that Mimosa would not be able to survive southwest of a line from Wankie to Gweru. http://eusoils.jrc.it/esdb_archive/EuDASM/africa/maps/afr_zw2001_cl.htm	2 The climate is arid and semi-arid, with low rainfall and high rates of evapotranspiration. Mean annual rainfall is 416 mm, ranging from 650 mm in the north to 250 mm in the extreme southwest. Rainfall occurs in the form of localized showers and thunderstorms, resulting in large temporal and spatial variations. Survival appears possible. http://www.fao.org/ag/agl/aglw/aquastat/countries/botswana/index.stm	4 The climate and rainfall are considered to be suitable especially in the lower Shire valley (the Rift valley) with average temperature ranging between 14°C and 32°C Precipitation in the area are between 700mm/yr and 2400mm/yr. The average rainfall for the country is 1200mm/yr. http://www.fao.org/ag/agl/aglw/aquastat/countries/malawi/index.stm	2 The central area of the country is formed by a high plateau (>1,000m high) where precipitations are also sufficient (1,000-1,200mm/yr). The temperature however can drop significantly in the winter time with frost regularly recorded. Mimosa can not survive temperatures lower than 13 degrees Celsius (Lloyd Environmental, 2006). The southern part of the country is warmer but rainfall would not allow Mimosa to survive (<200mm/yr)
Establishment risk climate match	4 The lowest rainfall in the country reach 750mm in the south which is the minimum requirement for Mimosa that can grow in any wet-dry tropical climate. Therefore climat is suitable throughout the country. Mean annual rainfall for the country is 1000mm/yr. Despite the high altitude of the country and the sub-tropic temperature conditions, mean temperature are between 16 and 21 degrees throughout the year making the surviv of Mimosa likely, especially in warmer river valleys. http://www.fao.org/ag/agl/aglw/aquastat/countries/zambia/index.stm	2 Rainfall only allow for the survival of Mimosa in the northeastern part of the country where precipitation exceeds 750mm on average. It is expected that Mimosa would not be able to survive southwest of a line from Wankie to Gweru. http://eusoils.jrc.it/esdb_archive/EuDASM/africa/maps/afr_zw2001_cl.htm	2 The climate is arid and semi-arid, with low rainfall and high rates of evapotranspiration. Mean annual rainfall is 416 mm, ranging from 650 mm in the north to 250 mm in the extreme southwest. Rainfall occurs in the form of localized showers and thunderstorms, resulting in large temporal and spatial variations. While survival is possible, long term establishment appears more difficult. http://www.fao.org/ag/agl/aglw/aquastat/countries/botswana/index.stm http://www.nationsencyclopedia.com/Africa/Botswana-CLIMATE.html	3 The climate and rainfall are considered to be suitable especially in the lower Shire valley (the Rift valley) with average temperature ranging between 14°C and 32°C Precipitation in the area are between 700mm/yr and 2400mm/yr. The average rainfall for the country is 1200mm/yr. http://www.fao.org/ag/agl/aglw/aquastat/countries/malawi/index.stm	1 The North of the country provides with suitable climate conditions with a tropical climate: warm average temperautres and rainfall in excess of 1,500mm/yr. The central area of the country is formed by a high plateau (>1,000m high) where precipitations are also sufficient (1,000-1,200mm/yr). The temperature however can drop significantly in the cooler and drier period with frost regularly recorded. Mimosa can not survive temperautres lower than 13 degrees Celsius (Lloyd Environmental, 2006). The southern part of teh country is warmer but rainfall would not allow Mimosa to survive (<200mm/yr)

Political Stability (Kaufmann et al.)
This index is one of six indices developed to measure governance. The authors draw 194 different measures from 17 different sources of subjective governance data constructed by 15 different organizations. These sources include international organizations, political and business risk rating agencies, think tanks, and non-governmental organizations. The Political Stability index measures perceptions of the likelihood that the government in power will be destabilized or overthrown by possibly unconstitutional and/or violent means, including terrorism. This index captures the idea that the quality of governance in a country is compromised by the likelihood of wrenching changes in government, which not only has a direct effect on the continuity of policies, but also at a deeper level undermines the ability of all citizens to peacefully select and replace those in power. The component indicators are aggregated using an unobserved components model that expresses the observed data in each cluster as a linear function of the unobserved common comp

	Zambia	Zimbabwe	Botswana	Malawi	Angola (except Northern region)
habitat match	5 There are a number of nature reserves and national parks that are particularly vulnerable to Mimosa compared to more intensively managed agricultural land. Variable water levels contribute to the risk of establishment of Mimosa. There is no significant water salinity throughout the country (http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch 3.34)	2 Zimbabwe is located on a plateau and hence there are few small flood plains. These are found in the Zambezi Valley and around the Save-Runde confluence in the southeastern part of the country. http://www.fao.org/DOCREP/003/X6611E/x6611e02g.htm Therefore, the identified habitat match is located downstream of the Kariba dam along teh Zambezi river.	2 The habitats in Botswana are made up of wetlands and floodplains in the northeastern part of the country that would be suitable for the survival of Mimosa. It is expected however that the establishment would be moer difficult in regards to temperature, low precipitation and variability of rainfall. http://www.fao.org/ag/agl/aglw/aquastat/countries/botswana/index.stm http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.3	4 The topography of Malawi si very diverse and include mountainous areas. There is a limited number of areas presneting suitable habitat match for Mimosa and they include the wetlands north of the Bua River and the lower Shire River valley .	3 Angola is located on a plateau and hence there are few small flood plains. These are found in the Zambezi and Okavango systems, and at the proximity of waterways. http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.1 http://www.fao.org/ag/agl/aglw/aquastat/countries/angola/indexfra.stm
Proximity of existing infestation	5 Mimosa has been established in a number of areas in Zambia including the Kafue basin (Kafue flat) for more than 20 years Lloyd Environmental, 2006	4 Mimosa pigra is reported in Zimbabwe. No detailed information on exact location was found. http://www.ildis.org/LegumeWeb/6.00/taxa/76.shtml	4 Mimosa pigra is reported in Botswana. No detailed information on exact location was found. http://www.ildis.org/LegumeWeb/6.00/geo/g4.shtml	4 Mimosa pigra is reported in Botswana. No detailed information on exact location was found. www.ildis.org/LegumeWeb/6.00/geo/g26.shtml	4 Mimosa pigra is reported in Angola No detailed information on exact location was found. http://www.ildis.org/LegumeWeb/6.00/taxa/76.shtml
Control possibilities Organisational resources	3 In addition to dedicated governmental departments (Department of Water Affairs and the Water Development Board of Zambia), Zambia is involved with Zimbabwe in the Zambezi River Authority. There is no indication available on attempts to address Mimosa infestation (Salvinia only) http://www.fao.org/ag/agl/aglw/aquastat/countries/zambia/index.stm http://www.zaraho.org.zm/index.html	3 In addition to dedicated governmental departments (Department of Water Development, Zimbabwe National Water Authority) and a number of catchment councils, Zimbabwe is involved with Zambia in the Zambezi River Authority. There is no indication available on attempts to address Mimosa infestation (Salvinia only). http://www.fao.org/ag/agl/aglw/aquastat/countries/zimbabwe/index.stm http://www.zaraho.org.zm/index.html	2 The Department for Water Affairs is the lead agency in water resources and provides support to the National Conservation Strategy Agency in the implementation of the National Conservation Strategy (Okavango) http://www.fao.org/ag/agl/aglw/aquastat/countries/botswana/index.stm Botswana is also getting involved in a number of international projects with objectives of improving water management and environmental conservation (eg. IUCN). http://www.iucn.org/themes/wani/news/wssd.html	3 Government structures are in place with a number of governmnetal bodies that may contribute to the development and implementation of control policies: Ministry of Water Development (MWD), the Department of Environmental Affairs, the Water Resources Board, the Department of National Parks and Wildlife. There are also a number of policy documents that could be used as a basis: the Water Policy (1996), the Water Resources Management Policy and Strategy (2000) developed by the MWD, and the Environmental Management Policy (1996). http://www.fao.org/ag/agl/aglw/aquastat/countries/malawi/index.stm	4 Water/Environment management is done under a complex network of governmental organisations (at least 5 services of 2 ministries). Environmental issues do not appear to receive a particular attention. http://www.fao.org/ag/agl/aglw/aquastat/countries/angola/indexfra.stm http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.1
Political stability (Political Stability Index: 2002 from http://humandevelopment.bu.edu/dev_indicators/show_info.cfm?index_id=117&data_type=1)	1 Zambia has long been recognized for its economic and political potential. It is an important influence in regional peacemaking and has had a history of political stability since independence in 1964. http://www.acdi-cida.gc.ca/zambia (PSI:-0.02)	4 Political stability is one of the challenges that Zimbabwe is currently facing. http://www.un.org/ecosocdev/geninfo/afrec/subjindx/123land.htm (PSI:-1.62)	1 Botswana has been called an "*basis of peace and tranquility*" on the African continent. It has a history of political stability, a low crime rate, and is one of Africa's most successful economies. http://www.iasted.org/conferences/2006/botswana/estw.htm (PSI: 0.75)	3 Malawi has relative political stability but remains vulnerable. Ministerial corruption continues. http://allafrica.com/healthafrica/cca/resources/view/00010494.pdf (PSI: 0.31)	5 Political stability is one of the challenge that Angola is currently facing. The problem is worthened by the current impact of AIDS/HIV in the country eg. http://www.pbs.org/wnet/wideangle/shows/angola/index.html (PSI: -1.60)
Total risk	**35**	**30**	**26**	**32**	**33**

	Zambia	Zimbabwe	Botswana	Malawi	Angola (except Northern region)
River length	The proportion of cropped land available from the IUCN eAtlas map was used to correct the river length to determine sensitive river length in addition to river stretches located in natural parks and protected areas. (http://www.iucn.org/themes/wani/eatlas/html/af27.html) 20% **Results:** Lower Zambezi NP : 120km -> 120km2 Luangwa NPs (Nth and Sth): 125km -> 125km2 Lochinvar NP: 20km -> 200km2 (26km2 already infested) Kafue NP: 100km -> 100km2, Kafue flats: 150km -> 150km2 Zambezi: 1,425km, Kafue: 855km, Luangwa: 780km, Chambezi: 465km, Luapula: 555km Total: 4,080km (-515km)= 3,565*0.8=2,852km -> 2,852km2 **Grand total: 3,547km2**	Risks are essentially located on the Lower Zambezi downstream of Kariba dam to Kanyemba (246km ->246km2) http://www.zambezi.co.uk/safari/activity/maplz.html http://www.africa.upenn.edu/CIA_Maps/Zimbabwe_19893.gif	Okavango River: 70km -> 70km2 Linyanti River: 210km -> 210km2	Shire River 520km -> 520km2 http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.19 Bua River 350km -> 350km2	In excess of 6,000km -> 6,000km2 http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.1
	Zambia	**Zimbabwe**	**Botswana**	**Malawi**	**Angola (except Northern region)**
Wetlands and lakes	18,000 km2 of wetlands with temporary floods (http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch 3.34)	no information found other than floodplains above	Okavango: 10,000km2	Floodplains: exclusively located along the Shire River, a number of areas are turned into wetlands during the wet season: Elephant and Ndinde marshes. The total area is estimated at 550km2 http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.19 North of the Bua River, wetlands are also mentioned that could represent 2,000km2 http://www.iucn.org/themes/wani/eatlas/html/af27.html	Part of the Okavango: approx. 1,000km2 http://www.iucn.org/themes/wani/eatlas/html/af27.html http://www.africa.upenn.edu/CIA_Maps/Angola_19838.gif
	Note: In determining the areas at risk of infestation by Mimosa, it is assumed that a band of upto 500m on each side of the river was likely to be infested. Only river stretches located in national parks or in areas clearly identified as not being cultivated were considered. The figure determined is conservative but can be re-assessed if required.		Note: Number of temporary water bodies and waterways are difficult to quantify.		

Angola (Northern region)	Tanzania	Namibia	Democratic Republic of Congo (ex-Zaire)	Mozambique
5 There are numerous rivers in Angola representing as many introduction pathways to Mimosa: Zaire Basin: including the Kasai and Kwango rivers Zambesi Basin: including the upper Zambesi and tributaries: Lungue and Cuando Okavango Basin with the Cuito and Cubango rivers Numerous coastal rivers in the North including the Cuanza river Cunene Basin http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.1	4 Tanzania has nine major drainage basins that, according to the recipient water body, that represent a vast network of possible pathways: Draining to the Mediterranean Sea: The Lake Victoria basin, which is part of the Nile River basin. Draining to the Indian Ocean: The Pangani River basin; The Ruvu/Wami River basin; The Rufiji River basin; The Ruvuma River and Southern Coast basin; The Lake Nyasa (Lake Malawi) basin, which is part of the Zambezi Riv basin; Draining to the Atlantic Ocean: The Lake Tanganyika basin, which is part of the Congo River basin. Rift Valley (endorheic) basins, of which amongst others: The Lake Eyasi and Bubu depression; Lake Manyara; The Lake Rukwa basin. http://www.fao.org/ag/agl/aglw/aquastat/countries/tanzania/index.stm The number of permanent rivers is however limited by the central arid region in Tanzania http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.29	2 There is a very limited number of waterways that would form infestation pathways to Mimosa. There are essentially located in the extreme north part of the country and include: The Okavango River The Omatako River http://www.lib.utexas.edu/maps/africa/namibia.gif The Orange River forming the border with South Africa is not believed to be suitable due to climatic conditions. Risks associated with the Zambezi in the Caprivi strip are covered in the Risk Assessment for Zambia	5 The country roughly corresponds to the Congo River basin with a number of large tributaries to the Congo River: the major ones being the Ubangui, the Lualaba, the Luapula, the Lulonga and the Chuapa. In total, major waterways in RDC represent about 33,000km of possible pathways. There are also a number of lakes in the Rift valley area. http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.33	4 There is a large number of waterways in mozambique that may offer introduction pathways to Mimosa. The two major basins ending on the coast of Mozambique are th Zambesi and the Limpopoa basins. In addition, there is a dozen of Rios that flow in the country. Mozambique also feature a number of lakes such as the Lake Malawi, Lakes Chilwa and Chiuta and the lake formed upstream of the Cabora Bassa Dam. http://www.africa.upenn.edu/CIA_Maps/Mozambique_19859.gif
4 Potential for mechanical dispersal is high given the number of vectors of dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)	4 Potential for mechanical dispersal is high given the number of vectors dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)	4 Potential for mechanical dispersal is high given the number of vectors of dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)	4 Potential for mechanical dispersal is high given the number of vectors of dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)	4 Potential for mechanical dispersal is high given the number of vectors of dispersal of Mimosa seeds: wind, water, animals and anthropic. It is clear that some of the vectors would be present in any context. (Lloyd Environmental, 2006)
5 There is a limited number of dams in Angola, meaning that the heavy rainfall events that occur translate into regular flooding of variable magnitude Especially in the Okavango and Zambesi basins http://www.africa.upenn.edu/CIA_Maps/Angola_19838.gif http://visibleearth.nasa.gov/view_rec.php?id=6925	5 River regimes follow the general rainfall pattern. River discharge and lake levels start rising in November-December and generally reach their maximum in March-April with a recession period from May to October/November. Floods occur regularly. http://www.fao.org/ag/agl/aglw/aquastat/countries/tanzania/index.stm There is also a number of dams that have been identified as providing particularly suitable flow conditions. http://en.wikipedia.org/wiki/Category:Dams_in_Tanzania	2 Flow regimes are expected to be suitable for the Okavango River with a number of high flow periods flooding the plains. It remains unclear due to the high variability of the flows of the Omatako River if flow regimes would be suitable. http://www.fao.org/ag/agl/aglw/aquastat/countries/namibia/index.stm	5 Flow regimes are largely dominated by regular floods that provide with extensive floodplain areas where Mimosa can survive.	4 The majority of the rivers have a highly seasonal, torrential flow regime, with high waters during 3-4 months and low flows for the remainder of the year, corresponding to the distinct wet and dry seasons. http://www.fao.org/ag/agl/aglw/aquastat/countries/mozambique/index.stm The Zambesi is controlled by dams (Kariba/Cabossa) that avoid floods. As a result of these regulations the flood regime on the lower Zambezi is now greatly reduced, erratic, and mainly out of season. http://www.fao.org/DOCREP/003/X6611E/x6611e02b.htm
5 The North of the country provides with suitable climate conditions with a tropical climate: warm average temperautres and rainfall in excess of 1,500mm/yr.	4 The climate is largely suitable in Tanzania for the survival of Mimosa with tropical to sub-tropical conditions in most of the country except for the central arid region. The climate is largely dominated by a bi-modal monsoon in the North and an uni-modal monsoon in the rest of the country. http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.29	2 While temperature conditions are suitable in most fo the country for Mimosa to survive (except a few cooler areas) , the major issue is the water availability. Mimosa needs about 750mm/yr of water as a minimum survival condition. This figure is hardly reached in the "wet" northern part of the country which receives approx. 700mm/year. In addition, the rainfall is sparse and erratic. http://www.fao.org/ag/agl/aglw/aquastat/countries/namibia/index.stm	5 Equatorial climate: warm, humid in the centre of the country and more tropical towrds the North and the South. Rainfall vary between 800 and 1,800mm/yr with an average of 1,500mm/yr. There is a short (4 months) dry period. http://www.fao.org/ag/agl/aglw/aquastat/countries/congo_dem_r/indexfra.stm	4 Temperature and precipitation are suitable in most of Mozambioque for Mimosa to survive. It is expected however that risks would be more limited west of a North-South line from Espungabera to Inharrime due to unsufficient rainfall (<600mm/yr). http://www.reliefweb.int/mapc/afr_sth/cnt/moz/mzsemrc.gif http://www.africa.upenn.edu/CIA_Maps/Mozambique_19859.gif
5 The North of the country provides with suitable climate conditions with a tropical climate: warm average temperautres and rainfall in excess of 1,500mm/yr. The central area of the country is formed by a high plateau (>1,000m high) where precipitations are also sufficient (1,000-1,200mm/yr). The temperature however can drop significantly in the cooler and drier period with frost regularly recorded Mimosa can not survive temperautres lower than 13 degrees Celsius (Lloyd Environmental, 2006). The southern part of teh country is warmer but rainfall would not allow Mimosa to survive (<200mm/yr)	4 The climate is largely suitable in Tanzania for the survival of Mimosa with tropical to sub-tropical conditions in most of the country except for the central arid region. The climate is largely dominated by a bi-modal monsoon in the North and an uni-modal monsoon in the rest of the country. http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.29	1 While temperature conditions are suitable in most fo the country for Mimosa to survive (except a few cooler areas) , the major issue is the water availability. Mimosa needs about 750mm/yr of water as a minimum survival condition. This figure is hardly reached in the "wet" northern part of the country which receives approx. 700mm/year. In addition, the rainfall is sparse and erratic. http://www.fao.org/ag/agl/aglw/aquastat/countries/namibia/index.stm http://www.nationsencyclopedia.com/Africa/Namibia-CLIMATE.html	5 Equatorial climate: warm, humid in the centre of the country and more tropical towrds the North and the South. Rainfall vary between 800 and 1,800mm/yr with an average of 1,500mm/yr. There is a short (4 months) dry period. http://www.fao.org/ag/agl/aglw/aquastat/countries/congo_dem_r/indexfra.stm	3 Temperature and precipitation are suitable in most of Mozambique for Mimosa to establish. It is expected however that risks would be more limited west of a North-South line from Espungabera to Inharrime due to insufficient rainfall (<600mm/yr). http://www.reliefweb.int/mapc/afr_sth/cnt/moz/mzsemrc.gif http://www.africa.upenn.edu/CIA_Maps/Mozambique_19859.gif

Angola (Northern region)	Tanzania	Namibia	Democratic Republic of Congo (ex-Zaire)	Mozambique
3 Angola is located on a plateau and hence there are few small flood plains. These are found in the Zambezi and Okavango systems, and at the proximity of waterways. http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.1 http://www.fao.org/ag/agl/aglw/aquastat/countries/angola/indexfra.stm	5 Many of the larger rivers have flood plains, which extend far inland with grassy marshes, flooded forests and ox-bow lakes.	1 Habitats in Namibia are largely dry and desertic. It is unlikely to find any suitable habitat in most of the country except for a small area near the Okavango River . http://www.fao.org/ag/agl/aglw/aquastat/countries/namibia/index.stm	5 Floodplains that are required by mimosa are largely prese in DRC with extensive areas of floodplains, particularly in the depression of Kamulongo and in the region of Mbandaka where the Congo and Ubangi rivers meet. http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.33	In numerous places in Mozambique Mimosa will find suitable habitat conditions as wetlands are present along all of the following waterways: Rivers of Maputoland Limpopo system Inharrime river and the interior of Inhambane Province Save, Gorongosa, Buzi, and Pungoé rivers Lower Zambezi river Rivers of Zambezia Province Rivers of the Northeast Coast http://www.fao.org/DOCREP/003/X6611E/x6611e02b.htm
4 Mimosa pigra is reported in Angola. No detailed information on exact location was found. http://www.ildis.org/LegumeWeb/6.00/taxa/76.shtml	4 Mimosa pigra is reported in Tanzania. No detailed information on exact location was found. http://www.ildis.org/LegumeWeb/6.00/taxa/76.shtml	4 Mimosa pigra is reported in Namibia. No detailed information on exact location was found. http://www.ildis.org/LegumeWeb/6.00/geo/g31.shtml	4 Mimosa pigra is reported in the country. No detailed information on exact location was found. http://www.ildis.org/LegumeWeb/6.00/geo/g31.shtml	4 Mimosa pigra is reported in Mozambique. No detailed information on exact location was found. http://www.ildis.org/LegumeWeb/6.00/taxa/76.shtml
4 Water/Environment management is done under a complex network of governmental organisations (at least 5 services of 2 ministries). Environmental issues do not appear to receive a particular attention. http://www.fao.org/ag/agl/aglw/aquastat/countries/angola/indexfra.stm http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.1	2 There are a number of relevant governmental bodies and organisations relevatn ot the issue of Mimosa that are currently in place: The Water Division within the Ministry of Water and Livestock Development (MWLD) which is responsible for the design, construction equipment, maintenance and operation of laboratories, water planning, water supply, water research, sewerage and sanitation. The Central Water Board (CWB) within the MWLD which is the principal advisory body to the government on matters pertaining to the utilization of water nationally and to the allocation of water rights. It is given executive power over pollution control. The National Environmental Management Council (NEMC) within the Ministry of Tourism, Natural Resources and Environment (MTNRE) which is the advisory body to the Government on environmental matters. http://www.fao.org/ag/agl/aglw/aquastat/countries/tanzania/index.stm	1 The Department of Water Affairs (DWA) within the Ministry of Agriculture, Water and Rural Development, which is responsible for all water resource projects http://www.fao.org/ag/agl/aglw/aquastat/countries/namibia/index.stm Namibia is also currently actively working on reviewing the Water Act form 1956 with greater emphasis on issues such as: The establishment of a Water Advisory Council as the nation's supreme advisory authority in water resources matters; The establishment of units of water resources governance at the river-basin level, wit broad-based stakeholder representation; and more. A number of parastatal organisations are also involved water management in Namibia including the Water Management Desk. http://www.drfn.org.na/water.htm It remains unclear if Mimosa is an issue currently addressed but there is a number of factors that may help Namibia to do so.	3 The Ministry for Environment, Water and Forests has Division of Water Resources in charges of water related environmental issues. It appears from the literature research however that little is being done in the field. http://www.fao.org/ag/agl/aglw/aquastat/countries/congo_dem_r/indexfra.stm	3 The National Water Directorate (DNA) within the Ministry of Publ Works and Housing (MOPH) is in charge of policy making and implementation, overall planning and management of the country's water resources and the provision of water supply and sanitation services. Its objectives are to ensure the proper utilization of ground- and surface water resources. In the DNA, a liaison office of international rivers was established. The Regional Water Administrations (ARAs) are basin authorities responsible for water development and management. They have administrative, organizational and financial autonomy but report the DNA. The ARAs are also in charge of collecting hydrological information. The National Water Council (CNA) was created in 1991 as a consultative body to the Council of Ministers. In general, however, the CNA has not been very effective and coordination between agencies involved in water resources management has been a constant source of concern. http://www.fao.org/ag/agl/aglw/aquastat/countries/mozambique/index.stm As often, the current focus is more on water supply and sanitatio
5 Political stability is one of the challenge that Angola is currently facing. The problem is worthened by the current impact of AIDS/HIV in the country eg. http://www.pbs.org/wnet/wideangle/shows/angola/index.html (PSI: -1.60)	2 Tanzania shows a fairly stable political stability with multi-party general elections being held regularly since its independence in the 1960's. http://www.dfid.gov.uk/countries/africa/tanzania.asp http://www.tanzania.go.tz/ (PSI:-0.25)	1 Namibia has been stable politically since its independence. http://www.usaid.gov/pubs/cbj2002/afr/na/ (PSI: 0.46)	5 The Democratic Republic of the Congo (DRC) is characterized by very weak governance and political disorder (rebellions, secessions, tribal warfare) stemming from a single-party dictatorship regime that was in power until May 1997. This regime caused the collapse of all public services and infrastructure as well as the full-scale erosion of most of the country's vast resources. http://www.unicef.org/emerg/files/drc_summary2005.pdf (PSI: -2.42)	2 Mozambique faced difficult and instable time between its independence in the 1970's and 1994. Since the democratic mul parties elections of 1994, Mozambique stability has improved significantly and democracy is now established and stable. http://www.un.org/esa/sustdev/csd/csd14/lc/presentation/mozambique.pdf (PSI: 0.55)
40	**34**	**18**	**41**	**28**

Angola (Northern region)	Tanzania	Namibia	Democratic Republic of Congo (ex-Zaire)	Mozambique
In excess of 4,000km -> 4,000km2 http://www.fao.org/docrep/008/n0084f/N0084F01.htm#ch3.1	The Pangani (360 km) -> 720km2 The Rufiji and its tributary the Ruaha (720 km) ->1,440km2 The Rovuma 640 km ->1,280km2 The Malagarasi approx. 560 km -> 1,120km2 http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.29	The Okavango River flows for about 370km and is bordered by about 1km on each side of floodplains -> 740km2 It was not possible to assess the risks associated with the Omatako River given its unreliable flows and the absence of evidence of significant flood periods. http://www.fao.org/ag/agl/aglw/aquastat/countries/namibia/index.stm	33,000km of rivers http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.33	Zambesi: 800km ->800km2 Limpopo: 400km (in a 2km wide river valley) -> 800km2 Save river: 300km -> 300km2 A rough figure was determined for the remaining coastal rivers: 1,900km -> 1,900km2 http://www.fao.org/DOCREP/003/X6611E/x6611e02b.htm http://www.fao.org/docrep/008/n0084f/N0084F02.htm#ch3.22 http://www.africa.upenn.edu/CIA_Maps/Mozambique_19859.gif

Angola (Northern region)	Tanzania	Namibia	Democratic Republic of Congo (ex-Zaire)	Mozambique
Very limited - no detailed information found	Total wetland area (suitable for irrigation ie. No salinity issues): approx. 8,500km2 http://www.fao.org/DOCREP/003/X6611E/x6611e04c.htm	-	25,000km2 of floodplains http://www.fao.org/docrep/008/n0084f/N0084F03.htm#ch3.33	Finding a realistic figure for the area of wetland proved to be quite challenging. Withouth further information a figure of 4,650km2 was proposed in the literature. http://www.imcg.net/gpd/africa/mozambique.pdf
	Information was found on the width of the floodplains in the area. It is suggested that for Tanzania the distance from the river should be increased to 1km on each side.	Note: Number of temporary water bodies and waterway are difficult to quantify.		

MIMOSA RISK ASSESSMENT SUMMARY

Mimosa Summary	Natural Risk (max 40)	Structural Risk (max 10)	Total Risk	Area	Adj. Area
Dem. Rep. of Congo (DRC)	33	8	41	58000	52844
Angola (northern region)	31	9	40	4000	3556
Zambia	31	4	35	21550	16761
Tanzania	30	4	34	11950	9029
Angola (ex. northern region)	24	9	33	7000	5133
Malawi	26	6	32	3420	2432
Zimbabwe	23	7	30	250	167
Mozambique	23	5	28	8450	5258
Botswana	23	3	26	10300	5951
Namibia	16	2	18	740	296