SANBI Biodiversity for Life
South African National Biodiversity Institute

BOTHALIA – African Biodiversity & Conservation
ISSN: (Online) 2311-9284, (Print) 0006-8241

Distribution of *Mimosa diplotricha* in eastern and southern Africa and its socio-ecological impacts in northern Malawi

Authors

Arne Witt[1]
Lilian Chimphepo[2]
Tim Beale[3]
Winnie Nunda[1]

Affiliations

[1]CABI, P.O. Box 633-00621, Nairobi, Kenya.
[2] Environmental Affairs Department, Lingadzi House, Private Bag 394, Lilongwe 3, Malawi.
[3]CABI United Kingdom, Nosworthy Way, Wallingford, Oxfordshire, OX10 8DE, United Kingdom.

Corresponding author

Arne Witt, a.witt@cabi.org

Dates

Submitted: 22 July 2019
Accepted: 18 March 2020
Published: 30 July 2020

How to cite this article:

Witt, A., Chimphepo, L., Beale,T. & Nunda, W., 2020, 'Distribution of *Mimosa diplotricha* in eastern and southern Africa and its socio-economic impacts in northern Malawi', *Bothalia* 50(1), a9. http://dx.doi.org/10.38201/btha.abc.v50.i1.9

Background: *Mimosa diplotricha* is an emerging or established weed in many parts of the world, including many countries in Africa, where it is impacting on biodiversity, crop and pasture production, and driving socio-ecological change.

Objectives: To establish the current distribution of *M. diplotricha* in eastern and southern Africa and its impacts on livelihoods in northern Malawi.

Methods: Records on current distribution were collected from roadside surveys, literature reviews and herbarium data. Household surveys were conducted in the Karonga District, Malawi, to understand its impacts on local livelihoods.

Results: *Mimosa diplotricha* is abundant in western Ethiopia, southern Tanzania, and northern and southeastern Malawi with isolated populations in western Rwanda, Burundi, Mozambique, and on the northern shores of Lake Victoria in Uganda. Most respondents said that *M. diplotricha* invasions were reducing the amount of grass and shrubs in rangelands, with over half saying it reduced crop yields. This invasive plant is also reducing the availability of medicinal plants and other natural resources.

Conclusions: *Mimosa diplotricha* has the potential to significantly expand its range in eastern Africa, and parts of southern Africa, and as such there is an urgent need to develop and implement an integrated management strategy, including biological control, to reduce the negative effects of this invasive plant on local livelihoods.

Disclaimer: These are the authors' views and not those of any institution/organisation

Introduction

People have been moving plants around the world for centuries for ornamental, medicinal, agro-forestry and other purposes (Pimentel et al. 2001). Only a small percentage of these introduced species have become invasive, having a negative impact on, among others, biodiversity, crop and/or pasture production, human and/or animal health, and water resources (Pimentel et al. 2001; Singh 1996; Tamado & Milberg 2000; Van Wilgen et al. 2008). Economic development can even be curtailed by the presence of invasive plant species, especially waterweeds, which can hamper hydro-electricity generation, bringing economic activity to a virtual standstill. As such, biological invasions are now considered to be among the most pressing issues facing the planet, especially in developing countries where the natural resource base on which millions of people depend is rapidly being eroded by the rapid proliferation of many invasive species (Shackleton et al. 2017a,b,c; Witt & Luke 2017; Witt et al. 2018).

The situation is exacerbated in developing countries because the rural poor don't have the means to control these rapidly expanding species (Witt & Luke 2017). To reduce the impacts of invasive species and contain their further spread, it is imperative that management interventions be developed and implemented. Failure to do so will make it virtually impossible for countries to meet many of their Sustainable Development Goals. In fact, Target 15.8 focusses only on invasive alien species; requiring countries to 'introduce measures to prevent the introduction and significantly reduce the impacts of invasive alien species on land and water ecosystems and control or eradicate the priority species by 2020'. One of the plant species having a significant impact on biodiversity and crop and pasture production at a global level, including Africa, is *Mimosa diplotricha* Sauvalle (Fabaceae; creeping sensitive plant), hereafter referred to as 'mimosa'.

Mimosa diplotricha as a global invader

Mimosa diplotricha is native to much of South and Central America, as well as the Caribbean (Holm et al. 1977; Parsons & Cuthbertson 1992). It has been introduced, either intentionally or accidentally, to a host of countries in Asia and Africa. It is a major weed in pastures, plantations and roadsides, and in some situations a serious pest in crops (Caunter & Shibayama 1999; Ogbe & Bamidele 2006; Sulaiman et al. 2004). More than 40 years ago it was already considered to be one of the 76 worst weeds in the world, having been recorded as a weed of 13 crops in 18 countries (Holm et al. 1977). Holm et al. (1979) regarded it as either a 'serious' or 'principal' weed in Borneo, Fiji, Malaysia, Melanesia, New Guinea, West Polynesia, Philippines, Taiwan, Australia and Indonesia. It is also a serious weed in the Pacific islands, South-East Asia, Mauritius and Nigeria (Waterhouse & Norris 1987).

In the Philippines, Malaysia, Thailand and Vietnam, mimosa is considered to be an important weed in upland rice (Caunter & Shibayama 1999). It is also one of the three main weed species of kale in Nakhon Pathom Province, Thailand (Pomprom et al. 2002) and a major weed of cornfields in Malaysia (Sulaiman et al. 2004). Mimosa densities of 630 000 plants per hectare reduced cassava root yield, 12 months after planting, by 80% in one study area in Nigeria (Alabi et al. 2001). In Benin City metropolis, Nigeria, where it has invaded farms, fallow fields and vacant land, it is regarded as the most noxious of all weeds (Ogbe & Bamidele 2006). In Papua New Guinea, mimosa has a direct negative impact on the growth, yield and harvesting of sugarcane. Harvesting crops by hand in fields invaded by mimosa is also particularly difficult and even harmful, especially in developing countries where this is a common practice and farmers have no protective gear, as the 'thorns can cause serious sores on humans' (Waterhouse & Norris 1987). Mechanical crop harvesters can also be jammed when used in invaded croplands (Parsons & Cuthbertson 1992).

Mimosa invasions also have a negative impact on pastureland, reducing livestock carrying capacities. Cattle ranches in the Markham Valley, Papua New Guinea (PNG), spend up to US$130 000 annually on the chemical control of this weed (Kuniata 1994), because it not only displaces valuable forage species but is also considered to be toxic to livestock (Gibson & Waring 1994; Waterhouse & Norris 1987). In Thailand, 22 swamp buffaloes died 18–36 hours after eating *M. diplotricha* var. *inermis* (Tungtrakanpoung & Rhienpanish 1992). There is also a report of *M. diplotricha* var. *inermis* poisoning of a two-year-old Jersey-cross heifer in India (Alex et al. 1991). Trials in Australia have demonstrated that this variety of mimosa is also toxic to sheep, and a report from Flores, Indonesia, suggests that it is toxic to pigs (Parsons & Cuthbertson 1992).

Mimosa can also change the structure and composition of natural vegetation by climbing over and smothering other plants (Schultz 2000). In western Australia, dense stands are adversely affecting the growth of native plant species (Werren 2001), posing a serious threat to the ecology of native plants and animals if allowed to spread further (Wilson 2004). It also constitutes a serious fire hazard, especially during dry periods when plants tend to die back (PIER 2008).

Very little is known about the distribution of mimosa in eastern and southern Africa, and particularly its socio-ecological effects in Malawi. This type of information is critical in guiding management decisions, especially with regard to preventing the further spread of this noxious weed and implementing control where it is already well established. This paper contributes to a better understanding of the distribution of mimosa and its impacts on livelihoods in northern Malawi.

Methods

Distribution of *Mimosa diplotricha* in eastern and southern Africa

Broad-scale distribution mapping of naturalised and invasive plants was undertaken across eastern and parts of southern Africa (Figure 1) from 2008 to 2018, in a similar manner to those undertaken by Henderson (2007), Rejmánek et al. (2016), Shackleton et al. (2017 a,b,c), Witt (2017), Witt & Luke (2017) and Witt et al. (2018). Roadside surveys are a relatively cost-effective way of producing a rapid and broad understanding of the distributions of invasive species, especially where

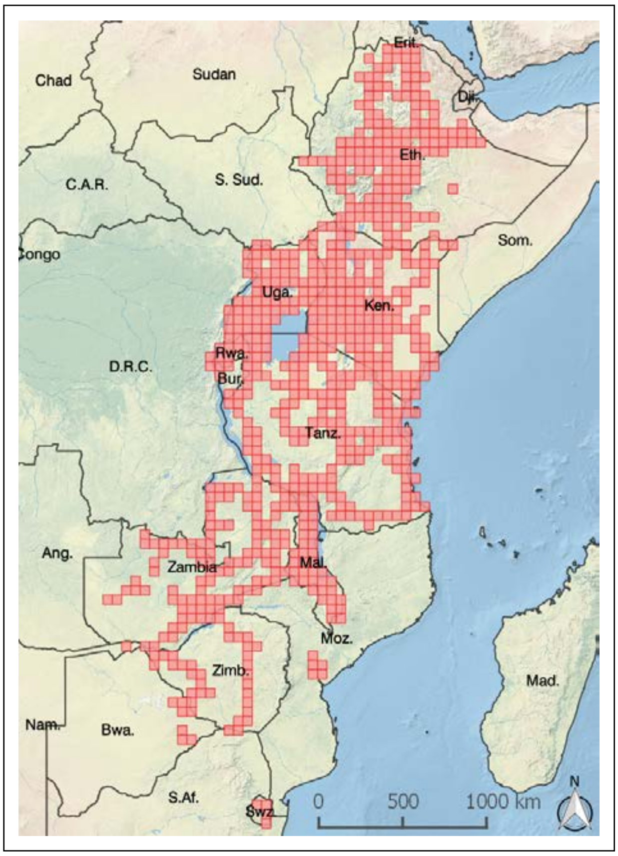

Figure 1: Map showing in red (~55 km × 55 km/half degree grid cells) the areas surveyed between 2008 and 2018 for *Mimosa diplotricha* species in eastern and southern Africa. Areas surveyed by others in eastern and southern Africa are not included.

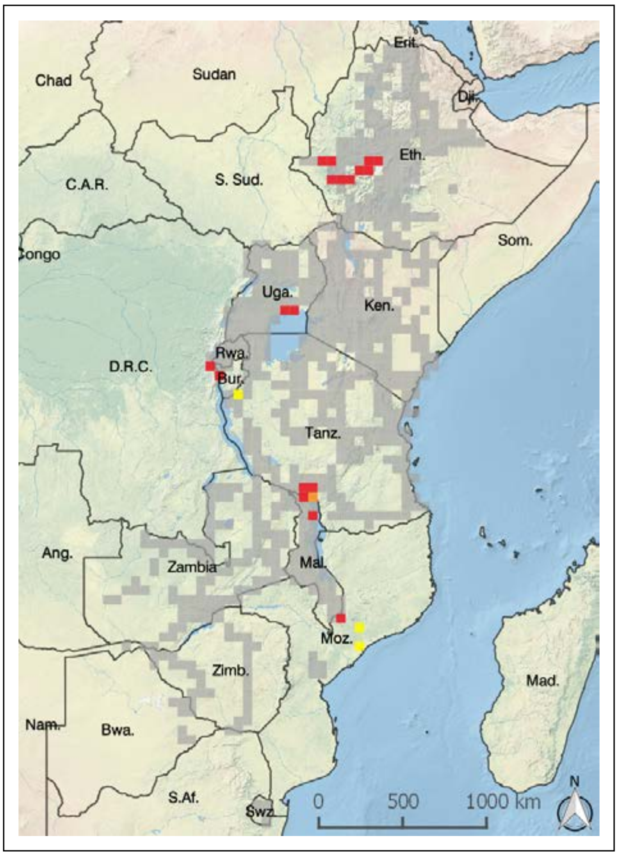

Figure 2: Map showing the current known distribution of *Mimosa diplotricha* in eastern and southern Africa (~55 km × 55 km/half degree grid cells) using data collected in this study and other sources of information. Grey grid cells show areas surveyed; red grid cells indicate areas where *Mimosa diplotricha* was found to be invasive (widespread and/or abundant); orange cells where it was present and/or naturalised; and yellow cells where it was recorded with no other information.

current information is scarce or absent. During these roadside surveys, the presence and status (naturalised or invasive) of *M. diplotricha* was mapped in Ethiopia, Kenya, Malawi, Eswatini, Tanzania, Rwanda, Uganda, Zambia, and parts of Botswana and Zimbabwe.

Lack of resources, insecurity and poor road access in some parts of these countries limited the extent of surveys. The presence of invasive alien plants (including mimosa) was noted in half-degree grid cells (~55 km × 55 km; Figure 2), but recorded presence does not imply full coverage, as the whole cell was not necessarily covered in the survey. It would also be extremely difficult and time consuming to record the exact location of every invasive plant seen, especially if it is growing some distance from the road. As such, coordinates, at or within 1 km of each locality where mimosa was found to be present, naturalised or invasive, as defined by Blackburn et al. (2011), were recorded using a hand-held GPS unit (Figure 2). We assumed that if mimosa was not seen within a grid square, during our surveys, that it was not present there. As such, it is therefore highly likely that we have under-represented the true distribution of mimosa in eastern and southern Africa.

Socio-ecological study site

To assess people's insights, understanding, and attitudes to the invasion by mimosa, we interviewed community members in Karonga District in northern Malawi (Figure 3). This district (9° to 10° S; 33° to 34° E), covering an area of 3 355 km², is bordered by Lake Malawi in the east, the Songwe River and floodplain in the north (border with Tanzania) and the Central African plateau and Nyika escarpment in the west and south (Chilima et al. 2006). The months from December to April are typically warm and wet with an average temperature of 24°C; cool and dry from May to August; and hot and dry from September to November (Chilima et al. 2006). The mean annual rainfall is more than 1 600 mm in the north and 800–1 200 mm in the south (Chilima et al. 2006). Soils are generally loamy and acidic to neutral in the north, and sandier and more acidic to alkaline in the south (Chilima et al. 2006).

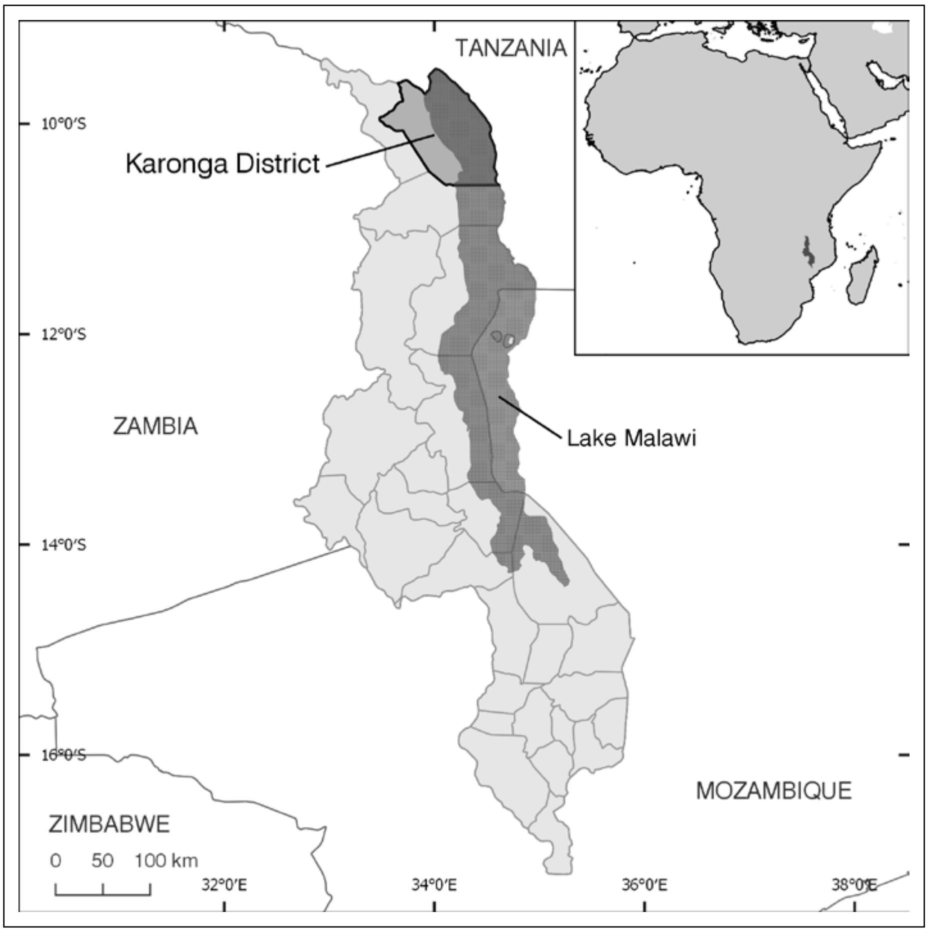

Figure 3: Map showing the location of Malawi in Africa (inset) and Karonga District in Malawi where the socio-economic surveys were undertaken.

The terrain is variable, with a flat coastal plain along the lake, which is dominated by croplands and mimosa invasions, rising to hills and the plateau (± 2 600 m a.s.l.) to the west. Despite high rates of deforestation, Karonga District is still largely dominated by miombo woodlands, which are dominated by trees in the genera *Brachystegia*, *Julbernardia* and *Isoberlinia*, with other tree species such as *Pterocapus angolensis* DC. (Fabaceae), *Albizia* spp. (Fabaceae) and *Afzelia quanzensis* Welw. (Fabaceae) (Missanjo et al. 2014). Rivers, which arise on the plateau in the west, are associated with dense vegetation and with swamps where they flow into Lake Malawi (Denys et al. 1999).

The people of Karonga District include several language groups, predominantly Tumbuka in the south and Nkhonde in the north, with a total population of about 365 000 people. The majority of residents are small-scale farmers with approximately 79 000 farming households (Government of Malawi/Ministry of Agriculture, Irrigation and Water Development 2016). An assessment of a community living in the south of the district found that only 3% of homes have electricity, 16% have piped water; the most common construction materials are burnt brick walls (59%), grass thatch roofs (57%) and mud flooring (76%) (Unknown 2019). The main sources of household income are farming (43%), regular employment (15%), trading (11%), casual labour (9%) and fishing (7%). A radio is owned by 62% of households, 52% own a clock or a watch, 44% have a bicycle and 19% own cattle (Unknown 2019). We are assuming that these figures will be similar for other communities living in Karonga District.

Livelihoods survey on local knowledge and perceptions of *Mimosa diplotricha*

We conducted interviews in 151 randomly selected households in areas with mimosa invasions, using semi-structured questionnaires. Surveys were conducted in 32 villages across Karonga District, to obtain as broad a representation as possible. We make the assumption that the impacts of mimosa in this area will be similar to those experienced elsewhere. All households on randomly selected roads in each village were interviewed by one of the co-authors. The head of the household or next oldest member of the family was interviewed in their local language. The questionnaires had four sections that covered (1) demographics of the respondent, (2) aspects of his/her knowledge and perceptions about the introduction and spread of mimosa, (3) perceptions and knowledge on the negative impacts and benefits of mimosa with a particular focus on crop and pasture production, and (4) perceptions and practices relating to the management of mimosa.

Results

Current distribution of *M. diplotricha* in eastern and southern Africa

Based on our surveys, mimosa is abundant in western Ethiopia, southern Tanzania on the northern shores of Lake Malawi, and northern and southeastern Malawi, with localised invasions on the northern shores of Lake Victoria in Uganda and in southeastern Rwanda (Figure 2). It has been recorded in Burundi, on the border with Rwanda (GBIF 2017), Madagascar (GBIF 2017) and Mozambique (Flora of Mozambique 2017; GBIF 2017; M. Hyde pers. comm., 19 December 2018), with no records for South Africa (Henderson 2007; GBIF 2017; L. Henderson pers. comm., 10 January 2019), Zimbabwe or Zambia (Flora of Zimbabwe and Zambia 2017; GBIF 2017; M. Hyde pers. comm., 19 December 2018), Angola (Rejmánek et al. 2016; GBIF 2017), Botswana (GBIF 2017; K. Keotshepile [Peter Smith University of Botswana Herbarium], pers. comm., 15 January 2018), and Namibia (GBIF 2017; C. Mannheimer [Consultant Botanist], pers. comm., 20 January 2018). It was first recorded as present in East Africa in 1943 (Witt & Luke 2017), and in southern Africa, in Mozambique, in 1949 (Figueira 2017).

Based on the Köppen Climate Classification it is currently present in areas with a Tropical Savanna (Aw) (southwestern Ethiopia, Rwanda, Burundi, Mozambique and southeastern Malawi), Tropical – Rainforest (Af) and Tropical – Monsoon (Am) (northern shores of Lake Victoria), and Temperate – Dry winter – Hot summer (Cwa) (northern Malawi) climates (Peel et al. 2007). Invasions in southern Tanzania are a mix of Aw and Cwa (Peel et al. 2007).

Socio-demographic characteristics of the surveyed households

Of the 151 individuals interviewed, 91% were male, and the mean (± SD) age of respondents was 43 ± 14 years. Just over half (57%) of respondents had a primary school education and the majority were farmers (84%). Every household owned livestock, with the majority owning at least two or more cattle while only 62 households owned goats, none had sheep and only two had pigs. Most (62%) farmers grazed their livestock within 1 km of their homes. Depending on the availability of grazing some farmers would move their livestock to grazing lands further afield but then only once in every three or more months. All respondents were also involved in crop production with the primary crops grown being rice (100%), cassava and maize. Just over a quarter (26%) of respondents had fields between 2 and 3 acres (0.8–1.2 ha.) in extent, followed by 23% who had 1 to 2 acres (0.4–0.8 ha.) of land under crop production.

Local knowledge of Mimosa diplotricha *presence and introduction in Malawi*

About 58% of respondents said that mimosa was first seen in the area where they live more than ten years ago, while 22% noticed it three to five years ago, and a smaller percentage (6%) for the first time in 2018. This supports the view of most (71%) respondents who claim that mimosa density and distribution is increasing, with 97% saying that it is already present in areas where they graze their livestock. According to 61, 31 and 8% of the respondents less than 25, 26–50 and 51–75% of grazing land is currently invaded, respectively, with most invasions occurring along rivers, in croplands and on roadsides. Most (86%) of those interviewed were unsure as to why mimosa was introduced with just over 41% saying that it was spreading naturally, with 30% having no idea as to how it found its way to the areas where they reside. Some (8%) felt that it had been accidentally introduced with machinery during road construction while others (20%) thought that livestock were spreading the seeds. The fact that 63% of respondents did not find any use for the plant is an indication that intentional spread by people is unlikely or very low based on the fact that only 19% of those interviewed used the plant for medicinal purposes.

Socio-ecological stressors

Residents of Karonga District, Malawi, face a number of challenges. Livestock production is severely compromised by the prevalence of diseases and insufficient grazing, of which the latter could be further compromised by the prevalence of unpalatable plants, including weeds. However, only 14 respondents were of the opinion that weeds and other poisonous plants were having a significant impact on grazing. *Mimosa diplotricha* was considered to be the worst weed in rangelands, closely followed by its congener, *Mimosa pigra* L. (Fabaceae) another introduced invasive plant native to South America (Table 1). In crop production areas *M. diplotricha* was also considered to be the worst weed, followed by *Striga* spp. (Orobanchaceae), *M. pigra* and *Bidens pilosa* L. (Asteraceae) (Table 1).

Impacts of *Mimosa diplotricha*

Based on responses, mimosa has a significant impact on livelihoods. All respondents said that mimosa hampered

Table 1: The percentage of respondents (n = 151) who selected a particular weed species as having the largest negative impact on either rangelands or crops in Karonga District, Malawi

Species	Family	Rangelands (%)	Croplands (%)
Ageratum conyzoides	Asteraceae	2	1
Bidens pilosa	Asteraceae	14	7
Tithonia diversifolia	Asteraceae	2	1
Xanthium strumarium	Asteraceae	2	1
Trichodesma zeylanicum	Boraginaceae	3	3
Sedges and grasses	Cyperaceae and Poaceae	-	9
Mimosa diplotricha	Fabaceae	28	33
Mimosa pigra	Fabaceae	22	15
Hyptis suaveolens	Lamiaceae	9	5
Striga spp.	Orobanchaceae	6	22
Argemone mexicana	Papaveraceae	3	1
Datura stramonium	Solanaceae	5	1
Lantana camara	Verbenaceae	1	-
Stachytarpheta spp.	Verbenaceae	1	-

the movement of people and livestock. In addition, the majority of those interviewed said that invasions reduced the abundance of grasses and shrubs, while 50% of respondents said that it had a negative impact on trees (Table 2; Box 1). In contrast, only 8% of respondents said that mimosa was reducing the abundance of medicinal plants, with the majority (89%) being unaware of any negative impacts. Despite its negative impacts on livestock fodder (grass and shrubs) only 48 and 25% of respondents felt that invaded rangelands had a negative impact on cattle or goats, respectively, with only 25% saying it resulted in weight loss in their cattle. Just over 50 and 73% of respondents said that they had seen cattle eat mimosa flowers and leaves, respectively, with a much lower figure recorded for goats (flowers, 33%; leaves, 38%). Over half (56%) of the respondents said that mimosa had a negative impact on crop yields while only 21% felt that it increased yields.

Box 1: Quotes from villagers on the impacts of Mimosa diplotricha *invasions in Malawi*

'Mimosa is a very serious weed, fast spreading and if not removed timely cause huge losses in crops, it can be so helpful if ways of eradicating it completely can be found.'

'If mimosa is cut and burnt it improves soil fertility and any crop grown in those soils grows with vigour. However, it is a serious weed if left uncontrolled.'

'If chemicals to eradicate mimosa could be found it would be very helpful.'

'Mimosa has caused a lot of challenges; it grows fast and needs to be controlled almost every day, if you fall sick you won't harvest anything.'

'Mimosa causes a lot of losses in crops and our livestock have difficulties in finding pasture as it has covered most valuable pasture lands.'

'In 2015, I was in hospital with my son, mimosa took over my rice garden and I harvested nothing.'

Management of *Mimosa diplotricha*

Just over one-quarter of respondents actively managed mimosa in grazing lands while 97% tried to control it in croplands. Slashing (16%) was the most common control method used in rangelands followed by burning (7%). In croplands just over half (54%) used a hoe or pick to remove mimosa, followed by slashing (21%) and hand pulling (18%). Over half (59%) of respondents said that they paid individuals to help them clear mimosa from their croplands. Of these 39% said they paid others between US$14 and US$28 to clear an acre (0.405 ha.) of land while 11% said that they paid around US$56 per household. Fifty-seven per cent of those that use herbicides spend between US$14 and US$70 on chemicals per year. If mimosa were not controlled, maize and rice

Table 2: The percentage of respondents (n = 151) who regarded the effect of *Mimosa diplotricha* on a particular issue as either positive or negative, or who had no opinion on the issue, in Karonga District, Malawi

Issue	Percentage who regarded effect as a cost (%)	Percentage who regarded the effect as a benefit (%)	Percentage who thought it had no effect, or who did not know (%)
Grass	99	1	-
Shrubs	72	1	27
Trees	50	37	13
Water	7	3	90
Wildlife	-	1	99
Useful plants	8	3	89
Movement	96	0	4
Crop production	56	21	23
Cattle health	48	0	52
Goat health	25	0	75
Drive human relocation	32	0	68
Green manure	-	7	93
Medicinal plant	-	19	81
Garden plant	-	5	95
Hedge plant	-	5	95

Table 3: The percentage of respondents (n = 151) who used particular management practices to control *Mimosa diplotricha* in rangelands and croplands in the Karonga District, Malawi

Management practice	Rangelands (%)	Croplands (%)
Burning	7	1
Chemical control	0	3
Hand pulling	0	18
Hoeing	0	54
Nothing	72	3
Slashing or cutting	16	21
Ploughing	5	1

losses would be greater than 75% according to 72% and 79% of respondents, respectively. The majority of respondents all felt that their lives would be better if mimosa was not present, with over 80% saying that there would be increased grazing, improved livestock health and improved crop yields.

Discussion

Mimosa diplotricha occurrence

The field surveys, literature reviews and questionnaires indicate that *M. diplotricha* is relatively widespread with localised invasions in a number of countries in eastern Africa but less so in southern Africa, with significant invasions only in the north and southeast of Malawi with some records from Mozambique, although the latter was never surveyed during this study, so its current status there is unknown. In Ethiopia, the plant is abundant along roadsides from Wolisso to Jimma in the southwest. In many areas the plant is scrambling over the edge of the road, blocking footpaths and waterways (Wakjira 2011). According to community members in Merewa Kebele in Kersa Woreda, Ethiopia, the plant has been invading roadsides for the past three to five years with road construction contributing to its spread (Wakjira 2011). In our study only eight per cent of respondents said that road construction contributed to the spread of mimosa with 41% saying that it was spreading naturally and with 31% being unsure.

Respondents to the questionnaire indicated that it is still spreading in Malawi, an indication that it has the potential to spread even further in the region as a whole, especially into tropical and sub-tropical regions within eastern and southern Africa. A CLIMEX eco-climatic model developed by T. Beale (unpublished) indicates that most of Uganda, Rwanda and Burundi have climates suitable for mimosa invasions while northern Tanzania and its coastline, extending across much of the interior towards Malawi, also appear to be a good climatic match. Our surveys further support the model by indicating that the southwest of Ethiopia and northern and southeastern Malawi are climatically suitable. Areas in which no mimosa was seen during surveys, such as the southwest of Kenya and its coastline are also a climatic match and as such likely to be invaded should mimosa be introduced and establish there. Much of the coastline of Mozambique, extending inland to southern Malawi, and the northeastern coast of South Africa also appear to be climatically suitable, together with the whole of the eastern Madagascan seaboard (T. Beale unpublished). It is unlikely to establish and proliferate in Zimbabwe, Botswana, Namibia and Zambia, but much of northern Angola appears to be a good climatic match. Low temperatures are also likely to limit the species, which means that high-lying areas/regions are unlikely to be invaded although it has been found at 1500–2000 m above sea level (Henty & Pritchard 1973; Kostermans et al. 1987).

Impacts of *Mimosa diplotricha*

Malawi is one of the poorest countries in the world with 50.7% of the population living below the poverty line, and 25% of those living in extreme poverty (Ministry of Finance, Economic Planning and Development 2017). More than 80% of the population live in rural areas and are dependent on subsistence agriculture to survive. Food security is compromised by a number of factors, such as frequent droughts and crop pests. The impacts of crop pests such as the fall armyworm (*Spodoptera frugiperda* J.E.Smith, 1797; Noctuidae) are well documented, but there is little data on the impacts of invasive plants, which are often ignored because their impacts on rangelands or crop production are not that direct or conspicuous. This study has suggested that an invasive plant such as *M. diplotricha* can have significant negative cross-cutting impacts on a range of sectors including biodiversity, and crop and pasture production.

Impacts of *M. diplotricha* on biodiversity have not been well documented with the exception of a few studies in India (Jayasree 2005; Vattakavan et al. 2002). Jayasree (2005) found that the smothering efficiency of mimosa increased from about 14 to 38% over a three-year period contributing to a 21% decline in grass cover, and a reduction in the occurrence of other broad-leaved weeds. Similar impacts on grass cover were reported by Basu & Ghosh (2003) with Vasu (2003) finding that mimosa inhibits the growth of especially grasses. This supports the findings of our study where the majority of respondents reported a significant decline in the abundance of grasses and shrubs in invaded areas. The absence of wildlife in most areas outside of protected areas meant that almost all respondents in Malawi did not know of any impacts on wildlife. However, mimosa invasions in the Kaziranga and Orang National Parks in India are displacing important forage species for the endangered greater one-horned rhino and other wildlife species (Lahkar et al. 2011; Vattakavan et al. 2002). Mimosa also blocks the trails used by elephants and rhinos (Vasu 2003). Invasion of protected areas in India by mimosa and other weeds 'is the biggest challenge in terms of habitat conservation' and as such poses a significant threat to protected areas in Malawi. As in India, invasions may threaten black rhinos, which were reintroduced to Liwonde National Park and Majete Wildlife Reserve, after the last rhino in Malawi disappeared from the Mwabvi Game Reserve in the late 1980s.

A reduction in the amount of forage will obviously also contribute to a reduction in livestock carrying capacities. It is considered a major threat to livestock pastures in Australia (Groves 1991), some Pacific islands (Swarbrick 1989), Papua New Guinea (Henty & Pritchard 1973), and the Philippines (Holm et al. 1977). In Vietnam, respondents also said that mimosa displaced other valuable forage species, reducing the amount of grazing available for livestock (Ta Thi Kieu Anh [Biodiversity Conservation Agency, Vietnam], pers. comm., 15 January 2015). However, 52 and 28% of respondents in Malawi said that its presence in grazing lands had no impact on goats and cattle respectively, while approximately one-quarter of respondents were unsure of its impact. That said, 25 and 19% of respondents said that its presence did result in weight loss in cattle and goats respectively, which we assume is a result of a reduction in the amount of available forage. On the other hand mimosa may be consumed by livestock and as such could be an alternative fodder source.

In our study respondents said that they had seen cattle and goats eat the mimosa flowers and leaves with no ill effects, with the exception of a few who noticed that livestock developed diarrhoea after consumption. This is contrary to other studies, which found mimosa to be toxic to livestock (Alex et al. 1991; Gibson & Waring 1994; Li et al. 1996; Rajan et al. 1986; Shridhar 2017; Tungtrakanpoung & Rhienpanish 1992; Waterhouse & Norris 1987). Shridhar (2017) reported on 16 cows and ten buffaloes that had accidentally consumed mimosa leaves. Of the 26 animals, 22 exhibited perineal oedema and died within 14 days of consumption (Shridhar 2017). Mimosine, which is present in mimosa and other legumes such as *Leucaena leucocephala* (Lam.) de Wit (Fabaceae) is said to be the cause of toxicity in animals (Mishra et al. 2002). Immature leaves, mature leaves and stems, flowers, and seeds of *M. diplotricha* contain 9.88, 6.32, 5.01, and 3.3% mimosine respectively, which is similar to that found in *L. leucocephala* although the seeds of leucaena contain significantly more mimosine (Jayasree 2005). There can also be significant differences in mimosine content among different cultivars of leucaena (Chathurvedi & Jha 1992; Forrajes, Chongo & Seull 2003), although this has not been determined for invasive *M. diplotricha* sub-species or varieties. Ubani et al. (2000) found that mimosine at more than 1% concentration in livestock feed is toxic to livestock. This was confirmed by Yami et al. (2000) who found that that diets containing 0.75% mimosine could be fed to goats without adverse effects. Kumar

Figure 4: *Mimosa diplotricha* invasions in southern Tanzania (top row), northern Malawi (middle row), and western Ethiopia (bottom row).

and Sharma (1997) found that 1.6% mimosine in livestock feed is safe for goats. Consumption of mimosa leaves and flowers by cattle and goats in Malawi, as reported by respondents, may be at levels below this, hence the fact that no significant livestock deaths have been reported in our survey. However, as mimosa invasions increase in extent and density, displacing more valuable forage species, consumption of mimosa by livestock is bound to increase, which may result in a significant increase in livestock deaths. However, the recurved spines/thorns on mimosa mean that livestock are often reluctant to feed on it anyway, and they usually avoid the large stands (Waterhouse & Norris 1987), which may also limit consumption.

Mimosa diplotricha also has a significant impact on crop production (Figure 4). Rajkowa et al. (2003) reported serious negative impacts of the weed on crop ecosystems and plantations such as tea, coffee, coconut, rubber and pineapple. It is considered to be one of the most important weeds of rubber in Indonesia, Malaysia and Papua New Guinea (PNG); coconut in Sri Lanka and PNG; sugarcane in Taiwan, Australia, India and the Philippines; tomato in the Philippines; lychee in Thailand; cassava, soyabeans, maize, apple, citrus and tea in Indonesia; banana and tea in India; and abaca (*Musa textilis* Née; Musaceae) and pineapple in the Philippines (Aliudin & Kusumo 1978; Groves 1991; Holm et al. 1977; Muniappan & Viraktamah 1993; Suwanarak 1988; Wong 1975). It is a weed of lowland rice in Indonesia, the Philippines, Thailand and Vietnam; of dry-seeded rice in the Philippines; and of upland rice in Indonesia, Laos, the Philippines, Thailand, and Vietnam (Kostermans et al. 1987; Moody 1989). It is potentially the worst weed in plantations and arable lands of Fiji, and the Philippines (Holm et al. 1977). It has also been recorded as having a negative impact on cassava root yield (Alabi et al. 2001), and on the height of okra (*Abelmoscus esculentus* (L.) Moench (Malvaceae) plants in Nigeria (Alabi & Makinde 2002). This agrees with our findings with more than 50% of respondents reporting a reduction in crop yields as a result of mimosa invasions, especially on the yields of the three most commonly grown crops, namely rice, cassava and maize. This reduction in yields can be ascribed to the smothering habit of mimosa, and the fact that it is allelopathic. Jayasree (2005) reported that incorporation of mimosa, at increasing concentrations, either directly into the soil, as a mulch, or as a water extract application, all significantly reduced rice and cowpea seed germination. Although rice heights were enhanced with increasing rates of mimosa concentrations incorporated into the soil, the opposite was true for mulching and water extraction while all three methods of application had negative impacts on cowpea height (Jayasree 2005).

Management of *Mimosa diplotricha*

Mimosa diplotricha has the potential to spread over much of the region and as such there need to be increased efforts to stop or inhibit further spread, and to reduce densities where it is already present. In Malawi there is little current effort to manage mimosa in rangelands, with manual removal being the most commonly used methodology in croplands. Cutting or slashing of plants in croplands is a practice used by 21% of the respondents despite this practice being largely ineffectual because plants vigorously regrow from the root crown (Parsons & Cuthbertson 1992; Waterhouse & Norris 1987). Hand pulling of young plants is practiced by 18% of respondents in croplands, just like farmers do in Indonesia (Suryatna & McIntosh 1982), despite the tiny thorns having the potential to cause injuries (Waterhouse & Norris 1987; Alabi et al. 2001). Just over 54% of respondents in Malawi said that they used a hoe or similar to uproot/remove plants in croplands. This practice appears to be very effective, consistently giving the highest cassava root yield in Nigeria (Alabi et al. 2004). In Vietnam 96% of landowners use sickles or similar to remove the above-ground parts of the plant and hoes to remove the root crown following by drying and burning (Ta Thi Kieu Anh [Biodiversity Conservation Agency, Vietnam], pers. comm., 15 January 2015). Many of these interventions were not seen to be effective, and often merely stimulated seed germination.

Mimosa diplotricha can also be effectively controlled using herbicides (Parsons & Cuthbertson 1992) although very few respondents in Malawi said that they used herbicides because of the associated costs. A similar survey in Vietnam revealed that only 4% of respondents used chemicals, despite it being the only effective control method (Ta Thi Kieu Anh [Biodiversity Conservation Agency, Vietnam], pers. comm., 15 January 2015). Another issue, which applies to much of Africa and even Asia, is the fact that no herbicides are registered for use against mimosa. For example, in Nigeria there are no effective herbicides for control of mimosa in cassava fields (Alabi et al. 2004). However, in countries such as Australia, foliar applications of herbicides containing the active ingredients picloram, clopyralid and fluroxypyr are known to be effective although they need to be applied on a regular basis to control seedlings (Parsons & Cuthbertson 1992). Dicamba (500g/L) is also recommended and should be applied in a foliar spray at 2g/L of water, fluroxypyr (333g/L) at 1g/L of water and glufosinate ammonium (200g/L) also at 1g/L of water (J. Vitelli pers. comm., Department of Agriculture and Fisheries, Queensland Government, Australia, 12 June 2016; Witt & Luke 2017). Pre-emergence chemicals such as atrazine + 2,4-D mixtures or tebuthiuron can be used, but they only remain active for a few months (Waterhouse & Norris 1987).

Biological control remains the most cost-effective intervention for resource poor farmers. *Heteropsylla spinulosa* Muddiman, Hodkinson & Hollis (Psyllidae), an agent collected on *M. diplotricha* in Brazil in 1982, causes stunting and distortion of the leaves and may prevent flowering due to the toxic effects of its saliva. Soon after its release in Australia there was a dramatic reduction in the growth of *M. diplotricha* and seed production was reduced by over 88% (Lockett & Ablin 1990). It has subsequently been released in Western and PNG (Kuniata 1994) where it is now established, and should be considered for release in Malawi. Despite the success of this agent elsewhere, any management strategy should incorporate the biocontrol agent in combination with other methodologies such as physical and chemical control, and in some cases also fire.

To further enhance the management of mimosa, concerted efforts need to be made to build additional awareness as to the negative impacts of this serious weed in the region. This should include further research on its negative impacts, especially with regard to livestock production, where its apparent toxicity has not yet been reported by the majority of livestock owners. There also needs for increased awareness as to best management practices, and support from local communities and government officials for the introduction of the biocontrol agent *H. spinulosa*. It should also be noted that areas cleared of *M diplotricha* may be invaded by other invasive species already present in Malawi. These may include *M. pigra*, *Prosopis juliflora*, *Lantana camara* and *Hyptis suaveolens* (L.) Poit. (Lamiaceae). In fact, *H. suaveolens*, an emerging weed in Malawi, is regarded as one of the world's most noxious weeds (Padalia, Kudrat & Sharma 2013) and was ranked very highly in our surveys in terms of its negative impacts. In Australia it is considered to pose the greatest threat to rangeland biodiversity. In order to be more effective in managing these and other invasive species we need to develop coordinated national and regional integrated management strategies. Failure to address current barriers to invasive species management will exacerbate poverty in Malawi, and the region as a whole.

Conclusions

Mimosa diplotricha is already present in a number of countries in eastern and southern Africa and likely to expand its range, exacerbating biodiversity loss and further reducing crop yields and rangeland productivity.

To inhibit its further spread, it is imperative that communities be informed as to its negative impacts and best management practices.

Acknowledgements

CABI gratefully acknowledges the core financial support from our member countries (and lead agencies) including the UK (Department for International Development), China (Chinese Ministry of Agriculture), Australia (Australian Centre for International Agricultural Research), Canada (Agriculture and Agri-Food Canada), Netherlands (Directorate-General for International Cooperation) and Switzerland (Swiss Agency for Development and Cooperation). See https://www.cabi.org/about-cabi/who-we-work-with/key-donors/ for details. The JRS Biodiversity Foundation provided resources for surveys and mapping.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

A.B.R.W. conducted the weed surveys and contributed to writing up the article. L.C. conducted the socio-economic surveys. T.B. was responsible for map development. W.N. conducted the weed surveys and was responsible for data entry.

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