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A risk assessment of the tropical wetland weed *Mimosa pigra* in northern Australia

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Background and approach

Mimosa pigra (mimosa) is an aggressive pan-tropical shrub that has been present in northern Australia for more than 100 years. Only in the last few decades has it become a major weed of the coastal floodplains of the Top End of the Northern Territory (NT). Mimosa has attracted a great deal of attention and tens of millions of dollars have been spent on research and management techniques.

This risk assessment follows the risk assessment framework developed for the Ramsar Convention on Welands (van Dam et al 1999, www.ramsar.org) and involves the following steps: problem identification; outline of the effects and potential extent of the problem; identification of the risks; and an outline of current management practices, including identification of uncertainties and information gaps in mimosa management. The assessment contains information from a variety of published and unpublished reports as well as information obtained through discussion.

Identification of the problem

Mimosa possesses many traits that make it a particularly invasive and successful weed. Some of these include adventitious roots that allow growth in a variety of hydrological conditions, rapid growth and maturation, a high production rate of easily dispersed and long-lived seeds, and low nutrient requirements. Mimosa has few or no natural enemies in its introduced range. In the absence of these enemies it rapidly colonises suitable wetland habitat, forming a near-monospecific shrubland. Control of the weed is expensive and is hampered by the size, inaccessibility and often the remoteness of infestations, regrowth of the seedbed over many years requiring continual follow-up control, and the thorny nature of the stems.

The potential effects of mimosa in northern Australia

The dominance of mimosa converts a range of structural types of vegetation into a homogeneous shrubland, reducing the diversity of flora and fauna, most likely including a number of vulnerable and/or endangered species. It can alter hydrological regimes and sometimes encroach into waterbodies, reducing them to a fraction of their former size as a result of increased sediment deposition. Mimosa provides ideal habitat and cover for feral pigs, decreasing the capacity to manage these pests. It can smother pasture grasses and result in the increased production costs of pastoral and agricultural enterprises. The aesthetics of wetlands are diminished and access to them impeded, threatening tourism incomes and recreational and commercial fishing endeavours and enterprises involving the sustainable use of wetland wildlife. Access to traditional Aboriginal hunting and important cultural/ceremonial areas could be reduced, as could the availability of Aboriginal traditional natural resources. Mimosa can also diminish the status of recognised important wetlands.

The potential extent of mimosa in northern Australia

Mimosa currently infests approximately 80 000 hectares of coastal floodplains in the Top End of the Northern Territory, from the Victoria River catchment in the west to the Phelp River in the east. The size of infestations varies greatly between river systems. Outside the Northern Territory, a relatively small infestation was found in 2001 near Proserpine on the central Queensland coast. Methods of seed dispersal include wind, water, animals, human clothing, vehicles, boats and machinery, adhering mud, waterbirds, and deliberate movements of seed-contaminated earth or plant/seed material by humans. Mimosa prefers seasonally inundated floodplains and will establish readily in disturbed areas.

For some time it has been predicted that mimosa would not be a serious problem outside of the 750 mm annual rainfall zone in northern Australia. CLIMEX modelling has largely supported this and has further predicted a large area of marginal suitability further inland, although the area of wetland habitat within this marginal zone is relatively small compared to the area of wetlands within the suitable zone. It is estimated that between 4.2 and 4.6 million hectares of wetlands in northern Australia are potentially at risk from mimosa infestation. Amongst these wetlands are a number that are valued as nationally and internationally important. The extent of invasion will depend somewhat on the individual characteristics of wetlands, including factors such as hydrology, soils, existing plant communities and in particular, the levels of disturbance by humans, fire, or feral and domestic animals. It cannot be concluded what effect global climate change will have on mimosa distribution, however, the indications are that growth conditions for mimosa will most likely be enhanced.

Uncertainty, information gaps and further research

Some important areas where additional information would benefit the management of mimosa and our knowledge of its potential extent in northern Australia include: site-specific assessments of wetlands at risk; the mapping and remote sensing of mimosa and wetlands at risk from infestation; more precise data on growth and environmental requirements; the role and timing of fire for both mimosa and uninfested habitat; what factors affect successful revegetation; the relationship between biological control agents and native species recolonisation; and the influence of global climate change. Other areas of beneficial research include: obtaining topographical map information at a finer resolution than is currently available; quantitative data on the environmental, economic, social and cultural impacts; the ecological impacts of herbicides used in control programs; and the identification of vulnerable and endangered biota.

Management implications

In the past few decades, a great deal has been learned about mimosa management. Current control strategies are the result of an extensive and integrated research program. As mimosa poses a national threat, a National Strategic Plan has been developed using a coordinated and collaborative approach involving Governmental and Aboriginal agencies from the Northern Territory, Queensland and Western Australia, as well as the CSIRO. The strategic plan has four main programs designed to inform and educate stakeholders and the community, prevent mimosa from spreading to and impacting on new areas, further develop the knowledge base and methods for effective and efficient management of mimosa, and reduce the current adverse impacts of mimosa infestations.

Education and awareness about mimosa issues are improving and most new mimosa infestations are being reported by members of the public. Aboriginal associations and communities are becoming pro-active with regard to weeds and other land management issues. Preventative management emphasising managing entire wetland plant communities to try and reduce susceptibility to mimosa invasion and establishment is being encouraged. Awareness that overgrazing and inappropriate fire regimes can remove native vegetation leaving the area prone to weed invasion is also being promoted. Impact reduction of existing infestations continues and many thousands of hectares of mimosa have been reclaimed for pastoralism, Aboriginal hunting and foraging, and other uses.

Acknowledgments

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The draft report was formally reviewed by external independent experts. Their comments were very helpful and have contributed to the report.

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1 Introduction

Tropical wetlands are renowned for providing many values and benefits for people and for supporting a diverse and plentiful biota (Finlayson & Moser 1991, Dugan 1993). There is also increasing pressure on such wetlands as human populations increase and development impacts both the wetlands themselves and their catchments. Responses to such pressures have varied, but as a general consequence many wetlands have been lost or degraded.

Amongst the many threats facing tropical wetlands, there is increasing concern over the impacts of invasive weeds. Across the tropics there are many wetland weed species with some of them being widely distributed, if not pan-tropical. These include mimosa[1] (*Mimosa pigra* Linnaeus), salvinia (*Salvinia molesta* Mitchell), and water hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laubach). These species have attracted a great deal of attention with the expenditure of large sums of money and effort on control techniques (Finlayson & Mitchell 1981, Storrs & Finlayson 1997, Douglas et al 1998). Fourteen of the top eighteen environmental weeds in Australia invade wetlands (Humphries et al 1991), with twelve of these species currently found in the Northern Territory.

The extent of invasion of wetlands has been described for some invasive species although often incompletely. In many instances, vital information on the ecological changes wrought by these species is often confined to a few isolated studies or to anecdotal evidence. Economic analyses of the losses caused by pest species are also not common, and studies on the social and cultural impacts of weeds have not generally been done (Finlayson & Spiers 1999).

A Global Biodiversity Forum held prior to the Ramsar Conference of Parties in 1999 addressed invasive species and agreed upon the following definition 'An invasive species is a species, often alien, which colonises natural or semi-natural ecosystems, is an agent of change, and threatens native biological diversity' (Pittock et al 1999). This concept is adhered to in this assessment with the additional recognition that agricultural diversity and production can also be threatened by invasive species.

Given that weeds are an increasingly serious problem in tropical wetlands, it is important that management prescriptions be developed at several levels. These include prevention at a national or regional level, and more specific interventions in local situations. Critically, for managers and users of wetlands, practical techniques and options are required that take into account local differences, priorities and resource levels. However, for localised effort to be effective a strategic framework is required that provides the necessary options and places

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[1] Examples of some areas where mimosa is a rapidly emerging problem include: the Kafue Flats region of Zambia in southern Africa (Bob Douthwaite pers comm 2002, Musonda Mumba pers comm 2002) and the floodplain of the Baro River near Gambella in south-western Ethiopia (Geoffrey Howard pers comm 2002); countries in South-east Asia that share the Mekong River Delta (Storrs et al 2001, Seppo Hellsten pers comm 2002, Samouth 2004, Triet et al 2004); areas of Wasur National Park in the Merauke district of Irian Jaya (Barano & Dess 2004); and the central and northwestern provinces of Sri Lanka (Marambe 2004).

particular weed infestations and their control into a regional perspective. A means of ensuring that the above aspects are not forgotten is through the adoption of ecological or wetland risk assessment (WRA) procedures as the basis for effective weed management.

Within this context, information on the biology and management of *Mimosa pigra* (mimosa) has been collated and analysed in a risk assessment of the weed in the regional context of northern Australia. Much of the information for this assessment has come from the Northern Territory where mimosa has been seen as a major weed for more than two decades, and has consequently attracted substantial research and management attention (Cook et al 1996, Douglas et al 1998, Finlayson et al 1998).

1.1 Project aims

This risk assessment was concerned with answering three questions:

1. What wetlands across northern Australia are at risk of invasion by mimosa;
2. What are the likely consequences of mimosa invading these wetlands;
3. What management actions are being undertaken or need to be undertaken to minimise the risks of further mimosa invasion across northern Australia?

The approach adopted to answer these questions is described below.

1.2 Approach

1.2.1 Wetland risk assessment framework

Over the last decade the concept of environmental risk assessment has developed and expanded from a narrow and precise analysis of quantitative ecotoxicological data to more general and qualitative/semi-quantitative analyses of environmental problems (van Dam et al 1999). This has led to the Ramsar Convention on Wetlands recommending a model for wetland risk assessment (figure 1) coupled with advice on the deployment of early warning systems for detecting adverse ecological change in wetlands. The Ramsar procedures are linked with a concurrent effort to espouse the values of wetlands and the maintenance of their ecological character. The former have been summarised by Finlayson (1996), as shown below.

- *Functions* performed by wetlands are the result of the interactions between the biological, chemical and physical components of a wetland, such as soils, water, plants and animals, and include: water storage; storm protection and flood mitigation; shoreline stabilisation and erosion control; groundwater recharge; groundwater discharge; retention of nutrients, sediments and pollutants; and stabilisation of local climatic conditions, particularly rainfall and temperature.
- *Products* are generated by the interactions between the biological, chemical and physical components of a wetland, and include: wildlife resources; fisheries; forest resources; forage resources; agricultural resources; and water supply.
- *Attributes* of a wetland have value either because they induce certain uses or because they are valued themselves, and include the following: biological diversity; geomorphic features; and unique cultural and heritage features.

The combination of wetland *functions, products* and *attributes* give the wetland *benefits and values* that make it important to society. The language used to describe these benefits and values has been reassessed in recent years and the terms *ecosystem goods and services* or *ecosystem services* are increasingly being used to describe the benefits and values derived from ecosystems, including wetlands.

In the context of the Ramsar Convention on Wetlands and the wise use of wetlands it is stressed that the use and management of a wetland and its resources should be done in a manner that is consistent with the maintenance of the ecological character of the wetland. Ecological character is now defined as (see www.ramsar.org/key_res_vii.10e.htm):

> the sum of the biological, physical, and chemical components of the wetland ecosystem, and their interactions which maintain the wetlands and its products, functions and attributes.

and the change in ecological character as:

> the impairment or imbalance in any biological, physical, or chemical components of the wetland ecosystem, or in their interactions, which maintain the wetland and its products, functions and attributes.

The generic wetland risk assessment model recommended for the Ramsar Convention (van Dam et al 1999, www.ramsar.org/key_res_vii.10e.htm) has been derived from those used for water pollution and ecotoxicological assessments (eg USEPA 1998) as well as the more general methods developed for assessing the vulnerability of wetlands to climate change and sea-level rise. The model provides guidance for environmental managers and researchers to collate and assess relevant information and to use this as a basis for management decisions that will not result in adverse change to the ecological character of the wetland. As the objective was to provide a framework for informed decision-making, it is not prescriptive.

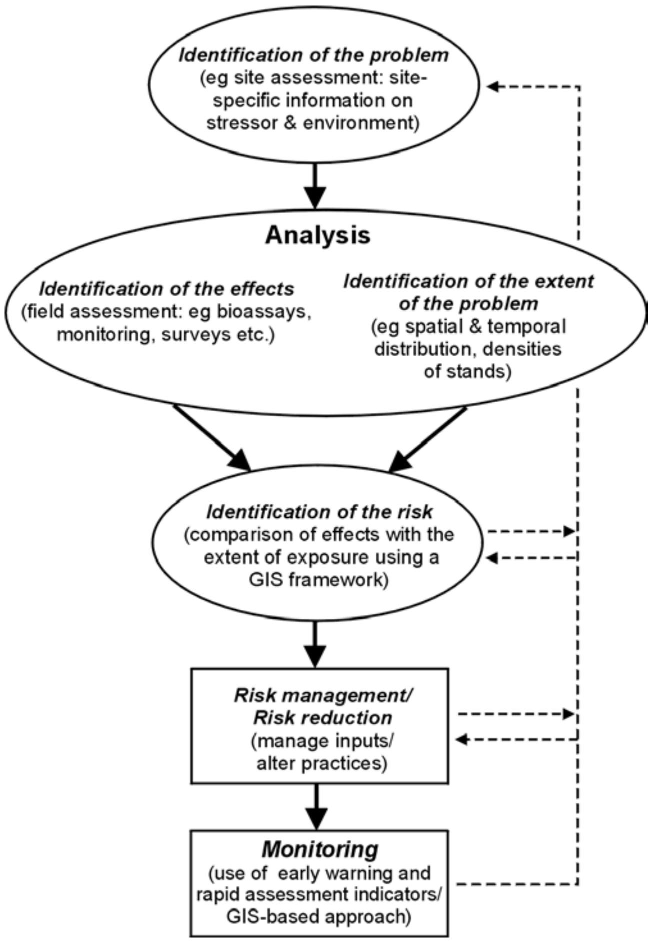

Figure 1 Wetland risk assessment framework (adapted from van Dam et al 1999)

The major steps in the wetland risk assessment (WRA) process presented in figure 1 are described briefly below, adapted from Ramsar Convention Bureau (2000) and van Dam et al (1999).

Identification of the problem: This is the process of identifying the nature of the problem and developing a plan for the remainder of the risk assessment based on this information. It defines the objectives and scope of, and provides the foundation for, the risk assessment.

Identification of the effects: This step evaluates the likely extent of adverse change or impact on the wetland. Such data should preferably be derived from field studies, as field data are more appropriate for assessments of multiple impacts, such as occur on many wetlands. However, literature reviews of existing information can often be sufficient for identifying effects.

Identification of the extent of the problem: This step estimates the likely extent of the problem on the wetland(s) of concern by using information gathered about its characteristics and extent of occurrence elsewhere. For biological (eg invasive species) and physical (eg land use) stressors, it might seek to obtain information on and define (map) current distribution, in order to estimate its potential distribution.

Identification of the risk: This involves integration of the results from the assessment of the likely effects with those from the assessment of the likely extent of the problem, in order to estimate the likely level of adverse ecological change within the study site. A GIS-based approach can be a useful technique for characterising risks to wetlands, by overlaying relevant information onto a map of the region of interest in order to link effects to extent/distribution. In addition to estimating risks, such an approach would also serve to focus future assessments and/or monitoring on identified problem areas. The uncertainty and information gaps associated with the assessment must always be described.

Risk management and reduction: This is the final decision-making process and uses the information obtained from the assessment processes described above, and in conjunction with other relevant information (eg political, social, economic, and engineering), attempts to minimise the risks without compromising other societal, community or environmental values. It is a multidisciplinary task usually requiring coordination by the land managers and communication between stakeholders.

Monitoring: This is the last step in the overall risk assessment process and should be undertaken to verify the effectiveness of the risk management decisions. It should incorporate components that function as a reliable early warning system, detecting the failure or poor performance of risk management decisions prior to serious environmental harm occurring. The risk assessment will be of little value if effective monitoring is not undertaken.

It is important to note that this assessment addressed the first four steps of the WRA process, in order to provide important information for the risk management process, which is a separate undertaking that must be the responsibility of the relevant State, Territory and/or Federal agencies. Nevertheless, the results of this assessment are discussed in the context of the current management of mimosa in northern Australia.

1.2.2 Information sources

Literature review

Much of the available information deals with aspects of mimosa control. Many reports detail aspects of the biology and ecology, and only a few address the specific impacts of mimosa. Most of the information on mimosa in northern Australia has been produced in the past 20 years. Published and unpublished reports or data were sourced and obtained through a comprehensive literature review process. Further relevant publications were then identified and obtained from within these sources.

Map information

Digital information was identified and obtained for use in a desktop GIS environment from a number of sources. These include:

The Australian Surveying and Land Information Group

1:250 000 digital topographic data (AUSLIG 1999)

1:250 000 land-use information (AUSLIG 1995)

Environment Australia

Estimated Climate Grids of Australia (EA 1997)

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Growth and stress indices used in the CLIMEX model

Department of Infrastructure, Planning and Environment

NT mimosa locations map adapted from Miller (1988) and updated with information from the Department of Infrastructure, Planning and Environment

Liaison with government, universities and industry

Territory and Commonwealth agencies involved in mimosa research were also contacted where necessary to obtain relevant information and seek advice. These included Parks Australia North (PAN), Commonwealth Scientific and Industrial Research Organisation (CSIRO) Division of Entomology, Parks and Wildlife Commission of the Northern Territory (PWCNT), Department of Infrastructure, Planning and Environment (DIPE), and Charles Darwin University (CDU) (see acknowledgments for specific experts consulted during the compilation of the report).

2 Identification of the problem

2.1 Biology of *Mimosa pigra*

2.1.1 Physical description

The following description is summarised from Lonsdale (1992) and Miller et al (1981).

When mature (figure 2a), mimosa is an erect much-branched prickly leguminous shrub reaching a height of up to 6 m, reproducing by seed and suckers. Mature plants branch from the base, and in seasonally inundated areas a skirt of fibrous adventitious roots is formed. The major root system consists of a 1–2 m taproot and lateral roots that extend up to 3.5 m from the stem. Stems are up to 3 m long, greenish at first but become woody, with randomly scattered slightly recurved broad-based prickles 5–10 mm long. The leaves are bright green, 20–25 cm long and bipinnate consisting of about 15 pairs of opposite primary segments about 5 cm long. Each segment has 20–42 pairs of sessile, narrowly lanceolate leaflets (3–8 mm long) per pinna that fold together when touched or injured and at night. Pairs of prickles sometimes occur between the branchlets on the main leaf stalk.

The flowers (figure 2b) are pink or mauve, small, regular and grouped into globular heads 1–2 cm in diameter, each head containing approximately 100 flowers. The heads are borne on stalks 2–3 cm long, with two in each leaf axil, while the corolla has four lobes with eight pink stamens. The fruit (figures 2c & 2d) is a thick hairy 20 to 25 seeded flattened pod borne in groups (about 7) in the leaf axils, each 3–8 cm long and 7–14 mm wide. The fruit turns brown when mature, breaking into one-seeded segments. The ripe seeds are brown or olive green, oblong, flattened, 4–6 mm long, about 2 mm wide and weigh between 0.006 and 0.17 g. The whole process from flower bud to ripe seed takes about 5 weeks.

Figure 2 *Mimosa pigra* (a) Adult plants, (b) flower heads, and (c) young and (d) mature seed pods (Photographs – CM Finlayson)

2.1.2 Biology

Germination of the hard seeds is dependent on breaking the physical barrier to moisture formed by the impermeable seed coat. Soil abrasion, microbial action, temperature fluctuations (Lonsdale et al 1988, Lonsdale 1993b) and, in some cases, fire (Miller & Lonsdale 1992) are most likely to break the dormancy of the seeds. Seed viability in excess of 5 years has been observed under laboratory conditions; under natural conditions, seed half-life varies from 9 to 99 weeks, depending on the soil type and depth of burial. Seed production has been measured at between 9000 and 12 000 m^{-2} per year per square metre of canopy (Lonsdale et al 1988).

Plants can survive the dry season by steadily losing leaves, while in permanently moist sites growth and flowering can continue more or less all year round (Wanichanantakul & Chinawong 1979). In the more dense stands, plant densities are in the order of 1–3 m^{-2} (Lonsdale et al 1995). There is a strong seasonality in growth rates with maximum rates in the field measured at 1.33 cm d^{-1} for seedlings, and 1.1 cm d^{-1} for plants >12 months old (Miller 1988). The main growth period is in the wet season with new shoots appearing with the first rains and a dense canopy forming within about a month.

Under ideal conditions plants can begin flowering 6–8 months after germination. The main flowering period is the mid to late wet season, but flower production may continue as long as water is available (Lonsdale 1988). Flower bud maturation usually takes 7–9 days from bud formation. Mature seed pods develop 25 or more days after the flower buds mature, with peak seed falls occurring between the late wet and early dry seasons (Lonsdale 1988).

2.1.3 Weediness

Mimosa has many features that are generally considered 'advantageous' to a weed. The greatest problem for plants growing in flooded soils is that their roots drown in the anaerobic conditions. Mimosa withstands such conditions by sprouting adventitious roots near the surface where they can take up oxygenated water (Miller et al 1981). Mimosa thickets can advance into waterbodies until little open water remains (Braithwaite et al 1989). Mimosa also has the potential to invade tidal zones (Miller 1983).

The plants mature quickly and can set seed in their first year of growth (Lonsdale et al 1985). The seeds of mimosa are well designed for easy and rapid dispersal. The seedpods break into segments when mature, with each segment containing a single seed. These segments are covered with bristles that enable them to adhere to animals and clothing, and to float on water for extended periods (Miller et al 1981, Lonsdale 1993a). The seeds are also dispersed in soil and mud, adhering to vehicles, machinery (Lonsdale et al 1985) and boats, and in the dung of livestock and native animals that sometimes graze on mimosa (Miller & Lonsdale 1987, Miller 1988).

The lifespan of the seeds in the ground depends greatly on their depth in the soil and the soil type. For example, half of a seed population was no longer viable after 99 weeks at a depth of 10 cm in a light clay soil, while a similar loss in viability was observed after only 9 weeks in a heavier cracking clay (Lonsdale et al 1988). In sandy soils, observations suggest that seed lifespan may be as high as 23 years (Lonsdale 1992).

Regular heating and cooling of the soil surface results in a soil temperature range from about 25 to 70°C, causing expansion and contraction of the hard seed-coats of mimosa species, eventually making them crack, breaking their dormancy. The deeper a seed lies in the soil, the less extreme is the temperature range and seeds buried deeper than 10 cm cannot successfully germinate (Lonsdale 1993b). However, as they can remain viable for long periods, such seeds could eventually germinate if brought to the surface by cultivation or disturbance by animals (Lonsdale et al 1988).

Seed rate production has been measured between 9000 and 12 000 m^{-2} per year depending on the conditions (Lonsdale et al 1988). The most productive plant observed in the field in Australia had a crown of about 8 m^2 and produced about 11 000 pods per year, equivalent to about 220 000 seeds (Lonsdale 1992).

The compound leaves of mimosa, like those of several other species in the genus, close in response to electrical, mechanical, thermal and light stimuli and wounding (Simons 1981). This may protect the leaves from damage in certain circumstances. This feature has also greatly assisted in the spread of the weed as humans value this novelty aspect and transport mimosa vast distances as a garden ornamental.

Under the right conditions mimosa grows quickly at a rate of about 1 cm per day, and infestations can double in area in one year. It can also withstand droughts, so the extended dry season, although slowing the growth rate and thinning the canopy, does not kill mimosa (Lonsdale 1993a).

If chopped down, mimosa will easily resprout from the stump (Wanichanantakul & Chinawong 1979). If mimosa is burnt, the foliage may become desiccated and fall, but up to

90% of mature plants and up to 50% of seedlings may regrow (Miller 1988, Miller & Lonsdale 1992).

Mimosa has low nutrient requirements and consequently can grow within a wide range of soil types including nutrient poor sands, alluvial red and yellow earths, silty loams and heavy black cracking clays (Miller 1983).

2.1.4 History of mimosa invasion in Australia

Exactly how and when mimosa was introduced to Australia is unknown. Miller and Lonsdale (1987) concluded that it probably arrived in Darwin in the 20 years prior to 1891, either accidentally in seed samples introduced for the Darwin Botanic Gardens, intentionally as a curiosity because of its sensitive leaves, or in the intestines of livestock imported from Indonesia (Swarbrick 1983). Mimosa was not found outside the Darwin City area until 1952 when it was discovered upstream from the Adelaide River township about 100 km south of Darwin. By 1968 it had spread downstream along the Adelaide River to the Marrakai Crossing. It was also reported at the old Daly River road crossing, 3 km upstream of the town, in 1958 and was found in the Batchelor–Rum Jungle area in 1968 (Miller et al 1981).

During the mid-1970s, unusually heavy seasonal rains caused extensive flooding that dispersed the seeds throughout the floodplains of the Adelaide River. Overgrazing and severe soil disturbance by feral water buffalo had removed most of the native vegetation available for competition, while the bare soils of the floodplains allowed ready establishment for mimosa seedlings (Lonsdale & Braithwaite 1988). In 1975 there were only a few mimosa plants on the Adelaide River floodplain. By 1978 the infestation had expanded to an estimated 200–300 ha of impenetrable thickets. By 1980 there were plants scattered over an estimated 4000 ha (Miller et al 1981), and in 1984 the population was estimated to cover about 30 000 ha in dense and scattered stands (Lonsdale 1993a).

Mimosa escaped from the Adelaide River system and over a relatively short period of time appeared in other areas such as the Daly (1979), Finniss (1979), Mary (1980), Moyle (1986), South Alligator (1981) and East Alligator (1983) systems (Miller 1988). Most of these systems now support large areas of mimosa. The most easterly Northern Territory location at the Phelp River was found in 1997, whilst the infestation in the Victoria River catchment to the west was found in 2001 (see section 4.1 and figure 4 for details of the current distribution).

The first occurrence of mimosa outside of the Northern Territory was in February 2001 where a relatively small infestation was discovered at Peter Faust Dam some 25 km to the west of Proserpine on the central Queensland coast (Bruce Wilson QDNR&M pers comm 2001, Chopping 2004).

2.2 Wetland habitats in northern Australia

Apart from mechanisms of, and issues relating to mimosa dispersal, the ability of mimosa to establish in a new habitat or region in northern Australia will depend largely on the type of wetland and the associated land use. While these issues are discussed in more detail in section 4, a brief overview is provided below of the major wetland categories in northern Australia as defined by Finlayson and Spiers (1999), whilst recognising that Lowry and Finlayson (2004) have shown that information on the distribution of wetlands across northern Australia is bedevilled by issues of scale and definition.

2.2.1 Coastal salt marshes

Coastal salt marshes encompass intertidal salt marshes and supratidal salt flats that can extend some 30–40 km inland (Blackman et al 1993). The marshes may be separated from inland salt flats by sand dunes and chenier ridges. Salt marshes occur along the coast and in embayments such as Cambridge Gulf and King Sound in the Kimberley (Semeniuk 1993) and extensively along the Arnhem Land/Gulf of Carpentaria coast (Love 1981, Galloway 1982, Blackman et al 1993). They are characterised by macro-tides (often 5–7 m range) that rise and fall across broad expanses of mudflats or seagrass meadows.

Plant diversity is not high. Overall, tropical salt marshes contain considerably fewer plant species than those in temperate areas (Stanton 1975, Saenger et al 1977, Specht 1981). Salt flats lacking vegetation are more common (Macnae 1966) and are found alongside many of the coastal mangrove communities.

Information on the fauna of these marshes and flats is sparse with the exception of migratory shorebirds. These birds also utilise the mudflats that are exposed at low tide. Watkins (1993) identifies the south-east Gulf of Carpentaria in Queensland and Roebuck Bay and Eighty Mile Beach in Western Australia as three of the most important areas for migratory shorebirds.

2.2.2 Mangrove-swamps

Mangroves are halophytic trees or shrubs that dominate sheltered, muddy, intertidal environments along tropical and subtropical shorelines. They range from a narrow coastal fringe to extensive forests and extend more than 40 km inland along rivers, covering about 4120 km^2 in the Northern Territory, 2520 km^2 in Western Australia (Galloway 1982) and a further 1140 km^2 (approx) in the Gulf of Carpentaria and northern part of Cape York (Dowling & McDonald 1982).

In general, mangrove forests vary from having distinct vegetation zones to being completely mixed, with the frequency of inundation by tidal water, fresh-water flow, soil type and drainage being important controlling factors (Bunt et al 1982, Semeniuk 1993). Probably the most common species is *Avicennia marina* which can tolerate a wide salinity range (Macnae 1966) and is a pioneer species commonly found on newly formed mudbanks in estuaries or on riverbanks. Semeniuk (1993) reports that there is a gradation from forests in the seaward parts of mangrove formations to scrub and heath in landward parts. Regional factors (coastal setting, climate and tidal range) that are inter-related influence the nature of mangrove habitats in any location.

The mangrove fauna, especially the macroinvertebrates, is not as well known as the flora (Hanley 1995). Relatively few surveys have been undertaken across the range of habitats. The larger animals are better known, but not necessarily in a quantitative manner. The saltwater or estuarine crocodile (*Crocodylus porosus*), a number of snakes, lizards, geckos, skinks and turtles plus mammals such as the fruit and insect-eating bats, water rats, feral buffaloes, pigs and cattle are known to utilise mangrove habitats (Hegerl et al 1979, Milward 1982).

2.2.3 Freshwater lakes

Finlayson and von Oertzen (1993) report that the classification and delineation of permanent waterbodies in tropical Australia is confused. The terms billabongs, waterholes, lagoons and ponds are used interchangeably. Further, there is a strong temporal pattern associated with such habitats that is not fully understood. The permanent waterholes that are features of many northern rivers – eg the Nicholson and Gregory Rivers, Queensland (Blackman et al 1993) – are not considered with the lakes, but with the freshwater ponds (see below).

Permanent and seasonal lakes are rare in northern Australia, only occur near the coast and are often associated with floodplain and dune ecosystems (Paijmans et al 1985, Blackman et al 1993). Artificial lakes are an important feature of the region, varying in size from small stock-watering dams (or tanks) to the extremely large Lake Argyle on the Ord River. Lake Argyle has great conservation value (Graham & Gueho 1995) in what was otherwise a fairly dry environment. The Ord River downstream from the lake now flows all year round. Along with Lake Kununurra it has become a significant drought refuge for waterbirds and a migration stop-over for many species (Jaensch & Lane 1993).

Another example is Fogg Dam, a permanent lake near Humpty Doo in the Northern Territory that was built to retain water for the ill-fated rice development scheme (Mollah 1982). It is relatively shallow and contains many water plants. To a large extent the flora and fauna of Fogg Dam is similar to that described for the permanent swamps and floodplains along the northern coastal zone.

2.2.4 Floodplains

Seasonally and intermittently flooding plains occur along most rivers that are influenced by monsoonal rains and have a very pronounced seasonal inundation cycle. The floodplains vary in size and occur across all of northern Australia. Those between Darwin and Arnhem Land have probably been the centre of more investigation and controversy than the others due to conservation, mining, weed and saline intrusion problems (Fox et al 1977, Finlayson et al 1988, Finlayson & von Oertzen 1993, Jonauskus 1996).

The northern climate and hydrology have a strong influence on the floodplains. The permanent waterholes (often inaccurately called billabongs) have fairly uniform physico-chemical conditions during periods of stream flow and a progressive increase in solute concentrations during the dry season.

General descriptions of the distribution of the major plant species on the floodplains in the Northern Territory can be made from various surveys (Wilson et al 1991). *Oryza rufipogon (meridionalis)* grasslands and *Melaleuca* spp woodlands are extensive and spread across most, if not all, of the floodplains. The sedges *Eleocharis* spp and *Fimbristylis* spp and the water lilies *Nymphaea* spp and *Nymphoides* spp are also common. Further surveys and collation of data are required for the Gulf of Carpentaria and Cape York Peninsula to supplement the information reported by Blackman et al (1993). Jaensch and Lane (1993) have reported on the floodplains of the Kimberley region.

An outstanding feature of the floodplain vegetation is the variation in floristic composition and foliar cover during the wet and dry seasons (Finlayson et al 1989, 1990). The success of the majority of species relies on mechanisms that enable them to survive the Dry season drought (Finlayson et al 1989, 1990, Finlayson 1993).

Examination of available data reveals that the Northern Territory floodplains hold high numbers of animals (Finlayson et al 1988). These include freshwater and saltwater crocodiles (Bayliss et al 1986, Messel & Vorlicek 1986), other large reptiles such as the file snake (Shine 1986) and freshwater turtles, freshwater fish (Bishop et al 1986), freshwater mussels (Humphrey & Simpson 1985) and a wide assortment of water birds (Morton & Brennan 1986, Morton et al 1990a,b, 1993a,b). When taken in conjunction with the sizes of the animals, these data convey the reality of a high standing biomass. It is expected that the same reality will apply to floodplains across northern Australia given reports on populations of at least some sectors of the fauna (Blackman et al 1993, Jaensch & Lane 1993).

2.2.5 Freshwater ponds and swamps

The uncoordinated drainage lines characteristic of the Barkly Tableland terminate in or have associated with them wetlands that are flooded frequently enough to support distinctive swamp communities. The Barkly Tableland lies on the southern edge of the monsoonal belt and contains intermittently flooded swamps that receive some rain in most years. Freshwater swamps also occur in the Kimberley (eg Lake Kununurra, Parry floodplain – Jaensch & Lane 1993), Gulf of Carpentaria (eg along the Nicholson and Gregory Rivers) and Cape York Peninsula (along the Archer and Jardine Rivers) (Blackman et al 1993).

Detailed descriptions of these areas are not available, though general reports such as that by Perry and Christian (1954), Jaensch and Lane (1993), Blackman et al (1993) and Jaensch (1994) list plant species and provide general information on seasonal changes and hydrology. In general, the drier areas are treeless except for small areas of *Eucalyptus microtheca* (coolabah) woodland, while the stream channels are fringed with *Muehlenbeckia cunninghamii* (lignum). The larger swamps contain assemblages of plants and animals similar to those described for the floodplains.

The summer filling of the swamps provides breeding areas for water birds such as *Anseranas semipalmata* (magpie goose), *Malacorhynchus membranaceus* (pink-eared duck) and *Dendrocygna eytoni* (plumed whistling duck), 'staging' grounds for migratory waders and 'summering' areas for *Glareola maldivarum* (oriental pratincole). The bird populations are immense and vary spatially and temporally. The long-haired rat *Rattus villasissimus* utilises the intermittent swamps as refugia and during good seasons will rapidly breed to plague proportions (Carstairs 1976).

2.3 Conceptual model

A conceptual model based on known information on mimosa, and the potential ecological, cultural and socio-economic impacts is shown in figure 3. This formed the basis of the risk assessment.

3 The potential effects of mimosa in northern Australia

3.1 Effects on ecosystems

Mimosa is an enormous problem for wetland conservation. In the Northern Territory, a largely intact natural landscape is being completely altered, with floodplains and swamp forest being covered by dense monospecific stands of mimosa, which have little understorey except for mimosa seedlings and suckers (Braithwaite et al 1989). The severity of the impact of mimosa results from the following: (1) the high dominance by the invading species; (2) the gross change in vegetation structure; and (3) the conversion of a wide range of structural types of vegetation to a homogeneous tall shrubland (Braithwaite et al 1989).

Due to mimosa's ability to sprout adventitious roots, it may even modify waterbodies. In the dry season, seedlings establish along the receding waterlines (Lonsdale & Abrecht 1989), and with the inundation of the next wet season, the natural water flows are reduced by the adventitious roots, resulting in increased sediment deposition. The thickets are able to continue their advance until only a tiny remnant of open water remains in the deepest parts. Even in the late 1980s, there was photographic evidence that mimosa had completely overgrown some billabongs (Braithwaite et al 1989).

Despite the acknowledged potential effects of mimosa invasion on native flora and fauna in northern Australia, very few studies have been done to assess these impacts. Unless otherwise cited, the following information on the effects on native flora and fauna is summarised from Braithwaite et al (1989), who investigated two study areas: one on the Adelaide River (6 sites) where the infestation was about five years old and relatively stable, and one on the Finniss River (8 sites) where the infestation was about three years old and still in the process of invasion.

Pressure:	*Mimosa pigra*

↓

Major exposure pathways:	Water, wind, vehicles, boats, stock, wildlife, feral animals, deliberate movements of earth and propagules

↓

Favoured wetland habitats:	Floodplains (land subject to seasonal inundation), freshwater ponds & swamps – particularly these habitats that have been disturbed

↓

Ecological, socio-economic & cultural effects:

- Competitive exclusion of native flora
- Loss of suitable habitat for native fauna
- Creation of suitable habitat for native fauna
- Loss of suitable food resources for native fauna
- Alteration of hydrological regimes
- Decreased capacity to manage vertebrate pests
- Competition with pasture grasses
- Reduced development, and increased production costs of pastoral and agricultural enterprises
- Reduced potential for sustainable utilisation of native wildlife
- Diminished aesthetics and threatened income from tourism
- Reduced access to recreational fishing
- Restricted access to traditional Aboriginal hunting areas and important cultural/ceremonial areas
- Reduced availability of other traditional natural resources
- Diminished status as a nationally or internationally important wetland

Figure 3 Conceptual model of *Mimosa pigra* in northern Australia

Both sites were undergoing relatively rapid change due not only to mimosa, but also to the dramatic reduction in the density of water buffalo (*Bubalus bubalis*) as a result of a national disease eradication program. Some studies have also been conducted at the Gunbalanya (Oenpelli) floodplain infestation (Cook 1992, 1993, 1994, Parry & Duff 1990), although for much of this work the emphasis was largely on the impacts of the chemical control methods and not specifically of the weed.

3.2 Effects on native flora

Once established, mimosa is able to out-compete native herbaceous layer vegetation for light, moisture and nutrients, although the relative importance of these three factors has not been determined. A comparison of incident light measurements beneath the mimosa canopy found that the sedgeland sites, which carry no trees, received 100% of the sunlight in the absence of mimosa, but only 62% (Finniss River sites) and 81% (Adelaide River sites) when it was present.

The *Melaleuca* dominated swamp forests fringing the floodplains have an open canopy and mimosa has also penetrated this habitat, preventing seedlings of the native forest trees from establishing. Incident light measurements revealed that although 75% passed through the native tree canopy, only 26% reached the ground flora with the additional presence of a mimosa canopy. Due to the demonstrated exclusion of native tree seedlings, it is proposed that the mature native tree canopy would eventually die out, and these swamp forests, like the sedgelands would become mimosa dominated shrubland.

The results indicate that the effect on the light regime at ground level, regardless of competition for moisture and nutrients, may be sufficient to account for the observed reduction in the number of tree seedlings, biomass and species diversity of the herbaceous layer. The light measurements were taken during the dry season when the weed has a relatively sparse canopy. The impacts could possibly be exacerbated in the wet season, when the denser canopy of a lush mimosa thicket may prevent around 90% of the incident light from reaching the ground.

Cook (1992) compared vegetation sites with and without mimosa for three different communities on the Gunbalanya floodplain. Under mimosa shrubs in floodplain margin and backswamp communities, the projected cover of native herbaceous species was less than one third and the species diversity was less than one half compared to where mimosa was absent. In the open floodplain communities, the cover of understorey species was similar and species richness was only slightly less where mimosa shrubs were present.

3.2.1 Recolonisation of native vegetation

Studies and observations show that herbaceous vegetation does recolonise following the removal of mimosa (Cook 1992, 1993, 1994, 1996, DPIF 1997, Searle & Fell 2000b). At the site of the Gunbalanya infestation, two years after the removal of mimosa, the diversity of herbaceous species had returned to levels similar to those found in the absence of mimosa. However, the actual cover of these species did not respond as rapidly as the diversity, and remained well below that found in areas yet to be invaded by mimosa (Cook 1992). Field observation has shown significant differences in the rate of native vegetation colonisation between wetland areas. Vegetation colonisation was very rapid within the Finniss River floodplain where effective colonisation of native species had occurred within two years, while in some areas of the Daly River, floodplain vegetation response has been very poor, and remained limited for four years following mimosa control. The degree of recolonisation of herbaceous species is dependent upon a variety of factors including, but not limited to, the amount of native seed importation, native seed soil stores, rainfall and inundation events, the effects of onsite ecological disturbance such as fire or vegetation removal from animal grazing or trampling, the accuracy of herbicide application rates in relation to different soil types and hydrology. As an example, over-application of herbicide can cause soil scalds where very little vegetation is able to establish (Cook 1996).

A possible contributing factor to differences in recolonisation rates and success could be the abundance of the various biological control agents that have established in the field. The CSIRO have found that native vegetation can colonise beneath mimosa that is defoliated by biocontrol agents, whereas unattacked plants are usually so dense that nothing grows beneath them. The most successful biocontrol agent, *Carmenta mimosa*, is abundant on the Finniss River floodplain, but has only recently established on the Daly and is absent from Gunbalanya. It is unlikely that this is the main reason for the considerable differences in native species recolonisation between catchments and more work is required on this issue (Quentin Paynter CSIRO pers comm 2003). An improved understanding of the recolonisation process following mimosa control is critical to achieving sustainable and long-term management of mimosa by limiting future mimosa seed germination and limiting seedling growth and development.

3.3 Effects on native fauna

Effects on native fauna result from the dramatic floristic and hydrological changes brought about by mimosa invasion. The structural change from sedgeland to tall shrubland has a more severe effect on the fauna than the clearing of native forest to make way for introduced pine plantations (Friend 1980). Braithwaite et al (1989) identified a number of species that were affected both adversely and favourably by mimosa invasion at the Adelaide River and Finniss River study sites. Using these data they were also able to hypothesise on the general effects of mimosa on patterns of animal abundance and diversity in these and other areas.

As other environmental factors in addition to mimosa appeared to act on the abundance of some species, multiple regression analysis was used to test 128 combinations of habitat variables to examine their influence.

3.3.1 Birds

The sedgeland-dwelling *Cisticola* spp. and the wet forest species *Conopophila albogularis* (rufous-banded honeyeater) and *Geopelia striata* (peaceful dove) exhibited lower abundance on sites invaded by mimosa, whilst the willie wagtail (*Rhipidura leucophrys*) appeared to increase in abundance. The abundance of terrestrial birds was positively related to both foliage height diversity and herbaceous biomass, and to woody species diversity. The species richness of terrestrial birds was positively related to both woody and herbaceous species diversities. This phenomenon was also observed on the Gunbalanya floodplain where the disappearance of many species of ground-feeding birds and the appearance of birds with other forage zones, was clearly due to the conversion of the natural grassland and sedgeland to a mimosa shrubland. The increase in diversity of terrestrial species was probably associated with the increased cover and nesting sites provided by the mimosa. The favourable effects of increased cover for terrestrial species were clearly demonstrated by the disappearance of the raptors *Tyto alba, Aquila audax* and *Elanus notatus* from areas with dense mimosa despite the presence of an abundance of their prey species (Cook 1992).

Waterbird abundance related negatively to river system, and to woody species diversity. Waterbird richness related negatively to foliage height diversity and positively to herbaceous diversity and root height. Treeless, species-rich, deep-water sedgeland is the prime habitat for waterbird populations as they rely on it for breeding and feeding. Further loss of this habitat through mimosa invasion would see an increasing negative impact on waterbird populations.

Some species such as the magpie goose (*Anseranas semipalmata*) and the brolga (*Grus rubicundus*) have either disappeared or are now much less common in other parts of Australia, increasingly using the wetlands of northern Australia as a refuge (Frith & Davies 1961, Blakers et al 1984). Indeed 60–70% of the total population of magpie geese in northern Australia seek refuge in two or three areas in Kakadu National Park towards the late dry season. The floodplains of the Adelaide and Mary Rivers encompass the most important nesting habitat in the Northern Territory for magpie geese, accounting for 32–52% of the total number of nests between 1984 and 1986 (Bayliss & Yeomans 1990).

The main rookery sites for species such as the sacred ibis (*Threskiornis aethiopica*), royal spoonbill (*Platalea regia*) and little pied cormorant (*Phalacrocorax melanoleucos*), and the main roosting and nesting sites of most of the raptors are found in the wet forests (paperbark, riparian and monsoon). As for the sedgelands, destruction of these habitats would impact greatly on these and other similar bird species.

3.3.2 Mammals

Small mammals seemed to favour the dense mimosa canopy. The rodent *Rattus colletti* greatly favoured the Adelaide River mimosa sites, whilst the small insectivorous dasyurid (*Sminthopsis virginiae*) was particularly abundant in the Finniss River mimosa sites, with all but one of the 28 captures being in the two mimosa/no paperbark sites. Analyses showed that mammal abundance related positively to mimosa cover/abundance and negatively to woody species diversity. Mammal species richness related positively to mimosa cover/abundance and negatively to river system and herbaceous species diversity.

The prime attraction of mimosa for small mammals is likely to be a favourable microclimate or protection from predation. The prickly canopy and dense skirts of adventitious roots at the base of mimosa stems provide ideal shelter and protection from avian predation and a nest site that is not readily flooded (Braithwaite & Lonsdale 1987). It is thought that these small mammals will probably survive only as long as the mimosa occurs in patches from which they can make forays into the surrounding sedgelands for food. If mimosa takes over all the sedgelands, the area will probably be unable to support the increased population (Lonsdale & Braithwaite 1988).

Large groups of flying-foxes (*Pteropus alecto* and *P. scapulatus*) roost and feed in the wet forests for much of the year (Friend & Braithwaite 1986). Severe destruction of this habitat as a result of mimosa invasion could potentially cause a decline in flying-fox populations. Flying-foxes are important as major pollinators and seed dispersers for trees throughout northern Australia.

3.3.3 Reptiles and amphibians

The majority of the reptiles captured during the Braithwaite et al (1989) study were skinkid lizards. The skinks *Cryptoblepharus plagiocephalus* and *Carlia gracilis* decreased in abundance at mimosa infested sites. The skinkid lizards are rarely found on the floodplains, preferring the forests and woodlands. Mimosa, however, appeared to provide an unsatisfactory microhabitat and few lizards were found in the mimosa-dominated areas.

Amphibians showed no distinct pattern with respect to mimosa. Abundance was positively related to mimosa cover/abundance, foliage height diversity and herbaceous biomass. Species richness showed some negative relationships with mimosa cover/abundance and root height and positive relationships with foliage height diversity and buffalo usage. Species richness is not unexpectedly related to the wetness of the site. The results were probably also affected by the difference in time of year of the sampling of the two river systems and detectability in ground vegetation of different density.

3.4 Vulnerable species

3.4.1 Fauna

There are a number of species that are rare and/or have a limited distribution (table 1) whose habitat may be threatened by mimosa infestation.

Table 1 Rare or vulnerable fauna potentially threatened by mimosa invasion in the Northern Territory

Species	Status and source
Xeromys myoides (false water-rat)	Near threatened – (DIPE 2000/DIPE 2002: New threatened species list)
	Vulnerable – (Environment Protection and Biodiversity Conservation (EPBC) Act 1999)
Lonchura flaviprymna (yellow-rumped mannikin)	Near threatened – (DIPE 2000/DIPE 2002: New threatened species list)
Tyto capensis (grass owl)	Near threatened – (DIPE 2000/DIPE 2002: New threatened species list)
Erythrotriorchis radiatus (red goshawk)	Vulnerable – (DIPE 2002: New threatened species list); (EPBC) Act 1999); IUCN 2002 red list)
Epthianura crocea tunneyi (yellow chat – Alligator Rivers subspecies)	Endangered – (Garnett & Crowley 2000); (DIPE 2000/DIPE 2002: New threatened species list)

The status is derived from the International Union for Nature Conservation red list categories (IUCN 2001). The false water-rat is known from only a few locations (coastal swamps and mangroves) in Arnhem Land, the Daly River and coastal Queensland. The yellow-rumped mannikin utilises riparian grassland and the grass owl utilises swampy sedgelands and grasslands. The red goshawk lives in coastal and subcoastal tall open forests and woodlands, and tropical savannas traversed by wooded or forested rivers and along the edges of rainforest (Marchant & Higgins 1993). There are thought to be fewer than 1000 (population stable) breeding birds left (Environment Australia 2000a, Woinarski 2002a).[2] The yellow chat occurs on alluvial grassy floodplains adjacent to large rivers (Blakers et al 1994), and there may be as few as 500 (population declining) breeding birds. The control of mimosa in areas occupied by or adjacent to such habitat has been recommended as a management option to aid the population recovery (Environment Australia 2000b, Woinarski 2002b). Yellow chats do occur patchily across northern Australia, but this subspecies is restricted to a small geographic area encompassing floodplains from the Mary River to the East Alligator River (Schodde & Mason 1999). There may be other data deficient species that are eligible for inclusion in table 1. Data deficiency (inadequate information to make a direct, or indirect, assessment of risk of extinction based on its distribution and/or population status) indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate (IUCN 2001).

Some migratory species such as the eastern curlew (*Numenius madagascariensis*), little curlew (*Numenius minutus*), Asian Dowitcher (*Limnodronius semipalmatus*) and oriental

[2] The Northern Territory has about one third (330 individuals) of the total population of the red goshawk, with about 120 found on Melville Island (Woinarski et al 2000). Forestry is expected to reduce this population by about 10%. Using these figures, the red goshawk actually qualifies as endangered in the Northern Territory (Woinarski 2002a).

pratincole (*Glareola maldivarum*) utilise the wetlands of northern Australia during their migration. These species could be adversely affected by significant habitat loss (NLC 1991), although they are not listed as threatened. The Japan-Australia Migratory Bird Agreement (JAMBA) and the China-Australia Migratory Bird Agreement (CAMBA) are not site specific but they oblige the signatory governments to pursue appropriate measures to ensure the conservation of migratory bird species (NLC 1991).

3.4.2 Flora

The herbarium of the Parks and Wildlife Commission of the Northern Territory (PWCNT) originally identified nine rare or vulnerable Northern Territory floodplain plant species that could be at risk through loss of habitat (NLC 1991). There was considerable taxonomic uncertainty and some data deficiency associated with this original list, and only four remaining species have been considered for inclusion at this stage (Ian Cowie, Northern Territory Herbarium, pers comm 2002) (entries 1–4 in table 2). The original list was also based on the earlier Rare or Threatened Australian Plants (ROTAP) criteria, with the revised list coming under the IUCN (2001) criteria. At present, *Monochoria hastata* is listed as vulnerable under the current *Territory Parks and Wildlife Conservation Act 2000* (DIPE 2000) and *Goodenia quadrifida* is listed as vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999*, and data deficient under the Territory Act. However, as per the fauna list, there may be other data deficient flora species eligible for threatened status.

Table 2 Rare or vulnerable flora in the Northern Territory potentially threatened by mimosa invasion

Species	Description and location
Aldrovanda vesiculosa	A free-floating aquatic herb found on wet floodplains and billabongs in Arafura Swamp, Fogg Dam, Girraween Lagoon and floodplains of the Reynolds and Finniss Rivers. Can be locally common in some of these sites.
Lemna tenera	A partially submerged free-floating aquatic herb known only from back-water swamps and billabongs on Magela Creek and Reynolds River.
Monochoria hastata	A perennial emergent aquatic herb that grows to approximately 1.2 metres in height. In Australia the only records are from the Northern Territory on floodplains of the Finniss, Reynolds, Mary and Wildman Rivers.
Goodenia quadrifida	An annual herb with branches to 30 cm long. A rare species known only from a few locations on floodplains of Hardy Creek (Mary River floodplain) and the upper Adelaide River at the top of the tidal influence and on the Marrakai plains.
Ptychosperma bleeseri	A slender clumping, feather-leaved palm with a small crown supported on a narrow trunk. Known only from eight populations within 200 km^2 of Darwin. A total of 1037 adult plants are known to exist. Occurs in small monsoon forest patches associated with lowland springs near the margins of riverine floodplains.
Nymphoides subacuta	An annual or perhaps perennial (where water persists) waterlily with deep yellow to orange flowers. Found in shallow freshwater swamps and lagoons near Darwin and in Kakadu National Park.
Nymphoides sp. (Nathan River entity)	Resembles another more common waterlily (*N. parvifolia*) but differs in the numbers and morphology of the seeds. Known only from mud flats on the edge of a swamp north of Nathan River Station between Borroloola and Roper Bar in the south-east corner of the Top End.
Nymphoides exiliflora	A small annual waterlily with yellow flowers. In the NT, known only from the Mann and Goyder River regions.

Source: NLC 1991, Cowie et al 2000, Kerrigan et al 2002a, Kerrigan et al 2002b

The rare palm *Ptychosperma bleeseri* is listed as endangered under the Northern Territory and the EPBC Acts. It is also referred to in the 'summary of mimosa impacts' section of ARMCANZ (2001). Three of the eight rainforest patches (see table 2) occur within the Black Jungle Conservation Reserve, with the remainder occurring on freehold or pastoral lease land. Although the rainforest habitat is thought to be less readily colonised by mimosa, the threat of invasion remains, particularly if other threats such as feral animals, other weeds and fire are present that have the potential to 'open up' the rainforest. Such impacts have already eroded the population substantially (Kerrigan et al 2002b).

There are several species of waterlily (*Nymphoides*) endemic to the Northern Territory, some of which may be threatened by mimosa invasion (ARMCANZ 2001). *N. subacuta* is considered near threatened under the Northern Territory Act whilst *Nymphoides* sp. (Nathan River entity) is not yet listed, but to date, is known only from one location (Cowie et al 2000) (table 2). *N. exiliflora* is considered data deficient under the *Territory Parks and Wildlife Conservation Act 2000*. It was considered as a species of probable conservation significance during vegetation surveys of the wetlands of the Maningrida region (Leach et al 1992, Griffiths et al 2000). Five outbreaks of mimosa have been recorded in the region (Griffiths et al 2000).

3.5 Socio-economic effects

In addition to adversely affecting native flora and fauna, mimosa also impacts upon the activities of humans. It interferes with stock watering, irrigation projects, tourism, recreational use of waterways, commercial fishing and the traditional lifestyles of indigenous peoples. The weed can also smother pastures, reduce the available grazing areas and make mustering difficult (Miller et al 1981), thus reducing the development of pastoral enterprises in addition to increasing the production costs. In areas of South-east Asia, mimosa is also reducing access to waterways, causing sedimentation and making river widths narrower and hence transportation on waterways more difficult (Storrs et al 2001).

The monetary cost of controlling mimosa represents a significant economic impact in itself. Up to 1996/97 it was estimated that $17.8 million has been spent by government and landholders on research and control of mimosa. Projected expenditure for 1999/2000 was estimated at about $3.9 million (Interim Mimosa Planning Group 1999). An up to date figure is not currently available, but would be likely to total in excess of $25 million (M Storrs NLC pers comm 2002). Despite this cost the Northern Territory remains infested with possibly 80 000 ha of mimosa. However, it is likely that without this expenditure and the subsequent acquired knowledge, this area of infestation would be much higher and the likelihood of infestations in Queensland and Western Australia would be much greater.

3.5.1 Pastoral activities and commercial fishing

The value of the Northern Territory's pastoral industry is approximately $200 million per annum (DBIRD 2002). The profitability of this industry has been affected by mimosa through reduced grazing and water resources, increased costs for herbicides, labour and revegetation, and increased difficulties in stock management, infrastructure maintenance and feral animal control (ARMCANZ 2001). In a recent survey by the Australian Bureau of Agricultural and Resource Economics, pastoralists throughout Australia recognised woody weeds as the most serious form of land degradation confronting them and they saw the problem to be increasing in importance.

Barramundi (*Lates calcarifer*) and mud crabs (*Scylla serrata*) are the most harvested commercial species in the Northern Territory (Storrs & Finlayson 1997). The mud crab industry is the most valuable wild-capture harvest with an annual value of $10.33 million, while the barramundi fishery is worth $5.13 million annually (L Cooper DBIRD pers comm 2003). These species targeted for commercial fisheries are intimately dependent on coastal wetlands throughout their life cycles (Storrs & Finlayson 1997) and may well be threatened by the degradation of wetlands under the threat of mimosa.

3.5.2 Tourism

Tourism and recreation are increasingly important land uses based on natural and cultural values. The Northern Territory is an attractive tourist destination because of its natural beauty, wildlife, traditional Aboriginal culture, quality recreational fishing and frontier image. The total expenditure by 786 000 visitors to the Top End of the Northern Territory in the 2001/02 financial year was approximately $498 million (1 953 000 visitors and $1027 million Territory-wide) (NT Tourist Commission 2003). The latter figure is approximately 5 times the income derived from the pastoral industry.

In many cases the economic impacts of mimosa are contingent with the ecological impacts. A diminishing of the aesthetic value of the Northern Territory wetlands and a decrease in wildlife numbers due to loss of habitat to mimosa infestations would most likely see a reduction in visitor numbers. This would not only affect tour operators but would flow on to all associated industries such as transport, retail, accommodation, catering and other service industries, who receive $2020 million and employ some 15 080 people as a result of the economic contribution (direct and indirect) from tourism (NT Tourist Commission 2003).

As early as 1981, the operations of a tourist river safari on the Adelaide River and its tributaries were affected by mimosa. The abundant wildlife of the area was a highlight of the safari. As the density of mimosa increased, reduced access and visibility resulted in some of the area being removed from the program (Miller et al 1981). The coastal lands to the north of the Wagait Aboriginal Land Trust (ALT), and the Finniss River to the coast, are also popular weekend destinations for Darwin residents. The Gunbalanya-East Alligator River floodplain is visible from the flight path of the major local aerial sightseeing tours in Kakadu National Park. The floodplains are also crossed by visitors travelling by road to Gurig National Park on Cobourg Peninsula. There are also a number of indigenous ecotourism operations on or near the Gunbalanya floodplain that have been affected and there is potential for more (Grant Flanagan DIPE pers comm 2002).

Mimosa also impacts on the recreational fishing industry by preventing access to rivers and billabongs (Miller et al 1981, Lonsdale et al 1995). The recreational fishing industry is well established, especially in the Top End with barramundi being a favoured species, and the Mary and Alligator Rivers being very popular destinations (Julius 1996, Griffin 1996). Recreational fishing contributes significantly to the Territory economy with an estimated annual direct expenditure of $50 million (DPIF 2001).

3.5.3 Cultural values

The above mentioned impacts of mimosa are not restricted to European land-use practices. Aboriginal people have control of, or have under claim approximately 50% of the Northern Territory (over 170 000 square kilometres in the Top End) including about 87% of the Top End coastline, and thus many of the major sub-coastal wetlands that are threatened by mimosa (Storrs 1998, Storrs et al 1999). It is thought that 34% of mimosa infestation is situated on Aboriginal land. The main infestations of mimosa currently occurring on Aboriginal land are found on the Wagait ALT, and the Daly River/Port Keats ALT to the west, and Gunbalanya floodplains in western Arnhem Land (Storrs et al 1999).

Aboriginal people continue to be reliant on the natural environment for both their spiritual and physical well being. Practices such as hunting and foraging not only provide people with food, but are closely tied to spiritual beliefs and traditional law, and allow each generation to share extensive environmental knowledge with succeeding generations (NLC & ***eriss*** 1997). Wetlands are the major traditional source of food for part of the year (Altman 1987) and the invasion of weeds physically impedes access to traditional hunting grounds and reduces the availability of foods such as magpie geese, file snakes, goannas, turtles and water lilies due to loss of native habitat. Sacred sites and other sites of cultural significance have been changed and their access impeded. Aboriginal interests are also investigating a mixture of land-use options, including ecotourism, sustainable commercial wildlife harvest and pastoralism (NLC & ***eriss*** 1997, Rea & Storrs 1999). Such enterprises give Aboriginal people economic independence in the long term. The impacts of mimosa on such endeavours, as outlined earlier, threaten this independence (NLC & ***eriss*** 1997, Storrs 1998, Storrs et al 1999).

3.5.4 Uses of mimosa (from Miller 2004)

Mimosa has been of botanical interest for over 100 years, mainly for the novelty aspect of its touch sensitive leaves that 'close up' when stimulated. In 1947 it was introduced into Thailand as a green manure and cover crop in tobacco plantations (Napometh 1983), and is also used for firewood, bean poles and temporary fences. Attempts at making fibreboard found that the product absorbed excessive moisture and was unsuitable for commercial use (Robert 1982). In Vietnam, processed, sterilised mimosa wood is being trialled as a medium for growing mushrooms (Tran Triet Vietnam National University pers comm 2002). At high densities, it increases soil fertility and redistributes nutrients higher up in the soil profile.

Due to the high protein content (20–30%), studies in Thailand have been conducted to assess the use of mimosa as a substitute for *Leucaena leucocephala* in animal feed (Vearasilp et al 1981a, Vearasilp et al 1981b). It is also heavily grazed in Nigeria by larger native herbivores such as elephants, antelope and buffalo (Geerling 1973). There are reports from Australia of browsing by horses, buffalo, cattle and goats (Miller 1988, Lonsdale et al 1995). In Thailand, cattle and goats have also been observed browsing on mimosa.

In Africa it is apparently used as a medicinal plant for colds, fever, toothaches, eye complaints (Horov's Tropical Seeds 1980) and snake bite (Irvine 1961). In Sumatra, a mimosa infusion is used to treat weak heart and pulse (Grosvenor et al 1995), and in Mexico it was a traditional Mayan medicine for diarrhoea.

In recent years, the harvesting of mimosa to provide tannins (NT Government 1997) and electricity generation (Sharp 2001) has been proposed. Neither project has commenced as yet, however, a number of feasibility and other studies have been completed by the Northern Territory Power and Water Corporation, the Department of Business, Industry and Resource Development, Biomass Energy Services and Technology Pty Ltd and Enecon on behalf of the Australian CRC for Renewable Energy (ACRE) (Enecon Pty Ltd 2001). Harvesting will not solve the weed problem and the literature stresses that there are some limitations to this process. Concerns have also been raised about spreading mimosa to new areas and committees overseeing mimosa management have supported the proposal provided stringent safeguards are implemented. As a class 'A' noxious weed, mimosa can not be viewed as a renewable crop (Miller 2004).

4 The potential extent of mimosa in northern Australia

This section deals with the current and potential distribution of mimosa in northern Australia, including factors influencing establishment, density and distribution.

4.1 Current distribution

Between 1980 and 1989 mimosa spread from 4000 to 80 000 ha in the Northern Territory (NT Government 1997). It is found in most major Top End river systems from the Victoria River in the west (approximately 50 km from the Western Australia border), to the Phelp River in south east Arnhem Land, and the Arafura Swamp to the northeast. The documented locations of mimosa in the Northern Territory as of 2003 are shown in figure 4. The map was first produced by Ian Miller in 1988. This version is based on earlier maps and updated with information from Guy McSkimming and Mark Ashley of the Northern Territory Department of Infrastructure, Planning and Environment. The size of infestations varies between river systems, with the largest infestations on the Adelaide, Mary and Finniss Rivers and in the Daly River/Port Keats ALT (table 3). Two small incursions have occurred at Nguiu on Bathurst Island and on Croker Island, but these have since been eradicated (Ian Brown NLC pers comm 2002).

Table 3 Important wetlands infested with mimosa in the Northern Territory (Source: Department of Primary Industry and Fisheries and Interim Mimosa Planning Group, January 1997, supplemented with 1998 data; M Ashley pers comm 2001)

Wetland system	Total area (ha)	Estimate of area infested with mimosa (ha)*
Adelaide River floodplain system	134 800	30 000
Arafura Swamp	71 400	5
Blyth-Cadell floodplain & Boucaut Bay system	35 500	>1
Daly-Reynolds floodplain estuary system	159 300	17 000
Daly middle reaches	1 650	>10
Port Darwin	48 800	500
Finniss floodplain & Fogg Bay system	81 300	17 484
Mary floodplain system	127 600	10 000
Moyle floodplain	48 100	1000
Murgenella-Cooper, East Alligator floodplain system	81 500	4000
Kakadu (South Alligator), West Alligator and Wildman River systems, Stray Ck, Phelp River, Scott Ck	190 000	10
Total area	979 950	~80 000

* Mimosa may occur as scattered plants over much larger areas. The above estimates will vary over time and success of control programs.

Although the current distribution of mimosa in the Northern Territory is fairly well known, the actual area of infestation is uncertain. The approximate figure of 80 000 ha has been widely quoted for over a decade and may still be valid, as control efforts and prevention of satellite outbreaks attempt to keep pace with the spread. The figure may even be slightly higher than 80 000 ha, as several new small infestations have been discovered in recent years (G Flanagan pers comm 2002).

The approximate breakdown of the estimated area of mimosa infestation as of 1998 is shown in table 3, where mimosa was recorded on eleven nationally important wetlands. As stated above, since these values were first presented, some of these areas have (to varying degrees) decreased in size whilst others have increased (G Flanagan, M Ashley & I Brown pers comm 2002). The Arafura Swamp and Blyth-Cadell infestations are now thought to be less than one hectare, and in the Daly middle reaches less than 10 ha (I Brown pers comm 2002). The Moyle floodplain and the Murganella-Cooper/East Alligator system (which includes the Gunbalanya floodplain) infestations are thought to be about 150 ha and 750 ha respectively (M Ashley pers comm 2001). Kakadu National Park stages I and II represent two of the three Ramsar wetland sites listed for the Northern Territory. Although mimosa is present on some of the wetlands within these sites, it is kept at very low levels through constant vigilance (I Brown pers comm).

Until recently, mimosa had been restricted to those Northern Territory wetlands in the area north of latitude 16°S. In February 2001 a small infestation of about one hundred (~ 1 year old) plants was discovered in Queensland on the edge of the Peter Faust dam approximately 25 km west of Proserpine (Bruce Wilson QDNR&M pers comm 2001, Chopping 2004), which is just below latitude 20°S. The dam is at the top of the pioneer catchment system. Initially, scattered plants were confined to the south-eastern edge of the dam and two mature infestations were discovered in five metres of water in the south-western area. The main infestation was approximately 30 x 30 m and the smaller about 3 x 3 m. Surveys in 2002 found substantial mimosa germination in the south-western area, where new growth had scattered over about five hectares. The new germination resulted from receding water levels within the catchment. Further germination is expected in the future as the dam water levels are predicted to drop. All known plants have been treated and the dam and surrounding areas are being closely monitored (Chopping 2004). It is uncertain how mimosa arrived at this site, although seed transport via fishermen (the dam is also used as a recreational facility) or construction equipment has been hypothesised (B Wilson pers comm 2001).

4.2 Invasion rates and pathways

Lonsdale (1993a) examined the spread rates of mimosa, both within a single wetland system on the Adelaide River floodplains, and across the entire western coastal region of the Top End. The results indicated that if wind were the only seed dispersal method, the most rapid linear increase of a mimosa stand would be 18.3 m per year[3]. Actual rates of spread determined from aerial photography were found to average 76 m $year^{-1}$ or greater in five out of six years. This indicated that the dispersal of seeds by flotation (rather than wind) was responsible for the rapid expansion of mimosa as observed in the region. Over the six year study period, the doubling time of mimosa within the river system was 1.2 years, compared with 6.7 years for the number of infestations across the region as a whole. This slower rate of expansion was thought to be due to the separation of the more suitable wetland habitats by eucalypt savannas that mimosa does not readily colonise. The rate of spread was greatly influenced by climatic conditions in that there was a strong relationship between the rainfall during the wet season and the proportional increase in the area of the stand in the following year (Lonsdale 1993a).

The calculated spread rate for the mimosa infestation on the Gunbalanya floodplains in western Arnhem Land, was a doubling time every 1.4 years. This resulted in an increase from ~200 ha in 1984 to ~6000 ha by 1991 (Cook et al 1996). Between 1981 and 1993 the number of new mimosa outbreaks in Kakadu National Park totalled about 160. The number of new outbreaks found each year fluctuated between 5 and 28 with a mean of 15 and no consistent trend over time (Cook et al 1996).

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[3] While wind is not considered to be a major cause of spread, tropical cyclones could contribute. High intensity winds and flooding associated with cyclones may carry seed over long distances (Benyasut & Pitt 1992).

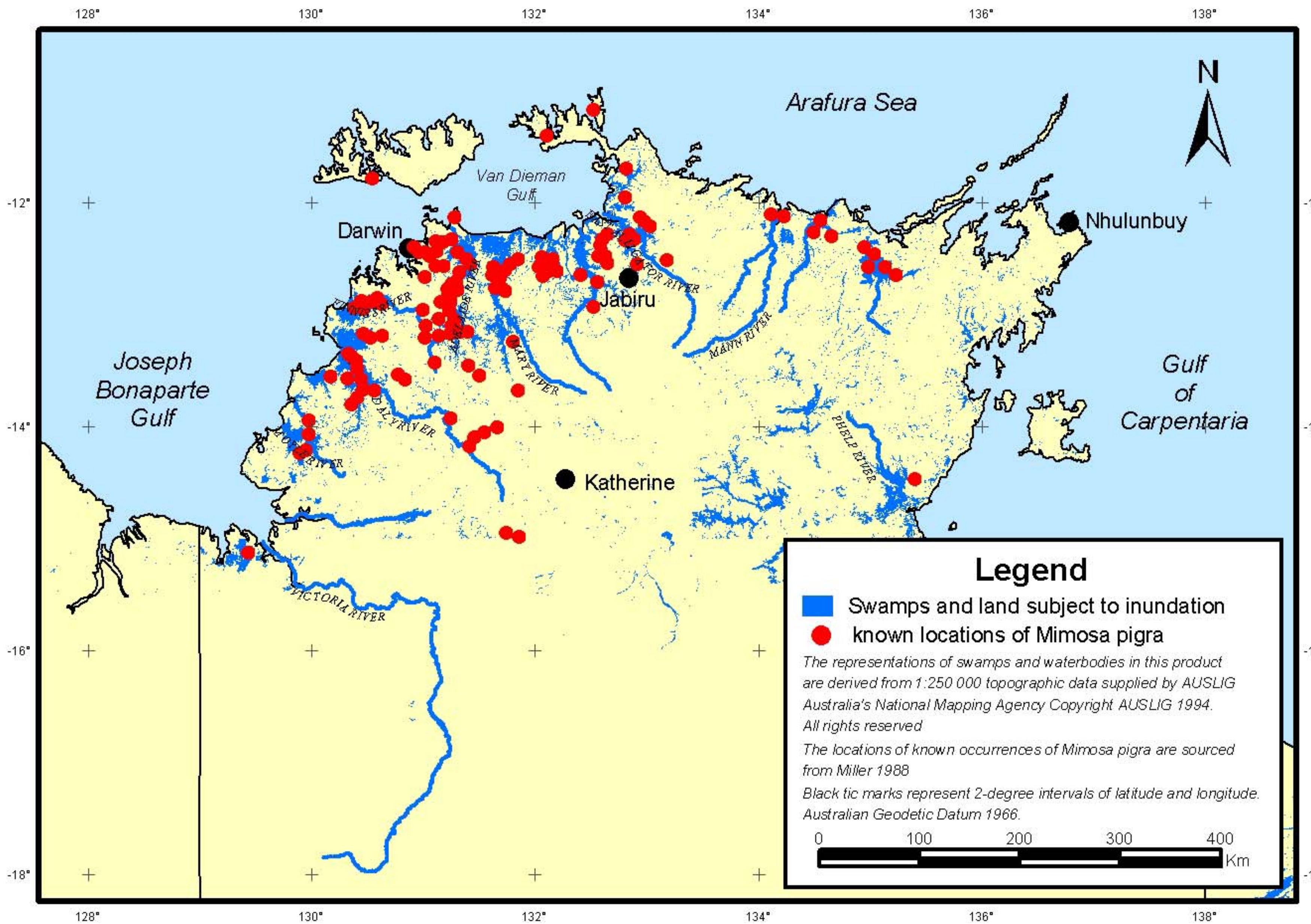

Figure 4 Documented locations of mimosa infestations in the Northern Territory as of 2002 (adapted and updated from Miller (1988))

The bristled seed pods float by surface tension and may be carried for extended periods of time over great distances particularly when maximum seed fall coincides with heavy flooding (Lonsdale 1993a). The seed pods adhere to clothing and animal fur, thus they may be spread both within and between catchments by humans and animals including buffalo, cattle, horses, pigs and wallabies (Miller et al 1981). Seeds may also be contained in the mud and debris that attaches to animals, vehicles, machinery and recreational fishing boats, or be lodged in the crevices of vehicles etc. Livestock and native mammals sometimes graze on mimosa plants (Miller 1988), so seeds may be dispersed in the dung of these animals (Miller & Lonsdale 1987). Although spending up to 36 hours in the gut of an animal, mimosa seeds may still be 70–90% viable (Benyasut & Pitt 1992). Physical removal of seed-contaminated sand for construction purposes is thought to be responsible for the spread from the Adelaide River to the Batchelor–Rum Jungle region and possibly other areas (Miller et al 1981). The rapid spread of mimosa in Thailand (Thamasara 1985) and Sri Lanka (Marambe et al 2004) is also thought to have been facilitated by movement of sand for landfill and construction work.

It is not known for certain if waterbirds are capable of dispersing mimosa seeds, although there is strong anecdotal evidence to suggest that this may occur. Initial surveys of the Phelp River infestation discovered a large single mimosa plant, visually estimated to be approximately 5–7 years of age, positioned immediately beneath a Jabiru nesting site, while the remaining mimosa infestation consisted of plants in a single age cohort of approximately 2–3 years. The nesting site was positioned in small melaleuca trees 3 metres above ground level and large quantities of black-necked stork (jabiru) faeces occurred in the immediate vicinity of the larger mimosa plant, suggesting mimosa-contaminated faeces may have resulted in the original seed importation (M Ashley pers comm 2001). In 1996/97 a similar scenario of a new, isolated single plant infestation was observed at the Mirrngadja area of the Arafura Swamp in north-eastern Arnhem Land (G Flanagan pers comm 2002). The most westerly Northern Territory infestation at Legune Station, approximately 50 km from the Western Australian border, consists of three separate small incursions totalling about half a hectare. Department of Primary Industry and Fisheries weed officers do not know the source of this infestation, but waterbirds have been hypothesised (M Ashley pers comm 2001).

Humans value mimosa for the novelty of the touch sensitive leaves. This is likely to increase the risk of deliberate introductions into new areas, even across interstate borders. It is possible that this scenario was the reason for the initial introduction of mimosa to Darwin (Miller & Lonsdale 1987) and subsequently the Adelaide River region.

4.3 Preferred habitats and environmental conditions

An understanding of the types of habitats and environmental/bioclimatic conditions preferred by mimosa is essential in predicting its potential extent across northern Australia. Habitats and environmental conditions are discussed together here as they are inter-related and often difficult to separate.

Mimosa has been introduced into most tropical regions of the world where it grows in comparatively open, moist sites such as floodplains, coastal plains and riverbanks (Miller et al 1981, Lonsdale et al 1985, Lonsdale 1992). In the introduced range, mimosa infests naturally or anthropologically disturbed places such as reservoirs, canal and river banks, roadside ditches, agricultural land and floodplains. In its native range, mimosa occupies similar habitats, especially in areas which have been disturbed, but usually occurs as small thickets or individual plants (Harley 1986). However, even in its native range, mimosa is now posing a threat in some areas. For example, in the rebublic of Costa Rica in Central America, mimosa is rapidly expanding in areas of rice cultivation, with many infestations now covering hundreds of hectares. The spread is often associated with the drainage channels that drain the rice fields. The infested areas are drier, with the frequency of flooding and the water depth greatly reduced (JA Jimenez pers comm 2002). Mimosa has also become common in overgrazed areas in Costa Rica (Boucher et al 1983).

4.3.1 Climate

In the Top End of the Northern Territory, mimosa experiences a wet–dry tropical climate with highly seasonal rainfall, and uniformly high temperatures and solar radiation. The wet season extends from October through April and is characterised by over 90% of the annual rainfall. The dry season extends from May to September where there is little or no rainfall. There is high interannual variation in rainfall, with markedly different trends over periods of 5 to 30 years (eg at Darwin, the drier periods have annual average rainfalls of around 1380 mm and the wetter periods have average annual rainfalls of about 1660 mm; Carter 1990). The most numerous and severe mimosa infestations occur in the region of 1200 mm to 1800 mm annual rainfall. Some of the more southerly Top End infestations are in the 900–1200 mm rainfall zone, whilst the Phelp River infestation in the south-east of the Top End is in the 600–900 mm rainfall zone.

The temperature tolerance range of mimosa has not been quantified (Lonsdale et al 1985). The average annual minimum temperature of Northern Territory mimosa infested areas is between 18°C and 24°C, the average annual maximum temperature is between 30°C and 36°C The coldest temperature regime experienced by mimosa populations in the Northern Territory is in the vicinity of the Daly River, which has a mean daily minimum temperature for July of 13.2° C (Lonsdale et al 1985).

The Central Mackay Coast bioregion in Queensland (where the mimosa infestation at Peter Faust Dam was discovered) is subject to a strong maritime influence and high atmospheric moisture. It is characterised by a hot wet season (December – April), and a mild winter and dry season (August – December). The average annual rainfall around the Proserpine region is between 1200 mm and 1800 mm. Although temperatures differ markedly during all seasons between lowland and highland areas (Blackman et al 2000), the average annual minimum temperature around the Proserpine region is between 15ºC and 18ºC, and the average annual maximum temperature is between 24ºC and 27ºC.

The native range of mimosa extends from northern Mexico (approx 25°N) to just south of Rio de Janeiro (approx 23°S) in Brazil. The climate within this range is similar to that of northern Australia where mimosa currently exists, and could potentially invade (see section 4.4). The city of Acapulco (16°N) in Mexico has a mean annual rainfall of 1400 mm and a mean annual temperature of 28°C. Rio de Janeiro has a mean annual rainfall of 1100 mm and a mean annual temperature of 24°C. These data indicate that regardless of other factors, mimosa has not yet invaded all suitable habitats within northern Australia.

4.3.2 Geomorphology and soils

The coastal wetlands of the Northern Territory, where mimosa has primarily infested, are predominantly a depositional landscape of estuarine and riverine alluvial deposits with some beach ridge development (Isbell 1983). The floodplains of the northern flowing drainage systems show remarkably low gradients, and they respond strongly to the monsoonal climate, being inundated with freshwater during wet season floods (Woodroffe et al 1986).

In Australia mimosa is not restricted to any one soil type (Miller 1983). Most outbreaks of mimosa (Miller 1988) have occurred on the floodplains which are dominated by black massive cracking clay soils (Northcote et al 1975). Some infestations have occurred on yellow mottled duplex soils on the Adelaide River (Miller 1988) and also on the Daly and

Moyle Rivers (Miller 1988, Northcote et al 1975). Miller (1983) has also reported the plant growing on alluvial red and yellow earths, silty loams, and coarse siliceous river sand.

The duplex soils consist of fine sand or silty loam overlying a dense clay subsoil (Miller 1988). Minor soils of the seasonally inundated areas include loams and sands on slightly elevated river levees and humic gley soils on the margins of floodplains, which frequently support paperbark forest. Mimosa also infests these lighter-textured soils, which occur in association with the more extensive cracking clay soils (Miller 1988).

A comparison of two sites in the Adelaide River found that seed production and seedling densities were found to be generally higher in heavy black cracking clays, than in lighter sandy clay soils (Lonsdale et al 1988). The longevity of plants varies on different soil types, the half-life of plants on black cracking clays being somewhat greater than for plants growing on the lighter soil. This may be because of the greater moisture holding capacity of the heavier soil (Lonsdale 1992). Seed longevity, in contrast, was found to be greater in the lighter soil (Lonsdale et al 1988).

4.3.3 Inundation

Mimosa is very tolerant of seasonal inundation due to its ability to produce adventitious roots. Glasshouse experiments suggest that permanent inundation would prevent seedling recruitment (Shibayama et al 1983). However, if a permanently inundated area were to experience several below average wet seasons or unusually prolonged dry seasons, seedlings could grow to maturity and colonise the area to some extent. In northern Australia, seedling densities have been found to vary greatly throughout the year, many being drowned by the floodwaters of the wet season (Lonsdale 1992, Lonsdale & Abrecht 1989).

Several consecutive above average wet seasons can inhibit the germination of mimosa seeds to some extent. Whilst they need moist soil to germinate, excessive waterlogging reduces the rate of seed germination possibly by rotting of the seeds or via oxygen deprivation. This phenomenon has been observed in the Northern Territory in regions of the Arafura Swamp and on the Phelp River floodplain (M Ashley pers comm 2001).

Reduced periods of inundation caused by prolonged seasonal drought can result in very high seedling mortality (Lonsdale & Abrecht 1989). In support of this, Cook et al (1996) found that of all the wetland habitats in Kakadu National Park, the open plains, which have a relatively short period of inundation, had the lowest density of mimosa outbreaks. High densities of outbreaks were found in the billabong/channel and backswamp habitats, both of which are inundated for a relatively long period of time compared with the open plains. Ground disturbance and plant competition can affect the success of mimosa despite the period of inundation (Cook et al 1996).

Artificially induced hydroperiod from structures such as dams and rice fields for example can facilitate the spread of mimosa. Examples of this come from the Kafue Flats of Zambia in southern Africa where mimosa was recorded from river levees as early as the late 1960s, but was scarce. Since 1983 it has colonised extensive areas in one of the national parks on the Kafue Flats. In the 1970s, flooding on the flats was regulated by hydro-electric dams and the main mimosa infestation that was formerly on the mid-level floodplain, is now on the edge of a permanent lagoon (Bob Douthwaite pers comm 2002, Musonda Mumba pers comm 2002). Also, in Tram Chim National Park in the Mekong Delta region of Vietnam, mimosa has been doubling every year to reach 1900 hectares in 2002. The cause of the initial expansion was thought to be the regulation of the water depth associated with rice cultivation (Triet et al 2004). The new germination of mimosa at Peter Faust Dam in Queensland was the result of receeding water levels within the catchment due to extended dry periods (Chopping 2004). It is likely that the mimosa seed bank had been present for some time and only germinated when conditions were favourable.

4.3.4 Salinity

The precise relationship between the distribution of mimosa and salinity levels remains to be determined. Salinity near infestations on the lower Adelaide River can reach 18 000 ppm (~ 50% salinity) late in the dry season (Miller 1983). In 1968 it was thought that the Marrakai crossing would mark the lower limit of the spread of mimosa on the Adelaide River system, as the crossing represents the limit of tidal influences on the river. Its subsequent invasion downstream to the floodplains has disproved this theory. This is because the water does not become saline until the mid dry season so seed washed down and deposited on the banks during the wet can flourish in the early dry season. After this period, little moisture is required to maintain mature plants (Miller et al 1981). Plants growing in saline areas appear to be stunted but this may be due to continual waterlogging.

4.3.5 Topography

Mimosa is usually found at altitudes of less than 500 m. However, isolated plants have been recorded at an altitude of 1670 m in Thailand and at 2000 m in Mexico (Miller 1988). In Australia mimosa has the ability to grow in ‘upland’ habitats, evidenced by its growth in quarries and on roadsides in the Northern Territory (Interim Mimosa Planning Group 1999), although these occurrences are not very far above sea level.

4.3.6 Fire

Mimosa habitats are often subject to fire. Green mimosa does not burn readily and fires generally stop just inside dense infestations unless carried by strong winds. This is due to a lack of understorey vegetation in dense thickets, and in some cases the infested areas remain wet during the dry season. Fire will pass through scattered infestations where understorey fuel is present (Miller & Lonsdale 1992). When infestations are burnt, the impact on mature plants can vary with the season and weather conditions. In one study, only a small proportion of mature plants were killed and more than half of the seedlings regrew after fire (Miller 1988). Mimosa has adaptive traits that stimulate regrowth from the stem base after fire (Miller & Lonsdale 1992).

4.4 Potential distribution in northern Australia

Mimosa has the potential to expand its area considerably in Australia. According to Miller (1983), if not controlled it may spread south west into the northern regions of Western Australia as far as Broome, south east into Queensland, to Cape York and southwards down the east coast to the Tropic of Capricorn, and possibly as far as northern New South Wales. This range of expansion would assume that the plant or its seeds are dispersed to new suitable habitat either by humans or animals, as there is no continuity of suitable habitat within this range. Therefore, the plant must move between river systems in quantum leaps, perhaps on vehicles, boats or animals (Lonsdale 1993a) (as described in section 4.2).

An indication of the potential spread of mimosa into the subtropics comes from its North American range, where it occurs in Florida as far north as Gainesville (latitude 29°), but as might be expected near the range margin, it is not as tall or aggressive as it is elsewhere in its introduced range. This is perhaps because the climate in the region, though warm enough to allow it to persist, has cool winters with freezing temperatures on average once in every four years (Lonsdale et al 1995).

Miller (1983) made the conservative prediction that except around dams and watercourses mimosa would probably not be a major problem in regions with less than 750 mm annual rainfall. Because of plant competition, mimosa is also thought unlikely to succeed in tropical rainforest areas where rainfall exceeds 2250 mm (Miller 1983), although major disturbance such as clear-felling where the forest canopy is thinned or removed would probably allow the establishment of the weed (Lonsdale 1992). Based on these estimated lower and upper rainfall limits, and a southern latitudinal limit equivalent to the northern-most documented location of mimosa in the northern hemisphere (ie 29°N), a prediction of potential mimosa distribution in northern Australia is shown in figure 5.

There have been two previous attempts at predicting the potential distribution of mimosa in Australia. Lonsdale (1992) used CLIMEX (Sutherst & Maywald 1985), to generate a climate response model for mimosa based on its known distribution in Africa, where the distribution of the plant was recorded in reasonable detail. The CLIMEX model correctly predicted the climatic suitability of Acapulco, Mexico, in the native range. The model also correctly predicted the current distribution in Asia and Australia. Comparison of the current and potential ranges showed that the weed has only just begun to colonise suitable habitats throughout the tropics. The global projections rested on the assumption that climate is the only limitation to the weed's introduced range, which is perhaps the correct scenario as mimosa has few or no natural enemies and little interspecific competition within its introduced range (Lonsdale 1992).

Lonsdale's map showed that in Australia, the predicted range for mimosa extends from Broome in Western Australia across to just south of Mackay in Queensland. The areas of highest suitability were the central and eastern coastal areas of the Top End of the Northern Territory and the tip of Cape York Peninsula. Suitability gradually decreased inland and stopped at approximately the margin of the 750 mm rainfall zone.

This information was further refined by Kriticos (in ARMCANZ 2001) by incorporating the climate information with growth and stress indices. This prediction initially used four suitability classes; unsuitable, marginal, suitable and highly suitable. For the purpose of this assessment, the latter two classes were combined, as the original areas of high suitability did not correspond to mimosa's current distribution where habitat suitability is known to be high. The indices were determined by adjusting the parameter values so that the predicted distribution matches the known distribution in all countries for which there is available information except the target region, in this case Australia (Kriticos & Randall 2001). Where available, data on growth and environmental requirements were also used (table 4). Because Australia was the target area for prediction, the Australian distribution of mimosa was not used in developing the model, as this would lead to a cyclic prediction, ie predicting what is already known. Each of the growth parameters is calculated on a weekly basis and, when multiplied together, form a single growth index. If either temperature or soil moisture are sub-optimal, the index for that week is reduced. In a similar manner the stresses are accumulated on a weekly basis. When the growth and stresses are balanced against each other on an annual basis, the result is an ecoclimatic index for mimosa which is, in essence, an indication of habitat suitability through time. The current boundaries for the habitat suitability classes are somewhat arbitrary. The values used to determine the boundaries were based on experience associated with the more subjective descriptions of habitat suitability. Figure 6 shows the predicted distribution of mimosa in northern Australia based on the CLIMEX parameters in table 4.

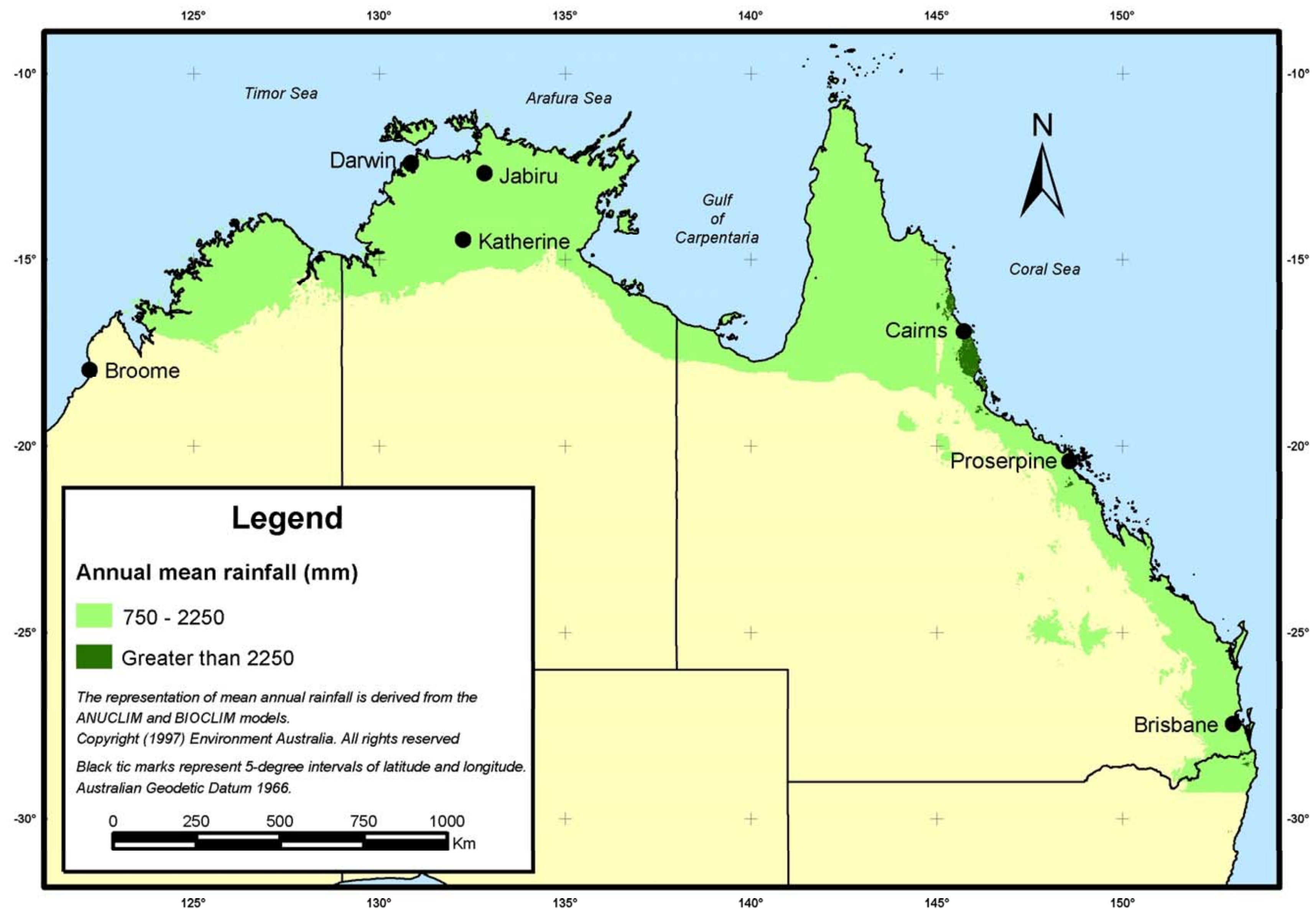

Figure 5 Potential distribution of mimosa in northern Australia – predicted by an annual rainfall between 750 and 2250 mm and a southern limit of 29°S (shown above)

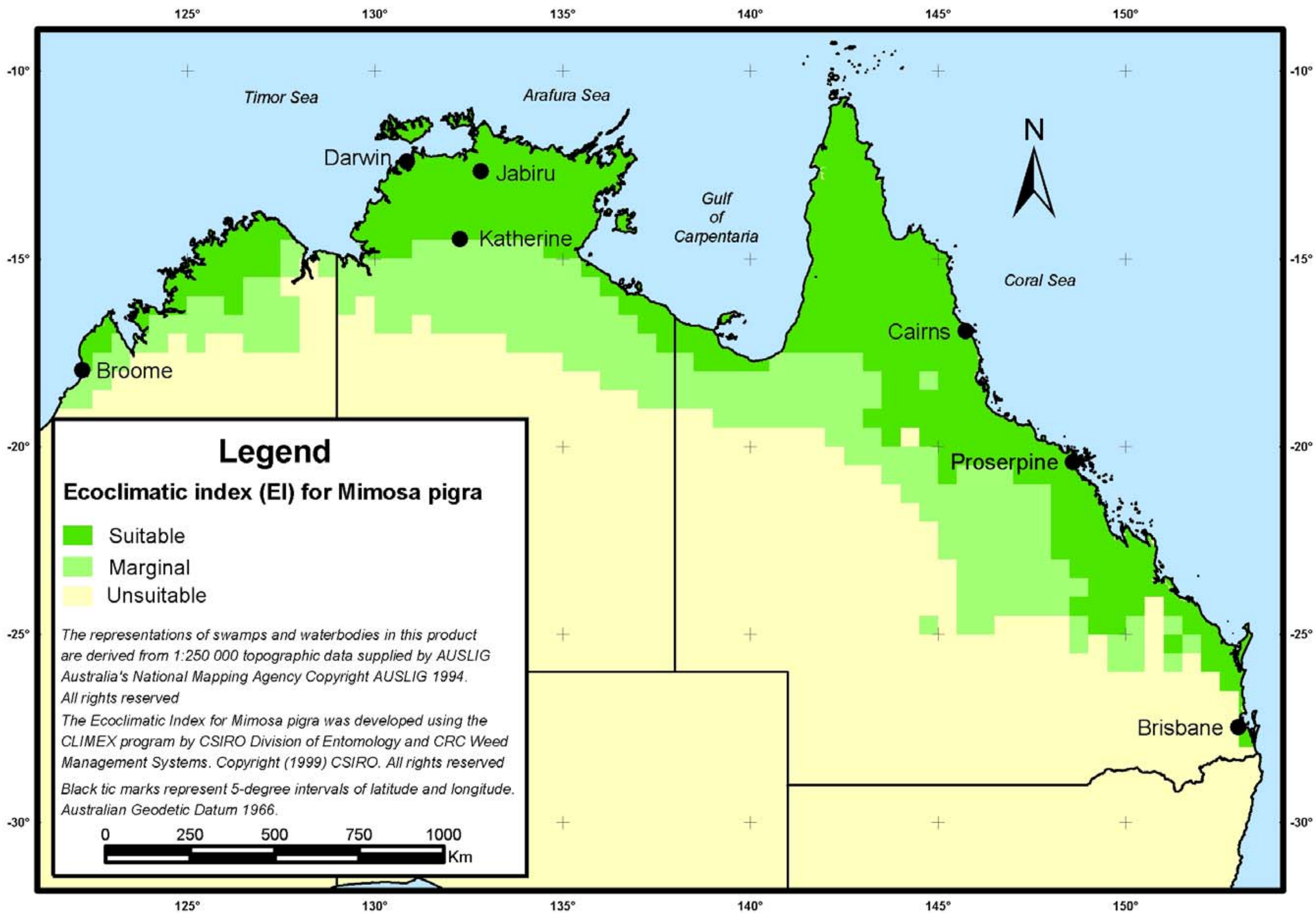

Figure 6 Potential distribution of mimosa in northern Australia using CLIMEX (see this section for details)

Table 4 Parameter values used for CLIMEX to predict the potential range of mimosa in Australia

Parameter	Description	Value
Growth		
Temperature index	DV values adjusted to provide adequate growth within the native range. PDD was not used because the pods require little time for development*	
DV0	Lower limiting temperature – no population growth takes place at or below this average weekly temperature	15.0
DV1	Lower optimal temperature – the lower limit of the range of ideal temperatures for population growth. Population growth rate is reduced if the average weekly minimum temperature is below this value	26.0
DV2	Upper optimal temperature – the upper limit of the range of ideal temperatures for population growth. Population growth rate is reduced if the average weekly maximum temperature is below this value	33.0
DV3	Limiting high temperature – no population growth takes place when the average weekly minimum temperature equals or exceeds this value	36.0
PDD	Minimum degree-days above DV0 necessary to complete a generation – not used	0.0
Moisture index	SM0 set to approximate permanent wilting point (PWP). Other soil moisture (SM) parameters set to accord with growth and rainfall data**	
SM0	Limiting low moisture – no population growth takes place at or below this average weekly soil moisture	0.15
SM1	Lower optimal moisture – the lower limit of the range of ideal soil moisture for population growth. Population growth rate is reduced if the average weekly soil moisture is below this value	0.6
SM2	Upper optimal moisture – the upper limit of the range of ideal soil moisture for population growth. Population growth rate is reduced if the average weekly soil moisture is above this value	1.9
SM3	Limiting high moisture – no population growth takes place at or above this average weekly soil moisture	2.1
Stress		
Cold stress	Threshold set to account for lethal effects of significant frost. A degree-day model was used to account for sub-lethal heat requirements	
TTCS	Cold stress temperature threshold – the average weekly minimum temperature below which cold stress accumulates	2.5
THCS	Cold stress temperature rate – the rate at which cold stress accumulates once temperatures drop below the threshold value of TTCS	0.2
DTCS	Cold stress degree-day threshold – cold stress begins to accumulate when this threshold number of degree-days above DV0 is not achieved	15.0
DHCS	Cold stress degree-day rate – the rate at which cold stress accumulates once the threshold number of degree-days above DV0 is not achieved	0.006
Heat stress	Values taken from wet tropical climate	
TTHS	Heat stress temperature threshold – the average weekly maximum temperature above which heat stress accumulates	36.0
THHS	Heat stress temperature rate – the rate at which heat stress accumulates once temperatures exceed the threshold value of TTHS	0.001
DTHS	Heat stress threshold – heat stress begins to accumulate when this threshold number of degree-days above DV3 is exceeded	0.0
DHHS	Heat stress degree-day rate – the rate at which heat stress accumulates once the threshold number of degree-days above DV3 is not achieved	0.0
Dry Stress	Threshold at Permanent Wilting Point (PWP)	
SMDS	Dry stress threshold – dry stress is accumulated when the average weekly soil moisture level drops below this value	0.15
HDS	Dry stress rate – the rate at which dry stress accumulates once the soil moisture drops below the dry stress threshold of SMDS	0.006
Wet Stress	Threshold set to SM3, to start accumulating stress if water-logging is excessive	
SMWS	Wet stress threshold – wet stress is accumulated when the average weekly soil moisture levels exceed this value	2.1
HWS	Wet stress rate – the rate at which wet stress accumulates once the soil moisture exceeds the wet stress threshold of SMWS	0.002

* Wanichanantakul & Chinawong 1979, cited in Lonsdale 1992; ** Data from Miller 1988, in Lonsdale 1992, figure 12

Comparison of the predicted distribution based on the rainfall zone and southern latitudinal limit (figure 5) and the 'suitable' category of the predicted distribution based on the CLIMEX model (figure 6) indicated reasonable concordance. This is not unexpected as the soil moisture indices, for example, would correlate with the higher rainfall. If rainfall is used as the only indicator, mimosa would have the potential to establish right down the eastern seaboard, into much of Victoria and into Tasmania. The CLIMEX ecoclimatic index eliminates this scenario as these areas experience minimum temperatures and frosts that are unsuitable for the growth of mimosa. Thus the southern limit of the Australian range predicted by CLIMEX only extends down to about 28°S, similar to the northern limit in the northern hemisphere.

4.4.1 Greenhouse effect implications

There is substantial uncertainty and variation in predictions of future climate trends for Australia. This is largely due to disagreement between the two types of global circulation models used (ie slab-ocean and coupled ocean), and uncertainty in both the climate system response to enhanced greenhouse gases and the actual level of future emissions (Suppiah et al 1998, IPCC 2001, CSIRO 2001a, Hughes 2003). The latest projections (CSIRO 2001a) suggest that by 2030, annual average temperatures over most of Australia will be 0.4–2.0°C higher relative to 1990. By 2070 annual average temperatures are expected to be 1.0–6.0°C higher. The projections for rainfall vary much more, both spatially and seasonally. The CSIRO (2001a) scenarios indicate that rainfall in tropical north Australia will vary by –5 to +5% by 2030 and –10 to +10% by 2070, representing little change from current conditions. At the regional scale (within Australia), significant reliable projections of the direction of change in precipitation in response to climate change are still not possible.[4]

Another important aspect of climate change will be the shift in the frequency and intensity of extreme temperature, ie a decrease in the frequency of low temperatures and an increase in the frequency of high temperatures (Suppiah et al 1998). Overall, the scenarios emphasise a more variable and unpredictable climate in Australia, with increased incidence of extreme events such as fires, floods, droughts and tropical storms (IPCC 2001, CSIRO 2003). Projected changes in mean global sea level rise range from 5–29 cm by the year 2050, and 9–88 cm by the year 2100 (IPCC 2001).

Notwithstanding the uncertainties, it would be possible to undertake a sensitivity analysis of the potential distribution of pest species such as mimosa in order to gauge the likely direction and extent of the change in potential range as a function of increasing temperatures, increasing water use efficiency and changes in rainfall (Kriticos 2001, Kriticos et al 2003). It is anticipated that this issue be addressed in future work using CLIMEX. Outcomes of such predictive modelling can be refined based on revised climate change scenarios, and would have value for decision making purposes.

In the meantime, some effects of climate change on mimosa in Australia can be hypothesised. Major changes in vegetation composition will come through shifts in rainfall pattern and increased runoff distribution. In conjunction with the 'CO_2 fertilisation effect' resulting from elevated CO_2 levels, a number of authors have stated that this will most likely favour the establishment of woody vegetation and encroachment of woody shrubs in many areas (IPCC 1998, IPCC 2001, Hughes 2003, and selected references below). The direct CO_2 fertilisation effect may lead to increased growth, particularly during periods of reduced soil moisture (Campbell et al 1996). A marked increase in woody biomass at the landscape scale has been

[4] Climate modelling in the Jabiluka region of Kakadu National Park in the Northern Territory, projected an average change (wet season) of –6 to +4% by the year 2030 (Jones et al 1999), which is similar to the projection for tropical Northern Australia.

reported for a wide variety of arid and semi-arid environments, as well as tropical eucalypt savannas (Bowman et al 2001) and open woodlands (Archer et al 1995, Henry et al 2002). This phenomenon, known as 'vegetation thickening', has generally been viewed as an example of vegetation recovery and succession following disturbance events including drought, fire and clearing (Gifford & Howden 2001). Although not the primary cause, atmospheric change may also be involved (Archer et al 1995). Where vegetation thickening has occurred in grazed rangelands it is known as the 'woody weed problem'. Berry and Roderick (2002) described landscapes in terms of the abundance of three different functional types of leaves. Using continental scale maps of past and present vegetation, they estimated the change in proportion of the three leaf types that has occurred as a result of increased CO_2, as opposed to land-use change. They concluded that increasing CO_2 would have exacerbated the woody weed problem. Whilst the above information is not specific to mimosa or its preferred habitat, there may be many circumstances where these factors could enhance the invasiveness of mimosa.

If rainfall zones shift due to climate change there may be no suitable habitat within the new areas of suitable rainfall, due to land-use changes having altered vegetation, or due to the lack of suitable soils. Ecosystems will not migrate *en masse* due to changes in temperature, rainfall and radiation/cloudiness, but will shift differentially (Mitchell & Williams 1996). Some species may be slow to migrate because of factors such as limited seed dispersal mechanisms (IPCC 1996) and species with better capacity for dispersal, including weeds, will have an advantage (IPCC 1998). The increased incidence of the extreme events mentioned earlier is likely to increase the disturbance of natural systems and render them more vulnerable to invasion by exotic species by increasing the stress on established vegetation (CSIRO 2001b).

It is difficult to say for certain that the issues outlined here will have an influence on the distribution of mimosa, as the weed is primarily an inhabitant of seasonally inundated, near-coastal landscapes. It has been hypothesised that climate induced sea-level rises may inundate and destroy some existing mimosa infestations in low-lying coastal floodplain areas (Dames & Moore International 1990). However, given the majority of evidence in the literature, it would appear that the effects of climate change will generally favour competitively superior species like mimosa. More frequent and intense flooding and an increased incidence of tropical cyclones as predicted from climate change scenarios would most likely enhance its spread. Large expansions of mimosa in the introduced range may depend on the occurrence of uncommon rainfall patterns to spread the seeds widely (Lonsdale et al 1985) and promote seedling establishment (Lonsdale & Abrecht 1989). The extreme wet seasons and subsequent extensive flooding in the 1970s when the mimosa population exploded in the Northern Territory is thought to be linked to multi-decadal climate variability (Sutherst 1995). Although this is not considered a direct greenhouse influenced effect, it is an example of climate-related feedbacks producing a non-linear impact with damaging consequences (Suppiah et al 1998). In support of the above, Williams et al (1995) stated that mimosa is expected to have its range extended by climate change, although the extent to which this will occur is unclear.

5 Identification of the risks

This section attempts to determine the extent of natural wetland areas across northern Australia that may be at risk of mimosa infestation, and to draw some preliminary conclusions regarding the major consequences and likelihood of invasion.

5.1 Wetlands at risk of mimosa infestation

Based on knowledge of the habitats that mimosa currently infests in the Northern Territory and areas infested in the introduced range overseas (see section 4), mimosa appears to favour seasonally or periodically inundated freshwater wetland habitats. Given the broad scale of this assessment (ie across northern Australia), information from 1:250 000 digital topographical data (Topo250K data – AUSLIG 1999) was used to identify relevant wetland areas. While information on wetland distribution is available for northern Australia from a variety of sources (Lowry & Finlayson 2004), the Topo250K dataset was the only one that was both consistently available across the whole of northern Australia at a standard useful scale and did not exclude wetland environments on the basis of their ecological significance. Thus, the wetland habitats represented in the Topo250K data by the classifications '*Land subject to inundation*' and '*Swamp land*' were considered as representing suitable mimosa habitat. This was supported by the fact that the majority of documented locations of mimosa in the Northern Territory occur on the above two wetland habitats (see figure 4).

Using the ArcView™ desktop Geographic Information System (GIS), the polygon features representing these wetland types were extracted from the Topo250K dataset. These features were then overlaid on the potential distribution of mimosa in northern Australia based on (i) the >750 mm rainfall zones and southern latitudinal limit of 29°S (figure 7), and (ii) the CLIMEX model (figure 8). These represent the wetlands in northern Australia that may be at risk of infestation by mimosa. The area estimates are detailed in table 5. The rainfall (and latitudinal) model of potential mimosa distribution provided a slightly more conservative estimate of the wetland area potentially at risk of mimosa infestation than the 'suitable' category of the CLIMEX model, although the total wetland area using CLIMEX (ie wetland in 'suitable' + 'marginal' areas) was greater. However, further work is required to better define the largely arbitrary suitability categories used with the CLIMEX model.

Overall, it appears that approximately 4.2–4.6 million ha of natural wetland habitat in northern Australia is potentially at risk of infestation by mimosa. However, it is acknowledged that actual habitat suitability will vary amongst these wetlands, and there will be areas that are more or less suitable for mimosa due to a range of factors including hydroperiod, soil type, salinity, local topography, plant communities and land use.

Table 5 Estimates of wetlands potentially at risk of mimosa infestation using two predictive models of mimosa distribution

Potential distribution model	Category	Wetland area (ha)*	Total (ha)
> 750 mm rainfall + southern latitudinal limit of 29°S	750 – 2250 mm	4 216 855	4 231 154
	>2250 mm	14 299	
CLIMEX	Suitable	3 959 800	4 628 000
	Marginal	668 200	

* wetlands are represented by 'land subject to inundation' and 'swamp land' from 1:250K topographical maps (AUSLIG 1999)

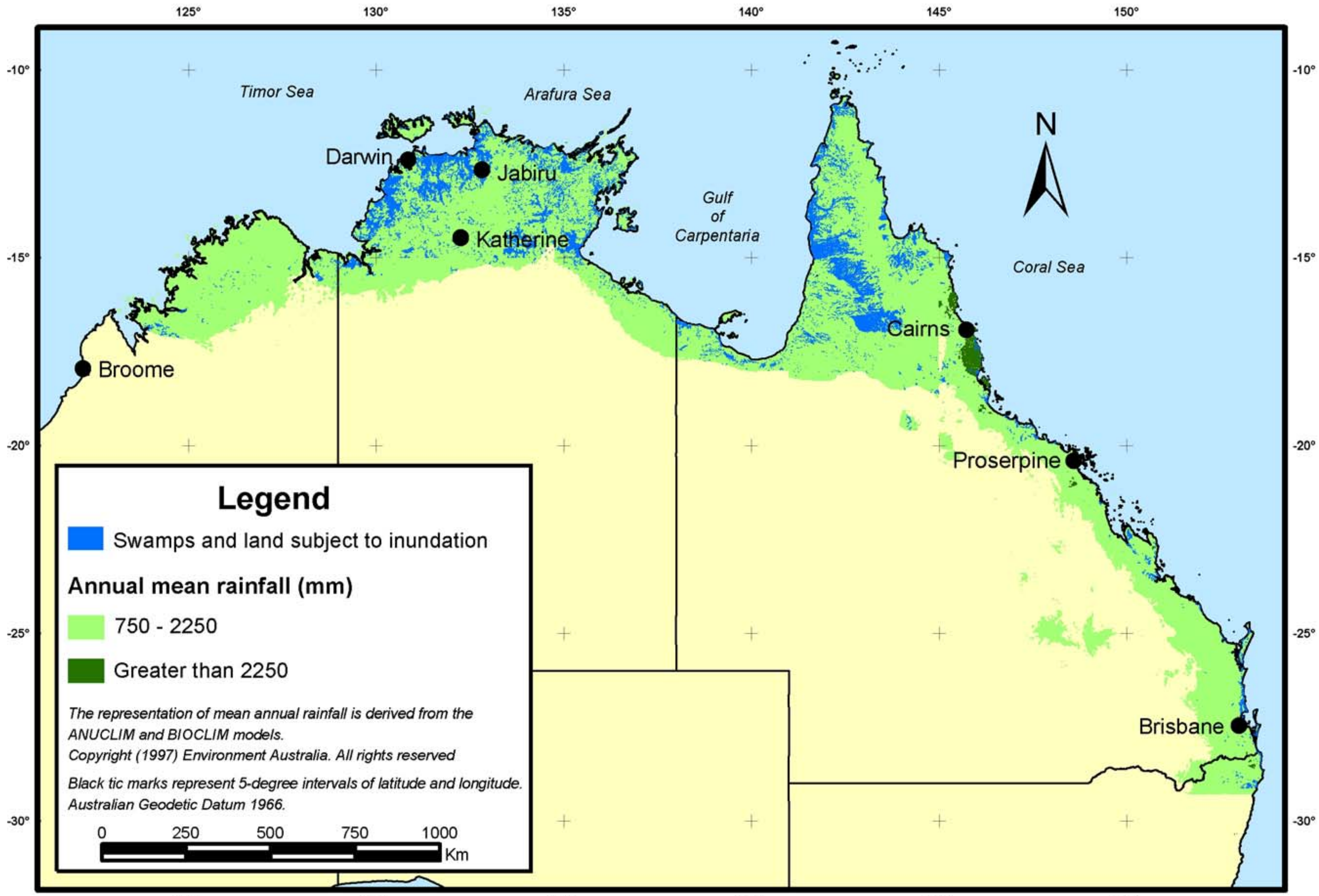

Figure 7 Wetlands across northern Australia potentially at risk of mimosa infestation, based on 1:250K topographical wetland data ('land subject to inundation' & 'swamp land') and potential distribution using mean annual rainfall >750 mm and a southern latitudinal limit of 29°S)

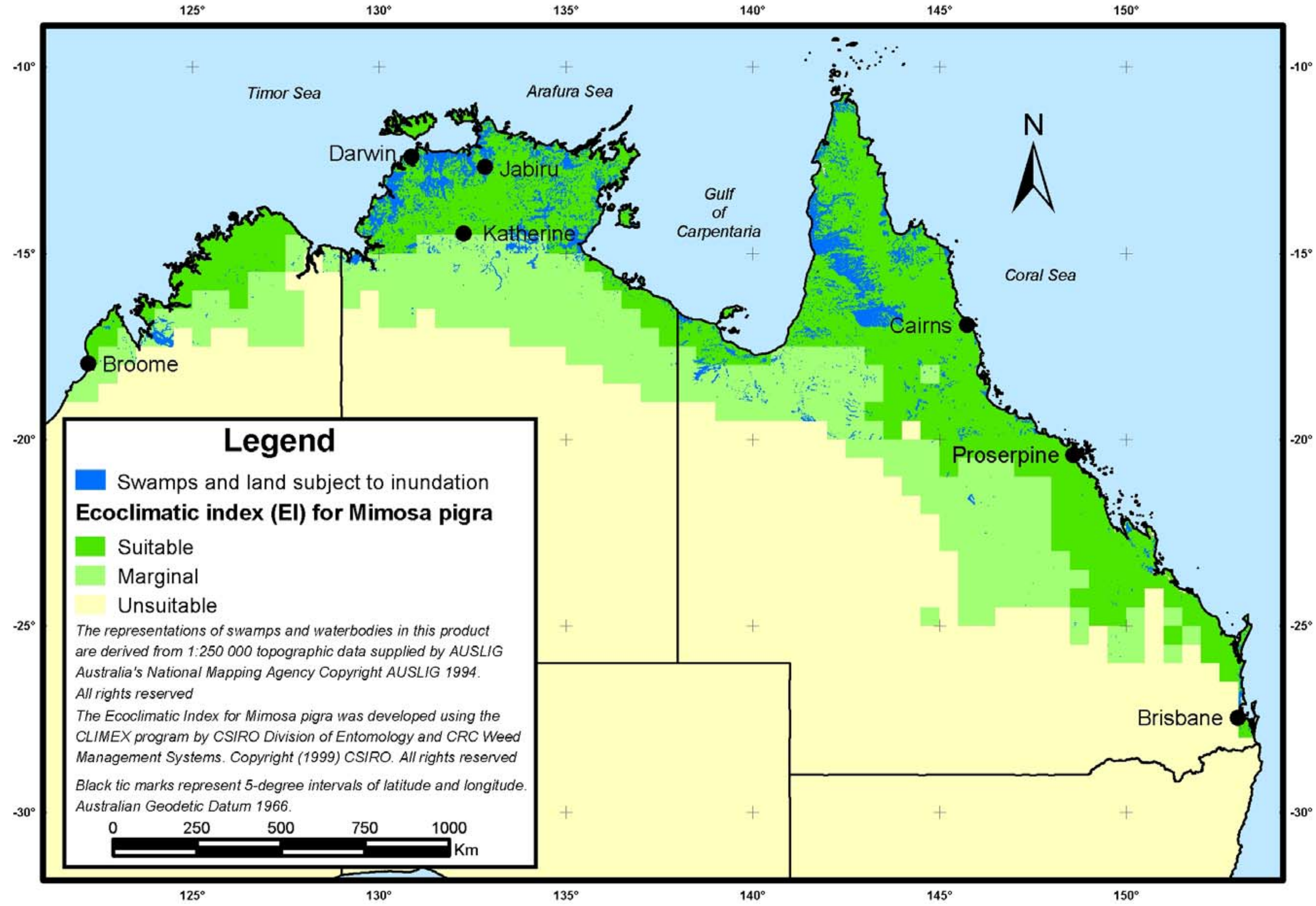

Figure 8 Wetlands across northern Australia potentially at risk of mimosa infestation, based on 1:250K topographical wetland data ('land subject to inundation' & 'swamp land') and potential distribution using CLIMEX (see section 4.4 for details)

5.2 Nationally and internationally important wetlands

Among the wetlands identified as potentially at risk, there exist a number that are of particular ecological importance.

5.2.1 Northern Territory

Environment Australia (2001) list 33 nationally important wetlands in the Northern Territory.[5] Within the northern most bioregions, where mimosa is present and still spreading (ie above 16°S), there are 21 wetlands of national and international importance of which 12 already have mimosa infestations varying from minor to extensive. Although the total area of the 21 wetlands is 3 227 490 ha, this does not reflect the actual area of swampland and land subject to inundation.

Three of 33 sites are listed as internationally important (Ramsar) wetlands, including Kakadu National Park stages I and II and parts of stage III. The combined area of these sites is 1 375 940 ha. Again, this area does not reflect the actual area of swampland and land subject to inundation in Kakadu National Park which is estimated to be 242 900 ha (Lowry & Finlayson 2004). The third Ramsar site is the Coburg peninsular system which covers 220 700 ha.

5.2.2 Queensland

In Queensland there are 165 nationally important wetlands of which 119 lie north of the tropic of Capricorn. The largest areas of wetlands are in the Cape York Peninsula and Gulf Plains bioregions, with 38 nationally important listed wetlands covering some 4.7 million ha (Blackman et al 2000). The new mimosa infestation at Peter Faust Dam lies within the Central Mackay Coast bioregion and is not within a nationally important wetland.

Queensland has 5 Ramsar listed sites. Four of these are listed as coastal bays, however, they do have some freshwater habitat and all lie within the potential range of mimosa. The fifth site is inland and far beyond the predicted range.

5.2.3 Western Australia

Of the 120 nationally important wetlands in Western Australia, 13 fall within the predicted range of mimosa in the Kimberley and west to Broome. Five of these are Ramsar listed sites. One of these sites (Roebuck Bay near Broome) is primarily a marine site noted for its extensive intertidal mudflats that support an abundance of migratory wader bird species. The remaining 4 sites are the Ord Estuary System, Parry Floodplain and Lakes Argyle and Kununurra covering a total area of 355 700 ha.

5.3 Geographical (proximity) implications

Wetlands that are currently mimosa free but close to infested areas are obviously more ‘exposed’ to invasion than remote wetlands. The Northern Territory mimosa population was originally restricted to the Adelaide River catchment, the seeds being locally dispersed by water, wind and animals. Within a relatively short period, nearby river systems were soon contaminated, probably via seed transport by vehicles, boats, possibly waterbirds and removal of substrate.

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[5] It is acknowledged that the knowledge of the flora and fauna within these environments is patchy, and understanding of their ecological functioniong often little better than rudimentary (Storrs & Finlayson 1997). Other states and Territories have similar data deficiencies to varying degrees (Spiers & Finlayson 1999).

Peter Faust Dam in Queensland is about 1600 km in a direct line from the nearest mimosa plant in the Northern Territory (see all figures) and is considerably further by road. This proximity would normally have the dam ranked at a very low risk of infestation, relative to other wetlands closer to the Top End. The outbreak at the dam is evidence that geographical distance ultimately presents no barrier to mimosa. If recreational fishermen were responsible for the seed transport, this emphasises the influence of transport pathways and land use on weed invasion (see next section). This could have occurred just as easily on any Queensland or Western Australian nationally important wetland, provided they are accessed by anglers.

Kakadu National Park has been described as 'an island in a sea of mimosa' (Storrs 1998), and is a good example of a high-risk area. It has a high volume of tourists including anglers, a highly mobile local population, multiple land use, world heritage value and large mimosa infestations to the west at Mary River, and until recently, the east at Gunbalanya. The mimosa threat to Kakadu (Cowie & Werner 1987, Miller & Schultz 1993, Storrs et al 1999) was largely the reason that the Gunbalanya infestation was given high priority for control, with ~$7 million dollars over five years of Commonwealth funds being committed to the removal of approximately 8000 hectares of mimosa. This large-scale reduction has no doubt greatly reduced the immediate risk to Kakadu National Park. The Daly River was seen as the next priority to prevent further westward spread (Dames & Moore International 1990). Kakadu remains free from serious infestation by the systematic survey and destruction of new outbreaks. This now involves four full-time staff and an annual budget of over $400 000 (Storrs et al 1999).

5.4 Land-use implications

Land use may often be the single most important factor that influences:

- the likelihood of mimosa actually arriving at a location;
- the extent that mimosa may establish and flourish;
- how the consequences of the threat and impacts of mimosa are perceived; and
- the control methods adopted.

There are many categories that cover the various land uses in Northern Australia. For the purposes of this risk assessment three broad types of land use are identified:

- Cultural – Aboriginal lands and culturally or historically significant areas;
- Ecological – heritage, national park and other conservation areas;
- Economic – pastoral/agricultural lands and areas of concentrated tourism.

Wetlands usually have multiple land uses, thus there will often be considerable overlap between the above categories. Aboriginal lands are often used for economic purposes including pastoralism, sustainable harvesting and eco-tourism. Many ecological areas gain revenue from tourism, whilst some, even nationally important wetlands, often have a pastoral component. Sites of cultural significance are sometimes an integral part of ecological areas, with Kakadu National Park being a prime example. This multiple use makes it difficult to compartmentalise different land uses with respect to weed invasion risks, although some generalisations can usually be made. There are also different degrees of protection assigned to wetlands. For example, some national park wetlands or other highly sensitive areas may have no public access, whilst others may have restricted or unrestricted access. Aboriginal lands often have restricted access for the general public.

Although mimosa has broad ranging impacts, the actual consequences of these are perceived by land custodians in different ways according to the land use of a specific area. Table 6 shows a brief summary of these perceived (negative) consequences based on those identified in the conceptual model of impacts in section 2.3. (see also section 3 for more detailed description of these effects).

Table 6 Perceived consequences of the impacts of mimosa for different land use

Land use	Consequences
Cultural	reduction of species and numbers available as traditional foods
	restriction of access to traditional hunting and gathering grounds
	contamination of sacred, historical and other culturally important sites
	reduced capacity for economic independence of Aboriginal people
	reduced status as a nationally important or Ramsar wetland
Ecological	reduction in biodiversity of flora and fauna
	loss of habitat for feeding, breeding and roosting of birds and bats
	restriction of access to watering holes for native animals
	provides protective habit for feral pigs
Economic	reduces available grazing and farming land
	restriction of access to watering holes for stock
	interferes with irrigation projects eg access and siltation
	restricts recreational use of waterways eg fishing and tourism

5.4.1 Mechanisms of seed transport

The primary vectors and other aspects of mimosa seed distribution have been outlined in sections 2.1.3 and 4.2.

History has shown that pastoral leases have a relatively high incidence and coverage of mimosa (and other weed) infestation. The risk of infestation is increased by the movement of livestock, vehicles and machinery within and between pastoral leases. Pastoral properties often employ trucks and machinery for activities such as dam and road construction, erosion control, animal transport, fencing and slashing. Where earthworks or similar large-scale soil movements are concerned, the extended dormancy of mimosa seeds could see plants emerge many months or even years after their arrival if they were to be deeply buried and subsequently exposed by erosion or animal activity. In Northern Australia, such properties are usually tens of thousands of hectares in size, incorporate many wetlands, and sometimes span more than one river system.

Any lands that have vehicular access are ultimately at risk from seed importation. Both the Aboriginal and non-Aboriginal populations of northern Australia are highly mobile, and vehicles (in particular four-wheel drives) regularly traverse within and between river systems. Indeed for Aboriginal people, travelling around floodplains by vehicle is a fundamental part of life. It is highly likely that a mimosa incursion discovered in June 2001 on Croker Island was the result of seed washed from a vehicle. The incursion was 100 m downstream from a roadway that crosses the largest floodplain on the island (M Ashley pers comm 2001). Lonsdale and Lane (1990) found that although vehicles were carrying weed seeds into Kakadu National Park, grasses were the most likely species to be carried by vehicles. Nearly half of the 304 vehicles sampled carried no seeds, and the majority of those that were carrying seeds, had less than three.

Combined with the high probability that seeds entering the Park on a car will also leave it in the same way, and that most germinating seeds would generally not survive to maturity, they concluded that vehicle screening measures were not necessary and that resources be best utilised towards public information and awareness, survey and control of existing infestations. They also recommended the monitoring of sand and earth brought into the region, and further investigations into the seed carrying capacity of construction vehicles, animals and those tourists that by-pass the more accessible camping grounds to venture into more remote areas (Lonsdale & Lane 1990).

Wetlands that support recreational and commercial fishing (or indeed any other boat access) are also at high risk. Seeds may be lodged in mud adhering to boats and trailers and also accumulate in the bottom of boats that brush up against mimosa overhanging the riverbanks. These seeds could stay jammed in crevices in the boat for extended periods and possibly become dislodged and washed out when the boat is drained near a slipway or even directly into the water, possibly a great distance and many catchments from the original seed source.

There is increasing evidence that waterbirds may be responsible for the distribution of mimosa seeds into remote areas (see section 4.2). If this is true, then all wetlands that support waterbird populations are at risk, and in particular, national parks and other ecological areas managed for their biodiversity where birds are not discouraged by hunting and other disturbances.

Wetlands of all the land-use categories are potentially at risk from incursions via deliberate introduction by humans. The weed has been moved to new areas as humans value the novelty of the touch sensitive leaves. Whilst people are more likely to plant mimosa in a garden environment rather than a floodplain, the risk of seed finding its way into a drain or waterway and eventually downstream to suitable habitat remains. Mimosa has also been actively planted in Thailand and other Asian countries to prevent erosion along irrigation channels, as a green manure and cover crop and for firewood (Napometh 1983, Thamasara 1985) (see section 3.5.4).

5.4.2 Factors affecting colonisation

The major factor that affects the colonisation of mimosa is the disturbance of natural habitat, usually associated with feral and domestic animal activity, fire, agriculture, logging and other clearing, high-use recreation, roadsides and quarries. The most well cited example of rapid colonisation following disturbance comes from the Adelaide River floodplain in the Northern Territory where trampling by feral buffalo destroyed the native vegetation, leaving a bare soil surface, enabling mimosa to readily establish and expand rapidly in the absence of competition. Throughout the Northern Territory, mimosa largely infests and continues to colonise areas that are currently, or have been in the past, highly disturbed by feral or domesticated animals. Queensland and northern Western Australia also have vast pastoral properties incorporating suitable mimosa habitat, and feral animals including buffalo, pigs, donkeys and horses remain in high numbers throughout much of northern Australia.

A good example of mimosa invasion into an agricultural environment comes from areas of South-east Asia where rice paddies and irrigation channels are severely infested and crop production is often greatly reduced (Robert 1982, Storrs et al 2001, Samouth 2004). At present there are no agricultural areas in Australia affected by mimosa, although such ventures are rapidly expanding in the Northern Territory and are extensive throughout much of the predicted mimosa range in Queensland. There is also concern for the considerable agricultural enterprises of the Ord River district of Western Australia (ARMCANZ 2001). Cultural and ecological lands could generally be considered at less risk provided they do not support pastoralism and/or agriculture.

Figure 9 shows the distribution of land use within the predicted range (CLIMEX and rainfall models combined) overlaid with the wetlands potentially at risk (refer to figures 7 & 8 for the boundaries of the rainfall zone and the suitable and marginal CLIMEX zones). Tables 7 and 8 show the areas of wetlands within the different land-tenure categories throughout the predicted range of mimosa, as defined by the rainfall and CLIMEX models respectively.

Table 7 Areas of land tenure (wetlands only) within the predicted range of mimosa based on rainfall

Land tenure	Area within lower rainfall zone (ha)	Area within higher rainfall zone (ha)	Total area (ha)	% of total area
Aboriginal	1 311 214	1 775	1 312 989	31
Forestry	16 143	96	16 239	0.38
Nature conservation	519 806	3 023	522 829	12
Private lands	2 196 863	8 270	2 205 133	52
Reserved Crown	28 022	166	28 188	0.67
Vacant Crown	51 673	426	52 099	1.2

Table 8 Areas of land tenure (wetlands only) within the predicted range of mimosa based on CLIMEX

Land tenure	CLIMEX – Suitable category (ha)	CLIMEX – Marginal category (ha)	Total area (ha)	% of total area
Aboriginal	1 316 176	10 476	1 326 652	29
Forestry	15 165	< 1	15 165	0.33
Nature conservation	511 808	7 735	519 543	11
Private lands	1 963 397	61 1501	2 574 898	56
Reserved Crown	18 175	21 615	39 790	0.86
Vacant Crown	49 744	5 915	55 659	1.2

The private land, Aboriginal and nature conservation land tenures account for approximately 95% of the wetlands within the entire predicted range of mimosa in northern Australia. Thus, the overall consequences of increasing mimosa spread are most likely to be those related to economic, cultural and ecological land uses respectively (see table 6).

6 Uncertainty and information gaps

6.1 Extent of mimosa

The 1:250 000 scale topographic map information used in this assessment represents a broad view of identifying the wetland habitats in question. For example, some mimosa infestations in the Daly River area in the Northern Territory did not initially appear to be near wetlands, however, an examination of 1:50 000 data showed that they were. While the availability of 1:50 000 data is steadily increasing, it is not presently available for all areas within the predicted range of mimosa. Thus the broader scale and classifications will probably fail to identify or discriminate between many of the smaller natural waterbodies, dams and other wetland habitats. Also, the need for detailed topographic and wetland habitat information to assist with the identification of potential mimosa habitats could possibly be used to support bids to complete the mapping required within the area of interest.

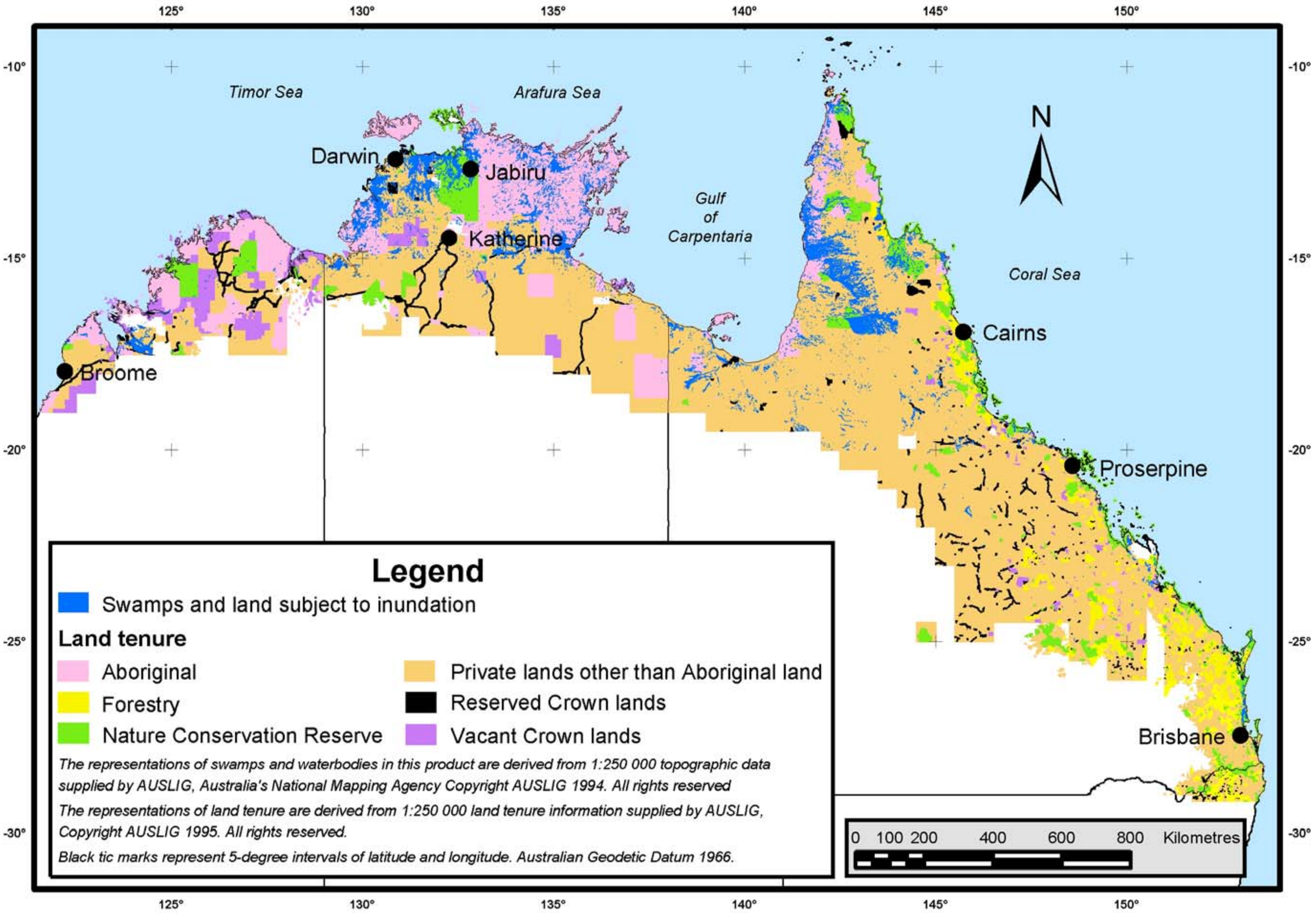

Figure 9 Land-use types within the predicted range of mimosa (CLIMEX and rainfall models combined) overlayed with swampland and land subject to inundation

There are also assumptions about which land-use practices promote invasion and/or establishment of mimosa, and to what extent. The issue of disturbance is probably the main issue, with natural versus non-natural disturbance further exacerbating the uncertainty. As mentioned in section 5.4, the overlap between the broad land-use categories may preclude links to a specific land use with the likelihood of mimosa invasion and spread.

The role of disturbances such as fire and animal grazing, following mimosa control, also warrants further investigation. Understanding the factors that affect the recolonisation process of native or pasture competition species is critical for long-term mimosa management (see section 3.2.1).

The current distribution of mimosa in the Northern Territory is uncertain and probably misquoted. The majority of infestations have been recorded but the size and density of many of them are either unknown or undocumented. The location and distribution of some infestations are based only on anecdotal field observations, are not mapped, and a significant proportion of the field records are dated. Although the detailed mapping of mimosa in the Northern Territory is a onerous task, considerable progress has been made. A number of studies have addressed the development of remote sensing techniques for classifying, detecting, and mapping mimosa in certain areas (eg Fitzpatrick 1989, Fitzpatrick et al 1990, Menges et al 1996, Lyons 1999, McIntyre 2001, McIntyre & Menges 2004). In addition to determining the current distribution, further research in this field would help monitor the effectiveness of control programs, facilitating operational planning, surveying areas at risk of infestation on a much broader scale, and developing a GIS database of known and new locations of infestations.

Whilst remote sensing can be a powerful tool there are still some problems associated with this technique, including:

- the comparatively high cost of acquiring imagery with a high spatial resolution which can detect mimosa, particularly isolated plants and small infestations;
- the comparatively low resolution (~30 metres) of the imagery which is most accessible (this limits the ability to detect individual plants / new outbreaks; only large established patches can be readily identified); and
- being able to accurately and repetitively isolate the signatures of mimosa under a range of temporal scales and conditions.

CLIMEX modelling has given us an insight into the potential range of mimosa in northern Australia. There are some aspects of the weeds physiology and ecology, including environmental preferences, that warrant further investigation. This information would be invaluable for the CLIMEX modelling with respect to better defining the present, somewhat arbitrary boundaries between the suitability classes of the predicted range (see section 4.4).

Detailed information on the characteristics of many wetlands in the predicted range of mimosa is not available. In many areas the characteristics have been summarised to varying degrees but are not detailed or quantified (see sections 2.2.4 & 2.2.5 for more detail and references). Some progress has been made in Queensland (Blackman et al 1995), but the inventory of northern Australian wetlands in general warrants further investigation. To further define the potential extent of mimosa and assess the invasive potential on a more local level, site-specific assessments investigating wetland characteristics including hydroperiod, soil types, salinity, local topography, plant communities, land use and disturbance are needed. Such assessments would provide valuable information to use as a predictive tool for land management and to be incorporated back into the CLIMEX model.

Another uncertainty is the precise relationship between climate change and the distribution of mimosa (see section 4.4.1). It is possible to hypothesise about the likely influence of climate change on mimosa distribution based on projected changes in temperature, rainfall, seasonal and interannual variation and extreme events, but the actual effects and extent of these remains unclear. It is also apparent from the information in section 4.4.1 that the degree and timing of onset of climate change is unpredictable and highly variable.

6.2 Effects of mimosa

Given that one of the major concerns of mimosa invasion is its effect on the native flora and fauna, there are surprisingly little quantitative data available. The aspects of severe habitat alteration are acknowledged but the resulting effect on flora and fauna seems to be poorly understood. There is also a need to better understand the impacts of mimosa control upon biodiversity values, and to what extent wetland biodiversity levels recover following mimosa control. In this context, further investigation is also needed for those threatened species whose habitat overlaps that of mimosa. Section 3.4 highlights probably just a few species that may be at risk. There are also species in the 'data deficient' category that could be worthy of a higher risk status and thus have their habitat protection viewed as a higher priority than at present.

Potential revenue loss arising from the impacts of mimosa on tourism, pastoralism and agriculture are also acknowledged, but again, there is very little quantitative data on these economic losses. Governments would be wise to compare the potential economic impacts with funding for spread prevention and control efforts. The impacts on social and cultural values are also recognised, but no studies have been done. The assumptions of land-use practices influencing the extent of mimosa also apply to the effects. Again, due to the overlaps in land use, it is difficult to be certain what the effects and consequences of the impact will be and how the tenants perceive them.

There have been some efforts to monitor and quantify the effects and risks of the herbicide tebuthiuron on native flora and fauna and its fate in the environment (Parry & Duff 1990, Cook 1992, 1993, 1994, Lane et al 1997, Camilleri et al 1998, van Dam et al in press). Large volumes of the herbicides fluroxypyr and metsulfuron methyl have also been used in the Northern Territory, with the latter being the most widely used for most current control programs. To date no studies on the effects of these on the local species have been conducted. Herbicide wetters and adjuvants have been shown to be toxic to aquatic environments and warrant further investigation (Ashley 2003).

7 Management implications

The predicted range of mimosa in northern Australia, based on rainfall requirements and climate modelling has been hypothesised for some time (Miller 1988, Lonsdale 1992, Kriticos in ARMCANZ 2001). This risk assessment attempts to consolidate some of this previous work and highlight the extent of wetlands within the predicted range that may be at risk. The following sections contain a brief outline of what is being done and what more needs to be done with regard to mimosa management.

There are a number of reports that discuss the management strategies of mimosa and other weeds (eg Storrs & Lonsdale 1995, Cook et al 1996, DBIRD 1996, Storrs 1996, Northern Land Council & ***eriss*** 1997, Northern Territory Government 1997, Storrs et al 1999, ARMCANZ 2001). These reports address issues such as information and education, early intervention, prevention of spread, research and development and impact reduction. These programs should be both interdependent and integrated to be most effective. There is general agreement that a mimosa control strategy should emphasise prevention and the reasons why the weeds are present, ie that area/habitat management is the priority. Mimosa establishment is not exclusively the result of inappropriate management practices (eg Arafura Swamp, Phelp River), however, the establishment and spread of mimosa may be exacerbated by poor land management.

The Mimosa Strategic Plan (ARMCANZ 2001) has evolved over more than five years and outlines the planning strategies to prevent further spread of mimosa in northern Australia and reduce the impacts of current mimosa infestations. As mimosa poses a national threat, a national approach is endorsed, with the Strategic Plan encouraging a coordinated and collaborative effort involving Governmental and Aboriginal agencies from the NT, Queensland and Western Australia, and the CSIRO. The Mimosa Strategic Plan is consistent and compatible with the National Weeds Strategy, the Northern Territory Weeds Management Strategy 1996–2005, and with other regional strategies and local catchment and property management plans.

The four programs of the Mimosa Strategic Plan are designed to:

- inform and educate stakeholders and the community about mimosa, its adverse impacts and the strategy for its control;
- prevent mimosa from spreading to and impacting on new areas;
- further develop the knowledge base and methods for effective and efficient management of mimosa; and
- reduce the current adverse impacts of mimosa infestations.

7.1 Education and awareness

Preventing mimosa or any other weed from initially becoming established is the most powerful and cost effective form of weed management. This can be achieved via the education of all stakeholders, and the enforcement of procedures for preventing the importation of mimosa to new areas. Legislation and regulations that pose substantial fines for the cultivation and sale/transport of mimosa, and the removal of soil material from contaminated areas can be a considerable deterrent, but only if the public is aware of the mimosa problem. Unfortunately, it is likely that deliberate introductions and the removal of seed contaminated earth material have largely been responsible for much of the establishment and spread of mimosa. In the Northern Territory, efforts have been made to ensure that the general public, recreational fishermen and hunters, pastoralists, farmers, Aboriginal communities and other landowners and managers are aware of the threat. Community awareness of weed issues has been raised through media items, show displays, posters, pamphlets and other activities (DPIF 2001). Resulting from this, community knowledge and awareness of mimosa and its potential impacts is generally better in the Northern Territory than in Queensland and Western Australia, although there is an increasing amount of educational material emerging from within these states. It is important to note that public education and awareness is only the first step in attempting to create behavioural change. Unless people actively report the discovery of mimosa plants or remove seeds from vehicles and recreational equipment, then the awareness campaign has not really achieved its ultimate goal (Hills 2004). The importance of a pro-active ‘weed aware’ public is demonstrated by the fact that nearly all new mimosa infestations discovered in the past 5–10 years have been reported by members of the public, whilst relatively few have been identified by broad-scale systematic surveys (G Flanagan pers comm 2002). The strategies to implement further information and education in northern Australia include:

- fostering good communication with stakeholders;
- developing community support for and understanding of mimosa issues;
- developing and distributing information and education material for all stakeholders in the Northern Territory and along Northern Territory/Queensland and Northern Territory/Western Australia borders; and
- supporting the other programs within the Strategic Plan (from section 7); ie evaluate, review and incorporate information from all programs and provide feedback.

The emphasis of information and educational material will vary depending on the target group, however, there are underlying issues that all of the community must be aware of including the identification of mimosa, the mechanisms of spread and the ecological, economic, social and cultural impacts. Anglers, hunters, recreational off-road users and tour operators in particular need to be aware of the potential for seed transportation, as these groups are highly mobile and will most likely encounter mimosa in more remote areas. All land managers should not only be able to identify mimosa, but also be trained on how to effectively remove early incursions. They should also be aware of what land management practices are most appropriate for preventing the invasion of mimosa.

Perhaps the most significant awareness-raising program on Aboriginal owned lands has been the recent development of groups of indigenous rangers across the Top End of the Northern Territory. In many cases these community based groups evolved from the desire to control mimosa and have now progressed to tackling other land management issues. These groups have played a pivotal role in locating and managing mimosa incursions in five strategic wetland areas and will be the lead organisations for the protection of wetlands on Aboriginal lands in the future (Storrs et al 1999, M Ashley pers comm 2001).

7.2 Prevention of spread

This management method is equally important for preventing the spread of mimosa to more distant and remote areas, and for targeting smaller satellite infestations on the extremities of known populations in an attempt to limit the spread of the total population. For all weeds, small isolated infestations are the most threatening but are nearly always ignored in favour of the control of large infestations (Moody & Mack 1988). Given the absence of mimosa in Western Australia and the presence of only one relatively small infestation in Queensland, preventative management is paramount for these states.

The strategies outlined in the Mimosa Strategic Plan aimed at implementing the prevention of spread program include:

- prohibit propagation, cultivation and sale across Australia;
- establish protocols to prevent the spread of mimosa to adjoining states;
- carry out surveillance and eradication of satellite outbreaks of mimosa;
- reduce the transport and dispersal of mimosa seeds to new areas;
- implement land management strategies that decrease the susceptibility of land to mimosa invasion; and
- encourage all State and Territory Governments to recognise mimosa under their noxious weed legislation

The activities of humans probably pose the greatest risk of spreading mimosa beyond the Northern Territory borders. However, as Northern Territory infestations are discovered ever closer to the borders, other vectors including local movements of waterbirds and animals may be of concern.

To date, preventative mimosa management in northern Australia has been largely reactive. Land managers limit survey activities to wetlands and catchments where mimosa is known to occur. Surveys in areas thought to be mimosa free have for the most part been lacking. The Mimosa Management Committee has instead chosen to raise public awareness and rely on members of the public to locate and report small strategically significant mimosa incursions. This decision is based on the assumption that a survey is not successful unless mimosa incursions are located. This thinking should perhaps be that broad scale mimosa surveys *are* considered successful if mimosa is *not* discovered

Another criticism of employing broad-scale surveys is that they do not increase the capacity of local community members to discover and manage small mimosa incursions. This is not necessarily the case, as surveys and public awareness activities should not be viewed as mutually exclusive. If raising awareness were combined with broad-scale surveys by local community members a powerful preventative weed management tool would emerge to assist with the location of mimosa incursions. Without this community approach utilising broad-scale survey techniques, mimosa will continue to spread across northern Australia, as has become evident with the recently discovered incursions on Croker Island, Legune Station, and near Proserpine in Queensland.[6]

Preventative management techniques should also be viewed as tools for improving the management of wetlands currently infested with mimosa. Mimosa control in the past has largely been conducted in isolation of other land management considerations. An improved approach is to manage the entire wetland plant communities in an attempt to decrease the susceptibility to mimosa invasion and establishment. This method of preventative management utilises competitive qualities of wetland plant communities to decrease the risk of invasive species establishing.

This concept was first explored by Miller (1992), who undertook pot trials to quantify the competitive relationship between mimosa and Koronivia grass (*Brachiaria humidicola*). The study found that Koronivia grass would actively suppress the germination of mimosa seeds and inhibit growth rates of immature mimosa plants. Native wetland flora may exhibit similar competitive characteristics (Miller 1992). Research is required to quantify the ecological relationship and determine safe native flora biomass thresholds. If such a competitive relationships exists, it may be utilised to restore floodplain ecosystems following mimosa control and limit the invasion and establishment of mimosa incursions.

Anecdotal evidence supports this method of preventative management. Land managers on the Finniss River floodplain have observed the spread of mimosa following the disturbance of wetland plant communities. They have commented on the rapid expansion of mimosa following burning of wetland areas and now actively exclude fire to limit the invasiveness of existing mimosa infestations. The response of mimosa populations to fire is worthy of research to document the effect it has upon germination and spread. Limiting this type of ecological disturbance may have a major role in lowering the risk of mimosa invasion and protecting wetlands currently unaffected by mimosa. However, exclusion of fire may alter

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[6] Although broad scale surveys allow the detection of infestations at a stage where they can be eradicated, the actual spread has already occurred.

wetland communities in other aspects (eg Boyden et al 2003). In general, the role of fire in wetlands is poorly understood and needs to be further investigated.

7.3 Research and development

In the past few decades much progress has been made on research towards biological and other forms of mimosa management. Control strategies are the result of an extensive and integrated research program with more than 80 published[7] papers on mimosa (ARMCANZ 2001). It is also acknowledged that there are still many gaps regarding mimosa research (see sections 6 and 8 for more detail).

The strategies of the research and development program come under four main headings:

1) Mimosa ecology

- to better understand the ecology of mimosa and susceptible habitats

2) Biological control

- provide remaining potential biological control agents and supporting information to an Australian quarantine facility;
- establish control agents widely across mimosa's range; and
- optimise the efficacy of biological control agents.

3) Integrated control

- further develop herbicidal, mechanical and other non-biological control methods;
- quantify the impact on mimosa of integrated control; and
- provide recommendations for strategic integration of the available control options.

4) Sustainable land management

- develop methods for restoring habitats invaded by mimosa; and
- develop and encourage land management practices that prevent mimosa invasion and re-establishment.

7.4 Impact reduction

This program is primarily concerned with the control and impact reduction of mimosa already established in the Northern Territory. For information on the adverse impacts of mimosa, refer to section 3. By definition, this program concentrates on those catchments where large stands of mimosa already occur, and on reclaiming the land for the multiple uses outlined below. This risk assessment reaffirms these criteria and further expands on the issues surrounding land use (see section 5.4).

The impact reduction program strategies include:

- reduce the incidence and adverse impacts of mimosa on biological diversity, Aboriginal use, pastoralism, tourism, fisheries, recreation and other industries and pursuits; and

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[7] A great deal of unpublished papers and other information also exists. See also proceedings of the 'Wise use of wetlands in northern Australia: Grazing management in wetlands and riparian habitats' workshop (Myers et al 2003) and 'Research and management of *Mimosa pigra* – Papers presented at the 3rd International Symposium on the Management of *Mimosa pigra*' (Julien et al 2004).

- continue control of the large infestation in western Arnhem land (ie the Gunbalanya floodplain)

The criteria used when implementing the strategy are:

1) Weed ecology

- upper catchments have higher priority than lower catchments because mimosa seeds spread downstream;
- smaller infestations have a higher priority than larger, because they are more easily controlled, but can expand rapidly;
- advancing infestations have a higher priority than static infestations; and
- roads, tracks and fence lines have a high priority because of the potential for seed to be carried by vehicles.

2) Land use

- areas of Aboriginal cultural significance have a high priority;
- areas of high conservation value will have a high priority; and
- areas of high value to industry have a high priority.

The Northern Territory Department of Infrastructure Planning and Environment (ex Department of Primary Industry and Fisheries), a number of Aboriginal associations, property managers and volunteer groups have all made significant progress on the impact reduction of mimosa. Some notable achievements have occurred on the Gunbalanya floodplain where 8000 ha of dense mimosa has been reduced by about 90% (DPIF 1997, G Flanagan pers comm 2002). Also, on Melaleuca Station in the Mary River district of the Northern Territory, where 2000 ha of grazable floodplain has been recovered from dense mimosa, and station managers are working on a five-year program to recover a further 3000 ha (Searle & Fell 2000a). The White Eagle Aboriginal Corporation initiated a mimosa control program on their land within the Wagait Aboriginal Land Trust and now have 5070 ha of mimosa under control programs which in turn has prevented infestation of approximately 10 000 ha of wetlands (Ashley 2003). About 2000 ha have been recovered at Twin Hills station on the Finniss River, and several other smaller infestations to the south east of Darwin (eg on the Wagait and Daly River/Port Keats Aboriginal Land Trusts) have also been eradicated (John Ross, G Flanagan, M Ashley pers comm 2002). There are also many other cases across the Top End where impact reduction of smaller infestations has been achieved.

An important issue for land managers to consider when tackling large-scale control operations is the cost of the follow-up treatment. In a case study on Melaleuca station, the new managers were faced with 10 000 ha (33% of the property) of dense mimosa that was unproductive land. The Northern Territory Government program cleared 2000 ha and the managers were systematically tackling the rest over a five-year program. As more country was cleared, the effort required to maintain it also increased and resources were not available to clear more old-growth areas. The annual budget of $250 000 per annum was fully devoted to maintenance by the time about 4000 ha had been cleared. However, experience gained and increasing efficiency has enabled the program to continue largely on schedule. Approximately 2000 ha are now back to productive land with reduced maintenance costs and the extra funds generated by cattle production will be used to clear old-growth mimosa (Searle & Fell 2000a, Tony Searle Melaleuca Station pers comm 2001).

In 2000−2001, strategic and cost effective mimosa management strategies were developed in collaboration with Aboriginal stakeholders. The Mimosa Services and Funding Agreement has provided for training and operational resources for communities in the Arnhem Land, Delissaville/Wagait/Larrakia and Daly River/Port Keats Aboriginal Land Trusts, coordinated by a Weeds Branch officer. Approximately 4000 hectares of mimosa is being treated annually, and the program has made significant inroads into mimosa management on Aboriginal lands (DPIF 2001).

Discussion of the various mimosa control options is largely beyond the scope of this risk assessment. However, in the context of the long-term management and impact reduction of existing and future infestations, the success of the CSIRO biological control program is crucial. The program has been running for over 20 years and during this time 13 agents have been released and more continue to be investigated. Six of these agents are currently confirmed to have established and persisted, and four of these are showing measurable impacts on mimosa, reducing the vigour of the weed and its seed production (Flanagan & Julien 2004, Paynter 2004). Biological control is non-toxic and is suitable for remote and inaccessible infestations of all sizes. Aside from the potential ecological impacts, other control methods can be expensive, as long-term follow-up control is needed in nearly all circumstances. Comparatively, for a limited amount of investment, biological agents will potentially play a substantial role in reducing, for the long term, the longevity, size and density of mimosa plants, and their rate of spread (ARMCANZ 2001). Importantly, in other countries where mimosa is a serious or emerging problem, mimosa managers can benefit from the biological control research developed in Australia (Flanagan 2004).

8 Further research

Sections 6 and 7.3 outline some areas where more research or information is needed to achieve improvements in mimosa management. This section lists these and any others that have been mentioned elsewhere in the risk assessment or from other sources (not in order of priority).

- Detailed site-specific assessments of wetland characteristics and land use (section 7.3)
- More precise data on growth and environmental requirements of mimosa and use of this information to refine CLIMEX distribution modelling predictions (section 4.4.1)
- The relationship between climate change and the potential range of mimosa using a CLIMEX sensitivity analysis (section 4.4.1)
- The mapping of mimosa infestations, GIS assimilation of the data and development of remote sensing techniques (section 6.1)
- A scale of topographical map information that is finer than 1:250 000 (section 6.1)
- The ecological impacts of the herbicides, wetting agents and adjuvants used for mimosa control (sections 6.2 & 7.3)
- Vulnerable and endangered fauna and flora within the entire predicted range of mimosa (section 3.4)
- Quantitative data on the environmental, economic, social and cultural impacts of mimosa (sections 3 & 6.2)
- Document the seed stores following broad scale integrated control programs (Ashley 2003)

- Quantify the competitive relationship between mimosa and other wetland vegetation (Ashley 2003)
- Quantify the effects of different grazing strategies upon the competitive relationship and the subsequent ability of wetland plant communities to suppress mimosa establishment and growth (Ashley 2003)
- Determine the factors that affect successful revegetation (G Flanagan pers comm 2002)
- Research on how to fine-tune the current best practice integrated management regimes, and how to best communicate this information to land managers and encourage them to adopt it (G Flanagan pers comm 2002)
- The role, timing and impact of wildfires as opposed to controlled burning in relation to both mimosa and floodplain management (sections 3.2.1, 4.3.6, 5.4.2, 6.1 & 7.2) (G Flanagan pers comm 2002, Ashley 2003)
- The relationship between native species recolonisation and the abundance of biological control agents (section 3.2.1) (Quentin Paynter CSIRO pers comm 2003)

9 Conclusions

This study aimed to assess the current impact of mimosa invasion and the potential risk to the wetlands of northern Australia. Within this, three key questions were addressed and the major conclusions arising from these area outlined below.

Aim 1: What wetlands across northern Australia are at risk of invasion by mimosa?

Other than the considerable area of mimosa infestation in the Northern Territory (estimated at about 80 000 ha), a great number of other wetlands of northern Australia (including nationally and internationally important wetlands) remain under threat from mimosa (see section 4). Their total area is estimated at between 4.2 and 4.6 million ha. However, the actual area of suitability within this range is unclear and dependent on further research into the characteristics and land management practices of the habitats, and also on some of the topics outlined in sections 6 and 8. CLIMEX modelling has provided a reasonable prediction of the potential range of mimosa in northern Australia. Information that enables refinement of the model, improved topographical map information and site-specific assessments will further assist in identifying wetlands at risk. The discovery of mimosa in Queensland, some 1600 km from the nearest plant in the Northern Territory, is an important reminder of its invasive potential. Wetlands that have been excessively disturbed by grazing, agriculture, clearing, high-use recreation, feral animals and inappropriate fire regimes are more prone to invasion than lesser disturbed wetlands that have competitive vegetation in place. Private lands and Aboriginal lands by far contain the greatest number of wetlands at risk, the two categories accounting for approximately 85% of the total. Wetlands of nature conservation account for only about 12% of those at risk (see section 5.4), but are often associated with highly valued flora and fauna.

Aim 2: What are the likely consequences of mimosa invading these wetlands?

In the Northern Territory mimosa has already greatly affected the environment, the economy and people’s lives in many ways (see section 3). Unfortunately, with little quantitative data about these impacts available, it is difficult to extrapolate the effect across the entire predicted range. It is quite likely that similar infestation in the neighbouring states will see impacts at least equal to, or greater than those currently experienced in the Northern Territory, due to the greater human population[8] in some areas and the considerable areas devoted to Aboriginal interests, pastoralism and agriculture. Biodiversity will be reduced, some vulnerable species may disappear, productive land will be lost and some people's livelihood and recreation will be affected. Controlling large-scale mimosa infestations is very expensive. Few land managers have the resources to tackle the problem and governments are generally allocating ever-decreasing funding to many environmental issues.

Because the current area of mimosa in the Northern Territory is uncertain, it cannot be assumed that the available resources and control strategies are keeping pace with mimosa. The expanding human population and advancing climate change may result in an increase in the spread of mimosa. Without maintaining or increasing resources for mimosa management, it will continue to spread throughout the Northern Territory and eventually to parts of Western Australia and Queensland. Experience in the Northern Territory has shown that new outbreaks, if not controlled, rapidly expand into major infestations in a few years. One of the challenges in the Northern Territory is that there are so few people to manage such a vast and remote area.

Aim 3: What management actions are being undertaken or need to be undertaken to minimise the risks of further mimosa invasion across northern Australia?

The current estimated distribution of mimosa represents less than 2% of the estimated potential distribution. Although the control of large infestations is seen as important from a local perspective, the prevention of spread to clean areas must be given the highest priority. It is also recognised that appropriate land management practices that reduce the susceptibility of these clean areas to invasion is a major factor of any management strategy. Integrated management strategies have been in place for many years and in some areas significant achievements have been made in impact reduction and spread prevention. At the centre of mimosa management in northern Australia, the mimosa strategy (ARMCANZ 2001) details the activities currently adopted for the implementation of the Strategic Plan. Other areas of research that may enhance the effectiveness of these activities are outlined in sections 6, 7.3 and 8.

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8 ie more people could be affected by the impacts outlined in section 3.5.

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