CSIRO PUBLISHING
www.publish.csiro.au/journals/asb *Australian Systematic Botany* **16**, 81–88

Worth the risk? Introduction of legumes can cause more harm than good: an Australian perspective

Q. Paynter[A,H] *S. M. Csurhes*[B], *T. A. Heard*[C], *J. Ireson*[D], *M. H. Julien*[C], *J. Lloyd*[E], *W. M. Lonsdale*[F], *W. A. Palmer*[G], *A. W. Sheppard*[F] and *R. D. van Klinken*[A]

[A]CSIRO Entomology, CSIRO TERC, PMB44, Winnellie, NT 0822, Australia.
[B]Pest Management Strategy, Queensland Department of Natural Resources and Mines, Locked Bag 40, Coorparoo Delivery Centre, Qld 4151, Australia.
[C]CSIRO Entomology, CSIRO Long Pocket Laboratories, 120 Meiers Road, Indooroopilly, Qld 4068, Australia.
[D]Tasmanian Institute of Agricultural Research (TIAR), New Town Laboratories, 13 St Johns Ave, New Town, Tas. 7008, Australia.
[E]CRC for Weed Management Systems, PMB1, Glen Osmond, SA 5064, Australia.
[F]CSIRO Entomology, GPO Box 1700, Canberra, ACT 2601, Australia.
[G]Alan Fletcher Research Station, Queensland Department of Natural Resources and Mines, PO Box 36, Sherwood, Qld 4075, Australia.
[H]Corresponding author; email: Quentin.Paynter@csiro.au

Abstract. Weeds are serious threats to Australia's primary production and biodiversity conservation. For example, a recent Australia Bureau of Statistics survey found that 47% of farmers across Australia have a significant weed problem. A literature review revealed that legumes represent a significant proportion of the national weed problem and most serious Australian legume weeds are exotic thicket-forming species that were deliberately introduced for their perceived beneficial properties, such as for shade and fodder, or even quite trivial reasons, such as garden ornamentals. The low economic value of the rangelands most of these species infest, compared with control costs, hinders chemical and mechanical control of these weeds, such that biological control, which takes time, is expensive to implement and has no guarantee of success, may represent the only economically viable alternative to abandoning vast tracts of land. We argue that, because the behaviour of an introduced species in a novel environment is so hard to forecast, better predictive techniques should be developed prior to further introductions of plant species into novel environments. We also discuss the potential of legumes currently being promoted in Australia to become weeds and suggest the recent trend of exporting Australian *Acacia* spp. to semiarid regions of Africa risks history repeating itself and the development of new weed problems that mirror those posed by Australian *Acacia* spp. in southern Africa.

Introduction

Legumes are important to the Australian economy. For example, the Centre for Legumes in Mediterranean Agriculture (http://www.clima.uwa.edu.au/) notes that pulses alone are worth A$500 million per annum and that the A$7.75 billion wool, beef and lamb and A$2.5 billion Australian wheat industries benefit from legumes through fodder crops, nitrogen fixation and disease breaks. Legumes are also important to Australia's A$500 million nursery industry (Nursery and Garden Industry Australia: http://www.NGIA.com.au/) and to forestry.

However, leguminous weeds are a burden on the Australian economy. Weeds cost Australia *c.* A$3.3 billion each year and the rate of ingress of new weeds is increasing. The cost to the environment is huge and incalculable. Lazarides *et al.* (1997) recognised approximately 2733 weed species, subspecies or varieties in Australia, of which *c.* 296 (11%) are legumes and 27 (*c.* 8%) of the *c.* 350 declared noxious weeds in Australia (from list compiled by the National Weeds Strategy Executive Committee) are legumes. Over the past decade there has been a developing awareness of Australia's weed threat, which achieved formal

 25 March 2003 10.1071/SB01025 1030-1887/03/010081

recognition with the launch of the National Weeds Strategy (Anon. 1997), the objectives of which are the following:

(i) to prevent the development of new weed problems;

(ii) to reduce the impact of existing weed problems of national significance; and

(iii) to provide cost-efficient and effective means for harnessing national action on weed management.

A central component of the strategy (Objective 2) was the 'identification of *Weeds of National Significance* (WONS) and the resultant coordinated actions across all States and Territories'. During this process, 71 weeds were nominated, of which nine are legumes (brooms: *Cytisus scoparius* (L.) Link, *Genista monspessulana* (L.) L.Johnson and *Genista linifolia* L.; gorse, *Ulex europaeus* L.; honey locust, *Gleditsia triacanthos* L.; mesquite *Prosopis* spp; mimosa, *Mimosa pigra* L.; parkinsonia, *Parkinsonia aculeata* L.; prickly acacia, *Acacia nilotica* (L.) Del. ssp. *indica* (Benth.) Brenan. and sicklepod, *Senna obtusifolia* (L.) H.Irwin & Barneby;). A ranking exercise resulted in the naming of 20 WONS, five of which (parkinsonia, mesquite, prickly acacia, mimosa and gorse) are woody legumes (Thorp and Lynch 2000).

The challenge of reducing the risks, whilst maintaining or increasing the value of beneficial introduced woody legumes has recently been recognised (e.g. Hughes and Styles 1989). Research is urgently required to ensure that proposed introductions are performed wisely and safely (Ewel *et al.* 1999). We document the origin of Australia's leguminous weeds, review how current weed problems are being treated and suggest how future weed incursions might be avoided.

The origin and control of Australian legume weeds

The origins of Australia's noxious leguminous weeds were determined from various sources, including Parsons and Cuthbertson (2001), Lazarides *et al.* (1997) and state government fact sheets, and these are summarised in Table 1 and below.

Widespread noxious legumes

Eight of the nine legume species nominated during the WONS selection process (see Introduction) are woody trees or shrubs that form impenetrable, usually thorny, thickets that displace native biodiversity, impede stock management, restrict access to water and reduce beneficial pasture and, therefore, carrying capacity. The exception, sicklepod, is a robust annual shrub growing up to 2.5 m tall, a weed of pastures and sugar cane. All but sicklepod were deliberately introduced as hedgerows, ornamentals or for fodder and shade (Table 1) and all but mimosa and sicklepod were deliberately widely planted. Although they are already so widespread that their eradication from Australia is not feasible, CLIMEX modelling indicates most legume WONS could still greatly expand their ranges.

Control of these weeds is possible, but often difficult due to regeneration from large, long-lived, seed banks following fire, chemical or mechanical treatments. Furthermore, legume WONS infest millions of hectares of Australia (prickly acacia alone infests *c.* 7 million ha). Recently quoted control costs ranged from *c.* $300 for mimosa to $700–1500 per ha for gorse (M. Ashley and J. Ireson, pers. comm.). The costs of eradicating legume WONS, if it were possible, would be astronomical. Remoteness and scale of many infestations and low economic land value, compared with control costs, have encouraged investment in biological control (Table 2). The history of the introduction and spread of prickly acacia, which is typical of many noxious legumes, is given below.

Prickly acacia [Acacia nilotica (*L.*) *Del. ssp.* indica (*Benth.*) *Brenan.*]

Prickly acacia is a perennial tree capable of living more than 100 years. It is one of nine subspecies of *Acacia nilotica* that are distributed from southern Africa to the Indian subcontinent. Prickly acacia was introduced from the Indian subcontinent to Queensland in about 1900 (Parsons and Cuthbertson 2001) and by the 1920s, it was grown extensively as a shade and ornamental tree in Central Queensland. In 1926, the then Department of Agriculture and Stock began recommending its culture in western Queensland. Over the next half century it was grown around homesteads, bore drains and dams for shade and because the pods are a rich protein source (Mackey 1997). It was recognised as a serious weed and declared noxious in 1957, after populations expanded following a series of wet years. In the 1970s, another series of wet years and a switch from sheep to cattle farming promoted further expansion (see below).

Prickly acacia infests nearly 7 million ha of an area roughly bounded by the Gulf of Carpentaria, Bowen, the NSW–Queensland border and Barkly Tableland in the Northern Territory. Major infestations on the Mitchell Grass Downs of north-western Queensland were recently demarcated by the National Prickly Acacia Containment Line under the National Weeds Strategy. Its potential distribution in Australia, predicted by CLIMEX, includes most of Queensland and tropical Northern Territory and Western Australia. (D. Kriticos, unpubl. data).

In arid western Queensland, trees growing along creeks, rivers or bore drains contribute most seeds in all but the wettest years and produce up to 30000 seeds per tree (Carter and Cowan 1993). Dispersal is mainly by cattle that feed on mature pods and pass viable, scarified seed (about 40% of seed passed are viable; sheep pass a much smaller proportion of viable seed). Seeds take 6 days to move through the gut and can therefore be dispersed over huge distances when moving stock by motor transport. Property hygiene to ensure clean areas are not infested is therefore vital.

Table 1. Australian noxious leguminous weeds and their origins
Taxonomy follows that of the International Legume Database and Information Service (ILDIS: http://www.ildis.org/). *'Weed of national significance'

Weed species	Native range	Date of introduction/first record	Notes
Native			
Acacia paradoxa DC.	Australia	—	Minor weed. Spiny shrub harbours rabbits[A]
Deliberate introduction			
Acacia catechu (L.f.) Willd.	Indo-Malaya	?	Infestation around Darwin botanic gardens[A]
Acacia karroo Hayne	Africa	1980s?	Garden ornamental[B,C]
Acacia nilotica (L.) Del. ssp. *indica* (Benth.) Brenan.*	Indian subcontinent	1900	Ornamental, fodder and shade tree[A]
Calicotome spinosa (L.) Link	Europe	1865	Ornamental and hedge plant[A]
Cytisus scoparius (L.) Link	Europe	1800	Ornamental and hedge plant[A]
Dalbergia sissoo DC.	Indian subcontinent	?	Shade plant and forestry[A]
Genista linifolia L.	Europe	1858	Ornamental[A]
Genista monspessulana (L.) L.Johnson	Europe	1803	Hedge plant[A]
Gleditsia triacanthos L.	North America	Mid-19th century	Ornamental and shade tree[D]
Mimosa pigra L.*	Tropical Americas	1870–1890	Escaped from Darwin botanic gardens[A]
*Mimosa pudica*L.	Tropical Americas	?	Ornamental[A]
Parkinsonia aculeata L.*	Tropical Americas	1876	Ornamental and shade tree[A]
Pithecellobium dulce (Roxb.) Benth.	Central America	?	Planted Cairns and Brisbane botanic gardens[E]
Prosopis spp. (4 spp. and hybrids)*	Tropical Americas	Before 1880	Fodder and shade tree[A]
Senna alata (L.) Roxb.	Tropical Americas	Before 1891	Garden ornamental[A]
Senna pendula (Willd.) H.Irwin & Barneby	Tropical Americas	?	Garden ornamental[F]
Sesbania punicea (Cav.) Benth.	South Americas	1995	Ornamental. Not established ferally[G]
Ulex europaeus L.*	Native to Europe	1803	Hedge and fodder[A]
Accidental/illegal introduction			
Mimosa invisa Colla	Tropical Americas	Before 1929	Contaminant of *Centrosema pubescens* seed[A]
Senna obtusifolia (L.) H. Irwin & Barneby	Tropical Americas	During WWII	
Senna occidentalis (L.) Link	Tropical Americas	?	
Senna tora (L.) Roxb.	Tropical Americas[H]	?	Garden herb. Potential for gum production being investigated by Rural Industries Research and Development Corporation
Unknown origin			
Alhagi maurorum Medikus	Asia	Before 1915	Possibly a contaminant of lucerne seed[A]
Totals: deliberate introductions, 21§; accidental introductions, 4; unknown origin, 1; native, 1			

[A]Parsons and Cuthbertson (2001); [B]Agriculture Western Australia Invasive Garden Plants List (http://www.agric.wa.gov.au/progserv/plants/weeds/weedsci4.htm); [C]Secomb (1999); [D]Csurhes and Kriticos (1994); [E]AFFA fact sheet no. 115 (http://www.affa.gov.au); [F]Lazarides *et al.* (1997); [G]Csurhes and Edwards (1998), [H]Holm *et al.* (1996).

Although seeds have a hard coat and can survive up to 10 years in dry soil, in most years there is sufficient rainfall to germinate most seeds. However, except in the wet years, most germinated seedlings fail to survive to the next year's wet season unless they are growing near permanent water. Juveniles that survive the first 1–2 years, as occurs with a series of wet years, have roots down to sufficient depth to withstand further climatic stresses and reach reproductive maturity after 3–5 years.

Various control techniques have been developed (March 2000). Chemical control is effective for light infestations and treatment of bore drains with Diuron is particularly useful. Mechanical controls include pushing, chaining or grubbing with large tractors. Use of fire has not been fully evaluated. Although effective techniques are available, control costs often exceed the value of the land; a situation exacerbated in recent years by drought and low commodity prices. The ultimate resolution of this problem will therefore depend on rigorous integrated control with a biological control component (Table 2).

If prickly acacia could be managed to prevent thicket formation, it would probably be considered a desirable plant for western Queensland. It provides useful shade, highly nutritive pods and valuable drought reserve. Sheep enterprises run on properties with light infestations produce better lambing percentages, heavier wool clips and better survival in droughts. However, when it occurs at high densities, productivity is greatly reduced, erosion and

Table 2. Status of Australian biological control programs against the nine noxious legume species nominated for consideration as 'weeds of national significance'

Weed species	Biological control program	Impact
Parkinsonia aculeata	Two seed-feeders and a mirid released in 1980s and 1990s. Surveys of Central and South America may yield new agents, but currently only impact evaluation is being conducted.	Only *Penthobruchus germaini* (seed-feeder) widely established. Recent studies indicate parasitism can prevent it reaching high densities.
Prosopis spp.	Program initiated in 1994. Four agents released. Further potential agents are available. Currently only impact evaluation is being conducted.	A leaf-tying moth (*Evippe* sp.), released in 1998, causes prolonged, heavy defoliation in some infestations and having a major impact on plant growth and fecundity.
Acacia nilotica	Program initiated in the early 1980s[A]. Five agents have been released and further agents are being evaluated.	Establishment only confirmed for the seed-feeding bruchid beetle *Bruchidius sahlbergi* Schilsky, which is ineffective[B].
Mimosa pigra	Program began in 1979. 12 agents (10 insects and 2 fungal pathogens) have been released, although too early to confirm establishment of all species. Further agents are being evaluated and impact evaluation is being conducted.	Promising signs of success. Combined attack from stem-mining moths *Carmenta mimosa* Eichlin & Passoa and *Neurostrota gunniella* (Busck) has major impact on fecundity and can kill plants. However, high attack rates largely currently confined to isolated plants and stand edges.
Ulex europaeus	A seed weevil was released in 1939[C]. A new project[F], linked with a New Zealand project[G] recently released two agents and two more are likely to be released soon.	Impact of the seed weevil, *Exapion ulicis* (Forster), is limited because autumn seed crop escapes herbivory[D,E]. It is too early to assess the impact of recently introduced control agents.
Senna obtusifolia	None. Difficult target due to taxonomic proximity to native Australian congeners. Assessment of pathogens as control agents in Australia has yet to be made.	
Cytisus scoparius	Three insect species have been released since 1993; a twig-mining moth, a psyllid and a seed beetle[H]. Two more potential agents are being assessed.	All agents released have established it is too early to assess impact. Results in New Zealand are encouraging.
Genista monspessulana	Biological control is in its early stages. Native range surveys commenced in 1999[I].	
Gleditsia triacanthos	Not tried.	

[A]Palmer (1996); [B]Radford *et al.* (2001); [C]Evans (1942); [D]Cowley (1983); [E]Hill *et al.* (1991); [F]Ireson *et al.* (1999); [G]Hill (1982); [H]Syrett *et al.* (1999); [I]CSIRO (2000).

ecological degradation occur and property management is more difficult. The costs associated with prickly acacia have been assessed and are estimated between A$4–9 million per year (Miller 1996; March 2000).

Legume weeds that are not yet widespread—potential 'sleeper' weeds

Currently localised weeds that have the potential to become widespread are covered by Objective 1 of the National Weeds Strategy: the early detection of small populations while eradication is still possible. There are too many species to discuss in this paper. Csurhes and Edwards (1998) recently identified a number of potential weeds in Australia, including several introduced African and South American *Acacia* species. They noted many introduced *Acacia* spp. are currently restricted to fodder-tree trial sites, zoos and wildlife parks (due to a recent trend for zoos to re-create the native surroundings of captive animals) and gardens [*Acacia tortilis* (Forsk.) Hayne and *Acacia senegal* (L.) Willd. are currently offered for sale by a New South Wales company]. A single specimen of *Acacia xanthophloea* Benth. was removed from a garden near Brisbane in 1992.

Two species are known to have naturalised in Australia: *Acacia karroo* Hayne was detected and subsequently removed from several sites in Western Australia and, it has also been recorded near Port Augusta in South Australia (Secomb 1999). Small stands of *Acacia catechu* (L.f.) Willd., occur around the Darwin Botanical Gardens (Parsons and Cuthbertson 2001).

Csurhes and Edwards (1998) noted that many *Acacia* spp. exotic to Australia possess characteristics identical to prickly acacia (see above) and have well-documented histories as major rangeland weeds in their countries of origin. In particular, *A. karroo*, which is a weed in its native southern Africa and is the most cold-tolerant of the southern African *Acacia* spp., has the potential to invade open grasslands and rangelands over much of south-eastern Australia (Scott 1991). Every effort should be made to ensure that non-native acacias are detected and removed.

Risk assessment and legal requirements for importing plant material—keeping out potential new weeds

Some species, such as *A. karroo* and *Sesbania punicea* (Cav.) Benth., have been identified as potential noxious weeds in Australia because of their history as weeds in other countries (Csurhes and Edwards 1998). However, species with no history of being weeds overseas could also become weeds in Australia. Attempts have been made to identify attributes that confer weed risk (reviewed by Csurhes and Edwards 1998) culminating, in 1997, with the Australian Quarantine and Inspection Service (AQIS) implementing a 'Weed Risk Assessment' system (WRA) to assess all proposed plant imports for weed risk, on the basis of a number of criteria including the following:

(i) history as a pest overseas,
(ii) climatic match and
(iii) various biological attributes (including dispersal vectors).

On the basis of these criteria, extremely risky or relatively 'safe' candidate species can be immediately rejected or accepted for import depending on their numerical score. Certain intermediate scores require the risks of a candidate species to be assessed in more detail to determine their safety. Currently, this is tantamount to a rejection because weed potential and, conversely, safety cannot be reliably predicted for these species. Quarantine law requires that all new plant species proposed for import into Australia go through the WRA process. For example, the Queensland Department of Natural Resources and Mines has assessed the weed risk of several hundred non-indigenous plant species and listed potential weed species considered to pose the greatest threat as 'declared potential weeds' under the Queensland Rural Lands Protection Act. It is an offence to introduce, cultivate or sell these plants in Queensland.

Discussion

For most Australian noxious legumes to be the result of deliberate introductions for their perceived beneficial properties (Table 1) there must have been inadequate consideration of their potentially detrimental attributes, prior to introduction. Behaviour of introduced species in novel environments is notoriously difficult to predict, although exotic species are normally more vigorous than native species (e.g. Hughes and Styles 1989). Many exotic Australian weeds are not weeds in their native habitats, where natural enemies can regulate populations (Huffaker *et al.* 1984). Both Hughes and Styles (1989) and Ewel *et al.* (1999) suggested that the use of native species, even if they are less productive, should be preferred over exotic introductions.

Hughes and Styles (1989) noted that certain habitats appear more likely to be weed-prone than others and suggested that invasions of natural pasture or rangeland by woody legumes is often due to mismanagement, such as overgrazing. They suggested that identifying appropriate and inappropriate habitats for introduced species may reduce weed problems. However, they also noted that the mobility of plants is problematic; releasing plants in areas where they are likely to be well managed may not prevent a weed problem from eventually emerging elsewhere. A good example in Australia is *Parkinsonia*, which was introduced as an ornamental and shade tree (Table 1.) and is now a major weed of pasture. Several plants introduced as ornamentals have also become major problems in Australia (Table 2). We believe the creation of national weed problems due to the desire for novelty in the nursery industry is unacceptable.

Fodder crops, such as *Leucaena*, are expected to form self-sustaining populations and will inevitably become weeds if they do not remain confined to the pastoral systems into which they were introduced (Lonsdale 1994). The interests of rural industries may, therefore, prove incompatible with environmental demands and lead to problems that are extremely difficult to resolve. Features desired of potential fodder crops are shared with many weeds; quick growing, aggressive, drought-tolerant, prolific seeders have been favoured (Low 1999). Worse still, another desired feature of introduced legumes is that they are not too palatable, or they risk being eliminated from the pasture (Low 1999). Clearly, however, a degree of unpalatability may confer a competitive advantage over more edible species to the detriment of the pasture. Furthermore, even palatable species, such as *Leucaena* (see below), can become weeds in ungrazed situations.

Between 1947 and 1985, 277 legume species were introduced into northern Australia as potential improved pastures (Lonsdale 1994). This might seem an extraordinary number. However, it is extremely difficult to predict whether an introduced species will establish in a new environment. The most robust generalisations regarding the potential establishment of an invader involve propagule pressure, habitat matching and previous success at invasion in other countries (Williamson 1996). The last may be unknown for a novel introduction and, although deliberate introductions seek to maximise success by ensuring an adequate supply of propagules and releasing organisms into an appropriate environment, many fail to establish (Williamson 1996), emphasising how poorly we can predict whether an introduction will fail or succeed.

Most of today's most serious noxious legume weeds were introduced many decades ago. For example, the five noxious legume WONS were first introduced into Australia between 1800 and 1900. It could be argued that more recently introduced fodder plants should have become serious weeds by now if they were predisposed to do so. However, some noxious legumes were benign, or even relatively beneficial, for decades after their introduction and became major problems following unpredicted future events. The spread and impact of the wetland weed, *Mimosa pigra*, was minor until seed reached floodplains heavily disturbed by feral water buffalo, another introduced species, approximately 100 years after both were introduced (Lonsdale *et al.* 1988). In 1926, prickly acacia was regarded as a beneficial source of shade and protein in sheep pasture, its introduction to cattle pasture was known to be risky because 'the seeds are not masticated and pass through the whole of the digestive tract, thus causing numbers of young trees to appear where they are not wanted' (Parsons and Cuthbertson 2001), but could those who promoted the plant in central Queensland in 1926 have predicted a shift from sheep to cattle pasture in the 1970s? Another factor that can influence the outcome of a plant invasion is the presence of mutualistic organisms. Richardson *et al.* (2000) documented the widespread dissemination of symbionts as a potential factor influencing plant invasions, noting that the introduction of *Leucaena leucocephala* into Australia failed until inoculated with an effective *Rhizobium* strain. Thus, species that may not have been invasive in the past can become so as the conditions change so we cannot rely too heavily on past perspectives when predicting the likely future of invasions.

Many plants disperse slowly so their colonisation is insidious. Paynter *et al.* (1996), for example, showed that ballistic seed dispersal of Scotch broom leads to populations advancing at a rate of only *c.* 1 m year^{-1}; considerably less than more mobile species, such as the cane toad, which has still taken over 65 years to disperse from tropical Queensland to the southern boundaries of Kakadu National Park (Low 1999). Large time lags are common between the introduction, establishment and spread of environmental weeds (Binggeli 2000). This should alert us that plants currently being promoted could become future weeds.

The list of legumes that entered Australia prior to the WRA being set up and are currently grown in Australian nurseries, offered for sale as seed or promoted for fodder is too large to be discussed in this paper. However, historical precedence indicates that woody legumes are particularly risky and large time lags may occur between introduction and the development of a serious weed problem. With the benefit of hindsight, continued promotion of woody legumes should be seriously questioned. We ran the WRA assessment system with the latest published information for two introduced fodder species, which were retrospectively classified as 'evaluate' (Pheloung 1995), and which, like most Australian noxious legume species, are relatively tall woody shrubs.

Cytisus proliferus *L.F.Syn.* Chamaecytisus palmensis *or* C. proliferus *(L.F.) Link.*

Noxious potential can be inferred by association (Forcella 1985); almost all introduced species of the tribe Genisteae, subtribe Cytisus–Genista (e.g. brooms, gorse) are noxious weeds in Australia. In Victoria, *C. proliferus* (tagasaste) has naturalised and exists in medium to large stands in a range of habitats (Carr *et al.* 1992). It is also established and spreading in New South Wales (A. W. Sheppard, pers. comm.), South Australia and in Western Australia, where it is being promoted as a fodder crop for cattle (Csurhes and Edwards 1998). By changing just two parameters, the existence of a congeneric weed, based on tagasaste now being considered a species of *Cytisus* (ILDIS: http://www.ildis.org/) and tagasaste being considered an environmental weed (Carr *et al.* 1992), the ranking changed from 'evaluate' (Pheloung 1995) to 'reject'. Furthermore, objections from those promoting tagasaste have curtailed biological control programmes against closely related weeds, especially Scotch broom (*Cytisus scoparius*), for which potential agents exist that pose no threat to native Australian plants but are a risk to tagasaste.

Leucaena leucocephala (*Lam.*) *De Wit or* Leucaena glauca (sensu *L. 1763*) *Benth.*

A small tree up to 6 m, this native of Central America is now found in most tropical and subtropical countries. *Leucaena* or coffee bush spreads by seed that are produced in vast quantities (Smith 1995). It is utilised by many countries as shade for coffee. In Australia, it is currently being promoted as a fodder for cattle, even though it can form dense thickets that exclude native vegetation and is becoming an environmental weed in northern Australia (Smith 1995). It is also weedy in a variety of situations worldwide; for example, in India, Hawaii, Ivory Coast and Taiwan (Snoeck 1971; Evensen 1982; Anon. 1986; Patil and Kumar 1990) and its use is also associated with soil acidification, which can result in increases in toxic aluminium and manganese, reducing production and crop options (Hughes and Jones 1998). It's classification as an environmental weed changes its status from 'evaluate' (Pheloung 1995) to 'reject'.

Even though both of the above species were classified as 'evaluate' when treated as novel introductions (Pheloung 1995), which would currently prevent their introduction into Australia (see section 2—Risk Assessment) and both have been subsequently described as environmental weeds in Australia, which changed their classification to reject (above), they are still being promoted. There is currently no mechanism to reassess the risks and benefits of continued planting of species that were introduced prior to the WRA being set up.

Export of Australian Acacia *spp. to Africa and elsewhere*

The potential of certain Australian dry-zone *Acacia* spp. for windbreaks, for fuel, to combat erosion (Hamel 1980) and as human food (e.g. Hamel 1980; Harwood 1994; Harwood *et al.* 1999) has resulted in several species being introduced to semiarid regions of Africa. For example, Hamel (1980) documented the introduction of 16 Australian *Acacia* spp. into Senegal and Harwood (1994) documented trials of three

Australian *Acacia* spp. in semiarid sub-Saharan Africa. There are many examples of woody legumes being useful in these situations (e.g. Hughes and Styles 1989). However, we believe it is misguided to assume that these species will be solely beneficial and more realistic to assume that there is a very high chance that at least some will become serious weeds. It could be argued that introduced woody legume species are less likely to become weedy in Africa than in Australia because it is intended that high rural populations will harvest the trees and/or their seed, thus providing effective biological control. However, earlier introductions to southern Africa have resulted in some of the region's worst weeds. Dennill *et al.* (1999) describe biological control programs conducted against *A. longifolia* Andrews (Willd), *A. pycnantha* Benth., *A. melanoxylon* R.Br., *A. cyclops* G.Don, *A. dealbata* Link and *A. mearnsii* De Wild. Introduced Australian *Acacia* spp. are spreading in Lesotho (Talukdar 1981), where one might expect the demand for firewood to be great. Furthermore, introductions are currently being guided by more scientific methods than in the past, such as bioclimatic modelling to match species to the intended site of introduction (Booth 1988; Booth 1990), so that fewer introductions might be expected to fail.

Final conclusions and recommendations

In Australia, the potential benefits of introducing woody legumes, mainly as fodder crops and as ornamentals, would appear to be fewer than in developing countries, where there may be acute shortages of fuelwood (e.g. Hughes and Styles 1989) and a need for alternative human food sources (e.g. Harwood *et al.* 1999). Furthermore, risks presented by the cost of controlling weeds in areas with low land values and in sparsely populated areas, where weeds can proliferate unmanaged, would appear to be greater in Australia. The detrimental effects of thicket-forming introduced weeds can easily outweigh benefits to the nation from increased stock production from introduced fodder plants and trade in garden ornamentals. Unfortunately, in northern Australia introductions of potential pasture legumes between 1947 and 1985 resulted in more weedy species being introduced than those regarded as useful (Lonsdale 1994). Control costs are often greater than the economic value of the land infested. Therefore, once a weed becomes firmly established over a large area, biological control, which takes time and is expensive to set up and has no guarantee of success, may become the only affordable potential means of control left and the only alternative to abandoning vast tracts of land. We suggest the following:

(i) Novel introductions should be discouraged if there are native species that could perform the tasks for which the exotic species is being imported.

(ii) Legally imported plants are the major source of leguminous weeds in Australia. The WRA can identify the most risky and most benign species. For many species classified as 'evaluate' by the WRA, improvements in the assessment of the risks and the benefits of introduction, based on sound ecological principals and appropriate cost–benefit analysis, and an agreed threshold level of risk are urgently needed.

(iii) Improvements in our ability to predict invasiveness should also enable 'sleeper weeds' to be identified more easily.

(iv) Currently, it seems environmentally and economically prudent to avoid introducing any new plant material, even if this means excluding some beneficial species, until our predictive ability improves.

(v) It is also environmentally and economically prudent to reassess the risks and benefits of continued planting of species such as *Cytisus proliferus* and *Leucaena leucocephala*, which were introduced before the WRA was set up.

(vi) The long-term consequences of supporting the introduction of leguminous species to other countries should be given serious consideration. Potential species should be assessed against a WRA appropriate for those countries. Only the benign species should be introduced.

Acknowledgments

We thank Drs Sue McIntyre and Garry Cook, who commented on an earlier draft of this manuscript and two anonymous referees for their helpful comments.

References

Anon. (1986) 'Taiwan Sugar Research Institute annual report 1985–1986.' (Tainan: Taiwan)

Anon. (1997) 'The National Weeds Strategy: a strategic approach to weed problems of national significance.' (Commonwealth of Australia)

Binggeli P (2000) Time-lags between introduction, establishment and rapid spread of introduced environmental weeds. In 'Proceedings of the III international weed science congress'. 6–11 June 2000, Foz Do Iguacu, Brazil. Manuscript number 8, 13 p. (CD-ROM). (International Weed Science Society: Oxford, MS)

Booth T (1988) Which wattle where? Selecting Australian acacias for fuelwood plantations. *Plants Today* **May–June**, 86–90.

Booth TH (1990) A climatic analysis method for expert systems assisting tree species introductions. *Agroforestry Systems* **10**, 33–45.

Carr GW, Yugovic JV, Robinson KE (1992) 'Environmental weed invasions in Victoria—conservation and management issues.' (Department of Conservation and Environment and Ecological Horticulture: Vic.)

Carter JO, Cowan DC (1993) Population dynamics of prickly acacia, *Acacia nilotica* subsp. *indica* (Mimosaceae). In 'Pests of pastures: weed, invertebrate and disease pests of Australia sheep pastures'. (Ed. ES Delfosse) pp. 128–132. (CSIRO: Melbourne)

Csurhes SM, Edwards R (1998) 'Potential environmental weeds in Australia: candidate species for preventative control.' (Environment Australia: Canberra)

Csurhes SM, Kriticos D (1994) *Gleditsia triacanthos* L. (Caesalpiniaceae), another thorny, exotic fodder tree gone wild. *Plant Protection Quarterly* **9**, 101–105.

Cowley JM (1983) Lifecycle of *Apion ulicis* (Coleoptera: Apionidae), and gorse seed attack around Auckland, New Zealand. *New Zealand Journal of Zoology* **10**, 83–86.

CSIRO (2000) Survey and selection of agents for the biological control of Montpellier broom, *Genista monspessulana.* CRC/DCF project 1999–2000. CSIRO Entomology contracted research report no. 59.

Dennill GB, Donnelly D, Stewart K, Impson FAC (1999) Insect agents used for the biological control of Australian *Acacia* species and *Paraserianthes lophantha* (Willd.) Nielsen (Fabaceae) in South Africa. In 'Biological control of weeds in South Africa (1990–1998)'. (Eds T Olckers, MP Hill) pp. 45–54. (Entomological Society of Southern Africa: Pretoria, South Africa)

Evans JW (1942) The gorse weevil. *Tasmanian Journal of Agriculture* **13**, 15–18.

Evensen CI (1982) Chemical and non-chemical control of *Leucaena*: preliminary studies. *Leucaena Research Reports* **3**, 79–80.

Ewell JJ, O'Dowd DJ, Bergelson J, Daehler CC, D'Antonio CM, Gómez LD, Gordon DR, Hobbs RJ, Holt A, Hopper KR, Hughes CE, LaHart M, Leakey RRB, Lee WG, LL Loope, Lorence DH, Louda SM, Lugo AE, McEvoy PB, Richardson DM, Vitousek PM (1999) Deliberate introductions of species: research needs. *Bioscience* **49**, 619–630.

Forcella F (1985) Final distribution is related to rate of spread in alien weeds. *Weed Research* **25**, 181–191.

Hamel O (1980) Acclimatization and utilization of phyllodineous acacias from Australia in Senegal. In 'Browse in Africa'. (Ed. HN le Houerou) pp. 361–374. (International livestock Centre for Africa: Addis Ababa, Ethiopia)

Harwood CE (1994) Human food potential of the seeds of some Australian dry-zone *Acacia* species. *Journal of Arid Environments* **27**, 27–35.

Harwood CE, Rinaudo T, Adewusi S (1999) Developing Australian *Acacia* seeds as a human food for the Sahel. *Unasylva* **50**, 57–64.

Hill RL (1982) The phytophagous fauna of gorse and host plant quality. PhD Thesis, University of London, UK.

Hill RL, Gourlay AH, Martin L (1991) Seasonal and geographic variation in the predation of gorse seed, *Ulex europaeus* L., by the seed weevil *Apion ulicis* Forst. *New Zealand Journal of Zoology* **18**, 37–43.

Holm L, Doll J, Holm E, Pancho J, Herberger J (1996) 'World weeds: natural histories and distribution.' (Wiley: New York)

Huffaker CB, Dahlsten DL, Janzen, DH, Kennedy GG (1984) Insect influences in the regulation of plant populations and communities. In 'Ecological entomology'. (Eds CB Huffaker, RL Rabb) pp. 659–691. (John Wiley: New York)

Hughes CE, Jones RJ (1998) Environmental hazards of *Leucaena*. *ACIAR* In '*Leucaena*: adaptation, quality and farming systems'. Proceedings of a workshop held in Hanoi, Vietnam, 9–14 February 1998. ACIAR proceedings no. 86 (Eds HM Shelton, RC Gutteridge, BF Mullen, RA Bray) pp. 61–70. (ACIAR: Canberra)

Hughes CE, Styles BT (1989) The benefits and risks of woody legume introductions. In 'Advances in legume biology'. *Monographs of Systematic Botany, Missouri Botanical Gardens* **29**, 505–531.

Ireson JE, Gourlay AH, Kwong RM, Holloway RJ, Chatterton WS (1999) Progress on the rearing, release and establishment of the gorse spider mite, *Tetranychus lintearius* Dufour, for the biological control of gorse in Australia. In 'Twelfth Australian weeds conference proceedings' 12–16 September 1999, Hobart, Tasmania (Eds AC Bishop, M Boersma, CD Barnes) pp. 320–324. (Tasmanian Weed Society: Devonport)

Lazarides M, Cowley K, Hohnen P (1997) 'CSIRO handbook of Australian weeds.' (CSIRO: Collingwood, Vic.)

Lonsdale WM (1994) Inviting trouble: Introduced pasture weeds in northern Australia. *Australian Journal of Ecology* **19**, 345–354.

Lonsdale WM, Harley K, Gillet JD (1988) Seed bank dynamics in *Mimosa pigra*, an invasive tropical shrub. *Journal of Applied Ecology* **25**, 963–976.

Low T (1999) 'Feral future.' (Penguin books Australia Ltd: Ringwood, Vic.)

Mackey AP (1997) The biology of Australian weeds 29. *Acacia nilotica* ssp. *indica* (Benth.) Brenan. *Plant Protection Quarterly* **12**, 7–17.

March N (2000) 'Prickly acacia best practice manual.' (Queensland Department of Natural Resources: Brisbane)

Miller EN (1996) A property level economic assessment of prickly acacia (*Acacia nilotica*) on the mitchell grass downs of Queensland. In 'Proceedings of the eleventh Australian weeds conference', Melbourne, Australia. (Ed. RCH Shepherd) pp. 227–230. (Weeds Society of Victoria: Frankston)

Palmer WA (1996) Biological control of prickly acacia in Australia. In 'Proceedings of the eleventh Australian weeds conference', Melbourne, Australia. (Ed. RCH Shepherd) pp. 239–241. (Weeds Society of Victoria: Frankston)

Parsons WT, Cuthbertson EG (2001) 'Noxious weeds of Australia, 2nd edn.' (CSIRO Publishing: Melbourne)

Patil MS, Kumar HDM (1990) Seed dispersion in Su-babul—a case study. *Indian Forrester* **116**, 598–599.

Paynter Q, Fowler SV, Hinz HL, Memmott J, Shaw R, Sheppard AW, Syrett P (1996) Are seed-feeding insects of use for the biological control of broom? In 'Proceedings of the IX international symposium on biological control of weeds', 19–26 January 1996 (Eds VC Moran, JH Hoffman) pp. 495–501. (University of Cape Town: Stellenbosch, South Africa)

Pheloung PC (1995) A report on the development of a weed risk assessment system commissioned by the Australian Weeds Committee and the Plant Industries Committee. Agriculture Protection Board, WA.

Radford I, Nicholas DM, Brown JR (2001) Assessment of the biological control impact of seed predators on the invasive shrub *Acacia nilotica* (prickly acacia) in Australia. *Biological Control* **20**, 261–268.

Richardson DM, Allsopp N, D'Antonio CM, Milton SJ, Rejmànek M (2000) Plant invasions—the role of mutualisms. *Biological Reviews* **75**, 65–93.

Scott J (1991) *Acacia karroo* Hayne (Mimosaceae), a potentially serious weed in Australia. *Plant Protection Quarterly* **6**, 16–18.

Secomb N (1999) 'Thorny trees in rangelands.' Primary Industries and Resources SA fact sheet. *Agdex* **640**.

Smith NM (1995) 'Weeds of natural ecosystems: a field guide to the environmental weeds of the northern Territory, Australia.' (Environment Centre: NT)

Snoeck J (1971) 'Report on chemical weed control trials in young robusta coffee plants in the Ivory Coast.' Symposium sur le desherbage des cultures tropicales. Antibes 1971. (COLUMA: France)

Syrett P, Fowler SV, Coombs EM, Hosking JR, Markin GP, Paynter QE, Sheppard AW (1999) The potential for biological control of Scotch broom (*Cytisus scoparius* (L.) Link) and related weedy species. *Biocontrol News and Information* **20**, 17–34.

Talukdar S (1981) 'The spread of Australian tree species and their displacement of the indigenous flora of Lesotho.' In 'Abstracts, XIII international botanical congress, Sydney, Australia, August 1981' 110 p.

Thorp JR, Lynch R (2000) 'The determination of weeds of national significance.' (National Weeds Strategy Executive Committee: Launceston)

Williamson M (1996) 'Biological invasions.' Population and community biology series: 15. (Chapman and Hall: London)

Manuscript received 8 February 2002, accepted 27 September 2002