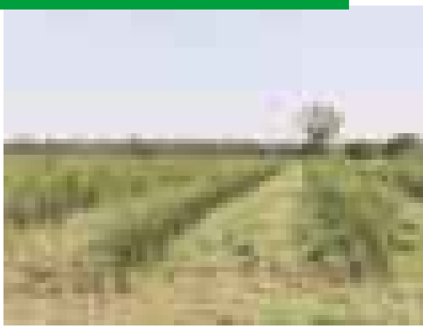
LEUCAENA

Leucaena (*Leucaena leucocephala*) in Queensland

PEST STATUS REVIEW SERIES – LAND PROTECTION

by
C.S. Walton



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1.0 Summary

Leucaena[1] (*Leucaena leucocephala*) is a perennial non-climbing, non-spiny shrub or tree. Native to tropical America, two of the three subspecies now have a pan-tropical distribution facilitated by its use as a fodder, wood source and reclamation species. Described as the 'alfalfa of the tropics', it is considered a versatile and widely used multi-purpose tree legume in the tropics. It is also considered a weed in over 25 countries around the globe.

In Queensland leucaena has become a 'conflict tree', primarily because two morphologically and genetically distinct subspecies are found in the state. *Leucaena leucocephala* ssp. *leucocephala*, was deliberately imported last century as fodder, fuel wood, shade, food and green manure, but is now a visible ruderal weedy shrub, mostly of roadsides, disturbed sites and creeks. Varieties of the second subspecies, *Leucaena leucocephala* ssp. *glabrata*, were developed in Queensland to be used in a productive tree/grass forage production system for cattle production. Work continues to provide varieties suitable to climatic conditions in Queensland and to reduce the impacts of several biological pests that currently constrain plantings in the state. Unfortunately, this subspecies is also showing a tendency to spread from planted sites, and this may be amplified by new varieties. Most people cannot tell the subspecies apart—although there are visible characteristics that can be used—but this means that both subspecies are effectively 'tarred with the same brush' and increased planting of cultivated varieties, along with the spread of older infestations of leucaena, is causing community concern.

Leucaena is essentially a tropical species requiring warm temperatures (25 °C to 30 °C) for optimum growth. It has poor cold tolerance, and significantly reduced growth during cool winter months in subtropical areas. It can grow on a wide variety of deep, well-drained fertile soils; ssp. *leucocephala* favours limestone, other alkaline soils and volcanic soils, while alkaline structured clay soils of the brigalow and softwood scrubs, alluvial and open downs country (the cropping soils) are suitable for ssp. *glabrata*. Currently, most plantings are in the Fitzroy Basin. Leucaena is presently constrained by the leucaena psyllid from areas with high humidity and rainfall over 800 mm.

Based on climate modelling, leucaena has the potential to grow within suitable habitats in coastal and inland parts of Queensland, extending into north-east New South Wales and across the tropical Australian north. Increased planting of leucaena, if not managed by graziers, may mean the species has the potential to

[1] The generic terms leucaena or *Leucaena leucocephala* will be used in this document to denote the whole species, but differentiation will be made between the subspecies when relevant.

colonise much larger areas than currently exist. The majority of problematic infestations are expected to be associated with riverbanks, waste areas and/or roadsides. Although leucaena does not readily invade undisturbed forests or woodlands, it invades riparian areas—both undisturbed and disturbed. Given the high rate of disturbance of water bodies, this species poses a threat to most coastal wetlands and in inland areas.

Reproduction occurs by seeds that can be spread by a number of vectors. Spread is generally slow; most new plants are controlled by grazing animals or grass competition. Seed production may be reduced by the new seed bruchid, but the total impact of this insect is not known. Breeding of shy seeders or sterile lines would also help to reduce the invasive potential of this species in the commercial plantings.

Small infestations of *Leucaena leucocephala* ssp. *leucocephala*, generally between 0.5–5 ha in size, are currently scattered throughout coastal and subcoastal areas of Queensland, often on roadsides and in riparian areas. The source of many of these infestations is not known, and they may date back to the 1920s. The majority of naturalised stands of *Leucaena leucocephala* ssp. *glabrata* originate from nearby grazing properties and have occurred over the past twenty years. To date, an estimated 1 000–9 000 ha of Queensland has been infested by leucaena, mostly *Leucaena leucocephala* ssp. *leucocephala*, and approximately 100 000 ha of *Leucaena leucocephala* ssp. *glabrata* have been planted.

Leucaena offers an economic benefit to the Queensland cattle industry. Live weight gains of 0.7–1.70 kg/head/day have been achieved in leucaena/grass pastures. This growth is comparable to, or higher than, grazing on buffel grass alone (0.47–1.30 kg/head/day) and to grain-fed lot feeding (1.41 kg/day). Annual benefits to the state from the current leucaena production systems and area are estimated at $14 million.
Control methods are available for leucaena, and control of infested sites is possible. The expenditure required to control the plant in areas where it is not wanted is currently minor, but will increase with more spread. Using a registered herbicide, control costs for treatment of dense leucaena infestations are estimated to be about $1,000 per hectare, although most infestations are made up of scattered plants and small stands, and much of the cost relates to the time taken to find and treat the scattered plants. The cost of immediate control of all infested sites in Queensland would be between $5.9 and $14.7 million, and would need to include ongoing, but cheaper, seedling control.

Enforced control on grazing lands in the state would be opposed by most graziers. Responsible management of leucaena pastures is being promoted under a 'code of good management practice for livestock' developed by farmers who cultivate leucaena in Queensland. This should reduce spread from planted areas substantially. Material found outside cultivation, regardless of the subspecies, should be removed if it is affecting the environmental or social values of the site.

2.0 Taxonomic status

Leucaena leucocephala (Lamark) de Wit 1961 is the most economically important species in the genus *Leucaena*, which is in the tribe Mimoseae of the subfamily Mimosoideae of the family Leguminosae (Fabaceae). Closely related genera are *Desmanthus, Calliandropsis* and *Schleinitzia*. There are no native species of this genus in Australia (Cowan 1998).

Leucaena is a genus of twenty-two species—six intraspecific taxa and two named hybrids (Hughes 1998c). Hughes reviewed the taxonomy of the genus in *Leucaena: Genetic Resources Handbook* (1998a) and in a taxonomic monograph (1998b). The current species descriptions are based on a review of morphological data gathered from over 2 800 botanical specimens and analysed using molecular data.

The complex taxonomic history of *Leucaena leucocephala* is covered by Hughes (1998c). Synonyms include *Mimosa glauca* sensu L. 1763; *Mimosa leucocephala* Lamark 1783; *Acacia leucocephala* (Lamark) Link 1822; *Leucaena glauca* (sensu L. 1763) Benth 1842; and *Leucaena glabrata* Rose 1897. This synonym list reflects the history of the genus Leucaena. Bentham split the genus Leucaena from the genus Acacia in 1842, while many Acacia species were first named in the genus Mimosa (Isely 1970).

Leucaena leucocephala has three subspecies. The two main variants are the 'common' type, which is shrubby, low-growing and highly branched, and the 'giant' type, which is arborescent (tree-like in growth), erect, and lightly branched (Zárate 1987). These variants were formally recognised as distinct subspecies *leucocephala* and *glabrata* by Zárate in 1987. Isozyme analysis has confirmed this intraspecific variability at a genetic level (Harris et. al. 1994a). A third subspecies was recently discovered in northern Guatemala and named *ixtahuacana* (Hughes 1998c).

This well-cultivated species has many common names—including cowbush (Bahamas); epil epil (Thailand); lead tree (Jamaica); wild lead tree (United States); wild tamarind (Seychelles); faux-acacia (France); faux-mimosa (New Caledonia); and stuipboom (South Africa) (PIER 2002, Legume WEB 2002, WESSA 2002). The common name used in Hawaii, 'koa haole', translates to 'foreign koa'; Hawaiian koa is *Acacia koa*, a large leguminous tree. All leucaena varieties developed in Hawaii are named K8, etc., with the 'K' denoting koa (NFT 1990). Australian common names used across the states include leucaena, lead tree, Vi Vi and coffee bush.

2.1 Description

Leucaena is a perennial, non-climbing, erect, thornless shrub or small tree, 5–10 m (rarely 20 m) tall. Fast-growing, with a trunk 5–50 cm in diameter, the bark on young branches is mid grey-brown with shallow orange vertical fissures, while older branches and bole are rougher, dark grey-brown with a deep red inner bark (Hughes 1998a). Trees can live from 20 years to more than 50 (Hughes 2002).

The taproot is long, up to 5 m, strong and well developed. In shallow soils, roots have been observed to branch and grow laterally at 30 cm, due to clay layers (Brewbaker 1987). Root hairs are poorly developed, and the plant appears to rely heavily on mycorrhizal associations for nutrient uptake, vesicular/arbuscular mycorrhiza and nodulation with *Rhizobia*, at least during seedling development (Brandon and Shelton 1993).

The evergreen bipinnate leaves are arranged alternately along the stem. Leaf petioles are 10–25 cm long, with 4–9 pairs of pinnae per leaf, and 13–21 pairs of leaflets per pinnae (figure 1). This species is facultatively deciduous; it can prematurely shed leaflets in response to environmental stress (Rosecrance 1990). The leaflets are grey-green, sessile, 1–2 cm long, less than 0.3 cm wide, and narrowly oblong to lanceolate in shape. The leaves produce an odour when crushed. All leaves have glands on the petiole, called 'extrafloral nectaries' because they occur on the leaf and secrete nectar. The petiole gland of *Leucaena leucocephala* occurs singly and is cup-shaped, sessile (not stalked) and concave, with a broad pore.

The individual flowers are small and cream–white, with ten free stamens per flower and hairy anthers. These small flowers are arranged 100–180 per dense, globe-like head, 12–21 mm diameter, on the end of long stalks. Flowers are hermaphroditic, largely self-fertilised and self-compatible. The flower heads are in groups of 2–6. Flowers occur on actively growing young shoots, with the leaves developing at the same time as the flowers.

The fruit pods are flat and thin, with a raised border. Starting green, they become dark brown and hard. They are 11–19 cm long and 1.5–2.1 cm wide. In *Leucaena leucocephala* they occur in crowded clusters of 3–5 to 20–45 per flower head. The pods dehisce (open when ripe) at both sutures. Seeds are copiously produced, 8 (ave. 18) to 30 per pod. The seeds are oval, flattish, and brown, 6.7–9.6 mm long and 4–6.3 mm wide. The medium sized seeds weigh 15 000–20 000 seeds/kg (Duke 1983, Hughes 1998a, Hughes 2002).

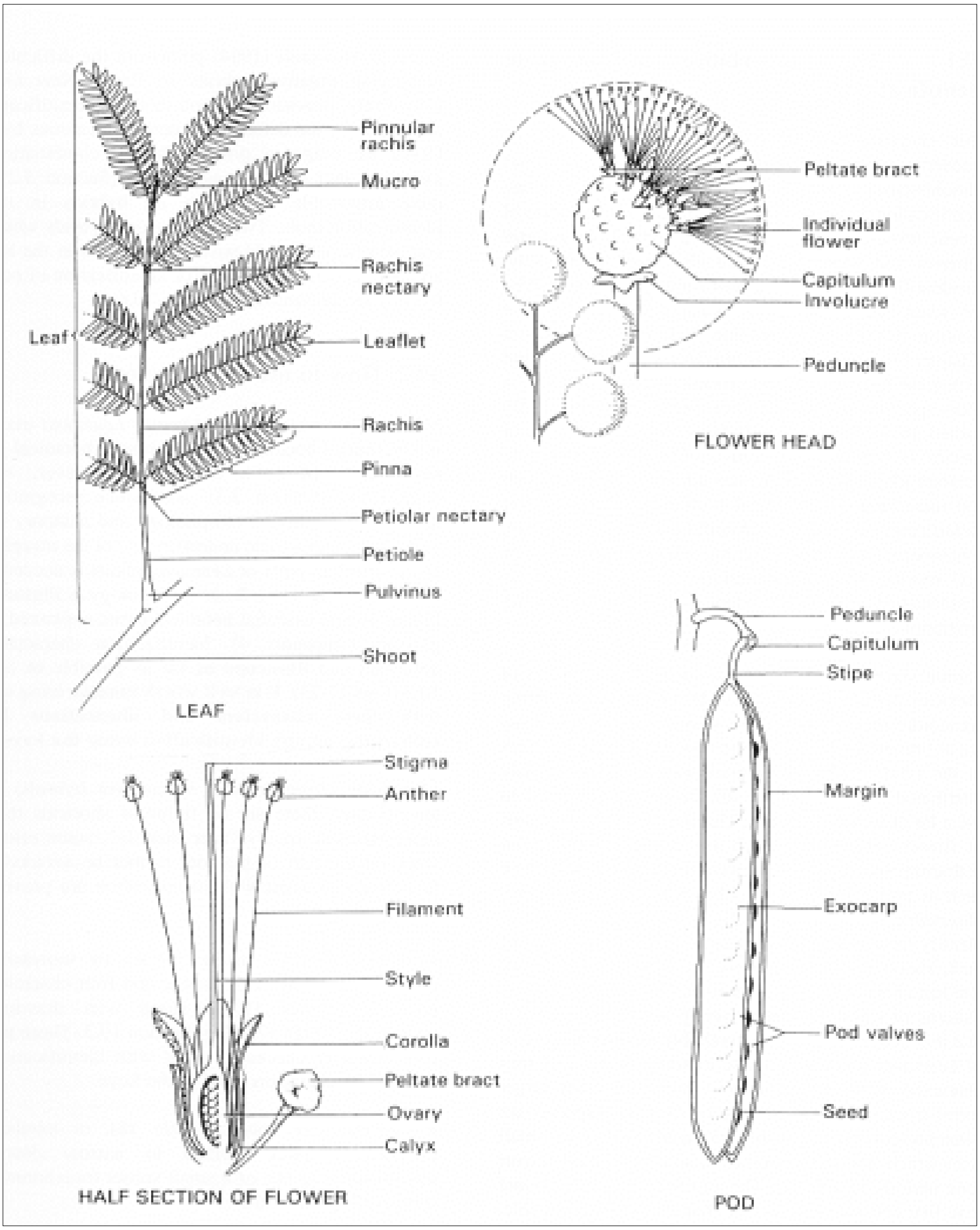

Figure 1: Morphological characters of Leucaena
(Reproduced with permission from Hughes 1998a)

Leucaena leucocephala is distinguished from other species in the genus by its intermediate sized leaflets and large pods in crowded clusters. Most species in the genus have only 1–4 pods per flower head (Hughes 1998a).

Hughes (1998a) separates the subspecies of *Leucaena leucocephala* by a number of characters:

Leaves >19 cm long and >12 cm wide, pinnular rachis >8 cm long, leaflets 16–21 mm long, average of 7 pairs of pinnae per leaf, 16 pairs of leaflets per pinnae; flower heads >18 mm in diameter, with >120 flowers per flower head; pods 12–19 cm long and 18–21 mm wide. New growth is glabrous (hairless). Trees grow to 8–20 m.

ssp. *glabrata*

Leaves <20 cm long and <12 cm wide, pinnular rachis <8 cm long, leaflets 9–13 mm long; flower heads 13–17 mm in diameter, with <125 flowers per flower head; pods 9–13 cm long and 13–18 mm wide. Young shoots, leaves and pods (whole or on margins) covered with dense whitish velvety hairs. Trees grow to 3–8 m.

ssp. *leucocephala*

Young shoots, leaves and pods glabrous.

ssp. *Ixtahuacana*

2.2 Distinguishing characters

Leucaena is similar in form to, and may be confused with, a number of other widespread or commercially grown leguminous species found in Queensland—Easter cassia (*Senna pendula* var. *glabrata*), *Acacia* sp. (*Acacia farnesiania*), parkinsonia (*Parkinsonia aculeata*), *Desmanthus virgatus* and albizzia (*Albizzia lebbek*) (Hughes 1998a). A program to treat leucaena in the Whitsunday Shire (Anon 2002b) has found that it may be confused with two native members of the family Mimosaceae—Mackay cedar (*Paraserianthes toona*), a rainforest tree with ferny leaflets; and forest sirus (*Albizzia procera*), a coastal tree with similar brown pods (Cowan 1998).

Leucaena is distinguished from all other mimosoid legumes by two diagnostic characters—first, its hairy anthers, which are easily visible with a hand lens; and second, its smooth pollen surface, which is finely perforated and lacking ornamentation. A number of other easier-to-use, but non-diagnostic, features present in all members of the genus are: shoots lacking thorns or spines; leaves always with petiole glands; flowers in a globose head, with more than 30 flowers per head; pendulous and more or less flattened dehiscent pods; and seeds with a glossy reddish chestnut brown seed coat. If a specimen has any of the following characters then it is not leucaena: thorns or spines (*Acacia, Mimosa, Prosopis*); leaves lacking petiole glands; flowers arranged in spikes; fewer than or more than 10 stamens (*Acacia*); stamens fused into a tube (*Albizzia, Calliandra*); flower heads with mixed colours (*Desmanthus*); or thickened, woody, indehiscent pods (other legume genera) (Hughes 1998a).

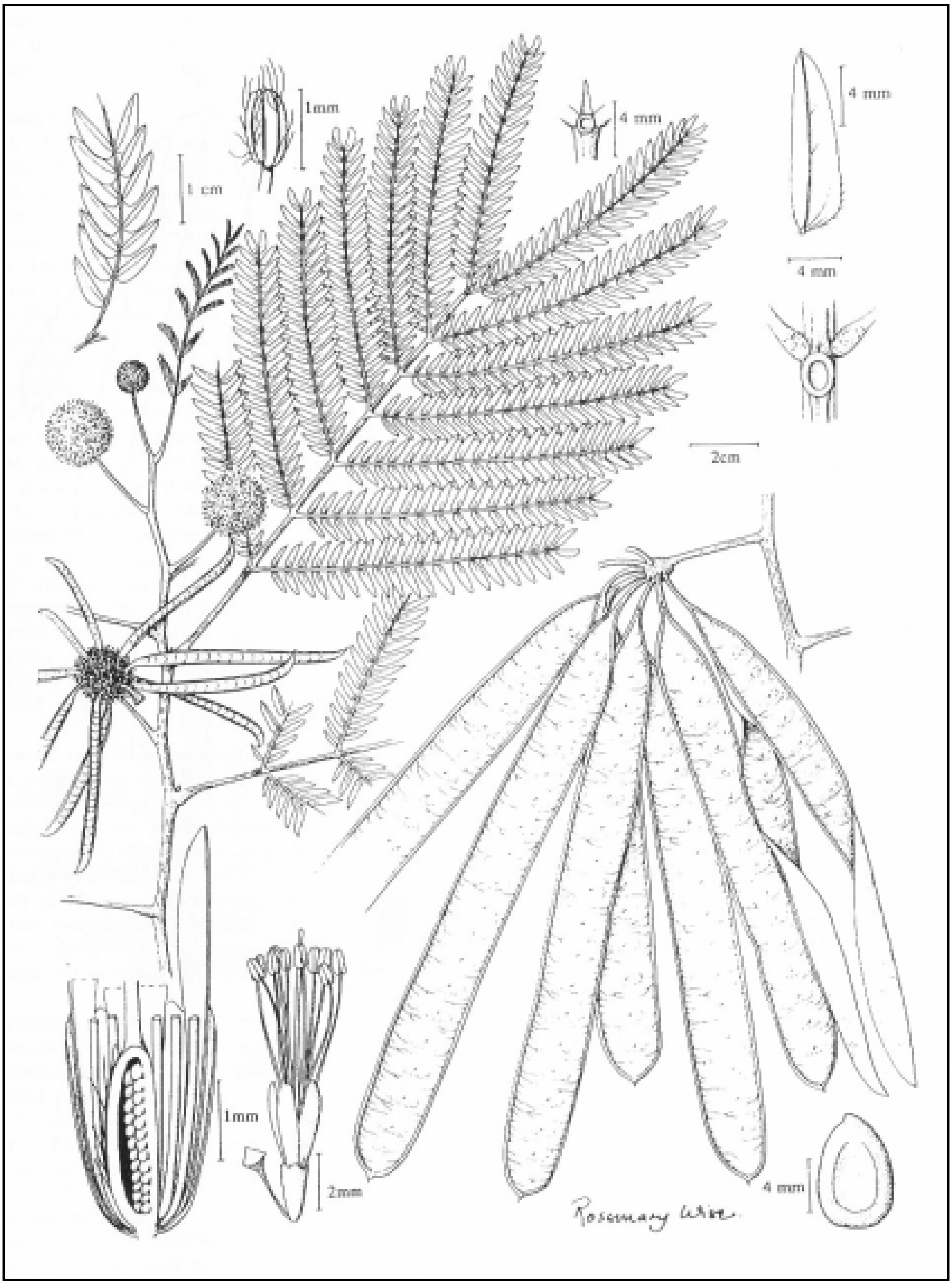

Figure 2: Morphological characters of *Leucaena leucocephala* ssp. *glabrata*
(Reproduced with permission from Hughes 1998a)

3.0 History of introduction and spread

Leucaena leucocephala ssp. *leucocephala* is first recorded in Australia at the end of the 19th century, imported from New Guinea or Fiji (Hutton and Gray 1959). The first plants collected in Queensland were from Herbert River (1921), Mourilyan (1923) and Brisbane (1924) (Queensland Herbarium 2002). In the annual report of the Department of Agriculture and Stock 1936–37, Mr Pollock states that *Leucaena glauca* (a synonym of *Leucaena leucocephala* ssp. *leucocephala*) was present as a weed in north Queensland for at least 17 years. He noted infestations of the plants, known as Vi Vi, at Macknade on the Herbert River, and at Bowen (Anon 1937).

It is not known why *Leucaena leucocephala* ssp. *leucocephala* was first introduced into Queensland. It is possible that it was imported for shade, soil stabilisation, or as an ornamental—roles promoted in Asia at the time (Brewbaker 1987). It was recorded as having been planted in the Brisbane City Botanic Gardens in 1932 (Queensland Herbarium 2002). Material from naturalised populations of *Leucaena leucocephala* ssp. *leucocephala* from Bald Hills (Brisbane) and Darwin were studied in the early pasture trials in the 1950s at Samford, but rejected due to high mimosine content (Hutton and Gray 1959).

Leucaena was promoted as a fodder tree in the leaflet *Use of fodder trees and shrubs* (Everist 1969), and it is possible that this is one of the first recommendations for the cultivars of subspecies *glabrata* (cultivars *Peru* and *El Salvador*) released in northern Australia in 1962. This followed selection, breeding and agronomic evaluation trials in various sites in Queensland started in 1954 (Hutton and Gray 1959). *Peru*, for example, was first planted in the Burnett region in the 1960s (Quirk 1994); however, adoption was slow during the 1960s to 1970s, as legume-based sown pastures were equally productive, less expensive to establish, and easier to manage (Lefroy 2002). Planting of the ssp. *glabrata* varieties expanded during the 1970s to 1980s, with a slump in cattle prices, reduced applications of superphosphate, and subsequent decline in productivity of sown pastures. In 1982, the DHP-degrading bacteria were introduced into Australia, removing the toxic effects of high leucaena diets to cattle. By 1990, 16 000 ha of leucaena was planted in central Queensland and a further 5 000 in other parts of northern Australia (Wildin 1994). This had increased to 40 000–50 000 ha in 1996 (Shelton 1996) and 60 000–80 000 in 2000 (Middleton 2000). The area of *Leucaena leucocephala* ssp. *glabrata* in Queensland was estimated by the Leucaena Network to be approaching over 100 000 in 2002 (McLaughlin, pers. comm., July 2002).

Current commercial cultivars are *Peru*, *Cunningham* (a cross between *Peru* and *El Salvador*) and *Tarramba* (K636) (Hughes 1998a, Oram 1990). These cultivars represent only a small subset of the collected materials and variation of this species. Trials are currently underway in Queensland on an interspecific cross KX2 F1 hybrid (*L. pallida* K748 x *L. leucocephala* ssp. *glabrata* K636), which has superior psyllid resistance and improved cold tolerance to *Tarramba* (Mullen et al. 1998b, Mullen and Shelton 1998). Release of this variety may see an expansion of this crop into cooler areas, and replanting on the coastal areas where leucaena growth is currently affected by the psyllid. Selection of shy seeding, self-incompatibility and delayed flowering in lines is noted as a way to reduce the risk posed by this new variety (Leucaena Network 2001), but it is not clear if this is a major priority of the current research project.

4.0 Current and predicted distribution

4.1 Distribution—overseas

Leucaena leucocephala is native to Mexico and Central America. The native distribution of the three subspecies of *Leucaena leucocephala* is mostly distinct (figure 3) (Hughes 1998a). *Leucaena leucocephala* ssp. *leucocephala* is found mainly in the Yucatan. Outlying occurrences occur north of Veracruz and, infrequently, across the Isthmus of Tehuantepec into Oaxaca. The precise native range of *Leucaena leucocephala* ssp. *glabrata* is blurred; however, it is widespread across much of Mexico and Central America, as far south as Panama. Subspecies *ixtahuacana* has a small, localised distribution in two valleys in northern Guatemala and southern Mexico.

Leucaena leucocephala ssp. *leucocephala* has a long history of deliberate transportation and spread, and is now one of the most widely naturalised of the non-European crop plants (National Academy of Sciences 1984). It may be naturalised in over 105 countries throughout the world's subtropics and tropics (table 1). It is possibly growing on up to 5 million hectares (Binggeli 1997). The Spaniards used this species as fodder and bedding for animals shipped from Mexico, thus introducing leucaena to the Philippines and South-East Asia after 1600 (Brewbaker and Sorensson 1990). Much of the material outside Central America is subsequently a single genotype, suggesting continual human movement of the original material from Mexico (Harris et. al. 1994b). *Leucaena leucocephala* ssp. *leucocephala* spread across the Pacific during the 1800s, being recorded in New Caledonia in 1855 (Sarrailh et. al. 1996), Hawaii in 1864, and the Marquesas Islands prior to 1893 (Bingelli 1997). By the late 19th century its value as shade for coffee and cocoa plantations in Asia saw it promoted further (Brewbaker and Sorensson 1990).

Blurred by indigenous food cultivation, the native distribution of *Leucaena leucocephala* ssp. *glabrata* remains unknown. It is now widespread within Mexico and Central America, where it is common in backyards, street plantings and orchards. Cultivars of this subspecies were widely introduced and planted across the tropics in the 1970s and 1980s, mostly promoted for use in reforestation programs by international agencies and non-government organisations. It is now very widely cultivated throughout the tropics and subtropics, and its worldwide distribution may now equal that of subspecies *leucocephala* (Hughes and Jones 1998, Shelton and Brewbaker 1994).

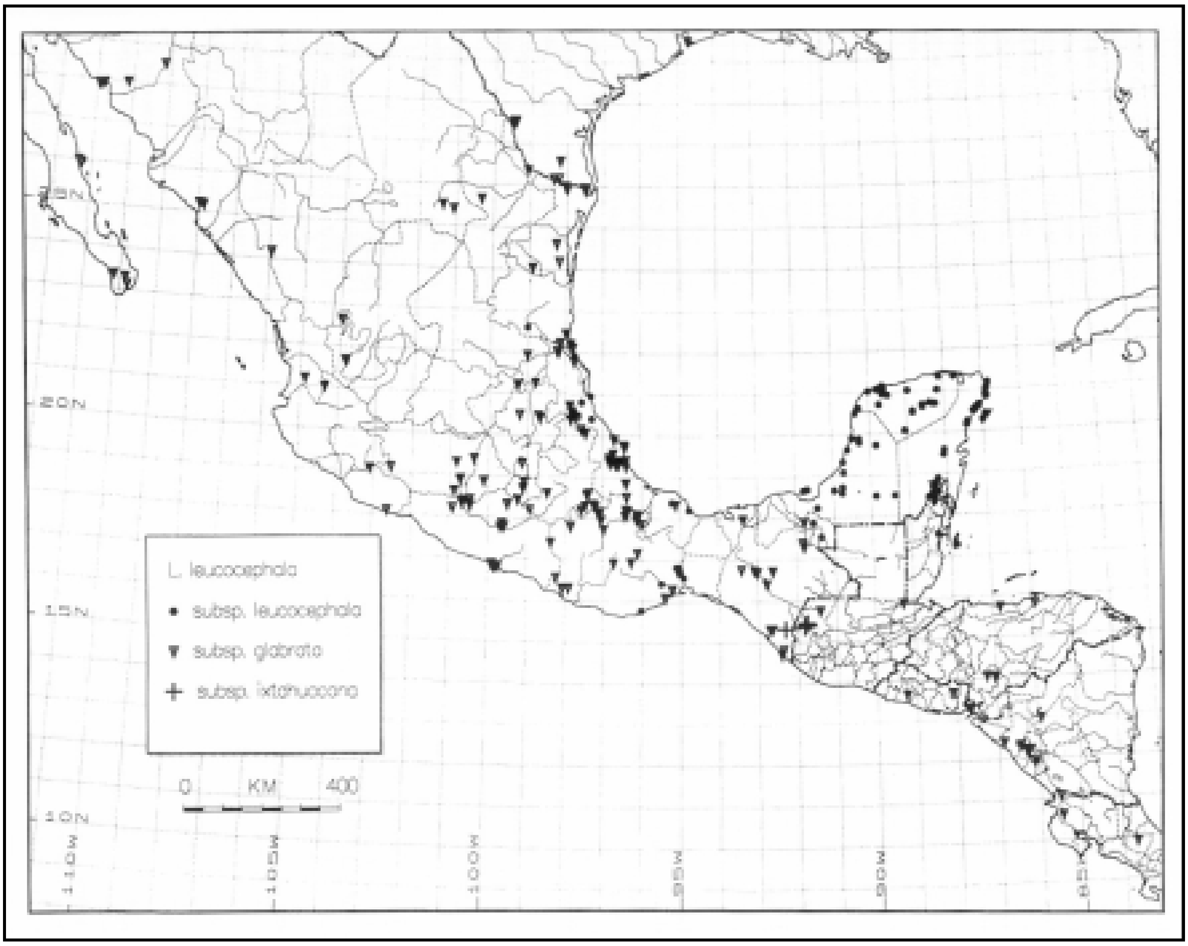

Figure 3: Native distribution of the three *Leucaena leucocephala* subspecies
(Reproduced with permission from Hughes 1998a)

4.2 Weed history—overseas

It is important to note that most records of weediness of *Leucaena leucocephala* are likely to be for *Leucaena leucocephala* ssp. *leucocephala*, which is widespread and known as a weed in over 25 countries across all continents, except Antarctica (table 1). In its native range, and across the globe, *Leucaena leucocephala* ssp. *leucocephala* is found outside cultivation in open (often coastal or riverine) habitats, semi-natural and other disturbed or ruderal sites (roadsides, abandoned fields and waste ground). It is occasionally found in agricultural land, generally spreading from shelterbelts of hedges into fallow land (e.g. in India), although only occurring within 40 m of parent plants (Bingelli 1997). It is not known to have invaded undisturbed closed forests.

In their review of the environmental hazards of leucaena, Hughes and Jones state that *Leucaena leucocephala* ssp. *leucocephala* is an important weed, but by no means the worst weed in the world (Hughes and Jones 1998). The IUCN's Invasive Species Specialist Group listed leucaena in its list of 100 worst invasive organisms (Lowe et al. 2000). The primary focus of this group is on invasive species that cause biodiversity loss, with particular attention to those that threaten oceanic islands

(Hughes 2002). Leucaena is among the most prevalent invasive species in the Pacific and is considered a serious problem in several islands, including Tonga and Hawaii (PIER 2002). Some Pacific islands have taken action to prevent spread of this species; for example, it is an offence to transport seed between islands in Vanuatu (Shelton et al. 1991).

Table 1 The global distribution of *Leucaena leucocephala*
(Status of the species: N = native, I = introduced, U = uncertain[1], W = recorded as a weed)
([1] Legume WEB 2002, [2] Holm et al. 1979, [3] Plants 2002, [4] PIER 2002, [5] Hughes and Jones 1998, [6] Binggeli 1997, [7] G Luckhurst, pers.comm., May 2002).

Region	Countries
Africa	Angola, Burundi, Cape Verde Is, Cameroon (W)[5], Chad, Djibouti, Egypt, Equatorial Guinea, Ethiopia, Ghana (W)[2], Guinea, Guinea Bissau, Ivory Coast, Kenya, Liberia, Malawi, Mali, Mozambique, Niger, Nigeria, Sao Tome & Principe, Senegal, Sierra Leone, Somalia, South Africa—escaping in subtropical areas of KwaZulu-Natal (W)[5], Sudan, Tanzania (W)[5], Togo, Uganda, Zaire (W)[2] and Zimbabwe (all I)
Asia	Bhutan, Cambodia, India, Indonesia (W)[5], Iraq, Irian Jaya, Laos, Malaysia (W)[5], Pakistan, Philippines (W)[5], Sri Lanka, Taiwan, Thailand, Vietnam and Japan—Ryukyu Is. (all I)
Australasia	Australia (W)[5], Papua New Guinea (New Guinea, New Britain and Bismarck Archipelago) (W)[5] (all I)
Caribbean	Bahamas (W)[5], Bermuda, Cayman Is, Cuba, Dominican Republic, Grenada, Haiti (W)[5], Jamaica (W)[2], Puerto Rico (W)[5;6], Trinidad (W)[2] and Virgin Is (all I)
Central America	Belize (N), Costa Rica (I), El Salvador (U), Guatemala (U), Honduras (I), Mexico (North & Central) (N), Mexico (South East) (N), Nicaragua (I) and Panama (I)
Europe	Madeira Island (Spain) (W) [7]
Indian Ocean	Aldabra, Chagos Archipelago, Madagascar, Mauritius (W)[5], Reunion Is. (W)[5], Rodrigues Is. (W)[5], Seychelles and Christmas Island (all I) [4]
Middle East	Saudi Arabia and Yemen (all I)
North America	United States—Arizona, Georgia, Virgin Islands, Texas (W)[5], Florida (W) [3] and Hawaii (W) [3] (all I)
Pacific Ocean	American Samoa (Tutuila, Ofu, Olosega, Ta'u), Cocos (Keeling) Islands, Christmas Island (Pacific Ocean), Commonwealth of the Northern Mariana Islands (Rota, Saipan, Tinian), volcanic Northern Marianas (Agrihan, Pagan, Sarigan), Cook Islands (Rarotonga), Federated States of Micronesia (Chuuk (seen on Weno, Tol and Fefan; probably on other islands as well), Kosrae, Pohnpei, Yap, Caroline outer islands (Ulithi, Satawal, Lukunor)), Fiji (W)[2], French Polynesia (Tahiti, Moorea, Mopelia Atoll, Huahine, Raiatea, Tupai, Maupiti, Marquesas (W)[6] and throughout the islands), Galapagos Islands, Guam (W)[5], Hawai'i (W)[5], Kiribati (Tarawa), Marshall Islands (Ailuk, Enewetak, Jaluit, Kwajalein, Likiep, Majuro, Utirik), Nauru, New Caledonia, Niue, Palau (Koror), Pitcairn Island, Samoa, Solomon Islands, Tonga (Tongatapu, 'Eua, Vava'u, Lifuka/Foa, Ha'ano, 'Uiha, Nomuka and throughout Tonga) (W)[5], Tuvalu, Vanuatu (W)[5], Wake Island and Wallis and Futuna Islands[4] (all I)
South America	Argentina, Bolivia, Brazil—Fernando de Noronha archipelago (W)[5], Chile, Colombia, French Guiana, Guyana, Peru, Surinam and Venezuela (all I)

Leucaena leucocephala ssp. *leucocephala* forms dense monospecific thickets, which, although relatively open, are often free of other vegetation and threaten endangered species. For example, it is classified amongst the 12 worst pests out of 86 alien species in Hawaii (Cronk and Fuller 1995) and is reported to be replacing native *Metrosideros–Diospyros* open forest on Maui. In Brazil, it is competing with native island endemics (*Ficus* and *Oxalis*), while in Ghana, rare endemic plant species occur in areas invaded by both *Leucaena leucocephala* and neem (*Azadirachta indica*) (Hughes and Jones 1998). In the Erap Valley of Papua New Guinea it forms monospecific stands in river valleys, replacing native riparian vegetation (G Werren, pers. comm., September 2002).

Case study: Guam

The lowland vegetation of many Pacific islands is now entirely dominated by introduced species, of which leucaena may be one (Bingelli 1997).

Guam, like other Pacific islands, was seeded with *Leucaena leucocephala* ssp. *leucocephala* after World War 2 to rehabilitate sites damaged during the war, although this species was present on the island from at least 1905. It has spread to all limestone soils and follows road construction using limestone, to highly acidic volcanic soils at the southern end of the island.

As an abundant species, leucaena has multiple uses—including as firewood, stakes for vegetable crops, and hedgerows. It is also an excellent nurse crop for establishment of native forest habitat/plant communities if managed in this way; If it is not controlled in revegetation sites, however, *Leucaena leucocephala* ssp. *leucocephala* crowds out the developing species, stopping the re-establishment of the multispecies, multistoried forest on Guam (B Lawrence, pers. comm., December 2000).

The weediness of *Leucaena leucocephala* ssp. *leucocephala* is attributed to its abundant, precocious and year-round seed production, build-up of a substantial seed bank, lack of pollinator specificity, ability to resprout after cutting or burning, drought tolerance, ability to produce thickets, and self-compatibility, meaning that it can spread from an isolated tree (Hughes and Jones 1998).

To date, *Leucaena leucocephala* ssp. *glabrata* has not been recorded as weedy; however, it must be noted that many people cannot tell the two subspecies apart. Most records of weediness are listed at the species (not subspecies) level, and it is also likely that the two subspecies now occur in the same places across the globe. Shelton (1996) states that *Leucaena leucocephala* ssp. *glabrata* variety *Tarramba* has less weed potential than subspecies *leucocephala*, as it is less precocious, is highly palatable to stock and does not set significant seed until the second year. Hughes and Jones (1998) suggest that these differences will not reduce the weed potential of this subspecies, especially in the long term. They suggest that the lack of international weed records may be a product of the short history of use of this subspecies—3 decades, compared to over 150 years of *Leucaena leucocephala* ssp. *leucocephala* worldwide.

Further concerns posed by *Leucaena leucocephala* subsp. *glabrata* are that, if not well-managed, the taller stature of the trees increases the risk of seed production out of reach of cattle, and the wider soil and climate tolerances extend its habitat range in Queensland away from the coast.

Four other species in the genus, *L. lanceolata*, *L. pulverulenta, L. shannonii* and *L. trichodes*, are known to demonstrate weedy tendencies (Hughes and Jones 1998), spreading and colonising ruderal sites such as roadsides and abandoned fields within their native ranges.

Hughes and Jones (1998) note that spontaneous hybridisation between introduced species is a possible additional hazard posed by leucaena. To date, only the two subspecies of *Leucaena leucocephala* have been widely cultivated in Queensland, but it is possible that low levels of crossing between these subspecies is already occurring in the field, possibly obscuring the differences between them. The introduction of new species, or interspecies crosses to Queensland, such as the *L. leucaena* x *L. diversifolia* hybrid promoted as K3 by the Hawaiian researchers, could increase the risk of fertile crosses with the material already in the state. K3 is apparently self-fertile, can be extremely seedy, and could pass these qualities on to the varieties currently planted in Queensland if it was planted alongside them.

4.3 Distribution—Australia

Leucaena leucocephala ssp. *leucocephala* is found at sites along coastal northern Australia and it has a long history of occurrence in riparian areas and disturbed sites. *Leucaena leucocephala* ssp. *glabrata* varieties have been planted in both coastal and inland areas since releases in the 1970s, and extend from the Ord River in Western Australia to south-east Queensland.

In Western Australia, *Leucaena leucocephala* ssp. *leucocephala*—lead tree, can be found near wetlands and riverine sites in Halls Creek, Kununurra (station homesteads and creeks), Cockatoo Island (around the old tailings area), Christmas and Coolan Islands, Broome and Derby (A Mitchell, pers. comm., June 2002, Hussey et al. 1997, Cowan 1998).

Leucaena leucocephala ssp. *glabrata* has been planted for pasture production in the Ord River Irrigation Area of the Kimberley (Larsen et al. 1998) since CSIRO plantings in the 1970s. After the discovery of the DHP destroying bacteria an industry began to develop, and over 2 000 ha of cv. *Cunningham* was under grazing in the area (Petty

et al. 1994). This area has been reduced in recent years, with several properties removing the planted trees and changing from grazing to horticultural crop production. This subspecies has spread over 60 km along the Ord River, between the Ord River Dam and the Diversion dam and downstream from the Diversion dam, to create dense riparian thickets (N Wilson, pers.comm., September 2002). Although it is not known if flying foxes eat the seed, they have taken to roosting in these trees.
In the Northern Territory, *Leucaena leucocephala* ssp. *leucocephala* is known as coffee bush and is probably the most abundant woody weed. It can be found in and around many coastal communities including Darwin, Nhulunbuy, Yirrkala and Howard Island (Smith 1995, 2002). It can be found in a high number of catchments—Adelaide, Blyth, Buckingham, Daly, East Alligator, Finnis, Liverpool and Moyle rivers (Smith 2001). In Darwin it is found on coastal cliffs, the edge of mangroves, and along most riparian systems. Control work on this species has increased in the last decade. The Ludmilla Creek Landcare Group, for example, transformed a 0.8 ha leucaena thicket, Coffee Bush Corner, into a native monsoon forest in less than three years (Northern Territory Government 2002a). This public site has become a major demonstration site, showing the ability of the community to make a biodiversity change in a short period. This species also makes an impact on indigenous communities—a project at Maningrida rehabilitated 'Djomi', a major sacred site infested with leucaena and other weeds (Northern Territory Government 2002b). Within a list of the major weeds on Department of Defence lands around Darwin, leucaena is the only non-declared species and is considered a longer-term problem due to the seed bank (P Jeffries, pers. comm., September 2002).

Some commercial plantings of *Leucaena leucocephala* ssp. *glabrata* can be found in the Northern Territory, on Tipperary Station, south of Litchfield National Park, near Daly River Mission, and near Fogg Dam past Humpty Doo. These plantings have not been seen to spread (C Wilson, pers. comm., June 2002).

Leucaena is recorded in New South Wales on Norfolk Island (Swarbrick and Skarratt 1994), but residents state it is not yet invasive (Queensland Herbarium 2002), and from Windsor, near Sydney (Cowan 1998). Leucaena is reported to be spreading in riparian areas in the Northern Rivers region of the state, including along the Clarence River in Grafton (R. Ensby, pers. comm., July 2002). It is possible that the latter material is *Leucaena leucocephala* ssp. *glabrata,* as it has only been noted in the last decade and small plantings have been trialed in the area.

4.4 Distribution—Queensland

No formal mapping for this species has been carried out in Queensland to date. A review of local governments by McNeill (Shelton et al. 2001) reported that either planted or weedy leucaena was found in 60 of the 83 shires that returned the questionnaire. The survey carried out as part of this report recorded leucaena in a further 19 local government areas across the state. The only parts of the state without leucaena were shires of the Lake Eyre Basin, some Gulf shires, and shires on the New South Wales border. The McNeill study estimated 1 000–9 000 ha in Queensland infested by leucaena and approximately 100 000 ha planted.

Leucaena has been collected from naturalised sites along coastal Queensland—from the Torres Strait Islands to northern New South Wales (Queensland Herbarium 2002). Most of these coastal infestations are *Leucaena leucocephala* ssp. *leucocephala*. Nineteen shires reported that leucaena infestations had existed in their shire for 10–50 years (Shelton et al. 2001), and it is likely that this represents the historical spread of *Leucaena leucocephala* ssp. *leucocephala* in the state.

Increasingly, leucaena is being found naturalised in inland sites in Queensland and in new sites in coastal areas. Eighteen shires responding to the McNeill survey noted leucaena infestations were less than 10 years old, which suggests either spread from the planted cultivars or spread from older weedy stands. The recent DNA study by McNeill (Shelton et al. 2001) found that a number of leucaena infestations in larger population centres—Cubberla Creek (Chapel Hill) in Brisbane, Townsville and Rockhampton—includes plants of both subspecies, as did infestations near plantings. To confirm identification of the subspecies in all infested areas, a thorough sampling of all stands in Queensland using taxonomic and/or genetic studies would be required.

Growers report that most grazed *Leucaena leucocephala* ssp. *glabrata* plots have not resulted in spread (Shelton et al. 2001). An example is Meadowbank Station (Herberton Shire) where, after 37 years, no seedlings have established outside a fenced trial plot; seedlings outside the plot are controlled by grazing stock (Kernot 2000). Nevertheless, sightings of the spread from planted ssp. *glabrata* in Queensland have been provided by Jones and Jones (1996), and McNeill (Shelton et al. 2001), who respectively recorded thickening up of stands of planted varieties over many years, and both inter-row and out-of-paddock spread after twenty years. In Broadsound and Sarina in the last 5 years, trial leucaena pastures have been seen to spread to streams and creeks within the proximity of paddocks (C Chopping, pers. comm., August 2002). The survey by McNeill (Shelton et al. 2001) also found cultivated varieties growing in a steep and eroded drainage line within the government research station in Gayndah and along roads away from the station. During the development of this document the author personally noted seedling establishment on roadsides or in disturbed sites outside planted paddocks near Rockhampton, Emerald, Rolleston (Bauhinia), Esk and Thuringowa.

A survey of local government pest management plans (table 2) determined that 18 local governments consider leucaena a pest plant worth listing in their plans. The level of action endorsed in these documents ranges from eradication, to monitoring current infestations. Most shires currently invest only small amounts for the control of environmental weeds. As leucaena is considered less important than declared weeds and, in some cases, is one of many such species listed, little money is likely to be directed to this species in most shires.

Table 2 The control activity on and priority given to leucaena by local government in Queensland (Source: Local government pest management plans)

Shire	Current actions and priority
Barcoo	Recently added to the plan, which aims to prevent establishment of this species along the shire's river systems.
Burdekin	Considered an unsightly weed of roadsides and disturbed areas in the urban areas of the shire. Local government is considering local declaration—P2 (all the shire); P4 (in beef production areas to stop spread).
Calliope	Listed as a minor weed problem. The plan requires monitoring and control of known infestations.
Cairns	Listed in the plan as a 'very dangerous' threat to conservation, but it is a medium priority.
Charters Towers	Listed as a growing environmental weed that requires mapping and control on council roads and reserves. There are isolated plants throughout the town.
Cook	*Leucaena leucocephala* is ranked as a dangerous threat to natural areas (strategic importance 2). Council considers that the plant should be contained or prevented from spreading. In order to meet its goal, Cook Shire Council will remove any leucaena on its property; educate landholders not to use the species as fodder; request DPI to stop recommending the species and instead recommend native alternatives; request Comalco to remove the material in regeneration areas and, in the interim, ensure no seed is contained in fodder sent to local properties; and request NR&M to investigate biological control for leucaena. Council locally declared *ssp. leucocephala* in 2002.
Flinders	Monitoring of leucaena in the shire is required. Not a problem yet, but there is concern due to problems in nearby local government areas.
Gladstone	A target species in city environs over the 2001–02 control season.
Hinchinbrook	Infestations are to be monitored; the species is common and widespread.
Ipswich	Classed as a high priority environmental weed; action taken on infestations in riparian areas and parks and reserves, when found.
Longreach	Noted leucaena spread from the town in drainage lines leading to the Thomson River. Council will support the eradication of this weed from all areas in the shire other than where approved by council. Council will support the Longreach Landcare Group in conducting Weedbuster days to assist town residents to remove leucaena. Council may approve plantings of commercial forage varieties of leucaena for animal production. Plantings should be consistent with the Code of Practice established by the Leucaena Grower's Network, and no closer than 200 metres from a watercourse. The species is not mulched to reduce spread.
Mareeba	Is to be controlled on council land.
Mackay	Listed in plan as an environmental weed; there is estimated to be 50–100 ha of *Leucaena leucocephala* ssp. *leucocephala* in the shire.
McKinlay	Not yet present in the shire; actions are listed to prevent introduction or spread.
Mount Isa	Is declared under a local law, outside of its use for fodder. Leucaena is an urban weed of disturbed areas in the city.
Noosa	A low priority environmental weed.
Rockhampton	Is declared under a local law requiring the containment of infestations to prevent spread by using treatments such as buffer strips.
Thuringowa	Leucaena is classed as a critical weed in conservation areas and waterways, and a moderate threat to recreation areas and state lands. Scattered plants occur along most creeks and drainage lines. Ross River at Sander Beach and drains in the shire are infested. An infestation near a government research station has been treated, as it was spreading on the roadside and creek. The species is also grown in gardens throughout the town. Actions listed include reduction of populations and removal of isolated populations.

Two shires with larger infestations are Fitzroy and Brisbane. In Fitzroy, the township of Kabra is heavily infested with *Leucaena leucocephala* ssp. *leucocephala*. A dense infestation is found in Middle Creek and along several roads, including Murphys Road and Moonmerra Road near the 'Old School', where it was planted about 50 years earlier. The creek has been cleared previously, as part of a rubber vine control program, but is heavily infested again. The total area of this infestation would be less than 20 ha. In Brisbane, a recent survey (Shelton et al. 2001) suggested that infestations occupy 100–1 000 ha, particularly along Cubberla Creek in Chapel Hill/Kenmore. Leucaena is also spreading along Kedron Brook and in the South Brisbane and Indooroopilly areas. Leucaena is also naturalised on a number of islands in Moreton Bay, including St Helena (Csurhes and Edwards 1998). A sole leucaena tree can be found in Mill Park next to the old mill in Spring Hill, in the centre of the city. The recent DNA survey showed that material in Chapel Hill was ssp. *glabrata*, although a sample from the Moggill Road Bridge was ssp. *leucocephala*, showing that both subspecies are currently present in the city.

Other shires noted by departmental land protection officers to have scattered infestations on roadsides or in creeks include Banana, Bauhinia, Bundaberg, Caloundra, Dalrymple, Duaringa, Esk, Gatton, Gayndah, Joh\stone, Kilcoy, Livingstone, Mt Morgan, Maroochy, Mirani, Pine Rivers, Townsville and Whitsunday. Plants were noted in towns, but were not spreading in Cloncurry, Winton, Ilfracombe and Aramac. Leucaena is also found on the islands of the Torres Strait—including coral and mud cays, and the granitic continental islands (Queensland Herbarium 2002).

4.5 Potential distribution in Australia

Various groups have worked on predicting the potential range of leucaena as a species of cultivation in Australia. It should be noted that these prediction models have been based on different criteria and the subsequent results differ significantly. Some of these predictions map the adaptive range, while others map the potential economic range.

Lascano and co-workers predicted areas best suited to leucaena as areas in Mexico, Central and South America (Lascano et al. 1995). This prediction produced maps based on even more criteria: soil pH >5.5, base saturation >40%, altitude <1 500 m and dry periods of 3, 4, 5 and 6 months. These criteria resulted in a map closely resembling the native distribution in Central America, and predicted sites in the Caribbean and South America where the species could be trialed. Unfortunately, this prediction was not extrapolated to other parts of the world.

Hutton and Gray (1959) estimated an adaptive area of approximately 144 000 square miles in Queensland, and 158 000 in other states, as suitable for *Leucaena leucocephala*. This prediction was based on areas where the annual rainfall was 30 inches or more with a summer incidence, and where the July mean temperature does not fall below 11.5 ^{o}C. These workers estimated that if half this area were grown it would mean a potential of 96 million acres (38 million ha) for this species.

Middleton and co-workers (1995) suggested a greatly reduced estimate of 3 to 5 million hectares of agricultural land in northern Australia suitable for leucaena cultivation. This prediction is based on the more rigorous criteria of soil fertility, pH and frost incidence, and is for *Leucaena leucocephala* ssp. *glabrata*. This area was estimated to be a subset of 11 million hectares of brigalow and bluegrass downs clay soils in Queensland. The authors suggest that, if psyllid and acid soil tolerant cultivars were available, many of the deeper soils, occupying 3 million ha of the coastal spear grass in northern Australia, could also be developed for this species.

A recent GIS study indicated *Leucaena leucocephala* ssp. *glabrata* variety *Cunningham* was adapted to 4.43 million ha of agricultural land in northern Australia. This map (developed by Fiona Coates) was derived from the area of clay soils in the 550 to 800 mm rainfall zone. The upper rainfall limit was included to eliminate areas prone to psyllid damage. It was estimated that the area that could be planted if a psyllid resistant cultivar was developed was an additional 1.24 million ha, or an additional 28% to 5.67 million ha (Leucaena Network 2001).

Hughes's handbook (1998a) gives detailed native distributions of the three subspecies of *Leucaena leucocephala.* This distribution map and other references were used to clarify the climate requirements for the two subspecies. Climate analysis using the CLIMEX ™ computer-modelling package (Skarratt et al. 1995) suggests that the climate of coastal areas of northern Australia is similar to that experienced by *Leucaena leucocephala* ssp. *leucocephala* in its native range (figure 4). It was suggested that *Leucaena leucocephala* ssp. *glabrata* was able to grow further inland in both the Northern Territory and Queensland, and further south along the coasts in Western Australia and New South Wales (figure 5).

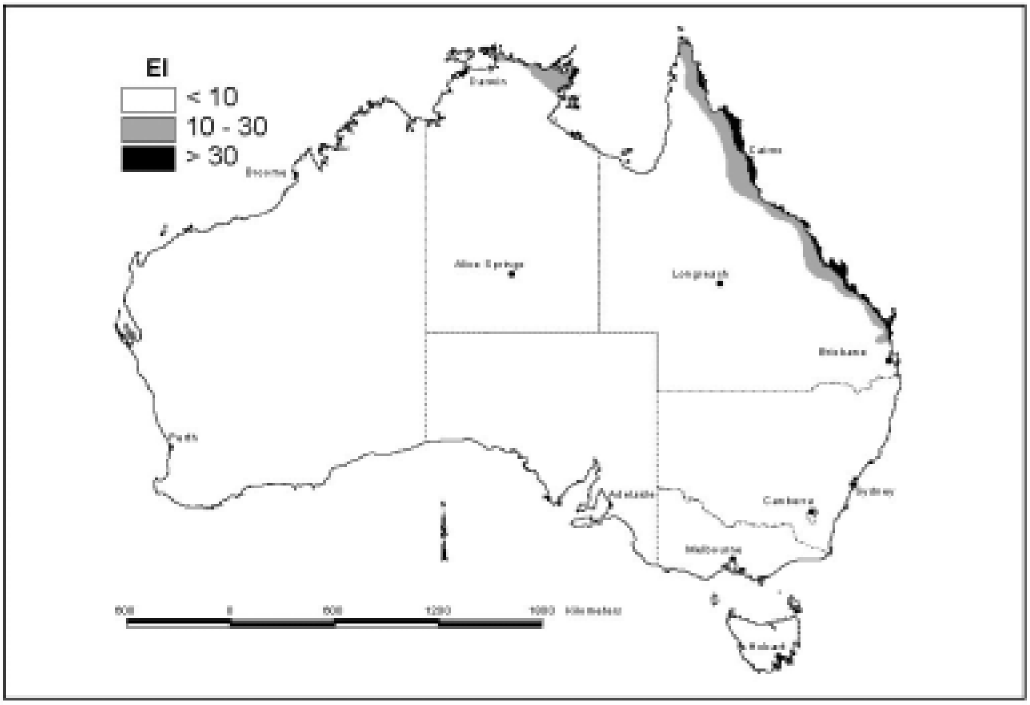

Figure 4: Potential distribution of *Leucaena leucocephala* ssp*. leucocephala*.
(Data is splined from a CLIMEX prediction. EI = Ecoclimatic index: EI<10 potential for permanent population low, EI>30 potential very high).

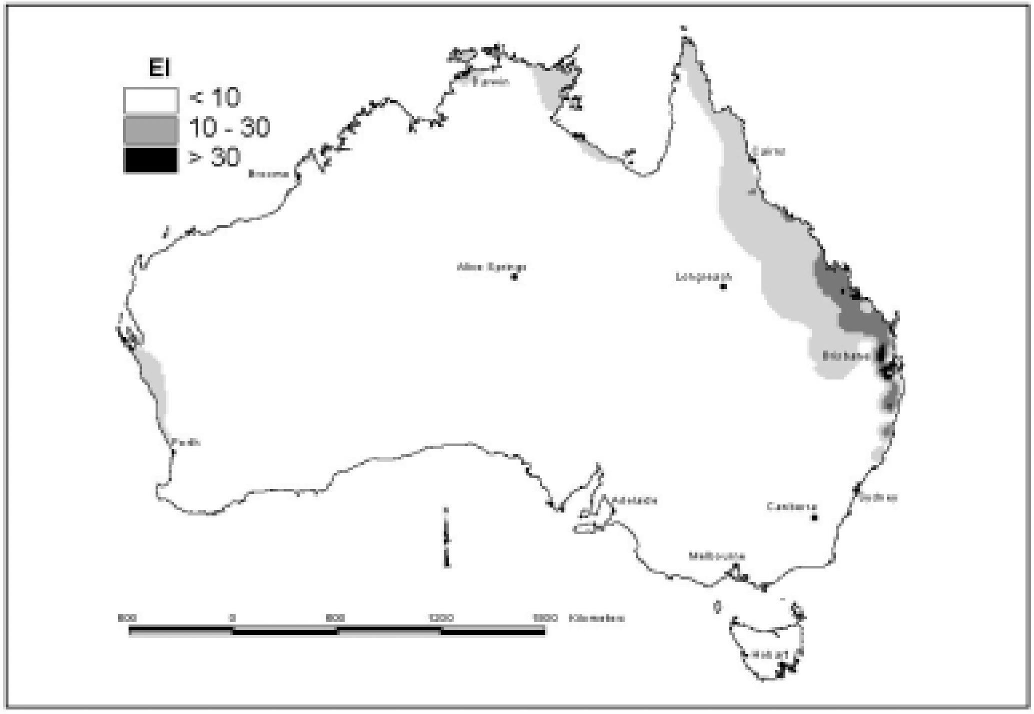

Figure 5: Potential distribution of *Leucaena leucocephala* ssp. *glabrata.*
(Data is splined from a CLIMEX prediction. EI = Ecoclimatic index: EI<10 potential for permanent population low, EI>30 potential very high).

5.0 Estimates of current and potential impacts

5.1 Primary production

5.1.1 Benefits

Commercial cultivars of *Leucaena leucocephala* ssp. *glabrata* are used in Queensland as a browse legume combined with improved (exotic) grass species (e.g. *Brachiaria decumbens*—signal grass, *Panicum maximum* var. *trichoglume*—green panic, *Digitaria eriantha*—pangola grass, *Chloris gayana*—common Rhodes grass, and *Cenchrus ciliaris*—buffel grass) in extensive broad-acre grazing systems for beef cattle production (Shelton and Brewbaker 1994). Most plantings are large-scale, 100–500 ha, and mostly in rows 4–10 m apart (Middleton et. al. 1995). The pastures are long-lived (over 40 years), drought tolerant and productive.

Leucaena is known for its high nutritional value and for the similarity of its chemical composition with that of alfalfa (Norton et al. 1995). Its forage can be low in sodium and iodine, but is high in ß-carotene (Duke 1983). Tannins in the leaves, and especially the stems, reduce the digestibility of dry matter and protein, but enhance the ‘bypass’ value of protein (Suttie 2002). Production from leucaena plantings can be measured in a number of ways. In Queensland, live weight gains of 0.7–1.70 kg/head/day have been achieved in leucaena/grass pastures, equalling >250 kg live weight gain/ha/year (Esdale and Middleton 1997). This growth is comparable to, or higher than, grazing on buffel grass alone (0.47–1.30 kg/head/day), and to grain-fed lot feeding (1.41 kg/day). The highest recorded live weight gains from a tropical pasture legume (over 2 000 kg live weight gain/ha/year) have been achieved on leucaena in the Ord River Irrigation Area (Lefroy 2002).

Significant cattle growth rates have been achieved with leucaena during autumn (March–June) at a lower cost than is possible with alternative supplementary feeds. Especially in the dry season, use of this system enables carrying capacity to be increased on one property from 1 beast/6 ac to 1 beast/2.5 ac (Yorkston 2002).

Weight gains of 1.1 kg/day were recorded on this property during a 70-day period. Quirk (1994) identified two distinct roles for leucaena in a review of the species in the Burnett region—it plays a role as a protein supplement over the cool dry months (April–October) and it has a role to finish steers allowing rapid growth. As a nitrogen fixing tree leucaena may increase soil fertility, especially in clay soils cleared of brigalow where productivity of sown grasses is declining due to reduced nitrogen availability, either through direct addition or nitrogen stock throughput (Clem and Hall 1994).

Establishment costs for leucaena plantings at 10 m rows in cropping soils range from \$100–\$140 per ha, or \$65–\$105, if planted into existing grasses (Chudleigh 2001). Cost of establishment is therefore 50–100% more than planting buffel grass. Weed control is a major factor in establishment of leucaena plantings, as the plant can be slow to establish and can be out-competed by weeds. Pre-sowing cultivation and pre-emergent herbicide treatments are required; Spinnaker® 700 WDG has recently been registered as a planting or post-planting weed control for leucaena. Planting is most successful in positive El Nino years (wet or above average rainfall). As stock will readily browse and destroy seedlings, planted paddocks must be locked away until the trees establish. This may require additional costs for infrastructure and the losses in stock production. The growing of leucaena in a broad-acre grazing system requires skills and equipment that some graziers do not posses. Additional training or skills development may be required for successful establishment of this system, or perhaps contractors could be used to facilitate successful plantings. The total development costs for a planting can therefore be high—up to \$1,200 per hectare for the first year, but this should establish a long-lived pasture system. The low management costs and long-lived nature of the tree (34 years, Brian Pastures, 50+ years, Samford) should be taken into account when assessing the total cost of production (J Wildin, pers. comm., 20 June 2002, Jones and Bunch 1995).

The seed used in Queensland is grown in Queensland and is available from seed merchants. In Queensland, current seed production, both for on-farm use and sale, is estimated to be 10–20 tonne per annum (Gutteridge, Shelton and Larsen 1999). Currently, seed can be sourced in Central Queensland at \$13.2/kg, \$15.4/kg and \$44/kg for *Peru*, *Cunningham* and *Tarramba* respectively. An additional dollar is added for the first two varieties for scarification before delivery.

From 1960–80, *Leucaena leucocephala* was promoted as a 'miracle plant' by development agencies worldwide (National Academy of Sciences 1984). Its identified potential uses include shade for crops (coffee, quinine and vanilla); firebreaks, timber production and firewood; pods used as a human food source, seeds as a coffee substitute (Philippines) or heated/eaten like popcorn; concoctions of barks and root taken for various purposes including internal pain, contraceptive and depilatory purposes (Latin America); planting for mine rehabilitation and sand binding (South Africa); seeds used to treat internal parasites (Philippines); seeds yield a gum very close to gum arabic; planted in rotation with maize to restore soil fertility (Central America); and planted in parks and gardens as a shade tree (Duke 1983, Brewbaker 1987, National Academy of Sciences 1984); however, in Queensland, it is not being used for most of these purposes.

Leucaena is, however, being promoted in Queensland both to reduce salinity and to contribute to the reduction in livestock greenhouse gas production by carbon sequestration. Both projects would see significant increases in the area planted with leucaena in Queensland, would require significant external funding, and are linked to the federally funded National Action Plan on Salinity and Water Quality and Greenhouse Gas Abatement programs respectively. Neither of these projects had been funded at the time of writing.

Case study: Pasture production in Central Queensland

A Rolleston property owner has adopted a leucaena-grass system in response to a noted drop in nitrogen in cleared brigalow areas and the need to have a sustainable system that did not require annual cultivation. This system replaced plantings of summer sorghum and winter oats crops. Parthenium weed is also a problem in this area, and the leucaena /grass pasture provides control for this species. The property owner has planted 4 500 ha of leucaena on both Downs and Brigalow shrub country, a large proportion of his 22 000 ha property.

The use of this species as a summer feed has resulted in a change in land use for this property. Rather than carrying stock year round, the property is generally de-stocked over winter, allowing grass regrowth. In effect, the property has been turned into an agistment property, as the high growth rate possible on the leucaena-grass system allows rapid turn-off of stock. Significant increases in productivity have been noted, with the Downs country stocking rates increasing from 1 beast/15 ha to 1 beast/5 ha, and Brigalow shrub country, from 1 beast/8 ha to 1 beast/4 ha.

The landowner has noted several important management techniques for leucaena. The faster turn-off of stock has resulted in smaller stock grazing on the leucaena, which means that they cannot reach as high, or knock over a much stem material, as older cattle. As the stock eat leucaena from the bottom up, it is important that the trees not be able to grow too high. To reduce the plants' height this landowner uses a bulldozer to bring the stems back to a grazing height once the trees are established, and he plants the lower growing variety, *Cunningham*. Frost damage has been an issue in one part of the property, and buffel grass has out competed the frost-affected plants in grazed paddocks. The frost risk in these paddocks was not evident from previous cultivation of these paddocks.

Start-up costs were approximately $130–$150/ha, although, the paddocks were also de-stocked for 18 months to allow establishment and inter-row weed control. The landowner did not incur additional costs, as he had the equipment needed to plant the crop. This landowner is aware of the mixed perceptions of others in the community about this species. He has not noted significant spread, but, as part of his management practices, he would control any material outside his paddocks if it were to spread.

The success of this grazing system on this property has resulted in plantings on another family property several shires further north.

5.1.2 Costs

There have not been any direct studies of the negative impacts on primary production in Queensland, but it is likely that most primary producers see leucaena as a positive species. Non-graziers are unlikely to have plants germinate on their property, unless deliberately planted, as seed does not spread far from planted areas, except for the low risk posed by animals and water. Two growers in the McNeill survey (Shelton et al. 2001) did, however, note that leucaena had spread to their property by floodwater. Increased plantings of *Leucaena leucocephala* ssp.

glabrata under practices that do not reduce spread from planted paddocks to either roadsides or riparian areas may, over time, result in spread to neighbouring landowners. Although it is unlikely that these plants would cost much to remove, it is likely that their removal would increase the community perception of this species as 'weedy'.

Landowners who have planted leucaena generally find that cattle remove most or all seedlings that arise outside planted paddocks (Kernot 2000), if they can be reached by these animals. If control activities outside plantings on roadsides and along riparian areas are undertaken, they are unlikely to require more than 1 man-day per annum per property. A nominal amount of chemical would be required to treat these escapees.

The toxin mimosine is found in leucaena, and its by-product, 3 hydroxy-4-1 H pyridone (DHP), is created during animal chewing. Although toxic to nonruminants, this substance does not deter ruminants from eating the plant. DHP accumulates and results in loss of appetite, goitre, and related symptoms, including hair loss (Norton et al. 1995). Ingestion of the DHP-degrading bacterium Synergistes jonesii is required in grazing animals to prevent leucaena toxicity (Pratchett et al. 1991). Producers without this bacterium may see negative impacts from browsing; for example, horses may lose their hair.

In central Queensland it was pointed out that many pastoralists ‘simply don’t like trees’, having spent many years clearing brigalow and other scrub/tree country to develop productive grazing lands. These landowners see replanting trees as counter-productive, and this will influence their perceptions of the value or otherwise of leucaena. A high rate of establishment failure in some areas in the past has also coloured the perception of some landowners that the plant is hard to grow and so not useful (Larsen *et al.* 1998); this may also influence community perception.

One possible negative impact of leucaena/grass systems and leucaena infestations is accelerated soil acidification rates (Noble and Jones 1997, Noble et al. 1998), although they may be less than in fertilised pastures. The first study compared a 22-year-old leucaena stand with adjacent grass pasture and showed significant acidification, and cation depletion to 70 cm. The soil pH under the leucaena was 5.0 at the surface and 5.4 at 60 cm, compared to 6.0 under the grass at the surface and at 60 cm. In the later study, leucaena N-fixation was compared with that of nitrogen-fertilised irrigated pastures after 36 years. This study found pH_{Ca} was lowered from 5.2 to 4.8 under leucaena, compared to 4.3 under pasture; the extent of acidification was higher under the nitrogen-fertilised system. The acidification rates over the top 90 cm of soil were 1.0 kmol H^+/ha/year in the leucaena system, and 5.1 kmol H^+/ha/year in the pasture. As impacts will differ with soil type, further studies are required before unambiguous comparisons of the impact of leucaena communities relative to other plant communities can be made.

The use of leucaena for soil stabilisation has only been documented for one site in Queensland (see the following case study), but this case has demonstrated the risk of not managing the seed production and seed spread of this species.

Case study: Weipa mine rehabilitation

Leucaena was planted at Weipa and Andoom in western Cape York beginning in 1973. It was planted as an improved pasture species, as a windbreak for agroforestry plantations, and as a soil nitrogen builder. Although *Leucaena leucocephala* ssp. *leucocephala* was the species originally used for the agroforestry (Middleton 1980), later plantings for fodder production are likely to have been *Leucaena leucocephala* ssp. *glabrata.* Growing conditions were good, plants were not subject to any seed control, and spread occurred along access roads, possibly carried on muddy vehicles and through movement of seed contaminated topsoil.

Leucaena (both subspecies) has subsequently become the dominant species at some sites (up to 100 000 stems/ha). In Weipa, the area of leucaena has spread from 172 ha planted to a further 376 ha, and at Andoom, from 277 ha to a further 411 ha of rehabilitated areas. The total infested area is now 1 000–1 200 ha; although, this ranges from dominant thicket and extensive cover (654 ha) to scattered individuals (275 ha). Due to competition from native vegetation, leucaena has not invaded undisturbed native eucalypt woodland surrounding the rehabilitated areas.

Comalco has developed integrated strategies for leucaena control on the mine site, the town of Weipa, and surrounding areas. In a 1999 study, the management costs of controlling plants and seedling recruitment using physical and chemical measures followed by native vegetation rehabilitation were estimated as $740/ha. The cost of using cattle to graze the area was $28/ha. Although reducing seedling recruitment, this treatment was not able to stop seed set, as the trees were taller than the cattle could reach. It was determined that the larger trees would need mechanical clearing to prevent seed production if grazing was to be a sustainable seeding control method. This case study shows that the species can become invasive on disturbed mine rehabilitation sites if not well managed, and that management of leucaena in disturbed sites may be an expensive exercise (Dalzell et al. 2002).

5.2 Environmental and social

Leucaena has a small but growing environmental impact in Queensland. Infestations are noted to occur in a number of ecosystems—wetlands, monsoon vine forests, and moist woodlands (Swarbrick and Skarratt 1994). The Queensland herbarium has records for leucaena from frontal dunes on the Sunshine Coast, rocky headlands on the coast of Mackay, and on the edge of bushland in Brisbane. Leucaena is often found in riparian systems, which are considered the vegetation type most susceptible to environmental weed invasion (Batianoff and Franks 1998).

Leucaena was ranked number 41 in the list of 200 environmental weeds of south-east Queensland (Batianoff and Butler 2002); however, it was not widespread, being found in only 24 of the 1413 sites surveyed in this study. Collection sites were either riparian areas or on the edges of roads or reserves. A similar prioritisation of weeds of Queensland's Wet Tropics listed *Annona glabra* (pond apple) and *Leucaena leucocephala* as the two highest ranked weed species in this bioregion (Werren 2001).

Most current leucaena infestations are small and scattered; however, dense thickets do occur, such as in the township of Kabra (Fitzroy Shire) or along Cubberla Creek (Brisbane), and these are thick enough to exclude native species. Without good statewide mapping it was impossible within this study to correlate leucaena infestations with possible impacts on rare and threatened species or ecosystems. There were no records found of this species in national parks or nature reserves.

Treatment costs are high for leucaena infestations, resulting in permanent rehabilitation and ongoing monitoring. This was demonstrated by the work in Weipa, where physical and chemical measures followed by native vegetation rehabilitation were costed at $740/ha (Dalzell et al. 2002*)*, and the Whitsunday case study (see below). A project in the Northern Territory involved removal of an 8 ha infestation cost more than $14,600 over 4 years ($7,000 in bulldozer costs for the initial control and a further $3 000 within the first year to control regrowth). Second-year costs were $2,500, third-year costs were $1,850, and ongoing costs of monitoring and treatment of seed germinating from the seedbed and from external supply of seeds from outside the site were costed at $250 per annum, or $1,825/ha over 4 years (P Jeffries, pers. comm., September 2002).

The statewide survey (Shelton et al. 2001) reported that most leucaena infestations across Queensland are on ungrazed sites, drainage, or riparian habitats. Most infested sites are partially or highly disturbed habitats (>50%) and an additional 23% of sites are in artificial habitats. Of more concern in this survey was that 11 councils reported leucaena in undisturbed natural habitats. This is contrary to most reports of leucaena as a ruderal or riparian weed (Hughes and Jones 1998, Hughes 2002), and should be followed up.

A number of communities in Queensland have declared leucaena within towns, as it is creating a problem in wastelands, roadsides and unused blocks of land. This problem will be exacerbated by the current use of leucaena by some in the community as a garden planting—as reported by 20 shires, or in parks—as reported by six shires (Shelton et al. 2001). Most shires actively discourage growing leucaena for these reasons.

One of the comments often made of leucaena is that it is an unsightly weed. It is a tall plant—more visible than many weedy grasses or herbs—with large, dark-coloured pods, which may be held on the plants for several seasons. Leucaena is visible to the most casual observer (even through the window of a car travelling at high speed), as many infestations are found along roadsides and in roadside creek crossings. These infestations possibly arose from use of leucaena for soil stabilisation, or were spread by mud on road maintenance equipment. It is possible that the perception that this species is a major pest in some areas is related more to its visibility than to any demonstrable impact on ecosystems. This comment is not intended to belittle the problem of visual pollution created by weed infestations, but it is important to put this impact into context.

Case study: Coastal leucaena management

Community concern at the thickening of leucaena stands between Shute Harbour and Cannonvale led to a joint community effort to control leucaena in the Whitsunday Shire. Stands of trees up to 15 m high with trunks of 40cm diameter were found to be creating dense thickets on public and private land, and it was decided to take action while the problem was small.

After initial surveys, the first control day involved activity by six shire and integrated catchment management group staff treating 15 sites along a 15 km stretch of road. Basal bark treatment of a total of 2 ha with Access®: diesel treated half the known sites at a cost of approximately $2,100.

After initial actions on public land it is hoped that local landholders will remove infestations on their own properties and remove plants from house gardens; this plant appears to have been used as a quick growing shade tree in backyards in the shire. To assist in the latter activity, a tree exchange program will be put in place to encourage the growing of local replacement species. Information on identifying leucaena was also provided, as it was found to look like two native rainforest species (Anon 2002b, S Hardy, pers. comm., September 2002).

5.3 Net benefit or cost to the state

To estimate the economic benefits of leucaena to the state cattle industry, data is required on the total area that could be planted with leucaena, and the dollar value that each hectare could produce per annum. While several papers report higher profitability of cattle production from leucaena-based pastures, no quantitative data between various forms of pasture, including establishment and the total costs of the system, could be found. These studies would need to compare the cost of a 300kg/animal/year sustainable leucaena-system live weight gain with the already established, high- producing (160–180 kg/animal/year), but possibly unstable, buffel grass system (Larsen et al. 1998). The benefits of the leucaena-grass system also include the use of this system to finish off cattle, avoiding the costs of growing forage crops or feed lotting (Partridge 2002).

Gutteridge estimates a figure of $10 million in annual benefits to the state from the current leucaena /pasture systems (Middleton et al. 2002), but with a planted area of 100 000 ha this could be up to $14 million.

The net cost of leucaena control is difficult to estimate, but primarily depends on three factors:

- The extent of infestations (i.e. the total area of land over which control is attempted).
- The control method used and its associated cost per hectare.
- The degree of difficulty associated with getting conventional spraying equipment into infestations (i.e. site access).

Control costs are in the order of $740–$1 845 per ha. With an estimated 8 000 ha of Queensland infested at present, the cost of a one-off control program for all infestations would be about $5.9–$14.7 million.

5.4 Potential impact of other new tree species

A recent review of cultivated forage trees (Lefroy 2002) found 200 000 ha planted in Australia—mostly Tagasaste (*Chamaecystis proliferus*), leucaena, and saltbush (*Atriplex* spp.). The area planted to these shrubs had increased six-fold in the past decade. While the review found a further 101 tree species from 33 genera identified in the literature as having potential for forage production in Australia, over the last ten years no new species achieved commercial levels of adoption.

Lefroy notes that, of the three scenarios for the wider use of forage trees and shrubs in Australia, the development of new exotic species is unlikely to be an acceptable option. With studies also showing that the second option—'development of new endemic species'—is unlikely to be successful, he goes on to suggest that the further development of the species currently in use is the most cost-effective and least environmentally risky option (Lefroy 2002). This interpretation suggests that it is unlikely that new exotic forage tree species are going to be added to the flora in Queensland in the near future.

Exotic trees in general are known to present a risk, given that the key selection criteria for a successful forage plant are rapid early growth and adaptation to a wide variety of environments. Hughes, in his papers on the risks of new forestry species (Hughes 1994; Hughes 1995; Hughes and Styles 1989), lists a number of genera with species which are used both in forestry and as the focus of eradication efforts—*Acacia, Acer, Ailanthus, Albizia, Cedrela, Dichrostachys, Eucalyptus, Maesopsis, Melaleuca, Melia, Parkinsonia, Pinus, Pittosporum, Prosopis, Prunus, Psidium, Robinia, Schinus, Swietienia, Tamarix* and *Toona*. A number of these genera are already weeds in Queensland and others are grown commercially.

6.0 Biology and ecology

6.1 Habitat

Leucaena is essentially a tropical species requiring warm temperatures (25–30 ^{o}C) for optimum growth, with poor cold tolerance and significantly reduced growth during cool winter months in subtropical areas (Hughes 1998a). Due to its cold intolerance, *Leucaena leucocephala* ssp. *leucocephala* is limited to below 500 m altitudes, while ssp. *glabrata* is found up to 2 100 m in its native region. Leucaena may grow in regions above 500–1 000 m with mean annual temps below 22 ^{o}C, but growth is slowed and less seed is set. In Queensland most *Leucaena leucocephala* ssp. *glabrata* is grown at the limits of its climatic tolerances in areas with low and seasonal rainfall and winter frosts because the soils are more suitable. It is grown mostly in central Queensland, 100–300 km from the coast, on alkaline clay soils with an annual rainfall of 600–750 mm.

Leucaena grows well in subhumid or humid climates with rainfalls between 650 mm and 3000 mm, although it can tolerate moderate dry seasons of up to 4–6 months (Lascano et al. 1995). It has demonstrated good drought tolerance in Queensland, confirmed in 1995 by the survival of plants subject to three years of drought in the Rolleston–Blackwater region (Jones and Middleton 1995). The species has similar drought tolerance to stylo; however, unlike stylo, which is a 'drought tolerator', leucaena is a 'drought avoider', dropping its leaves and decreasing growth to survive poor conditions (Brandon and Shelton 1993).

Leucaena shows low frost tolerance. Light frosts cause it to shed its leaves, with 13% dieback after one day of –5 ^{o}C (Shelton and Brewbaker 1994). Seedlings will be killed if the temperature remains below zero for more than a few hours at a time. Heavy frosts will kill all above ground growth, with 0% tree survival after one day of –10 ^{o}C, although trees often resprout the following summer. The southern limit for cultivation of ssp. *glabrata* in Queensland is referred to as 25 ^{o}S (Gayndah) due to the effects of winter leaf drop either from frost or low rainfall (Cooksley, Prinsen and Paton. 1988), but this subspecies has been established further south in Ipswich, Samford and Gatton.

Leucaena grows on a wide variety of deep, well-drained fertile soils, including limestone and other alkaline soils, as well as volcanic soils. Subspecies *leucocephala* mostly colonises subhumid alkaline soils, especially coralline islands, but never colonises well on sand dunes (Brewbaker 1987). This subspecies likes disturbed sites and will grow in disturbed wet areas, but will not be the dominant species. In Queensland the alkaline structured clay soils of the brigalow and softwood scrubs, alluvial and open downs country (the cropping soils) are most suitable for ssp. *glabrata* (Anon 2000).

Leucaena is known to be intolerant to soils with low pH (below pH 5.5), low potassium, low calcium, high salinity, high aluminium and waterlogging (Brewbaker 1987). Adult trees can survive intermittent waterlogging, although seedlings cannot (Shelton and Jones 1995). A recent study showed that saline water and gypsum do not greatly affect growth or nodule formation, but high sulphur decreases the pH and results in aluminium toxicity, which does affect both (Stamford et al. 2000). Leucaena does not grow well on shallow duplex soils with clay subsoil close to the surface, due to possible waterlogging. A degree of salt tolerance of leucaena can be seen by growth on the edge of saltwater creeks in Cairns, frontal dunes on the Sunshine Coast and Darwin, and near salt scalds in Central Queensland.

Having moderate shade tolerance, leucaena can grow under its own canopy, with only 35% of full illumination (Piggin et al. 1995), and under lantana (Binggeli 1997). It is not able to grow under the dense shade of undisturbed forest.

6.2 Morphology

Leucaena leucocephala differs from other members of the genus in that it has intraspecific diversity in tree size and form. The shrubby 'common' (ssp. *leucocephala*) is small (less than 5 m) and highly branched. The tree 'giant' types (ssp. *glabrata*) are medium sized, with a short clear main stem up to 5 m, upright angular branching, and a narrow, open crown, 3–15 m tall, with a 1–50 cm bole diameter (Hughes 1998a). The varieties of *glabrata* also differ in height—after two years cv. *Cunningham* grows to 1.5 m, while cv. *Tarramba* will grow to 1.8 m (Jones 1998). The new KX2 F1 hybrid grows taller even faster—2.3 m in the same time period.

Leucaena can form dense impenetrable stands, where crowded, slender trunks are formed with a short bushy tuft at the crown. 'Instant forests ' can occur when leucaena is transplanted well, with canopy closure in 3 months. Plants will spread if singly grown. Plants will regrow from cut stumps, 5–15 branches, depending on the diameter of the cut surface, and this may result in denser growth. Leucaena wood is resistant to attack by termites, although seedlings may be eaten (Jones, Brewbaker and Sorensson 1992).

The primary leucaena root system is a taproot, with feeder root development following. The taproot averages 3 m in brigalow soils (J Wildin, pers. comm., 20 June 2002, Mekonnen 1992). Waterlogged trees may develop aerial roots to increase air intake into the root system (Brandon and Shelton 1993). Mekonnen (1992) found that most roots of a related species, *L. diversifolia,* occur in the top 20–40cm, and that removal of shoot material significantly reduces root density. Fifteen-week-old seedlings of *Tarramba* were found to have 40% of the biomass below ground, and this was not correlated with plant size (Fownes and Anderson 1991). Coppiced plants shed both nodules (30%) and roots (10%) during the two weeks following cutting and it is likely that grazing would also have this effect (Fownes and Anderson 1991).

Field studies using single and mixed strains of inocula have demonstrated that the early growth of *Leucaena leucocephala* is significantly improved by inoculation with specific *Rhizobium* (Piggin et al. 1995), although native *Rhizobium* strains may be effective in some soils, and so it can grow without additional soil inoculum (Jones and Date 1995). Vesicular/arbuscular mycorrhizas are also important for good growth (Brandon and Shelton 1993).

6.3 Phenology

The genus *Leucaena* has a short juvenile phase for a woody species in that it can commence flowering 3–4 months after planting. Plant maturity of *Leucaena leucocephala* follows this pattern. In Botswana, *Leucaena leucocephala* flowered from 2–4 months after field planting (Kaminski et al. 2000). This is faster than many of the species in the genus. Although ssp. *glabrata* is generally noted not to set seed until the second year, time to first flowers for *Tarramba* was recorded at 246 days (190–289) (Anon 1997).

Kaminski and co-workers studied the phenology of *Leucaena* species in southern Brazil. The vegetative period (the number of days from leaf regrowth to first flower buds) for *Leucaena leucocephala* ssp. *leucocephala* was 80–139 days*,* and ssp. *glabrata*, 56–170 days. Onset of fruiting (days from first flower buds to first pods) was 32–48 and 24–62 days, and onset of maturation (from first pods to pod maturation) was 100 days and 75–115 days respectively for the two subspecies (Kaminski et al. 2000).

Flowering in *Leucaena leucocephala* ssp. *leucocephala* appears to be independent of environmental factors, as it can be continuous, with flowering and seed production occurring all year, generally cyclically every six months. This continuous flowering differs from other species in the genus that have distinct flowering and fruiting patterns (around 2–5 months), and do not flower and fruit quite so abundantly or so early (Hughes 1998a). Flowering also increases under moisture stress or with the onset of shorter days in the subtropics. Peak flowering for cv. *Peru* occurs in March–April, similar to cv. *Cunningham*, which has peaks in November and March–April (Anon 2002a).

6.4 Floral biology, seed and dispersal

The globular leucaena flower heads contain numerous, tiny, hermaphrodite white flowers. These flowers are largely self-fertilised and self-compatible, which promotes seed production even on isolated individuals and allows the species to seed true to type. Flowers last only for one day, opening at night, with anther dehiscence taking place early in the morning. The clumped pollen falls directly on the stigmas and pollen grains become lodged in the stigmatic cups, where they germinate. This ensures a high degree of self-pollination. Within an hour the anthers have retracted so that the stigmas stand above the anthers. Pollinators, such as bees, are generally rare at this point, which is when cross-pollination could occur. By mid-afternoon the anthers have turned brown and retracted, and no further flowers open until the next morning. The species does not need specialist pollinators, being cross-pollinated by a range of generalist insects, including large and small bees (Hutton and Gray 1959). Once the seeds mature, the pods shatter by opening simultaneously along both margins. Therefore, seed dispersal is largely passive, by gravity, with seeds dropping when pods open. Seed spread is generally less than 20 m, if unaided. Wind-assisted movement of *Leucaena leucocephala* ssp. *leucocephala* pods has been recorded over 100 m from parent plants on coastal cliffs in the Northern Territory (P Jeffries, pers. comm., September 2002). Other modes of spread include water; deliberate spread for cultivation in the nursery trade; landscaping; soil stabilisation; agriculture and, possibly, agroforestry; accidental spread by vehicles machinery, mud on machinery; or in contaminated hay—although, the risk from most of these vectors is low (Hughes 2002).

Animals including birds, rodents and cattle may be seed vectors. In Brisbane, an animal vector—possibly possums—is proposed as responsible for the spread of leucaena into city suburbs, although, the species has not been determined (E Miller, pers. comm., July 2002). It is commonly believed that cattle are unlikely to spread leucaena, as they eat only green seeds. Mature seed either would have fallen from pods or been in dry pods that are unattractive to grazing cattle; however, Jones and Jones (1996) report seeing seedlings from dung excreted from cattle that have been grazing leucaena.

Surprisingly little information has been published comparing the seeding rates of the two subspecies. The early Queensland study by Hutton and Gray (1959) showed that two-year-old Hawaiian strains (*Leucaena leucocephala* ssp. *leucocephala*) produced 277–388 pods (3 974–6 058 seeds) per plant, while the strains *El Salvador* and *Peru* (*Leucaena leucocephala* ssp. *glabrata*) produced 545 pods (8 666 seeds) and 45 pods (585 seeds) respectively. The low seed set of *Peru* strains was thought to be related to its maturity occurring later than that of the faster-growing Hawaii strains. This is consistent with this subspecies being slower to mature. A study of the effect of plant density on seed production (Bhatnagar and Kapoor 1987) showed cv. *Tarramba* seed production ranging from 600–5 140 seeds per plant in India. In his thesis, Mullen (2001) noted that, at one site, 50 trees of a ssp. *glabrata* variety produced 40 kg of seed in the second year of growth. With an average of 22 000 seeds per kilogram, this would suggest a seed production of 17 600 seeds per plant at this site.

A seed yield of 3 999 kg/ha was measured from a small seed production orchard in Hawaii (Brewbaker 1987), but, as this reference does not note the density of trees, it is impossible to extrapolate production per tree. Actual harvested yields are generally quite low due to harvesting problems; either the plants are too tall to harvest and/or ripening is uneven, which means only a fraction of seed is collected at one time. Pod and seed set is affected by tree density, with a lower number of pods, flowers and seeds per plant in high-density stands (40 000 trees/ha) (Bhatnagar and Kapoor 1987).

Cultivated leucaena can be direct seeded, or planted as seedlings, stump cuttings or bare-rooted seedlings. A form of the KX2 hybrid has been planted in Vietnam using rooted cuttings (as this form of the hybrid is sterile), but this material is not being developed in Queensland (Shelton 2002). Leucaena seeds are hard seeded and germination occurs over a prolonged period after seed dispersal. *Tarramba* is significantly harder seeded than other cultivars (Hopkinson 1997). It is not triggered to germinate by a hot water treatment (boiling water for 4–5 seconds) and needs significant scarification. Most seed of *Tarramba* is purchased after scarification. Hard seededness means that this species can build up a persistent seed bank. Seed longevity of 7 years after removal of parent trees (Jones and Jones 1996) has been noted, although, 20 years seed viability is mentioned in some papers (Hughes 2002).

7.0 Efficacy of current control methods

Although leucaena is relatively easy to kill, once established, the species can be difficult to eradicate, as the soil seed bank can remain viable for at least 10 years after removal of seeding trees. A number of non-native insects are now present in Queensland and are reducing the vigour and seed production of both subspecies. Although these insects have reduced the cultivation of leucaena in some areas and should be reducing the seed bank, it is not clear if they are dropping seed production enough to reduce the spread of this species outside managed plantings.

7.1 Chemical control

One herbicide is currently registered for the control of leucaena. Access® is registered for both the basal bark and cut stump treatment of leucaena in a 60:1 dilution with diesel distillate (Dow AgroSciences 2002). Longreach Council has a minor off-label-use registration for Glyphosate360 herbicide as a foliar spray—1 L/100 L, plus BS10000 at a ratio of 1:500. Comalco Minerals and Alumina, Weipa, have registered a minor off-label-use registration for control of leucaena on mine rehabilitations sites using 1 part Grazon DS: 200 parts water, plus wetting agent, for foliar spray of seedlings (Department of Primary Industries 2000).

A replicated field trial on leucaena by scientists at the Alan Fletcher Research Station showed that a number of other herbicides are effective on this species—Lontrel® (foliar spray 5 mL/L), Roundup® (foliar spray 10 mL/L), Garlon® (basal bark 16.7 mL/L), Starane® 200 (basal bark 35 mL/L), and Tordon® TCH (stem injection 333 mL/L) all controlled the species (Pest Management Research 2002). Applications would need to be made to the chemical companies to register these products if they are not covered by the current registrations. Sorensson (1989) notes that neat diesel applied on the same day to chainsawed stumps (86–98%) and foliar spray of 3–5 leaf stage seedlings (96%) caused high rates of plant mortality without chemical addition.

7.2 Mechanical/physical control

Leucaena can be controlled by a number of mechanical/physical methods, but the roots must be dug out, as it will resprout vigorously after cutting. A blade plough can cut the root low enough, and cultivation will also kill most trees and roots. In South Africa, plants (including roots) are manually removed using a lasso/winch method (WESSA 2002). Leucaena can be mulched and the area then replanted with fast-growing plants (Smith 2001). The mulch produced from the cut leucaena provides a good green manure to help planted material establish. When put back as thick mulch (with seed pods removed), this material will also suppress new leucaena seedlings.

7.3 Fire

A serendipitous study suggests that fire may be a useful management tool for leucaena (C Middleton, pers. comm., June 2002). An early summer hot fire in a dense stand of ssp. *leucocephala* and guinea grass (*Panicum maximum*) (fuel load 7 000 kg/ha dry matter) showed an average kill of 75%. Small plants <2 m high had a very low survival rate (6%). The plant density fell from 0.88 to 0.2 plants/m^2 across the burnt area. Monitoring after the fire showed that some plants quickly regrew, either at or below ground level, reaching just under a metre within 2 months of the fire. Unfortunately, good rain within a month of the fire saw a very high seedling germination rate of 74 plants/m^2, indicating both a high seed bank and possible seed scarification by the fire. This study suggests that at least a second burn or chemical control would be required to reduce the adults and seedlings effectively in an established thicket. A further problem may be that many established stands shade out the understorey, leaving little to burn. Smith (2001) also noted that cool fires thicken up stands due to coppicing, but a hot fire will kill adult plants.

7.4 Biological control

A number of non-native insect pests have been imported into Australia accidentally. These agents are now widespread in Queensland, and reduce both seed set and plant growth. Although they reduce seed production, it is not clear yet whether these agents are sufficient to reduce the weediness of the two subspecies. Specific studies of the impacts of the insects on weediness or seed production have not been carried out.

7.4.1 Leucaena seed bruchid

The bruchid beetle, *Acanthoscelides macrophthalmus,* is a seed predator native to Central and South America. It feeds only on species in the genus Leucaena. Research was carried out to introduce this bruchid deliberately into South Africa as a biocontrol agent (Nesser 1994) and it was released in 2000 after years of controversy (S Nesser, pers. comm., 12 July 2002). As South Africa has many bruchid predators and parasites, and a larger native bruchid flora, concerns were raised that it may not be as effective there as in Australia. The bruchid was first found in Townsville in May 1996 (Jones 1996); after seven years it is now found wherever this species is grown in Australia (Elder 2002a).

Eggs are laid either on the surface of the leucaena pod, over a seed, or directly on exposed seeds. They are less than 1 mm in length. The larva hatches and chews into the seed, where it passes through all its moults until the adult bruchid emerges. The circular escape hole can be seen in pods that have matured and dried out. The beetle is 2–3 mm in length and flies readily when disturbed. The bruchid is only of importance to leucaena seed producers, as seed is the only part of the plant affected. It is recorded that 95% or more of seed may be infested (Elder 2002a), but, in the field, impacts from this insect are patchy and seasonal. It is possible that reductions in seed production due to this beetle have decreased the weediness of the species in Queensland, but currently there is no data to confirm this.

Other leucaena-specific bruchids of the Family Acanthoscelides possibly may be new biological control agents. These insects have not been investigated to date, but may provide increased control on spread. Bruchids that decrease seed production without affecting leaf production should help to reduce the invasiveness of the species. Methods currently used by seed producers to counter the impacts of *Acanthoscelides macrophthalmus* should be effective for other bruchids, if introduced.

7.4.2 Leucaena psyllid

The psyllid defoliator, *Heteropsylla cubana,* is native to Cuba and is found only on *Leucaena* species and hybrids. The accidental spread of the psyllid across the globe since 1983 has caused cyclical defoliation in areas where *Leucaena leucocephala* was planted. Mullen and co-workers (1998a) provide a comprehensive review of the psyllid's impact. The psyllid was first noted in Queensland in Bowen 1986 and is now found wherever this species is grown.

Eggs are laid on or in unopened leaves. Adults are aphid-like, 2 mm in length, winged, and light green in colour. The nymphs are similar to adults, but smaller. All growth stages affect the plant by sucking the sap of terminal leaves, buds and flowers. Flowering, and hence seedpod formation, is prevented. Where large numbers of psyllids are present, sooty mould may grow on their sugary excretions, preventing light from reaching the surface and decreasing photosynthesis. This insect does not kill trees, but affected shoots are less vigorous and have shorter and thinner stems, and it will reduce the percentage establishment of seedlings (Elder 2002b).

Current production losses due to psyllid damage are estimated to cost the Central Queensland beef industry in excess of $2 million per year (Mullen et al. 1998a). The psyllid has reduced the growth of leucaena within about 100 km of the coast in central and in northern Queensland, as they prefer high humidity and temperatures in the high 20s (°C). A study in Samford showed edible material of var. *Cunningham* was reduced 40–52% and yield of stems reduced by 46–83% (Bray and Woodroffe 1991). The psyllid is sensitive to changes in temperature or humidity, and does not significantly affect most plantings of ssp. *glabrata,* as it is grown in areas of less than 800 mm rainfall and lower humidity (Middleton et al. 1995). Of the current varieties, *Tarramba* recovers quickly from psyllid damage by the production of side branches from axillary buds (Castillo 1993), but the others recover more slowly. Research to develop a variety with greater psyllid resistance is continuing in Queensland.

7.4.3 Other insects

A caterpillar of a small moth native to Florida*, Ithome lassula*, was found in Townsville in 1980. The caterpillar is of importance only to leucaena seed producers, as it feeds on the base of flower buds, resulting in a tenfold reduction in pod production (Elder 2002c). This could help reduce the weed potential in some areas, although, its annual impacts are not known. The long soft scale, *Coccus longulus*, is a worldwide pest found on a wide range of horticultural crops—including custard apple, lychee, fig and many ornamentals (Elder 2002d). The scale produces honeydew that may cover lower foliage and stems, resulting in sooty mould growth. The loss of sap through the sucking activity of the scale may reduce the growth of leucaena. A native sap-sucking cicada was reported to damage shoot growth on a property in Injune in 1996 (Peart 1996).

7.4.4 Fungal pathogens

A basidiomycete fungus, *Pirex subvinosus*, first found in India and Sri Lanka, was found responsible for dieback of flood-irrigated leucaena in the Ord River in 1993 (Petty 1995). Similar tree dieback was found in Blackwater in 1994–6 and resulted in dead circular patches 100 m in diameter. Shivas and co-workers (1996) reported a fungal disease, *Cerosporella leucaenae,* from the Ord, but an endemic fungus almost immediately colonised it, suggesting that natural biological control may limit the impact of this disease. Boa has reviewed other potential pathogens (Boa and Lenné 1995) and these may be possible biological control agents if the species becomes so widespread that this form of control is required.

7.5 Land management practices

Grazing by native animals and livestock can be a control option for leucaena. Cattle, rabbits, hares, marsupials, termites and grasshoppers have all been recorded as destroying seedlings if they are allowed to eat them before the plants are well established (Brandon and Shelton 1993). Goats have been shown to control koa haole in Hawaii (PIER 2002). Grazing cattle will remove most pods of low plants, and high grazing pressures may damage low plants. Cattle will browse to a height of 1.7 m. More can be eaten if they walk over the plants, thus bending more material to browsing height. If cattle are excluded for too long, the trees may grow up to 7 m and, as the seeds are held at out of reach at the top of the plants, cattle cannot then influence seed production of these trees.

It is often noted that establishing a good crop of leucaena in a paddock requires good weed control. Maintaining a non-disturbed native ecosystem is a good way of reducing seedling germination of this species. It is important to note that seedlings are not killed by weed competition alone (Piggin *et al.* 1995); if leucaena seed has been spread to a site, treatment may be needed to control seedlings that survive this competition.

8.0 Management and control practices

8.1 Legislative status in Australia

Currently, *Leucaena leucocephala* is not declared at a state level anywhere in Australia.

8.2 Legislative status in Queensland

Leucaena is not a declared plant in Queensland under the *Rural Lands Protection Act 1985* (Qld). Declaration under this Act confers responsibility for the control of declared plants on the occupiers or managers of land, and does not imply government resourcing for this activity. Without state declaration there are currently no resources for, or legal requirement that, leucaena be controlled, unless local government has listed it under local law. Rockhampton City has listed *Leucaena leucocephala* as a noxious plant under local law. Similarly, Cook Shire has listed *Leucaena leucocephala* ssp. *leucocephala*, and several other local governments are considering similar measures either for one or both subspecies. Researchers in the Department of Natural Resources and Mines have carried out chemical control trials for this species and policy staff are working on a whole-of-government policy for this and other released pasture species.

8.3 Demand for declaration and control in Queensland

The increased occurrence of infestations of leucaena in riparian areas across Queensland, both near planted paddocks and in built-up areas (Anon 2002b), and concerns over approval of tree clearing permits in river catchments for fodder crops, including leucaena (Dickie 2000), has resulted in increasing demands for enforced control of this species. At the same time, grazier groups and researchers have expressed concern at the 'bad publicity' directed at *L. leucocephala* ssp. *glabrata* in the Queensland media in recent years, and are quick to defend the plant’s value as a forage crop for finishing steers without feed lotting. (Middleton 2000, Partridge 2002).

The identification of the subspecies involved in the infestations often becomes a point of discussion, but the origin of infestations is often unclear without explicit methods to separate the subspecies. Also, with no accurate mapping of the subspecies across the state, it is impossible to estimate the spread from cultivation or the total impact of the species as a whole. Recent surveys show that, although the species is widespread, its total impact is currently minor; however, the density of infestations in Darwin (Northern Territory) demonstrates that these can increase to form substantial thickets. Ultimately, most groups agree that, regardless of the subspecies, material found outside cultivation should be removed if it is adversely affecting the environmental or social values of the site. The issue then becomes one of responsibility for removing or managing this material.

Some promoters of the leucaena grazing system blame weed concerns raised by environmental groups as the reason for lack of uptake of this species (Middleton 2000). Lefroy (2002) notes that other reasons for poor adoption to date include the need to increase the skills of potential users, misconceptions and myths concerning the expense and difficulty in establishment, failure to clearly articulate the benefits, and leucaena representing a relatively small increase in production compared to the transition from native to sown herbaceous pasture. In an analysis of the costs of establishing leucaena, Chudleigh suggests, for example, that in some situations other short-term ley species, such as butterfly pea, may be lower risk and allow greater flexibility of planting (Chudleigh 2001). The pest status assessment also suggests that landholder dislike of tree species in pasture systems may be another component of their reluctance to adopt this species.

8.4 Containment and management strategies

Leucaena leucocephala ssp. *leucocephala* has been naturalised in Queensland for over 80 years and is now widespread across the state. Due to their low impact, the long-lived trees of this subspecies are currently unlikely to be controlled in many areas across the state. As a visible but small component of the weed flora, they are a low priority for control for many local governments and land managers, although, roads and riparian areas are subject to controls for other weeds. Local governments can declare (and have declared) this species to contain or manage impacts where concerns have been raised. Many of the current infestations are found on lands—wastelands, roadsides and riparian areas—where management roles and responsibility may not be clear, making enforcement of control difficult.

Leucaena leucocephala ssp. *glabrata* is generally found in paddocks, where management can contain seed production and spread. As seed production takes energy from leaf production, seed set should be discouraged to maximise returns from the pasture. To reduce the risk of seed spread from plantings, property management actions, as set out by the producer code of practice (section 8.5), can be taken. Recently, a number of leucaena properties have undertaken preventative property controls. The high returns obtained from using this species as forage provide a strong incentive for maintenance of this pasture system, but it is to soon to evaluate whether all leucaena growers will implement the code.

Plantings of either subspecies in areas where the spread cannot be managed (e.g. in parks and gardens, or for soil stabilisation) will increase the risk posed. Parties responsible for the planting or management of these sites should endeavour to prevent spread, or remove these plants.

Without the need for enforced control (declaration), containment of spread by the community may be possible for both subspecies following a number of actions:

- Non-pasture plants of either subspecies should be destroyed where found.
- Shires with leucaena in gardens and public places should replace it with non-invasive species.
- Control of leucaena should be included in local government pest management plans with other roadside management programs.
- The rapid increase in planting by pastoralists should be a catalyst for the removal of current infestations so that planted areas can be monitored and action taken to ensure landholders contain planted leucaena.
- Leucaena growers need to know about, and comply with, the code of practice. Most costs for managing the spread of leucaena are born during establishment. Annual management costs are minor, consisting of topping trees and chemical control of escapes.
- Better management of riparian areas in general would reduce the risk from this species, which establishes mostly in disturbed sites.
- Weed control programs for roadsides should include removing the small stands of leucaena currently found there.
- Development of new pasture varieties with nil or low seed production or low shrubby forms, rather than arborescent forms, which quickly grow out of the reach of cattle.

More coercive action may be required if future monitoring shows that these suasive methods are not effective. It may be that leucaena producers can develop and adopt an accreditation scheme to ensure that seed, if not animals, produced from leucaena properties are grown under conditions that comply with the code. Community groups can take action on new infestations, similar to the Whitsunday Shire initiative, without the need for declaration. Some have called for bonds to be placed on a number of primary production actions, including forestry and grazing, along the lines of the environmental bonds paid by mining companies. This may be applicable to this crop.
A lack of producer adoption of the code or the introduction of higher risk varieties are actions that may lead to a legislated approach to management. Enforced control within catchments containing natural wetlands of high conservation value may be desirable, especially if leucaena is not currently grown as a pasture species in these areas. Declaration would require a statewide ban on the sale of the species and the management of the impacts of all plants, including pasture plantings. Enforced control of leucaena on grazing lands in the state would be opposed by most graziers.

Seed production and spread is an area of biology requiring further research to assist in determining best management strategies. To estimate the impact of other control actions, an accurate determination of seed production by the subspecies and varieties in different environments is required. Without this data it is impossible, for example, to know if the impacts of the bruchid are significant. The modes of seed dispersal also need better study; for example, the importance of native and grazing animals as seed vectors, including the fate of seeds consumed by these animals, is still not well understood. This information is required to ensure that containment is achievable.

8.5 Property management strategies

Management practices aimed at minimising the risk of spread and invasion by *Leucaena leucocephala* ssp. *glabrata* varieties are being promoted under a 'code of good management practice for livestock' developed by farmers who cultivate leucaena in Queensland (see appendix 1). The code aims to minimise the risk of commercial leucaena adding to the existing problems with the 'common' leucaena invading ungrazed and urban areas. Major aims of the code are:

- limitations on leucaena planting adjacent to ungrazed areas where it can spread and thicken
- a reduction in seed production in grazed stands
- limiting the risk of live seed dispersal
- control of plants that escape from sown pasture areas.

The code is a product of the Leucaena Network, a group established in Central Queensland in 2000. The Network's members include graziers, seed producers, and research and extension personnel. Its aims are to promote and facilitate the adoption and improvement of the leucaena-based pasture systems. This code was first drafted in April 2000 and, although the Network is considering the development of a process of accreditation for growers to ensure that leucaena pastures are managed effectively, uptake of the code has not been measured to date.

Some requirements in the code may need to be strengthened; for example, the current 10 m buffer between plantings and fence lines may need to be increased to 20 m to be more conservative. Concerns over spread by cattle in dung require a guideline about holding cattle in a leucaena-free paddock for a week before movement, or direct selling of cattle fed on non-seeding leucaena.

Consistent with the code's property management strategies would be ensuring that breeding programs include shy seeding or sterility as a way to decrease the risk of weediness from cultivated varieties. Successful sterility has already been demonstrated for leucaena; for example, a sterile triploid hybrid of *L. leucocephala* x *L. esculenta* has been developed that, as well as being completely sterile, is very vigorous and incorporates the psyllid tolerance of *L. esculenta* (C Hughes, pers. comm., October 2002). A sterile form of the KX2 F1 hybrid cultivated by vegetative propagation is currently being tested in Asia, (Shelton 1998) for use in intensive livestock production systems. The challenge is to produce commercial quantities of seed of these sterile hybrids to allow for development of large-scale plantings.

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Appendix 1 A code of practice for the sustainable use of leucaena-based pasture in Queensland

Purpose of the code

This code aims to minimise the risk of commercial leucaena adding to the existing problems of 'common' leucaena invading ungrazed and urban areas.

Features of the code

The code targets those features of leucaena that predispose it to escape from designated sown areas and advocates management to limit its impact. The code aims to achieve:

- limitations on leucaena planting adjacent to ungrazed areas where it can spread and thicken
- a reduction in seed production in grazed stands
- limiting the risks of live seed dispersal
- control of plants that escape from sown pasture areas.

In planting leucaena for pasture, the following guidelines should be strictly followed:

1. Only plant leucaena if you need it and are prepared to manage it.
2. Do not plant leucaena near creeks or major waterways where it may spread. Maintain a dense grass buffer between the leucaena and the high water mark of the creek bank.
3. Control unwanted seedlings/plants that establish outside your paddock or on public roadsides, creek banks and other adjoining areas where cattle do not normally have access.
4. Plant it in a fully fenced paddock so that the very small chance of stock spreading ripe seed is avoided. Keep leucaena at least 10 m away from external fence lines.
5. If the original establishment within rows was sparse then allowing the leucaena to drop ripe seed will not correct the problem—either maintain it as it is, or replant it.
6. Graze or cut leucaena to keep it within reach of animals and reduce unwanted seed set.
7. Graze leucaena in summer so as to minimise flowering and seed set.
8. Maintain a vigorous grass component in the inter-rows. This will provide ground cover to prevent erosion. It will also provide competition that reduces the chance of seedlings establishing in the inter-rows.
9. Do not plant leucaena in pure stands with no grass, as this system will be more prone to erosion. A pure stand on light-textured soil may also cause soil acidification over time.
10. Assist your local government to identify any stands of escaped leucaena so that action can be taken to control it.
11. Give a copy of this code to your leucaena-growing neighbour.

(Prepared by the *Leucaena Network*, April 2000)

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