Review

The biology of Australian weeds
42. *Leucaena leucocephala* (Lamark) de Wit

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Name

Leucaena is derived from the Greek *leukos* (white), in reference to the white flower heads of its species. The genus *Leucaena* is in the tribe Mimoseae of the subfamily Mimosoideae of the family Leguminosae. The genus has 22 species, six intraspecific taxa and two named hybrids (Hughes 1998a). There are no native species of this genus in Australia.

Leucaena leucocephala (Lamark) de Wit 1961 is the only member of the genus naturalized in Australia. Synonyms of *L. leucocephala* include *L. glauca* (Willd.) Benth. 1842, *L. glabrata* Rose 1897 (Cowan 1998), *Mimosa glauca* L. 1753, *M. leucocephala* Lamark 1783 and *Acacia leucocephala* (Lamark) Link 1822.

Leucaena leucocephala has three subspecies: *leucocephala* (white headed) derived from the Greek *leukos* (white) and *cephalç* (head), *glabrata* (with glabrousness) is from the Latin *glaber* (hairless) and refers to the hairless condition of the plant surface and *ixtahuacana* (indicating the region of its discovery in Mexico).

Common names for *L. leucocephala* in Australia are leucaena, lead tree, Vi Vi and coffee bush. This widely cultivated species has many common names overseas, some of which include: cowbush (Bahamas), ipil ipil (Philippines), lead tree (Jamaica), wild lead tree (United States), wild tamarind (Seychelles), faux-acacia (French), faux-mimosa (New Caledonia) and stuipboom (South Africa).

Description

Leucaena leucocephala is a perennial, non-climbing, erect, thornless shrub or small tree, 3–10 (rarely 20) metres tall and is fast growing, with a trunk 5–50 cm in diameter (Hughes 1998b). The bark on young branches is mid grey-brown with shallow orange vertical fissures, while older branches and bole are rougher, dark grey-brown and with a deep red inner bark. Trees can live from 20–50+ years (Hughes 2002).

The 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 extra-floral nectaries because they occur on the leaf and secrete nectar, which are cup-shaped, sessile (not stalked), and concave with a broad pore.

The individual flowers are small, cream-white, with 10 free stamens per flower and hairy anthers. Inflorescences are arranged 80–180 flowers per dense globe-like head, which is 13–21 mm diameter and located on the end of a long stalk. Flowers are hermaphroditic and largely self-fertilized. The flower heads are in groups of 2–6. Flowers occur on actively growing young shoots, with leaves developing at the same time as the flowers.

The fruit pods are flat, thin and have a raised border. Starting green, pods become dark brown and hard at maturity. They are 9–19 cm long and 1.3–2.1 cm wide. In *L. leucocephala* pods occur in crowded

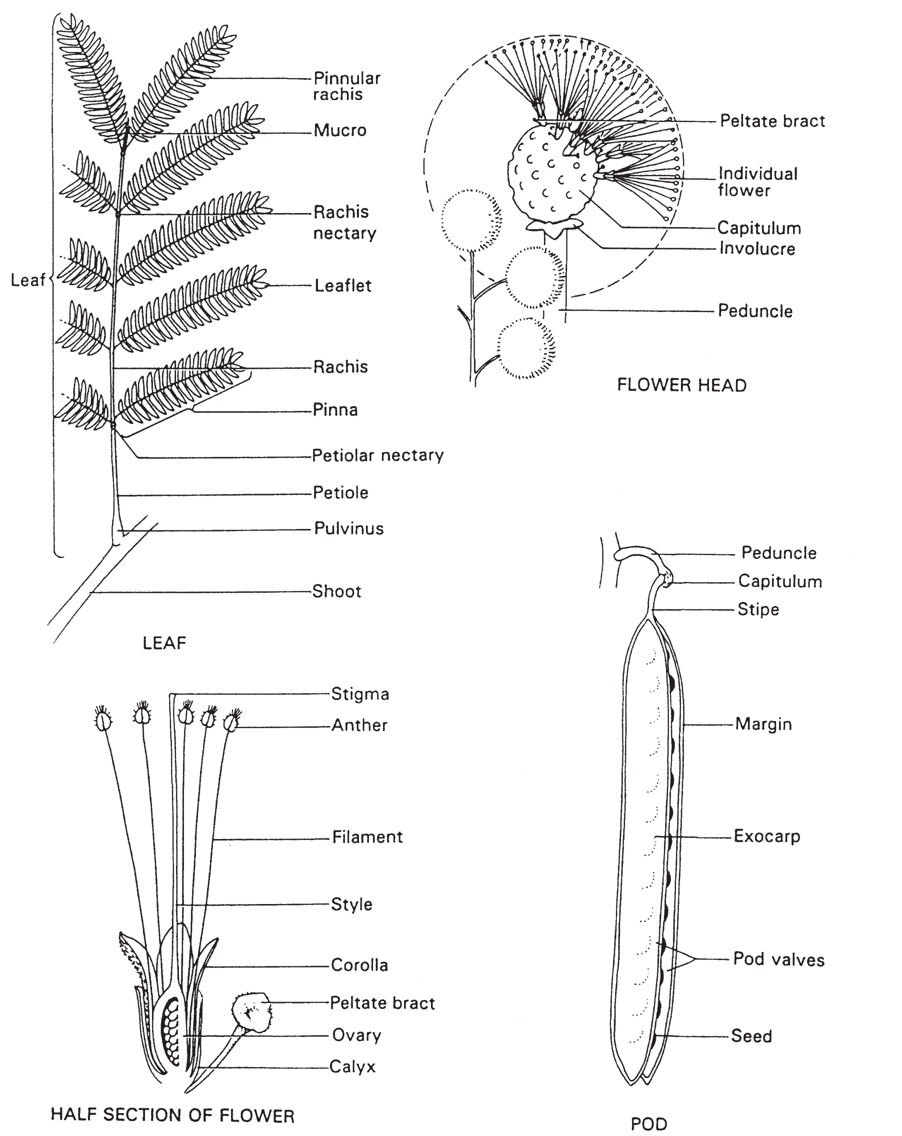

Figure 1. Morphological characters of *Leucaena* species. (Reproduced with permission from Hughes 1998b).

clusters ranging from 3–45 per head. The pods dehisce (open when ripe) at both sutures. Seeds are copiously produced, 8–30 (average 18) per pod. The seeds are oval, flattish, and brown, 6.7–9.6 mm long and 4–6.3 mm wide. There are approximately 15 000–20 000 seeds per kg (Duke 1983, Hughes 1998b, 2002).

The diploid chromosome number for the genus *Leucaena* is $2n=2x=52$ or $2n=2x=56$. *L. leucocephala* is a tetraploid species with a chromosome count of $2n=4x=104$ (Harris *et al.* 1994).

Distinguishing characters

Leucaena is distinguished from all other mimosoid legumes by two diagnostic characters, firstly its hairy anthers, which are easily visible with a hand lens and secondly the pollen surface is smooth, 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 petiolar 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 (Hughes 1998b). If a specimen has any of the following characters then it is not leucaena: thorns or spines (*Acacia* Mill., *Mimosa* L., *Prosopis* L.), leaves lacking petiolar glands, flowers arranged in spikes, fewer than or more than 10 stamens (*Acacia*), stamens fused into a tube (*Albizia* Durazz., *Calliandra* Benth.), flower heads with mixed colours (*Desmanthus* Willd.) or thickened, woody, indehiscent pods (other legume genera) (Hughes 1998b).

Intraspecific variation

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 1998b). Subspecies of *L. leucocephala*, while there is some overlap, are separated by a number of characters:

Subspecies *glabrata*. New growth is glabrous (hairless). Leaves >19 cm long and >12 cm wide, leaflets 16–21 mm long, flower heads >18 mm in diameter with >120 flowers per head, pods 12–19 cm long and 18–21 mm wide. Trees grow to 8–20 m.

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

Subspecies *ixtahuacana*. All characters similar to ssp. *leucocephala* except young shoots, leaves and pods glabrous.

History

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). It is not known why ssp. *leucocephala* was first introduced into Australia. It is possible that it was imported for shade, soil stabilization or as an ornamental, all roles promoted for this species in Asia at the time (Brewbaker 1987).

Selection, breeding and agronomic evaluation trials on *L. leucocephala* ssp. *glabrata* began in Queensland in 1954 (Hutton and Gray 1959), and it was commercially released in 1962 (Shelton *et al*. 2001). Planting of ssp. *glabrata* varieties expanded in the 1970 and 80s with the introduction of 3 hydroxy-4-1 H pyridone (DHP) degrading bacteria into Australia, thereby removing the toxic effects of high leucaena diets to cattle (Pratchet *et al*. 1991). By 1990, 16 000 ha of leucaena was planted in central Queensland and a further 5000 in other parts of northern Australia. This had increased to 40–50 000 ha in 1996 and was estimated to be approaching over 100 000 in 2002 (K. McLaughlin, personal communication, July 2002).

Distribution

Australia

Leucaena leucocephala ssp. *leucocephala* has a long history of occurrence in riparian areas and disturbed sites along coastal northern Australia, from Cockatoo Island in Western Australia (Hussey *et al.* 1997) to Windsor (near Sydney) in New South Wales (Cowan 1998). In the Northern Territory, ssp. *leucocephala* is probably the most widespread exotic woody weed, as it can be found in many coastal communities including Darwin, Nhulunbuy, Yirrkala and Howard Island, and in many catchments (Smith 1995, 2002). It is recorded in New South Wales on Norfolk Island (Swarbrick and Skarratt 1994), but residents state it is not invasive there. A survey in Queensland suggests it may currently occupy up to 10 000 ha in the State (Shelton *et al*. 2001), with infestations in the Fitzroy Basin (Figure 2), Torres Strait, Townsville, Mackay and south-eastern Queensland. A prioritization of weeds of Queensland's Wet Tropics listed *Annona glabra* L. (pond apple) and *L. leucocephala* as the two highest ranked weed species in this bioregion (Werren 2001).

Leucaena leucocephala ssp. *glabrata* varieties have been planted in both coastal and inland areas of Australia, since released commercially as a fodder species in 1962 (Shelton *et al*. 2001). This species is planted in the Ord Irrigation Area in Western Australia, some grazing properties in the north of the Northern Territory and on over 200 properties in Queensland (north of Charters Towers, throughout the Fitzroy Basin and in south-eastern Queensland) (Figure 3). Spread from these planted paddocks, outside the reach of grazing animals, has been noted onto roadsides and in riparian areas in Queensland (Jones and Jones 1996, Shelton *et al*. 2001), in northern New South Wales, e.g. the Clarence River in Grafton (R. Ensby, personal communication, July 2002) and along 50 km of the Ord River in Western Australia (N. Wilson, personal communication, September 2002).

In the Queensland Shires of Broadsound and Sarina, trial plots of leucaena have given rise to spread to nearby streams and creeks within the last five years (C. Chopping, personal communication, August 2002). In Longreach, spread of ssp. *glabrata* into drainage lines leading to the Thomson River led to the Shire Council locally declaring this subspecies

Figure 2. *Leucaena leucocephala* ssp. *leucocephala* weed in a creek in central Queensland.

a weed. A number of infestations in cities and towns across Queensland, including Brisbane (Figure 4), Townsville, Mackay and Rockhampton, have been shown to include ssp. *glabrata* (Shelton *et al*. 2001).

The potential range of *L. leucocephala* in Australia has been predicted by a number of workers who have looked at the agronomic potential of the species. Hutton and Gray (1959) estimated a suitable area of approximately 37 M ha in Queensland and 41 M ha in other states. Middleton and co-workers (1995) suggested a reduced estimate of 3 to 5 M ha of agricultural lands in northern Australia, while a more recent study indicated ssp. *glabrata* var. *Cunningham* was adapted to 4.43 M ha of agricultural lands in northern Australia (Coates 1997). This prediction was derived from the area of clay soils in the 550–800 mm rainfall zone. The upper rainfall limit was included in this study to eliminate areas prone to psyllid damage, but it is likely that this area could still be suitable for both subspecies. This suggests a total of 5.67 M ha as suitable across northern Australia.

Climate analysis, using the CLIMEX™ computer-modelling package (Skarratt *et al*. 1995) suggests the climate of coastal areas of northern Australia is similar to that experienced by ssp. *leucocephala* in its native range (Figure 5). The model predicts that ssp. *glabrata* would be 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 6).

Outside Australia

The native distributions of the three subspecies of *L. leucocephala* are mostly distinct. *L. leucocephala* ssp. *leucocephala* is found mainly in the Yucatan Peninsular in Mexico with outlying occurrences north of Veracruz; ssp. *glabrata* is widespread across much of Mexico, and Central America while ssp. *ixtahuacana* has a small-localized distribution in two valleys in southern Mexico/northern Guatemala (Hughes 1998b).

Leucaena leucocephala ssp. *leucocephala* has a long history of deliberate transportation and spread and is now one of the most widely naturalized of the non-European crop plants (National Academy of Sciences 1984). It may be naturalized in over 105 countries (Figure 7), throughout the world's sub-tropics and tropics. It is possibly growing on up to 5 million ha (Binggeli 1997). It is known as a weed in over 25 countries, across all continents except Antarctica (Hughes 2002). The World Conservation Union's Invasive Species Specialist Group listed the species *L. leucocephala* in its list of 100 worst invasive organisms (Lowe *et al*. 2000). This group's primary focus is on invasive species that cause biodiversity loss, with particular

Figure 3. *Leucaena leucocephala* ssp. *glabrata* as a planted pasture in central Queensland.

Figure 4. *Leucaena leucocephala* ssp. *glabrata* spreading in a suburban creek (Brisbane).

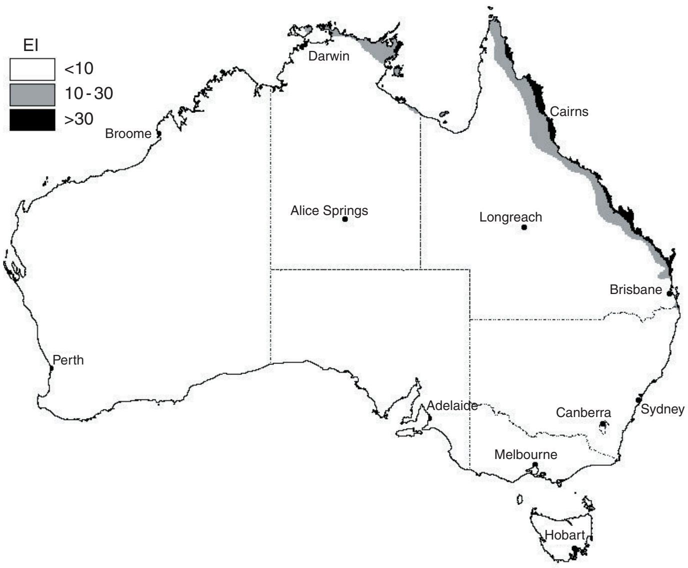

Figure 5. Potential distribution of *Leucaena leucocephala* ssp. *leucocephala*. Data is splined from a CLIMEX prediction. EI = Ecoclimatic index: EI <10 potential for permanent population low, EI >30 potential for permanent population high.

attention to those that threaten oceanic islands (Hughes 2002). *Leucaena leucocephala* is amongst the most prevalent invasive species in the Pacific and is considered a serious problem in several islands, including Tonga and Hawaii (Pacific Islands Ecosystems at Risk 2002).

Leucaena leucocephala ssp. *glabrata* has not specifically been recorded as a weed overseas, but as it has been planted for less than 30 years it is likely that it is in the early phases of invasion (Hughes and Jones 1998). Cultivars of ssp. *glabrata* were widely introduced and planted across the tropics in the 1970s and 80s, mostly promoted for use in reforestation and grazing programs by international agencies and non-government organizations (National Academy of Sciences 1984). It is now very widely cultivated throughout the tropics and subtropics. Its worldwide distribution may now equal that of ssp. *leucocephala*.

Habitat

Climatic requirements

Leucaena leucocephala is essentially a tropical species requiring warm temperatures (25–30°C) for optimum growth, with poor cold tolerance and significantly reduced growth during cool winter months in subtropical areas (Hughes 1998b). *Leucaena leucocephala* ssp. *leucocephala* is limited to below 500 m altitude due to its cold intolerance, while ssp. *glabrata* is found up to 2100 m in its native region (Hughes 1998b). In Queensland most ssp. *glabrata* is planted at the limits of its climatic tolerances, in areas with low and seasonal rainfall and winter frosts, because the soils are more suitable.

Leucaena leucocephala grows well in subhumid or humid climates with rainfall between 650 and 3000 mm; 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 survival of plants subject to three years of drought in the Rolleston/Blackwater region (Jones and Middleton 1995).

Leucaena leucocephala shows low frost tolerance. It sheds its leaves with light frosts, with 13% dieback after one day of -5°C (Shelton and Brewbaker 1994), and seedlings will be killed if the temperature remains below zero for more than a few hours at a time.

Substratum

Leucaena leucocephala grows on a wide variety of deep, well-drained fertile soils. Subspecies *leucocephala* mostly colonizes sub-humid alkaline soils, especially coralline islands, but never grows well on sand dunes (Brewbaker 1987). This subspecies prefers disturbed sites and will grow in disturbed wet areas, but will not be the dominant species. Alkaline structured clay

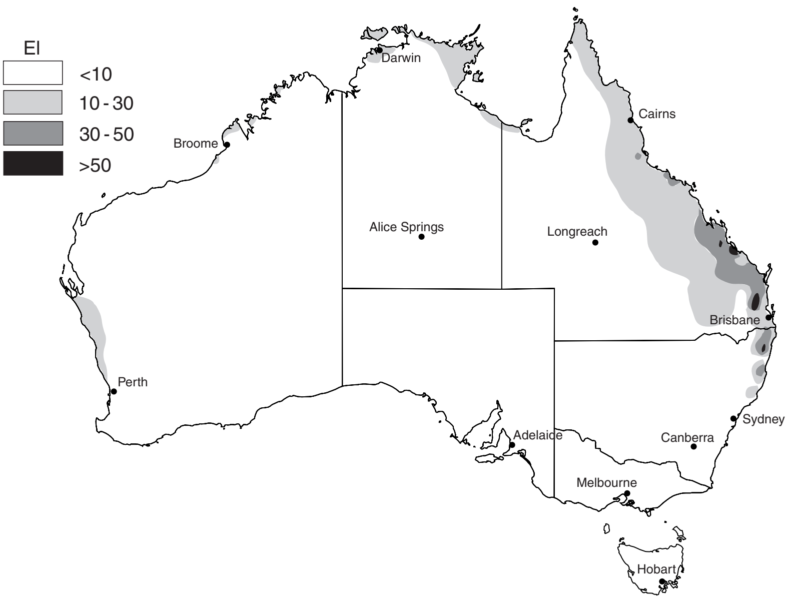

Figure 6. Potential distribution of *Leucaena leucocephala* ssp. *glabrata*. Data is splined from a CLIMEX prediction. EI = Ecoclimatic index: EI<10 potential for permanent population low, EI >50 potential for permanent population very high.

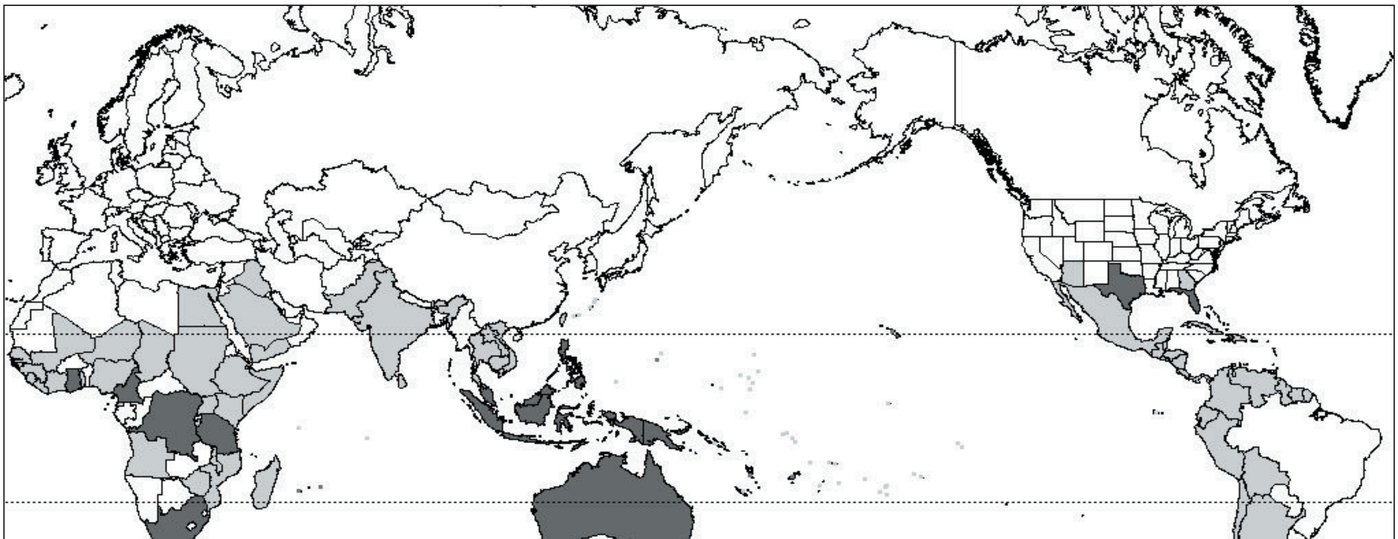

Figure 7. The current world distribution of *Leucaena leucocephala*, with countries in which it is recorded as a weed marked in darker shading. (Sources: Legume WEB 2002, Holm *et al*. 1979, Plants 2002, Pacific Island Ecosystems at Risk 2002, Hughes and Jones 1998, Binggeli 1997 and G. Luckhurst, personal communication, May 2002).

soils of the brigalow and softwood scrubs, alluvial and open downs country is most suitable for ssp. *glabrata* (Anon 2000).

Leucaena leucocephala is intolerant to soils with low pH (below pH 5.5), low potassium, low calcium, high salinity, high aluminium and waterlogging (Brewbaker 1987). Although seedlings cannot tolerate waterlogging, adult trees can survive intermittent waterlogging (Shelton and Jones 1995).

Growth and development

Morphology

Leucaena leucocephala differs from other members of the genus in that it has considerable intraspecific diversity in tree size and form. The shrubby 'common' type (ssp. *leucocephala*) is small (total height 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 1998b). Under cultivation ssp. *glabrata* may look like ssp. *leucocephala,* with multiple branched regrowth due to damage to the main stem, but in undisturbed areas it will grow to a much larger plant with a single stem.

Leucaena leucocephala can create 'instant forests', growing into dense impenetrable stands with canopy closure in three months (Hughes 2002). The canopy of the plants will spread and the plants are larger if singly grown.

The primary *L. leucocephala* root system is a taproot with feeder root development following this. The taproot averages 3 m in brigalow soils. Waterlogged trees may develop aerial roots to increase air intake into the root system (Brandon and Shelton 1993). Fifteen-week-old seedlings of ssp. *glabrata* were found to have 40% of the biomass below ground and this was not correlated with plant size (Fownes and Anderson 1991).

Phenology

The genus *Leucaena* has a short juvenile phase for a woody species; it can commence flowering within 3–4 months of planting. *Leucaena leucocephala* follows this pattern, with flowering 2–4 months after planting in Botswana (Kaminski *et al*. 2000). Although ssp. *glabrata* generally does not set seed until the second year, time to flowering for var. *Tarramba* was 246 days (range 190–289 days) (Anon. 1997).

The phenology of *Leucaena* species was studied in southern Brazil (Kaminski et *al.* 2000). The vegetative period (the number of days from leaf regrowth to first flower buds) for *L. leucocephala* ssp. *leucocephala* was 80–139 days, 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) 100 days and 75–115 days for the two subspecies, respectively.

Flowering in *L. leucocephala* ssp. *leucocephala* differs from other species in the genus in that it can be continuous; flowering and seed production may occur all year, with peaks every six months (Hughes 1998b). Other species in the genus have distinct annual flowering and fruiting patterns (duration of 2–5 months) and do not flower and fruit quite so abundantly. Flowering in *L. leucocephala* also increases under moisture stress or with the onset of shorter days in the subtropics.

Germination of *L. leucocephala* seedlings occurs over a prolonged period after seed dispersal; emergence at seven years after removal of parent trees (Jones and Jones 1996) has been noted, although some papers report that seeds remain viable for 20 years (Hughes 2002).

Mycorrhiza

Root hairs of *L. leucocephala* are poorly developed and the plant appears to rely heavily on symbioses with a variety of bacterial and fungal strains for nutrient uptake, at least during seedling development (Brandon and Shelton 1993). These workers found that the plants growing in soil with low vesicular/arbuscular mycorrhiza activity suffered phosphorus deficiency, but that there is no practical method of inoculating leucaena with fungal strains.

Field studies using single and mixed strains of inocula have demonstrated that the early growth of *L. leucocephala* may be significantly improved by strains of *Rhizobium* in the soil (Piggin *et al.* 1995). Although the plant showed strain specificity in some studies (Piggin *et al.* 1995), it was noted that it is possible to grow leucaena in Australia without additional soil inoculum (Jones and Date 1995).

Physiology

Having moderate shade tolerance, seedlings of *L. leucocephala* can grow under its own canopy, ~35% of full light transmission (Piggin *et al*. 1995), and under lantana (Binggeli 1997). *L. leucocephala* is not able to grow under dense shade of closed forest.

Reproduction

Floral biology and pollination

The globular *L. leucocephala* heads contain numerous tiny hermaphroditic white flowers; floral biology was well studied by early workers (Hutton and Gray 1959). These flowers are largely self-fertilized, which promotes seed production even by isolated individuals and allows the species to seed true to type. Flowers last for only 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. Within an hour the anthers have retracted so that the stigmas stand above the anthers. Pollinators, such as bees, are generally inactive 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 doesn't require specialist pollinators and is cross-pollinated by a range of generalist insects (Hutton and Gray 1959).

Seed production and dispersal

Leucaena leucocephala is a high seeding tree; ssp. *leucocephala* has been recorded to produce 277-388 pods (4000–6100 seeds) per plant (Hutton and Gray 1959) while ssp. *glabrata* varieties produced 8666 and 17 600 seeds per plant in Queensland (Hutton and Gray 1959) and 600–5140 seeds per plant in India (Bhatnagar and Kapoor 1987).

Seed dispersal is generally less than 20 m if unaided. Wind assisted movement of ssp. *leucocephala* pods has been recorded over 100 m from parent plants on coastal cliffs in the Northern Territory (P. Jeffries, personal communication, September 2002). Other modes of dispersal include: water, deliberate spread for cultivation in the nursery trade, landscaping, soil stabilization, 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. It is commonly believed that cattle are unlikely to spread *L. leucocephala,* as they eat only green seeds and as mature seed would either have fallen from pods or remain in dry pods that are unattractive to cattle. However, seedlings have been reported in dung from cattle that have been grazing ssp. *glabrata* (Jones and Jones 1996).

Vegetative reproduction

Leucaena leucocephala does not naturally reproduce vegetatively. Although it can be induced to form offspring using biotechnological techniques, e.g. a sterile form of the KX2 F1 hybrid (*L. pallida* K748 × *L. leucocephala* ssp. *glabrata* K636) has been developed and is being cultivated by vegetative propagation (rooted cuttings) in Asia. Plants will, however, regrow from cut stumps, 5–15 branches per stump depending on the diameter of the cut surface and this may result in denser growth (Jones *et al.* 1992).

Hybrids

Spontaneous hybridization between and within species is a possible additional hazard posed by *L. leucocephala;* natural hybrids are recognized in the genus (Hughes and Jones 1998). To date only two subspecies of *L. leucocephala* have been widely cultivated in Australia and it is already possible that a low level of crossing between these subspecies is occurring in the field, obscuring the differences between them. The introduction of new species or interspecific crosses to Australia, such as the *L. leucaena* × *L. diversifolia* hybrid, promoted as K3 by Hawaiian researchers, could increase the risk of fertile crosses with the material already present. K3 is apparently self-fertile and is a prolific seeder; it could pass these qualities on to the varieties currently planted in Australia if it were planted alongside them (C. Hughes, personal communication, October 2002).

Population dynamics

Except in instances where severe disturbance has lead to rapid expansion, such as after Cyclone Tracy in Darwin, the spread of ssp. *leucocephala* has been slow to date. The spread of ssp. *glabrata* from paddocks and in built-up areas in south-eastern Queensland has been more rapid. Several biological characteristics could promote the spread of *L. leucocephala*: its abundant, precocious and year round seed production, 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).

Importance

Detrimental

Leucaena leucocephala has been called a 'conflict tree' (Hughes 1998b). A major component of this conflict is that two morphologically and genetically distinct subspecies are found in the country. *L. leucocephala* ssp. *leucocephala* is a visible, ruderal, weedy shrub mostly of roadsides, disturbed sites and creeks, while ssp. *glabrata*, was developed in Queensland as a productive tree/grass forage production system for cattle fodder. Unfortunately, ssp. *glabrata* is also showing a tendency to spread from planted sites and further planting and new varieties may amplify this. Higher weed risk posed by *L. leucocephala* ssp. *glabrata* arises from the taller stature of the trees, increasing the risk of seed production beyond the reach of browsers. Moreover, its wider soil and climate tolerances extend its habitat range in Australia. Increased planting of the cultivated varieties, along with the spread of older infestations, is causing community concerns about this species.

Leucaena leucocephala has an increasing environmental impact in Australia. It forms dense mono-specific thickets, resulting in the suppression of native species, exacerbated erosion and impedance of animal movement. Thickets may threaten endangered species, e.g. in Hawaii it is reported to be replacing native *Metrosideros* (Banks) ex Gaertn – *Diospyros* L. open forest on Maui (Cronk and Fuller 1995). Infestations are already noted to occur in a number of ecosystems: wetlands, monsoon vine forests and moist woodlands (Swarbrick and Skarratt 1994). Although *L. leucocephala* does not readily invade undisturbed forests or woodlands, it invades riparian areas, both undisturbed and disturbed (G. Werren, personal communication, September 2002, Hughes 2002). *L. leucocephala* is also a visually unsightly weed, easily seen on roadsides due to its multiple branches and dark pods.

The toxin mimosine is found in *L. leucocephala* and its by-product DHP is created when it is chewed by animals. Toxic to non-ruminants, this substance does not deter ruminants from eating the plant but 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* Allison, is required in grazing animals to prevent mimosine toxicity (Pratchett *et al.* 1991).

Treatment costs for *L. leucocephala* infestations are estimated at \$740–1845 ha^{-1}, this outlay includes the cost of on-going monitoring due to the long-lived seed bank (Dalzell *et al.* 2002, P. Jeffries, personal communication, September 2002).

Beneficial

Commercial cultivars of *L. leucocephala* ssp. *glabrata* are used in Australia as a browse legume in a system combined with improved (exotic) grass species (e.g. *Panicum maximum* var. *trichoglume* Jacq. (green panic), *Chloris gayana* Kunth (common Rhodes grass) and *Cenchrus ciliaris* L. (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. The pastures are long lived (over 40 years), drought tolerant and productive. Annual benefits to Queensland from the current leucaena production area are estimated at \$14 M per annum (Middleton *et al.* 2002).

Leucaena leucocephala is known for its high nutritional value and for the similarity of its chemical composition with that of lucerne, *Medicago sativa* L. (Norton *et al*. 1995). Its forage can be low in sodium and iodine but is high in ß-carotene (Duke 1983). In Queensland live weight gains equal to >250 kg live weight gain ha^{-1} year^{-1} (Esdale and Middleton 1997) have been recorded on this forage. This growth is comparable to or better than that from other feed sources (Table 1). The highest recorded live weight gains from a tropical pasture legume (over 2000 kg live weight gain ha^{-1} year^{-1}) have been achieved on leucaena in the Ord River Irrigation Area (Lefroy 2002). In Hawaii, fresh leaf matter yields of 40–80 tonnes ha^{-1} year^{-1} have been recorded when moisture was not limiting and 20–50 tonnes ha^{-1} year^{-1} when moisture is seasonally limiting or in subtropical climates (Brewbaker 1987).

Both subspecies of *L. leucocephala* were promoted in the 1960–80s by development agencies worldwide as a 'miracle plant' (National Academy of Sciences 1984). However, most of the potential uses are not employed in Australia. These uses include: shade for crops, firebreaks, timber production and firewood, pods as a human food source, concoctions of barks and root are taken for various medicinal purposes, planting for mine rehabilitation and sand binding, production of a gum very similar to gum Arabic from seeds, planting in rotation with maize to restore soil fertility and planting in parks and gardens as a shade tree (National Academy of Sciences 1984, Brewbaker 1987).

Legislation

Leucaena leucocephala is not currently declared as a weed by any State in Australia. The Kimberley Land Protection Board has recently requested that *L. leucocephala* be listed under Western Australian weed legislation as Category P5 (weeds to be controlled on public land or land under the control of local government) but this proposal had not been accepted at the time of writing. *L. leucocephala* is not a declared plant in Queensland under the *Rural Lands Protection Act* 1985. A number of local governments in Queensland (e.g. Rockhampton City) have, however, declared *L. leucocephala* a weed within towns under local laws where it is creating a problem in town wastelands, roadsides and on unused land. Cook Shire has specifically declared ssp. *leucocephala,* requiring control action, and it also requires ssp. *glabrata* to be grown in accordance with a code of practice. Several other local governments are considering similar

Table 1. Comparison of cattle growth on various feed systems from animal performance feedback trials held in Rockhampton (Esdale and Middleton 1997).

Treatment	Average live weight gains (kg head^{-1} day^{-1})
Leucaena/grass pasture	1.26 (range 0.7–1.70; n = 153 steers)
Buffel grass alone	0.83 (range 0.47–1.30; n = 151 steers)
Grain-fed lot feeding	1.41 (range 0.96–2.20; n = 201 steers)

measures on either one or both subspecies of *L. leucocephala*.

Weed management

Herbicides

Access® is currently registered for the control of *L. leucocephala*; both for basal bark and cut stump treatment in a 60: 1 dilution with diesel distillate (Dow AgroSciences 2002). A number of other herbicides effective on trees have been studied and all controlled this species, but these are not currently registered by the National Registration Authority. Sorensson (1989) notes that neat diesel applied on the same day to chainsawed stumps and foliar application of diesel to 3–5 leaf stage seedlings caused high rates of plant mortality, 86–98% and 96% respectively, without chemical addition.

Other treatments

Mechanical/physical control. *Leucaena leucocephala* can be controlled by a number of mechanical/physical methods but, as it will resprout vigorously after cutting, methods must ensure that the roots are dug out. A blade plough can cut the root low enough and cultivation will also kill most trees and roots. In South Africa, plants are manually removed, including roots, using a lasso/winch method (Wildlife and Environment Society of South Africa 2002). *L. leucocephala* can be mulched and the area then replanted with fast growing plants (Smith 2001). The mulch produced from the cut *L. leucocephala* provides a good green manure to help the establishment of the planted material. Put back as thick mulch (seed pods removed), this material will also suppress seedling emergence.

Fire. Fire may be an effective tool for management of this species, although Smith (2001) noted that cool fires thicken up stands due to coppicing, but a hot fire will kill adult plants. Observations in Queensland suggest a follow-up fire or chemical control would be required to effectively reduce the adults and seedlings in an established thicket (C. Middleton, personal communication, June 2002).

Land management practices. Grazing by native animals and livestock can be a control option for *L. leucocephala*. Cattle, rabbits, hares, marsupials, termites and grasshoppers have all been recorded to destroy seedlings before the plants are well established (Brandon and Shelton 1993). 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 cattle walk over the plants, thus bending more material to browsing height.

It is often noted that establishing a good crop of *L. leucocephala* in a paddock requires good weed control. Maintaining a non-disturbed native ecosystem is then a good way of reducing seedling establishment of this species. It is important to note that seedlings are not killed by weed competition alone (Piggin *et al.* 1995), so sites may need treatment to control seedlings that survive this competition.

Management practices aimed at minimizing the risk of spread and invasion by *L. leucocephala* ssp. *glabrata* varieties are being promoted under a 'Code of good management practice for livestock', developed by farmers who cultivate *L. leucocephala* in Queensland (Shelton *et al.* 2001). The code aims to minimize the risk of commercial varieties adding to the existing problems with *L. leucocephala* ssp. *leucocephala* invading ungrazed and urban areas. As well as actions taken inside the property to reduce spread, the code advocates that the land manager remove material found outside cultivation, regardless of the subspecies, if it is impacting on the environmental or social values of a site.

Natural enemies

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

The bruchid beetle, *Acanthoscelides macrophthalmus* Schaeffer, a seed predator native to Central and South America, was first found in Townsville in May 1996 (Jones 1996). It is now found wherever this species occurs in Australia. It feeds only on species in the genus *Leucaena* and it is has been recorded to infest up to 95% of seed (Elder 2002a). However, impacts from this insect are patchy and seasonal in the field. Research was carried out to evaluate this bruchid as a biocontrol agent in South Africa (Nesser 1994) and it was released in 2000 after years of controversy. Other leucaena-specific bruchids of the Family Acanthoscelides may be possible biological control agents but these insects have not been investigated to date.

The psyllid, *Heteropsylla cubana* Crawford, a sap-feeder native to Cuba, was first noted in Queensland in Bowen 1986, and it is now widespread. The accidental spread of the psyllid across the globe since 1983 has caused significant damage to *L. leucocephala* plantings. Mullen *et al.* (1998) provide a comprehensive review of the psyllid's impacts. This insect does not kill trees but affected shoots are less vigorous, have shorter and thinner stems and it will reduce the establishment of seedlings. The psyllid has reduced the growth of *L. leucocephala* within about 100 km of the coast in central and northern Queensland, as it prefers high humidity and temperatures in the high 20°C.

Other possible insect enemies include a caterpillar of a small moth native to Florida, *Ithome lassula* Hodges, which feeds on the base of flower buds resulting in reduction in pod production (Elder 2002b), and a long soft scale, *Coccus longulus* Douglas, which is a worldwide pest found on a wide range of horticultural crops, including custard apple, lychee, fig and many ornamentals (Elder 2002c).

Leucaena leucocephala is host to a number of pathogenic fungi. A basidiomycete fungus, *Pirex subvinosus* (Berk. & Broome) Hjortstam, first found in India and Sri Lanka, caused dieback of flood-irrigated *L. leucocephala* in the Ord River in 1993 (Petty 1995). Boa and Lenné (1995) reviewed other potential pathogens and these may be possible biological control agents.

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