Review

The biology of Australian weeds 58. *Baccharis halimifolia* L.

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Name

The genus name *Baccharis* is after the Greek *bakkaris*, an oil producing plant (later called 'Celtic valerian') (Parsons and Cuthbertson 1992). The species name *halimifolia* is derived from the Greek *alimos* meaning 'seas' and the Latin *folium* meaning 'leaf' (Parsons and Cuthbertson 1992). *Baccharis halimifolia* L. belongs to the family Asteraceae which is the largest family of flowering plants, comprised of over 1100 genera and 19 000 species (Zomlefer 1994). *Baccharis* is a large genus, comprised of over 400 species (Mahler and Waterfall 1964, Zomlefer 1994) distributed over seven geographical areas: Brazil, Andes Mountains, Andes-Patagonia, Guyanarum, south-eastern Brazil, Mexico (including western United States) and the Antilles (including the eastern United States) (Boldt 1989). In Australia, *B. halimifolia* is most commonly known as groundsel bush. 'Groundsel' refers to the groundsel-like flowering heads, as in plants in the *Senecio* genus (Parsons and Cuthbertson 1992). In its native region it is often referred to as saltbush (Stevenson 1969, Proffitt *et al.* 2005), groundsel tree (Altfeld and Stiling 2006), sea myrtle (Caccamise 1977, Dickens and Boldt 1985) and eastern baccharis (Adlerz 1980).

Description

Baccharis halimifolia is an erect woody perennial shrub that grows to about 6 m high (Mahler and Waterfall 1964); the bases of stems have been found up to *c.* 18 cm in diameter (Winders 1937). It is diploid and the chromosome number in all Australian and American species is $2n = 18$ (Westman *et al.* 1975). In its native range, *B. halimifolia* is deciduous. However, in Australia it is evergreen (Westman *et al.* 1975). Stems are initially green, becoming brown with age. They are erect and woody and the bark of more mature stems is deeply fissured (Parsons and Cuthbertson 1992). Shoots are described as being diageotropic (growing in a horizontal manner) (Kupfer 1903). Leaves are arranged alternately along the stem (Parsons and Cuthbertson 1992) and are distinctly petiolate or sessile (Bailey 1899) (Figure 1). They are present at flowering and are elliptic to rhomboid in shape. The leaf bases are cuneate, margins are coarsely serrated (teeth 1–3 pairs) and abaxial surfaces are glabrous. Leaves are prominently 1-nerved with two lateral nerves extending from the midrib above the leaf base (eFloras 2009). Large leaves are *c.* 2.5 to 5 cm long and 2.2 cm wide (Parsons and Cuthbertson 1992) (Figure 1).

Baccharis halimifolia is a dioecious species. Male flowers are yellow due to the large amount of pollen and female flowers (*c.* 1.2 cm long; Parsons and Cuthbertson 1992) are white due to the pappus attached to each achene (Krischik and Denno 1990a) (Figure 2). The inflorescences are widely paniculate and the receptacles are green and flat to convex (eFloras 2009). Achenes (hereafter referred to as 'seeds') are ribbed, approximately 1–1.7 mm long and have a dry weight of *c.* 0.1 mg (Panetta 1979a) (Figure 3). The pappus is *c.* 3–4 mm long with a flaccid plumosed tip (eFloras 2009). *B. halimifolia* plants have a deep branching taproot with many fibrous laterals in the upper soil layers (Parsons and Cuthbertson 1992). There is no difference

Figure 1. Leaves of *Baccharis halimifolia*. Photo by Nikki Sims-Chilton.

Figure 2. Female inflorescences of *Baccharis halimifolia*. Photo by Nikki Sims-Chilton.

between male and female plants in leaf morphology, branching pattern or plant size (Krischik and Denno 1990a).

History

Baccharis halimifolia is believed to have been introduced to Australia as an ornamental species in 1888 (Bailey 1899). By 1900 it was reported to have escaped from gardens into waste places of areas surrounding Brisbane (Winders 1937) and it had become a serious weed in coastal areas of south-eastern Queensland by the 1930s. In the 1970s it was reported to have established south into areas of northern New South Wales to Macksville (30° 42' 23.34" S, 152° 55' 15.51" E) (Auld 1970) and further north in Queensland to about Miriam Vale (24° 19' 43.14" S, 151° 33' 38.12" E). *B. halimifolia* was officially declared noxious in 1951, due to its ability to invade pastures and native *Melaleuca* wetlands (McFadyen 1973). Since then, the status of *B. halimifolia* as a pest appears to have decreased (Sims-Chilton *et al.* 2009). A number of factors may have contributed to its decline, including mechanical and chemical control efforts by landholders and councils, the introduction of biological control, land use changes and development, and changes in climate (Sims-Chilton *et al.* 2010).

Distribution

Baccharis halimifolia is native to North America where it is found along the Gulf and Atlantic coasts. Its approximate range extends from Texas to Massachusetts (Figure 4). It has also been recorded in Spain, France and Australia, where it is considered an invasive species. In Spain and France, *B. halimifolia* is found along the Biscay Coast (Parsons and Cuthbertson 1992). It was introduced to France in 1863 as an ornamental plant. It is problematic in areas of most Spanish estuaries from the Ria of Tina Mayor (region of Asturias) to the border with France (Campos *et al.* 2004), where it is noted as the biggest problem in the region (Meaza and Cadiñanos 2000, cited in Campos *et al.* 2004). It has invaded over 128 ha of the subhalophilous saltmarsh of the Urdaibai Biosphere Reserve in Spain (Onaindia *et al.* 2001). *B. halimifolia* was found to be one of the most abundant species in degraded salt marshes of Urdaibai and Galera (Bay of Biscay coast) (Onaindia *et al.* 2001) and has recently been listed among the priority weeds for management in the Mediterranean Basin (Brunel *et al.* 2010).

In Australia, *B. halimifolia* has been recorded only in Queensland and New South Wales (Figure 5). An assessment of the potential distribution of the species suggests that it has potential for spread, particularly further south into New South Wales and Victoria (Sims-Chilton *et al.* 2010) (Figure 6). However, predictions show that the growth potential of

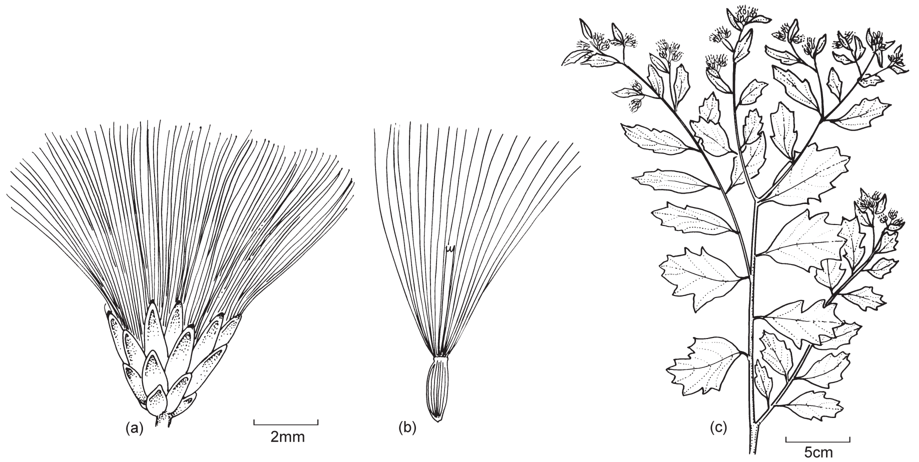

Figure 3. Reproductive structures of *Baccharis halimifolia*: (a) capitulum from female plant, (b) seed plus pappus, and (c) flowering branch of male plant. Drawings by Nicola Oram, Botanical Gardens Trust.

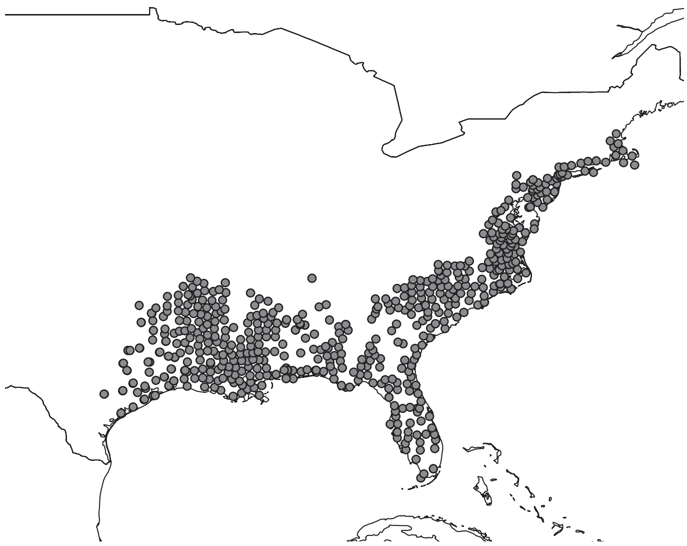

Figure 4. Distribution records of *Baccharis halimifolia* in North America (Sims-Chilton *et al.* 2010, with permission).

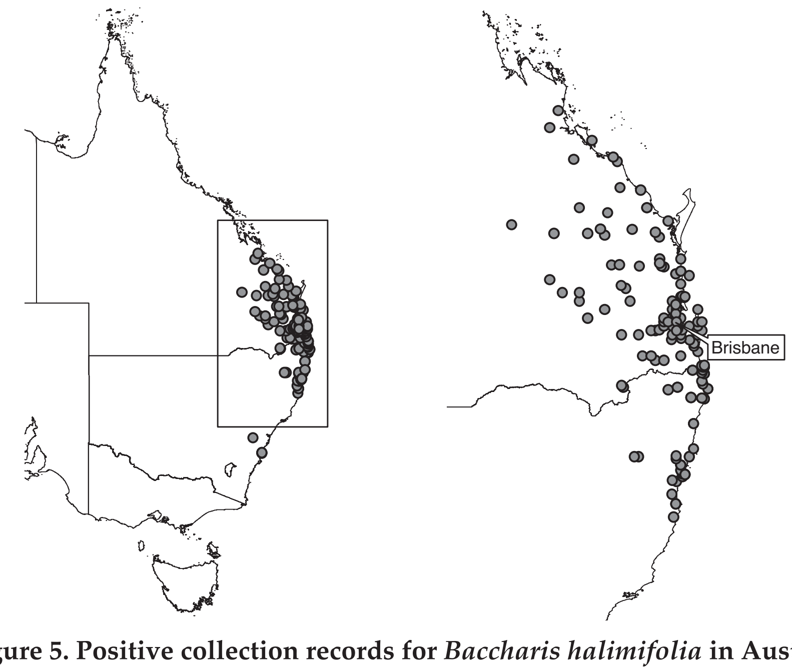

Figure 5. Positive collection records for *Baccharis halimifolia* in Australia (Sims-Chilton *et al.* 2010, with permission).

B. halimifolia is highest in areas which it now occupies (Figure 7).

Habitat

Climatic requirements

Baccharis halimifolia is able to germinate and grow over a wide range of temperatures. In its native region, it is found in Florida, which has a humid sub-tropical to tropical climate, and also in areas such as Connecticut, which has snowfall in winter. For annual development and seed ripening in Australia, *B. halimifolia* requires a long warm summer and an annual precipitation of more than 900 mm, mainly occurring in summer (Winders 1937, Westman *et al.* 1975). Such conditions generally occur along the coast. Further inland, rainfall is lower and growth is better in moist areas such as creek banks and swamps (Winders 1937). Similarly, in its native range, *B. halimifolia* is recorded along shorelines, coastal canals and irrigation channels (Westman *et al.* 1975).

Substratum

In its native region, *B. halimifolia* is a late seral species on foredunes above the tidal reach. It is also found inland (e.g. in sandy loams in Florida) (Kurz and Wagner 1954, cited in Westman *et al.* 1975) and in freshwater swamps. *B. halimifolia* has been found on a wide range of soil types in Australia, from dry infertile forest soils to rich volcanic loams and low-lying clay soils with high moisture content (Winders 1937). It typically grows in moist soils with high organic content (Egler 1952, cited in Allain and Grace 2001). In both its native and invasive ranges, it is often found in soil covered by brackish water with a salt content ranging from 0.5 to 2% (Boldt 1989). It also has a wide tolerance to soil pH values and has been found in soils with a pH ranging from 3.8 to 9 (Westman *et al.* 1975, Young *et al.* 1994, Ensbey 2001) and chlorinity from 0 to 2%. Plants in Queensland were reported at sites with a Kjeldahl nitrogen range from 560–5500 ppm (mean ± SE 2390 ± 413 ppm) (Westman *et al.* 1975). In Spain, *B. halimifolia* was associated with high elevations and coarse sand, and fewer plants were found at high soil moisture, silt content and conductivity (Onaindia *et al.* 2001). This is in contrast to the positive associations with moisture referred to in other studies (Westman *et al.* 1975, Boldt 1989).

Plant associations

Baccharis halimifolia has the ability to establish within a wide variety of vegetation associations, from exotic pine plantations (*Pinus elliottii* Engelm.) to native tea-tree (*Melaleuca quinquenervia* (Cav.) S.T.Blake) swamps (Panetta 1979b). In an Australian study, the most common nearest neighbour of *B. halimifolia* was itself, indicating that the plants are highly aggregated (Westman *et al.* 1975). *Imperata cylindrica* (L.) P.Beauv. (blady grass) was its second most common neighbour. *B. halimifolia* was also closely associated with *Themeda australis* (R.Br.) Stapf, *Paspalum dilatatum* Poir., *Pteridium esculentum* (G.Forst.) Cockayne, *Tristania conferta* R.Br., *M. quinquenervia* and *Eucalyptus intermedia* (R.T.Baker). In Australia *B. halimifolia* may also be associated with the following tropical pasture species: *Setaria sphacelata* (Schumach.) Stapf & C.E.Hubb., *Melinus minutiflora* P.Beauv., *Phaseolus atropurpureus* DC., *Desmodium intortum*

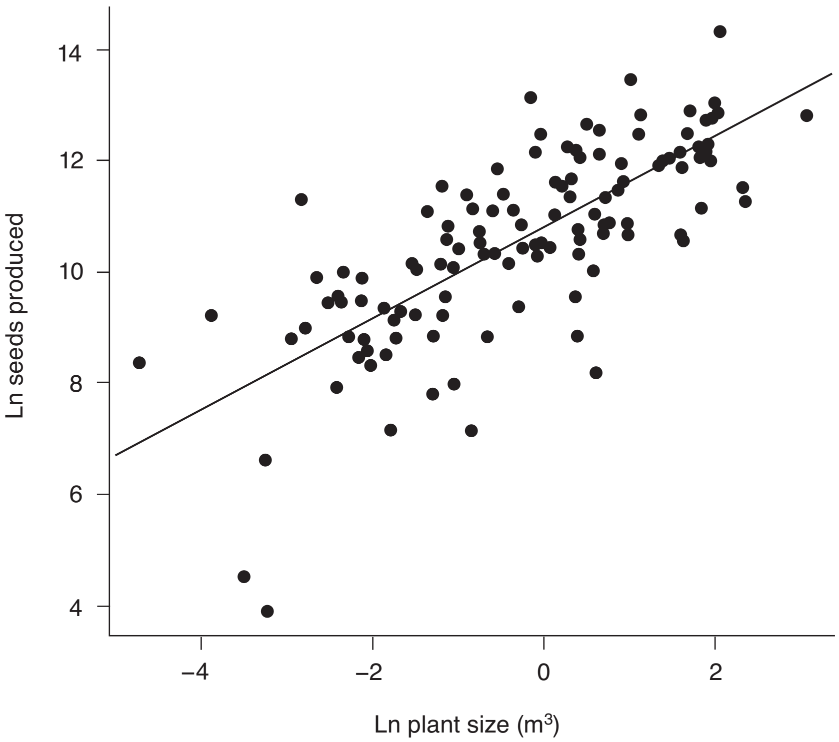

Figure 6. Number of *Baccharis halimifolia* seeds produced in relation to plant size. Plot from Sims-Chilton *et al.* (unpublished).

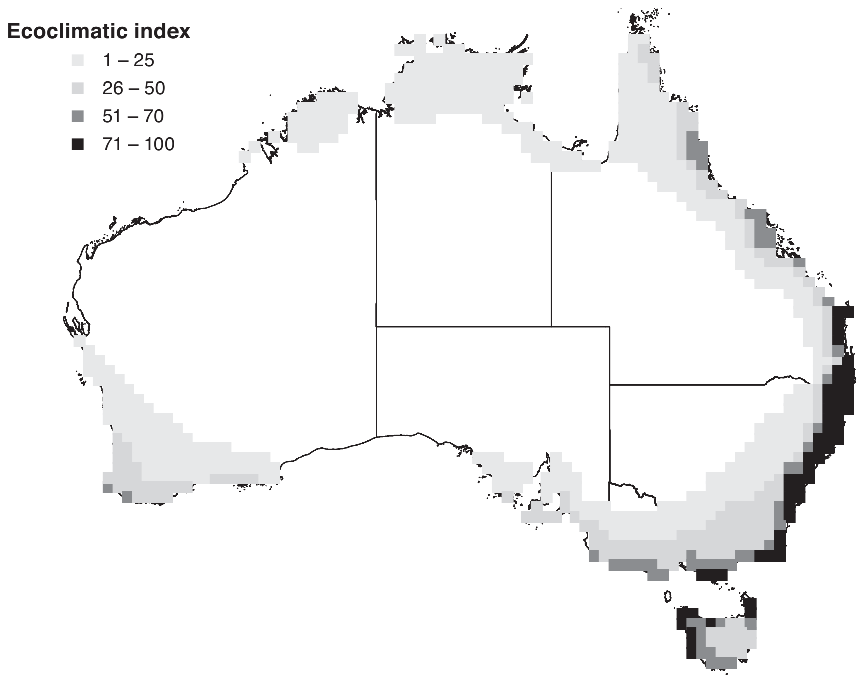

Figure 7. CLIMEX model for *Baccharis halimifolia* (modified from Sims-Chilton *et al.* 2010). A higher Ecoclimatic Index indicates a more favourable location for growth and persistence of the species.

(Mill.) Urb. and *Glycine javanica* L. (Panetta 1977).

In its native range, *B. halimifolia* is abundant in swamps dominated by *Melaleuca leucadendron* (L.) L. and along sandy shorelines consisting of *Casuarina equisetifolia* L. (Westman *et al.* 1975). It is commonly associated with *Iva frutescens* L. (McCaffrey and Dueser 1990, Tolliver *et al.* 1997) and *Myrica cerifera* L. (McCaffrey and Dueser 1990, Tolliver *et al.* 1997, Wang *et al.* 2006), both perennial shrubs that are found along the east coast of North America. In a survey of the plant communities in the Kissimmee River floodplain, *B. halimifolia*, along with *Paspalum notatum* Alain ex Flüggé, *Rubus cuneifolius* Pursh, *M. cerifera* and *Thelypterus interrupta* (Willd.) K.Iwats., dominated the community (Toth 2005). In New Jersey, USA, *B. halimifolia* was successfully used (with *M. cerifera* and *I. fructescens*) to help inhibit the spread of the invasive plant, *Phragmites australis* (Cav.) Trin. ex. Steud. in brackish marshes (Wang *et al.* 2006).

Growth and development

Baccharis halimifolia is a small-seeded species and consequently has only moderate seedling growth potential (Panetta 1977). Slow growth during the establishment phase of seedlings may lead to extended periods of drought susceptibility. Root growth exceeds that of the shoots at the seedling stage (Parsons and Cuthbertson 1992). Growth increases during summer and plants reach approximately 1 m in their first year of growth (Parsons and Cuthbertson 1992).

Shade has been found to have a significant impact on seedling growth, particularly during the first 11 weeks (Panetta 1977). Heavily shaded seedlings took much longer to reach maximum root allocation than those more exposed to sunlight. During the first 13 weeks of its growth, *B. halimifolia* can tolerate low nitrogen conditions (Westman *et al.* 1975). While these authors found a significant negative effect of low nutrient (Hoagland's nutrient solution) and phosphorus treatments on the total dry weight of young *B. halimifolia* plants, they found no effect of low levels of nitrogen. Foliar nitrogen concentration has been recorded as approximately 1.7% of dry mass of *B. halimifolia* plants in its native range (Moon and Stiling 2004, Altfeld and Stiling 2009).

There is no difference between male and female *B. halimifolia* plants in the number of shoots/branch, frequency of flowering shoots/branch and the number of flowers/shoot (Krischik and Denno 1990b). However, male shoots are longer, grow faster and have more tender leaves than females (Krischik and Denno 1990b). The effect of density and nutrients on growth, survival and flowering was examined on *B. halimifolia* plants in their native range (Krischik and Denno 1990a). The study showed that plants in low densities with high nutrient availability had the longest shoots, the highest survival rates and the highest incidence of flowering.

Physiology

It has been suggested that *B. halimifolia* engages in C_3 (Calvin cycle) metabolism (Westman *et al.* 1975). High levels of amino acids are present in leaves in summer (Brodbeck *et al.* 1990). Total amino acid xylem concentration was documented as 4.5 mM (Andersen *et al.* 1989).

Baccharis halimifolia remained free of visual symptoms of salt injury when irrigated with solutions of up to 12 g kg^{-1} salinity (Graves and Gallagher 2003). This level of irrigation reduced photosynthesis by 10% but had no effect on stem elongation. *B. halimifolia* had low stomatal conductance when exposed to freshwater and saltwater flooding (Tolliver *et al.* 1997). At 2 and 5 g L^{-1} salinity, *B. halimifolia* demonstrated reduced stomatal conductance and at salinities greater than 10 g L^{-1}, mortality occurred.

Phenology

Seasonal changes of leaf quality have been recorded for *B. halimifolia*; from spring to summer there is a general increase in leaf biomass, thickness, toughness and size (Kraft and Denno 1982). Flowers are produced in late summer to early autumn (Krischik and Denno 1990a) and at this stage leaf biomass slowly decreases (Kraft and Denno 1982). Flowering peaks in areas of high elevation in Australia occurred 3–4 days later than those in coastal areas (Westman *et al.* 1975). Male flowers are produced approximately two weeks before female flowers (McFadyen 1972 and personal observations).

Most *B. halimifolia* seeds germinate after seed shed, which occurs in late autumn to early winter, depending on seasonal conditions and site-to-site variability (Ensbey 2001). At this time, tropical grass and legume pasture species enter a quiescent phase due to the low temperatures and shading of *B. halimifolia* seedlings by these species is minimal (Panetta 1977).

Reproduction

Floral biology

Baccharis halimifolia is a dioecious species and generally produces flowers after one year (Anon. 2007). The sex ratio in most cases is 1:1 (Doley 1973, cited in Westman *et al.* 1975). Plants allocated a high water and nutrient treatment were significantly more female-biased whereas plants grown under poor conditions were significantly more male-biased (Krischik and Denno 1990a). Plants grown under moderate conditions demonstrated no bias towards either sex. Female flowers are wind- and sometimes insect-pollinated; pollen grains have a diameter of approximately 14–15.5 μm (Westman *et al.* 1975, Panetta 1979b).

Seed production and dispersal

Baccharis halimifolia is allogamous (cross-pollinating) and is recorded as being one of the most prolific seeding plants (Panetta 1979b). Floral initiation and seed fill are both sensitive to small differences in light intensity. For flowering to occur, *B. halimifolia* plants required a 60–70% Integrated Solar Track (IST) value (IST: percentage of open sky in the area bounded by the lines formed by the sun's positions, 1000–1400 hours; Panetta 1979c). Plants are capable of producing seeds under low light conditions (3% sunlight), but heavy shading results in a major reduction in seed yield (Westman *et al.* 1975, Panetta 1979c).

The number of seeds produced per female plant is closely correlated with both plant size (Figure 7) and dry weight (Panetta 1979c). Estimates of seed production range between 10 000 (Auld 1970) to 1 500 000 (Westman *et al.* 1975) seeds per plant. As the plants age, seed production decreases; plants that were nine years old produced 31% less seed than four year old plants (Boldt 1989).

Seeds (Figure 3) are attached to a pappus and are readily dispersed by wind (Boldt 1989) and water (Panetta 1977). They have been recorded as drifting up to 140 m from a 2 m high plant (Diatloff 1964). However, most seeds fall within a few metres of the parent plant (Parsons and Cuthbertson 1992).

Physiology of seeds and germination

Germination at constant temperature and continuous light is markedly reduced where light has low red/far red (R/FR) ratios (Panetta 1979a), but under conditions of fluctuating temperature and intermittent light, maximum levels of germination occur in light regimes with both high and low R/FR ratios (Panetta 1979a). In the absence of light, germination at constant temperature is minimal (<5%), but approximately 25% of seeds germinate in darkness with a 7.5°C diurnal temperature fluctuation (Panetta 1979a). This suggests that deep seed burial may enforce a high level of dormancy in a seed population. Some of the seeds that had been buried at 5 cm for two years were capable of germination upon excavation, although this work did not involve quantitative retrieval (Panetta 1979a).

Under constant light, germination of *B. halimifolia* seeds was found to be most rapid at a temperature of 25°C. However, total cumulative germination was highest between 15–20°C (Westman *et al.* 1975). Similarly, Panetta (1979a) found 18°C was optimal for germination of *B. halimifolia* seeds, with germination percentage declining steadily with increasing temperatures. Seeds pretreated at 5°C demonstrated higher cumulative germination than those pretreated at 0°C or maintained at room temperature (Westman *et al.* 1975). Removal of the achene outer layers also improves germinability of *B. halimifolia* seeds (Kuti *et al.* 1990).

Field observations by Westman *et al.* (1975) indicated that *B. halimifolia* seeds germinate within a month of seed set in Queensland, suggesting little or no dormancy in the absence of burial. Thus, if conditions are suitable, germination of seeds is rapid. The mean time to 50% cumulative germination of field-stored seeds (for three months) was only 2.2 days versus 5.0 days in seeds that had been lab-stored for the same period (Panetta 1979a). Germination rates did not differ between seeds that had been stored on the soil surface or buried in the field (Panetta 1979a).

Salinity has been found to have a negative effect on germination (Young *et al.* 1994). At 2 g L^{-1} salinity, 20% of *B. halimifolia* seeds germinated, whereas at 20 g L^{-1} less than 5% of seeds germinated.

Hybrids

Baccharis halimifolia has been recorded as having hybridized with *B. neglecta* and *B. angustifolia* in its native range in Arkansas, Louisiana, and east Texas. In Florida, *B. halimifolia* is known to hybridize with *B. angustifolia* (eFloras 2009).

Population dynamics

Baccharis halimifolia has the ability to invade habitats where native vegetation is periodically disturbed by fire, flooding or animal activity (Panetta 1977). There are no published studies of the complete population dynamics of *B. halimifolia*, but a partial analysis has been undertaken (Sims-Chilton *et al*. unpublished). Mature *B. halimifolia* plants generally have a high survival rate (>90%) and rapid growth (Wang *et al.* 2006, Sims-Chilton *et al.* unpublished). A complete fertilizer was applied to a native heath community in the coastal lowlands of south-eastern Queensland in 1952–3. Fourteen years after the addition of fertilizer, *B. halimifolia* and another serious weed (*Imperata cylindrica*) became established in the native vegetation (Connor and Wilson 1968). This indicates that disturbances which increase fertility may favour the invasion of *B. halimifolia* over native species (Westman *et al.* 1975).

The effect of fire on *B. halimifolia* growth has been examined. One year after fire, mean shoot density and plant height were reduced significantly and remained lower compared to their original values. The rate of recovery of the plants, however, varied from site to site (Allain and Grace 2001).

Panetta (1979d) found evidence of self-thinning of *B. halimifolia* populations, since the density of plants in a four year old stand was negatively correlated with mean dry weight of the plants. Comparison of two different aged populations of *B. halimifolia* (four and nine years old) indicated cessation of annual recruitment in the older stand as no small seedlings were found (Panetta 1979d). This may have been due to a reduction in light, or an increase in the amount of litter in older stands.

Spartina alterniflora Loisel. clones growing on elevated sediments play a facultative role in the colonization, growth and survival of *B. halimifolia* plants (Egerova *et al.* 2003). Greater growth and survival in the clones is thought to be the result of micro-environmental conditions such as moisture or salinity.

Importance

Detrimental

In Australia, *B. halimifolia* is a major pest of pastures and native *Melaleuca* wetlands (Westman *et al.* 1975). Thick stands can inhibit the movement of stock and reduce the productivity of grazing areas (Ensbey 2001) (Figure 8). *B. halimifolia* consumes resources (water and nutrients) otherwise utilized by commercial pasture and timber species in coastal situations (Westman *et al.* 1975, Anon. 2007) and it may also be able to postpone overtopping by woody perennial competitors (Panetta 1979c). In melaleuca wetlands, it forms a thick understorey and suppresses growth of native sedges (Anon. 2007). It has little nutritional value for livestock and has been reported to be associated with livestock poisoning due to the cardiotoxic glucosides found in the leaves of the plant (Boldt 1989). However, there are very few records of poisoning, probably due to the low palatability of the plant. *B. halimifolia* is generally grazed only when grass is scarce (Everist 1974). Other studies have shown no poisoning effects. For example, White (1936) fed *B. halimifolia* to two heifers for 13 days. The animals appeared emaciated, but no symptoms of poisoning were evident. *B. halimifolia* is also reported to cause hayfever-type allergies (Moss 1967, cited in Panetta 1979b).

Baccharis halimifolia has reduced populations of many species and *Matricaria maritima* L. (Asteraceae) is now on the verge of extinction in Spain as a result of local dominance by this weed (Campos *et al.* 2004).

Beneficial

In Florida, *B. halimifolia* is recommended as a garden shrub/hedge as it is extremely hardy, resistant to salt spray and flowers in autumn. Many of the 250 species in the *Baccharis* genus are reported to possess medicinal properties in their native range and others are considered good fodder for horses (Bailey 1899). In its native range, *B. halimifolia* plants are utilized by a large suite of herbivores and pathogens (e.g. Kraft and Denno 1982, Palmer and Bennett 1988, Tomley and Willsher 2002, Moon and Stiling 2004) and for nesting and habitat by red-winged blackbirds (*Agelaius phoeniceus* L.) (Caccamise 1977) and coastal plain swamp sparrows (*Melospiza georgiana nigrescens* ITIS) (Beadell *et al.* 2003).

Legislation

In Queensland, *B. halimifolia* is declared as a class 2 pest under the *Land Protection (Pest and Stock Route Management) Act 2002*. By definition this means that the pest

Figure 8. Infestation of juvenile and flowering plants of *Baccharis halimifolia*. Photo from Biosecurity Queensland.

is established and 'is causing, or has the potential to cause an adverse, environmental or social impact in the State, another State or a part of the State or another State'. Landowners are legally responsible for taking reasonable steps to keep their properties free of a class 2 pest. It is an offence to keep or sell *B. halimifolia* without a permit. In New South Wales, *B. halimifolia* is a class 3 pest: 'plants that pose a serious threat to primary production or the environment of an area to which the order applies, are not widely distributed in the area and are likely to spread in the area or to another area'. As per Queensland legislation, measures must be taken to control *B. halimifolia*.

Weed management

As mentioned above, *B. halimifolia* is recognized in Australia as a serious weed and has been so since at least the 1950s. Its ability to grow and persist on a wide range of soil types and its capacity to produce large amounts of well-dispersed seed further enhances the problem. Management of *B. halimifolia* has taken a number of forms over the past 50 years but the weed is still very abundant in some areas in south-eastern Queensland and northern New South Wales. Mechanical and chemical controls were used in the initial stages of management. However, these methods are often laborious and expensive, so a biological control program commenced in the 1960s.

Mechanical control

Since being declared a noxious weed in the 1950s *B. halimifolia* has been controlled via mechanical and chemical means. Digging ('grubbing') is a process that aims to remove both above- and below-ground plant parts. In many cases, this method is beyond the capacities of landholders. Large infestations are often slashed which, if conducted at the right time, can suppress flowering and subsequently reduce seed production and spread (Ensbey 2001). Young *B. halimifolia* plants can be pulled out by hand, but this is feasible only in small infestations (Ensbey 2001). Ploughing and subsequent harrowing is practicable in patches of *B. halimifolia* where plants have not yet attained tree size. Burning *B. halimifolia* patches is also an effective method of control, but rapid regrowth is common (Allain and Grace 2001). In more recent times, mechanical control is the least favoured option.

Chemical control

The control of *B. halimifolia* can also be achieved through the use of a number of herbicides. An overall spray application of either 0.2% salts or esters of 2,4-D ((2,4-dichlorophenoxy) acetic acid) or 2,4,5-T ((2,4,5-trichlorophenoxy) acetic acid) in water easily controls *B. halimifolia* (Harvey 1990). Basal barking with esters in oil and cut-stumping using salts in water and esters in water or oil are also effective control methods (Armstrong and Wells 1979). In the 1950s, cutting ('brushing') was the most common method used. This is the process of cutting the plant and swabbing the stem with chemicals. Currently recommended chemical control methods are listed in Table 1.

Biological control

Since the biological control program was initiated against *B. halimifolia* in the 1960s, 35 agents have been imported into Australia for testing, 14 have been released (Table 2) and seven have established (Sims-Chilton *et al.* 2009). Some reasons for failed establishment of the introduced agents include unsuitable climate, low release numbers and unsuitable microsite conditions. Six insect species have established on *B. halimifolia* populations in Australia (Sims-Chilton *et al.* 2009). These include three species of Lepidoptera: *Aristotelia ivae* (Busck) (Gelechiidae), *Bucculatrix ivella* (Busck) (Bucculatricidae) and *Hellensia balanotes* (Meyrick) (Pterophoridae) (Figure 9); two species of Coleoptera: *Megacyllene mellyi* (Chevrolat) (Cerambycidae) and *Trirhabda bacharidis* (Weber) (Chrysomelidae), and a dipteran: *Rhopalomyia californica* (Felt) (Cecidomyiidae) (Figure 10) (Julien and Griffiths 1998). All of the species are native to North America (Palmer and Diatloff 1987, Diatloff and Palmer 1988, Palmer and Haseler 1992a, Palmer and Haseler 1992b) except for *M. mellyi* which is native to South America (McFadyen 1983, Boldt 1987). *Puccinia*

Figure 9. Stem damage resulting from *Hellensia balanotes*, a stem-boring moth introduced into Australia for the biological control of *Baccharis halimifolia*. Photo by Niels Hintzen.

Figure 10. Gall on *Baccharis halimifolia* from *Rhopalomyia californica*. Photo by Niels Hintzen.

Table 1. Herbicides registered for *Baccharis halimifolia* control in Queensland (after Anon. 2007).

Situation	Herbicide	Method of application[A]	Rate
Pastures; non-agricultural; industrial land; rights-of-way	2,4-D amine (500 g L^{-1})	Air – higher rate for bushes	3.6–5.5 L ha^{-1}
		High volume foliar spray	0.4 L 100 L^{-1}
		Cut stump	300 mL 15 L^{-1}
		Misting	1.2 L 15 L^{-1}
Pastures; non-agricultural land	2,4-D acid (300 g L^{-1})	Helicopter spraying	10 L ha^{-1}
		Basal bark or cut stump	33 mL L^{-1} kerosene
		Knapsack for foliar spraying	100 mL 10 L^{-1}
		Sprinkler spray – 1 L $100m^{-2}$	1 L 10 L^{-1}
Pastures	2,4-D ester (800 g L^{-1}) (600 g L^{-1})	Overall spray foliage	0.25 L ha^{-1}
			0.37 L ha^{-1}
		Basal bark or cut stump	1 L 10 L^{-1}
Commercial industrial land; pastures; rights-of-way	2, 4-D sodium (700 g L^{-1})	Spot spray	0.275 kg 100 L^{-1}
Irrigation channels/banks; non-agricultural commercial industrial land; home gardens; pastures; rights-of-way; forests	Glyphosate (360 g L^{-1})	Handgun	0.7–1 L 100 L^{-1}
		Knapsack foliar spray	100 – 150 mL 15 L^{-1}
		Splatter gun foliage	1:9 (2×2 mL dose 0.5 m^{-1} bush height)
Commercial industrial land; pastures; rights-of-way; forests	Picloram + 2,4-D (75 + 300 g L^{-1})	Spot spray foliage	0.65 L 100 L^{-1}
Commercial industrial land; pastures; rights-of-way; forests	Picloram + triclopyr (100 + 300 g L^{-1})	Handgun foliage	0.25–0.35 L 100 L^{-1}
		Misting foliage	2.5 L 100 L^{-1}
		Knapsack foliage	30 mL 15 L^{-1}
	(120 + 240 g L^{-1})	Basal bark or cut stump	1 L 60 L^{-1} diesel
Recreation commercial industrial land; pastures; rights-of-way; forests	Triclopyr (600 g L^{-1})	Overall spray foliage	0.16–0.32 L 100 L^{-1} water
		Basal bark or cut stump	1 L 120 L^{-1} diesel
		Knapsack foliage	20-50 mL 15 L^{-1}
		Overall spray foliage	50 g L^{-1}
		Basal bark or cut stump	120 g L^{-1} diesel
		Knapsack foliage	0.1–0.2 L 5 L^{-1} water
		Basal bark or cut stump	0.1 L 0.5 L^{-1} kerosene
Grass pasture	Dicamba + MCPA (80 + 340 g L^{-1})	Blanket spray	2.8–4 L ha^{-1}
		Overall spray foliage	0.19–0.27 L 100 L^{-1}
		Knapsack foliage	60 mL 15 L^{-1}
Pastures; forests; rights-of-way	Clopyralid (300 g L^{-1})	Handgun foliage	0.33–0.5 L 100 L^{-1}
Pastures	Tebuthiuron (200 g kg^{-1})	Hand application	1 g m^{-2}

[A] See source for restrictions on use (Anon. 2007).

Table 2. *Baccharis halimifolia* insects and pathogens released in Australia[A].

Biological control agent	Order: Family	Years released	Established?
Anacassis phaeopoda (Buzzi)	Coleoptera: Chrysomelidae	1976	N
Aristotelia ivae (Busck)	Lepidoptera: Gelechiidae	1969	Y
Bucculatrix ivella (Busck)	Lepidoptera: Bucculatricidae	1989	Y
Helipodus intricatus (Boheman)	Coleoptera: Curculionidae	1983	N
Hellensia balanotes (Meyrick)	Lepidoptera: Pterophoridae	1969, 1982	Y
Lioplacis elliptica (Stål)	Coleoptera: Chrysomelidae	1976	N
Lorita baccharivora (Pogue)	Lepidoptera: Tortricidae	1969, 1986	N
Megacyllene mellyi (Chevrolat)	Coleoptera: Cerambycidae	1978	Y
Metallactus nigrofasciatus (Suffrian)	Coleoptera: Chrysomelidae	1974, 1982	N
Metallactus patagonicus (Suffrian)	Coleoptera: Chrysomelidae	1969, 1985	N
Puccinia evadens (Hark)	Uredinales: Pucciniaceae	1997	Y
Rhopalomyia californica (Felt)	Diptera: Cecidomyiidae	1969, 1982, 1989	Y
Stolas fuscata (Klug)	Coleoptera: Chrysomelidae	1976	N
Trirhabda bacharidis (Weber)	Coleoptera: Chrysomelidae	1969, 1983	Y

[A] Table adapted from Julien and Griffiths (1998) and Tomley and Willsher (2002).

evadens Hark (Pucciniaceae) (groundsel bush rust) (Figure 11) was released in 1997 and has established over most of the distribution of *B. halimifolia* in Australia (Tomley and Willsher 2002, Sims-Chilton *et al.* 2009).

A survey conducted in the native range by Palmer (1987) found a wide variety of insect families associated with *B. halimifolia*: Orthoptera (one species), Hemiptera (nine species), Homoptera (13 species), Lepidoptera (nine species), Coleoptera (23 species) and Diptera (six species). This survey was conducted to determine an additional suite of insects to be tested for use as biological control agents in Australia (some of which are mentioned above). In the native range the number of flower heads was reduced with high levels of herbivory, indicating that herbivores may be able to lower the reproductive rate of this species (Krischik and Denno 1990a).

The distribution and levels of damage resulting from the established agents have been examined recently (Sims-Chilton *et al.* 2009). A survey was conducted throughout the current known distribution of *B. halimifolia* in south-eastern Queensland and northern New South Wales. Insect and pathogen damage was examined at 34 sites in this range. There was evidence of stem-boring (*M. mellyi* and *H. balanotes*), leaf holes (*T. bacharidis* or generalists) and leaf mining (*B. ivella*) at all sites. There were more stem-boring holes on larger plants, particularly in low density populations. Levels of leaf mining decreased with population density, most likely due to a dilution effect. Sori (*P. evadens*) and galls (*R. californica*) were patchily distributed throughout the sampling area. However, higher levels of sori were associated with areas receiving high annual rainfall.

The effect of *R. californica* was examined soon after its release (1982) at two sites in Queensland. Galled plants demonstrated a 93% reduction in the number of seeds produced (McFadyen 1984). Sims-Chilton *et al.* (unpublished) have also shown that simulated high levels of galling or stem-boring can lead to a decrease in the growth of *B. halimifolia* plants, indirectly reducing fecundity since plant size and fecundity are highly correlated. Such variability in the effectiveness of the released agents indicates that the biological control program has not been successful throughout the range of *B. halimifolia* and therefore alternative control measures should continue in these areas (Sims-Chilton *et al.* 2009).

Non-adapted insects are thought to be deterred by the acetone soluble secondary chemicals in the leaves of *B. halimifolia* (Kraft and Denno 1982). No study, however, has specifically examined herbivory on *B. halimifolia* by any species other than the biological control agents. Sims-Chilton *et al.* (2009) note the presence of generalist herbivores such as grasshoppers (Odonata) on *B. halimifolia*, but there is no evidence to indicate direct feeding of such species in Australia.

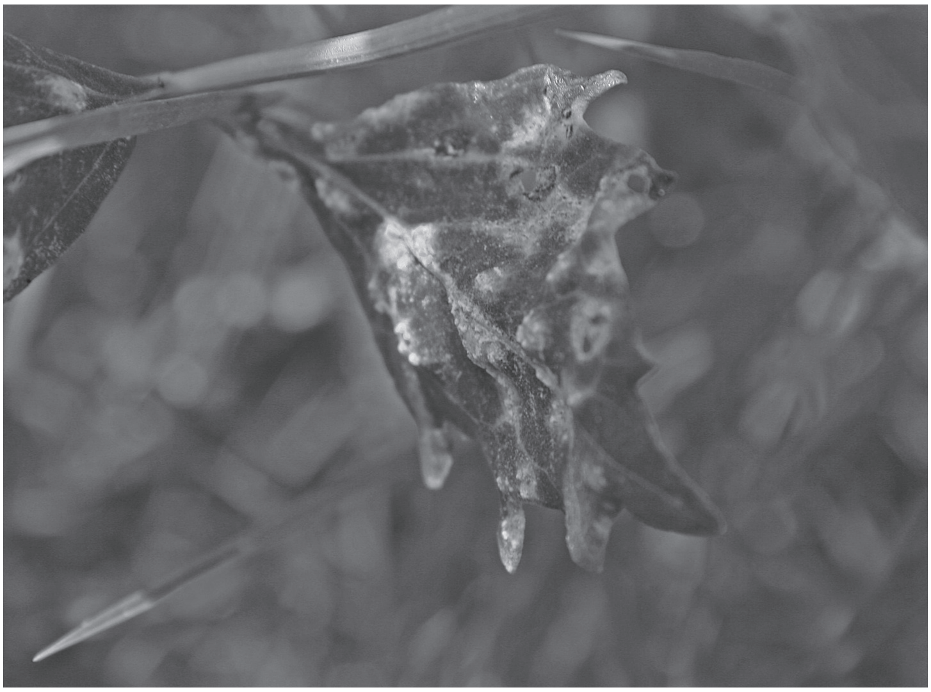

Figure 11. Biological control agent *Puccinia evadens*, a pathogen introduced for the control of *Baccharis halimifolia*. Photo by Nikki Sims-Chilton.

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