Review

Chrysanthemoides monilifera subsp. *monilifera* (L.) T.Norl. and subsp. *rotundata* (DC.) T.Norl.

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This is a revision of the Biology of Australian Weeds paper on *Chrysanthemoides monilifera* (L.) T.Norl. by Weiss *et al*. (1998). The revision was undertaken because a substantial amount of new information on *C. monilifera* has become available over the last decade. This information illustrates significant differences between the two subspecies and as such they are presented separately here.

Name

Chrysanthemoides is one of the six genera of South African Calenduleae (Asteraceae), which include only two species in the genus – *C. incana* (Brum. f.) T.Norl., and *C. monilifera* (L.) T.Norl. Six subspecies of the latter have been described, each with a well defined geographic range in South Africa (Norlindh 1943). Only two of these have been introduced into Australia: *C. monilifera* subsp. *monilifera* (L.) T.Norl. and subsp. *rotundata* (DC.) T.Norl. (Gray 1976).

The name *Chrysanthemoides* means 'chrysanthemum like' and *monilifera* is from the Latin *monile* meaning a 'necklace' because of the arrangement of the beadlike fruits forming a ring around the flower head, while *rotundata* refers to the rounded leaf margin of the subspecies. In Australia, accepted common names are boneseed (referring to the colour and hardness of the fruits) for subsp. *monilifera* and bitou bush (derived from the Afrikaans word 'bietou') for subsp. *rotundata*. A variety of other names have been used for both subspecies – South African star bush, African daisy, jungle weed, jungle flower, salt-bush, Higgins curse and Mort's curse. The latter name arose after the deliberate planting of *Chrysanthemoides* by G. Mort of the Soil Conservation Service on the north coast of New South Wales (NSW) to stabilize sand dunes (Mort and Hewitt 1953).

Description

The genus *Chrysanthemoides* is unusual in the Asteraceae in that the fruit are fleshy, edible drupes. Both subspecies present in Australia have fleshy leaves and are tolerant of salt spray.

Boneseed An erect vigorous perennial shrub, 1–3 m high, is the largest plant in the tribe Calenduleae. Leaves are toothed, ± stiff and semi-succulent, obovate to elliptic, tapering to the base. Juvenile leaves are covered in cobweb-like hairs. Inner involucral bracts (a series of bracts beneath the flower cluster) are 3–4 mm long. Inflorescences are a compound head of tiny male and female flowers surrounded by 5–6 (–8) bright yellow ray florets, borne in terminal or axillary corymbose cymes (Figure 1). The fruit contains a single seed which has globose putamina (hard seed coat) 6–7 mm in diameter, that are light brown to bone coloured when dry (Figure 2). The chromosome number, determined on plants from South Africa (Norlindh 1943) and Australia (Turner 1970) is $2n = 20$.

Bitou bush A prostrate or sprawling, sometimes erect perennial shrub, 1–3 m high and 2–6 m wide, with long decumbent stems. It has entire (or slightly toothed) obovate to broadly-obovate (or broad-elliptic) leaves, which are ± stiff, semi-succulent and glossy. Juvenile leaves are covered in cobweb-like hairs. Acuminate inner involucral bracts (beneath the flower cluster) are 4–5 mm long. Inflorescences are a compound head of tiny male and female flowers surrounded by 11–13 bright yellow ray florets, borne in terminal or axillary corymbose cymes (Figure 1). The fruit contains a single seed which has distinctly obovoid putamina 5.5–6.5 mm long by 3.5 mm wide, that are dark brown to black when dry (Figure 2). There is no information on the chromosome number of bitou bush.

History

Chrysanthemoides monilifera is naturalized in Australia (both subspecies), and subspecies *monilifera* is naturalized in New Zealand, Sicily, the island of St. Helena (Norlindh 1943), France (Tutin *et al.* 1976) and California (W.P. Armstrong personal communication).

Boneseed In Australia, boneseed was first recorded in Sydney in 1852 from MacLeay's garden; Melbourne in 1858 (and subsequently grown in Melbourne suburbs as a garden plant); Adelaide in 1892 from the West Terrace Cemetery; Armadale, Western Australia in 1948 and Ulverstone, Tasmania in 1931. It was cultivated in most states as a garden shrub and most of the present infestations are garden escapees. Deliberate plantings in the You Yangs and to stabilize coastal sand dunes between Nelson and Portland in western Victoria may have occurred (Garnet 1965).

Bitou bush The history of bitou bush's introduction in Australia is not particularly clear. Herbarium records document that it was first found in the Stockton area near Newcastle in NSW in 1908 (Gray 1976), where it was apparently introduced in dry ballast dumped on the north bank of the Hunter River by South African ships (Cooney *et al.* 1982). No other records of it exist until 1950 when a specimen was collected from the experimental area of the Soil Conservation Service of NSW at Port Macquarie. Following experimental trials at Ballina, Iluka, Mylestom, Port Macquarie and The Entrance North, seed was sown extensively by the Soil Conservation Service from 1946 to 1968 for stabilization of coastal sand drift (Mort and Hewitt 1953, Sless 1958a,b, G. Zaborowski personal communication). It was also used to revegetate coastal dunes after mining for rutiles and zircon, particularly at Redhead, Diamond Head, Port Macquarie, Crescent Head, Byron Bay, Hastings Point and Tweed Heads areas of NSW (Barr 1965, G. Zaborowski personal communication). Although it was the only subspecies used by the Soil Conservation Service, Mort and Hewitt incorrectly describe it as boneseed in their report. The only inland planting of bitou bush for sand drift control was near Broken Hill and Menindee where it has subsequently colonized adjacent areas (Cunningham *et al.* 1981) but it is not considered to be invasive in this region.

Distribution

In South Africa, boneseed occurs along the south-western and south-eastern coast and in adjacent mountains, while bitou bush has a largely coastal distribution along

Figure 1. Inflorescences showing the number of ray florets and fruit of (a) *Chrysanthemoides monilifera* subsp. *monilifera* (boneseed) – G. Sanders, and (b) subsp. *rotundata* (bitou bush) – H. Cherry.

the Transkei and Natal regions of the eastern coast (Figure 3: Norlindh 1943). The western-most occurrence of bitou bush is at Cape St. Francis in the Cape Province (Norlindh 1943).

Current distribution

Boneseed In Australia it is widely distributed throughout the southern states. In South Australia, extensive infestations occur around Adelaide, the Mount Lofty Ranges and in the Murray River and South-East regions. Scattered infestations also occur on the Eyre and Yorke Peninsulas. In Victoria, it is widespread with dense infestations around Melbourne, Portland, on the Mornington and Bellarine Peninsulas and in the You Yangs Regional Park near Geelong. In addition, scattered infestations occur throughout the western part of the state, along the Great Ocean Road, and in the Gippsland area. In Tasmania, boneseed infestations are concentrated around population centres and are mainly restricted to coastal and estuarine areas. Boneseed is common around Launceston and along the east and central-north coasts. Extensive infestations occur along the Tamar River and the lower reaches of the Huon River, around Hobart, Dodges Ferry, and Bicheno (Rudman 2001, Brougham *et al.* 2006). In NSW, boneseed occurs mainly in coastal areas from the Hunter River south to Moruya, as well as a few isolated inland infestations in the south-west (e.g. around Dareton) and the Blue Mountains area. There are about 35 discrete small infestations (i.e. <2 ha) scattered across the south-east of Western Australia (e.g. from Perth to Albany), all of which are under eradication (H. Cherry personal communication).

Bitou bush In Australia, while widespread, it is restricted to the coastal regions of eastern Australia, from Hervey Bay in Queensland along the coast of NSW to Ulladulla with isolated small infestations through to Melbourne. Isolated infestations also occur on Lord Howe Island, and in western NSW around Broken Hill and Menindee, where an eradication program is currently underway. An eradication strategy has been implemented in Queensland over the past 20 years, with all infestations surveyed and managed annually (C. McGaw personal communication). Love (1984) reported that by 1982 this subspecies occurred along 660 km or 60% of the NSW coastline and it was the dominant species along 220 km. Remapping of the NSW coastline in 2001 showed a 36% increase in its distribution over the intervening 20 year period. In addition, it had increased its distribution to 80% of the coastline (or 900 km), being the dominant species along 400 km (Thomas 2002, Thomas and Leys 2002).

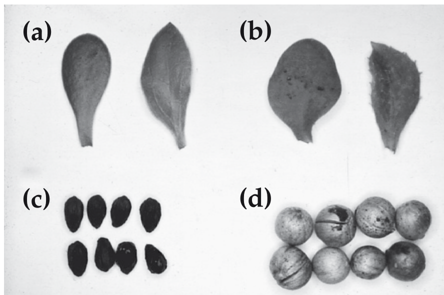

Figure 2. Leaves and putamina of *Chrysanthemoides monilifera* showing bitou bush leaves (a) with cotyledon (left) and first true leaf (right), boneseed leaves (b) with cotyledon (left) and first true leaf (right), putamina of bitou bush (c) and boneseed (d).

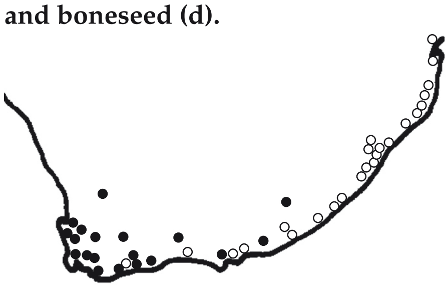

Figure 3. Distribution of boneseed (●) and bitou bush (○) in South Africa (from Norlindh 1943, Neser and Morris 1984).

Potential distribution
A climate-based analysis using BIOCLIM was used to predict the potential distribution of boneseed and bitou bush in Australia (see Figure 4).

Boneseed This analysis showed that boneseed could expand into vast tracts of southern Australia, with the exception of the Nullarbor Plain and extreme frost areas in Victoria, NSW, the Australian Capital Territory, and western Tasmania. Of specific concern is that the 35 small infestations in south-west Western Australia could invade over 37 million hectares of that State (see Figure 4a) if not controlled.

Bitou bush This analysis showed that bitou bush should mainly be restricted to its current coastal distribution (see Figure 4b), with a slight westward movement along inland waterways. This trend has already been observed with plants being detected up to 10 km inland from the coast (Thomas and Leys 2002).

Habitat

Climatic requirements
A comparison of the climate where *C. monilifera* occurs in South Africa and Australia shows a substantial similarity (Weiss 1983).

Boneseed Boneseed occurs in regions of South Australia that receive 200 mm of rainfall year^{-1}, as well as in areas of Tasmania that receive over 1000 mm year^{-1}.

Bitou bush Howden (1984) determined that soil moisture limited the distribution of bitou bush and temperature limits for growth in bitou bush were between 16.8°C and 26.7°C. In South Africa, bitou bush growth is restricted by the 30 frost-days isoline. This corresponds with observations of plants growing in inland NSW and indicates a much greater tolerance to frost by boneseed than bitou bush.

Substratum
Both subspecies grow on a range of soil types of both granitic and sedimentary origin, but the majority of infestations are found on sandy or infertile soils. Both also appear to tolerate salinity, being found at the edge of the high water mark in coastal areas. Boneseed is intolerant of water-logged soil conditions however it can grow along watercourses and in estuarine areas. Bitou bush will tolerate water-logged soils to a limited extent (e.g. it has invaded the edges of coastal swamps and wetlands).

Plant associations

Chrysanthemoides monilifera can grow in full sun or shade and both subspecies occur in a range of plant communities. Both subspecies can produce dense infestations and dominate native plant communities (Figures 5 and 6) as well as affect the composition of vegetation communities and the soil seed bank (see Thomas *et al.* 2006, Mason *et al.* 2007 and below).

Figure 4a. Current (●) and potential distribution (grey shading) of boneseed in Australia – BIOCLIM analysis (Clare O'Brien 2006, Department of Environment and Climate Change, NSW).

Figure 4b. Current (●) and potential distribution (grey shading) of bitou bush in Australia – BIOCLIM analysis (Clare O'Brien 2006, Department of Environment and Climate Change, NSW).

Boneseed It is capable of growing in coastal ecosystems such as dune forests and woodlands, dune scrub, estuarine areas, heathlands, headlands, grasslands and dry sclerophyll forests. It also occurs in a range of communities further inland, including mallee shrubland and open eucalypt woodland (Thomas *et al.* 2000, Brougham *et al.* 2006).

Bitou bush It is predominately confined to coastal ecosystems containing either fore-dunes, dune scrub, dune forest, open or closed heaths or littoral rainforest, sand-dune heathlands, headland heathlands or grasslands, various coastal woodlands, dry sclerophyll forests or wet sclerophyll forests (Dodkin and Gilmore 1984, DEC 2006, Thomas *et al.* 2006).

Animal associations
Numerous native birds and mammal species such as Bennett's wallaby, brushtail possum and quolls consume the fruits and foliage of **boneseed**. Sheep and cattle have also been observed to graze boneseed plants (Scurr 2006a,b). Feral animals such as foxes are known to consume boneseed fruits in large numbers and act as a dispersal vector for the seed (R. Adair personal observation).

The fruits of bitou bush have similar characteristics to those of some native species in terms of size and sugar content, making them an attractive and additional food source for native frugivores (Gosper 2004). The presence of bitou bush fruits at times of the year when native fruits are less abundant is a further attraction for consumption (Gosper 2004, Gosper *et al.* 2006). Numerous exotic and native birds as well as foxes ingest bitou bush fruits and act as dispersal vectors for the seed (Meek 1998, Gosper 1999). Despite the evident utilization of bitou bush fruits, Gosper *et al.* (2006) showed that removal of native fruit is unaffected by the presence of bitou bush in coastal vegetation.

French and Zubovic (1997) considered the possible impact of bitou bush on bird communities in coastal woodland in NSW and found little evidence of bitou bush negatively affecting the bird communities as a whole, particularly so for canopy-feeding generalists and understorey insectivores. Scavengers, raptors and bird species that rely almost exclusively on plant material however, were less abundant in bitou bush-infested habitats (French and Zubovic 1997).

Bitou bush can also affect the assemblage of other fauna populations within an ecosystem. For example, the composition of leaf litter invertebrates differed between bitou bush invaded sites and uninvaded (native) sites (French and Eardley 1997). This study found a lower abundance of litter invertebrates such as cockroaches, earwigs, wasps, bees, sawflies and ants (of the orders Blattodea, Dermaptera and Hymenoptera) which consume detritus or organisms consuming detritus, compared with a higher abundance of scavengers (of the order Collembola) of decaying vegetation which specifically favoured moist conditions (French and Eardley 1997). This result may be an artefact of the altered microclimate conditions imposed by bitou bush infestations (Lindsay and French 2004a) and the capability of Collembola to

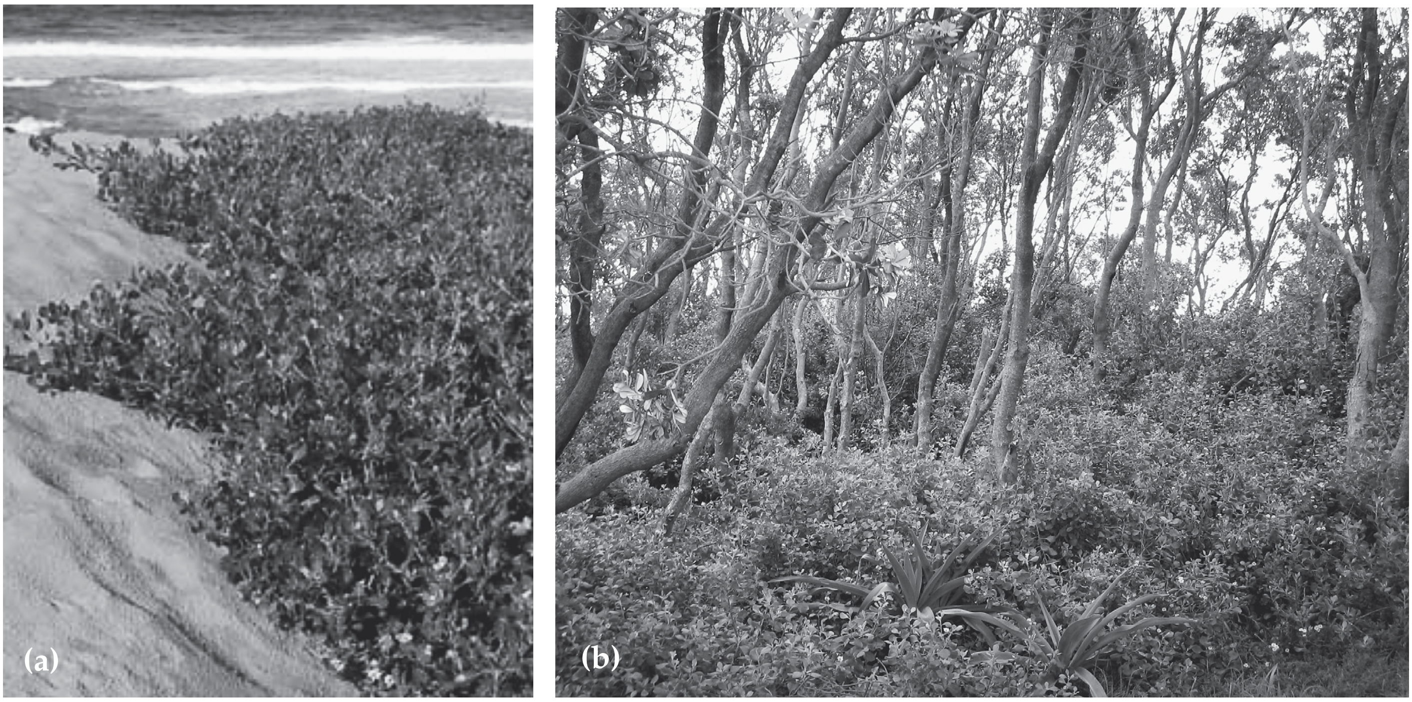

Figure 5. Habitats invaded by bitou bush: (a) bitou bush smothering foredunes (headlands near Sydney – H. Cherry); (b) bitou bush invasion in hind dune banksia woodland community (Wooli, NSW – P. Downey).

Figure 6. Habitat invaded by boneseed: invasion of Acacia woodlands where boneseed became dominant after fire (You Yangs, Victoria – CSIRO).

consume bitou bush leaf litter (French and Eardley 1997).

Growth and development

Plant habit

Boneseed Plants have an erect form typically with a single trunk up to 19 cm or more in diameter (H. Cherry personal communication).

Bitou bush Plants are often prostrate and straggly with an almost creeping habit. In addition mature plants senesce with age. In dune habitats, the growth form of bitou bush produces sand hummocks. As the sand and other debris piles around the semi-prostrate stems, the plants respond by growing upwards, thus binding this sand and debris into a hummock (Thomas 1997, Figure 7). This occurs in both the native and exotic range of bitou bush (P. Downey personal observation).

Fruit morphology

Fruit of *C. monilifera* consist of a fleshy pericarp which is initially green, but then turns black at maturity. After the fleshy pericarp dries out, the remaining endocarp protects the seed from further physical damage by weather and abrasion. Bitou bush fruits and endocarps are equivalent or smaller in all dimensions when compared to those of Australian native plants with a similar geographic range and habitat (Gosper 2004).

Root morphology

Bitou bush roots can form cluster root structures (similar to proteoid roots) which are focused around nutrient sources. This may make plants very effective in extracting nutrients in nutrient deficient soils (T. Mason and K. French personal communication).

Perennation

Chrysanthemoides monilifera is an evergreen perennial and does not exhibit a dormant period, although growth is slowed in winter. Boneseed plants have been dated to over 30 years of age using tree ring analysis (J. Scott personal communication), while bitou bush can live for over 15 years (J. Thomas personal communication). Adventitious buds along the stems and at the base of bitou bush plants enable them to regenerate after fire or physical damage. Regeneration after fire and mechanical damage has also been observed in boneseed.

Physiology

Bitou bush Assimilation rates in bitou bush vary from 3.4 to 10.0 mol CO_2 $m^{-2}s^{-1}$ under field and glasshouse conditions, respectively. The corresponding transpiration rates are from 1.8 to 5.4 mmol H_2O $m^{-2}s^{-1}$ respectively (Weiss 1983).

Shoot growth of mature plants in the field is greatest in summer (up to 12 mm per week). Relative growth rates of seedlings in the glasshouse vary from 0.4 to 0.8 g g^{-1} (of total weight) per week between four and 10 weeks after emergence.

There are six functional chemical groups in the roots of bitou bush, and some of these chemicals move into the surrounding soil with plant decomposition, root cell sloughing, mucilage secretions or exudation. All are possible causes of allelopathy and have not been found in soils of uninvaded vegetation where *Acacia longifolia* subsp. *sophorae* (Labill.) Court. (syn. *Acacia sophorae* R.Br.) dominates (Ens 2007). Germination of *A. longifolia* subsp. *sophorae* is lower under bitou bush leaf litter than under native leaf litter and seedling growth of this acacia is reduced in soil from under bitou bush plants (Vranjic *et al.* 2000a). However the exact mechanism of phytotoxicity is not yet known.

Figure 7. Hummock formations of bitou bush in mobile sand dunes (Stockton Beach, NSW – J. Thomas).

Phenology

Boneseed The phenology of boneseed is dependent on the regional climate. Flowering and seed production begin earlier in warmer regions and start later in the year in colder regions such as Tasmania. Flowering occurs on average between July and October with fruit production occurring during October to January. Seed fall occurs from November to April, extending into autumn in Tasmania due to the later flowering period. Boneseed seedlings emerge mainly in autumn (Brougham *et al.* 2006). Boneseed plants normally do not flower until they are at least 18 months old. However, plants may flower in their first year following fire (Melland 2006) or in areas with high soil moisture and nutrient content. Plants growing in poor conditions may not flower until they are two to three years old.

Bitou bush The phenology of bitou bush is also influenced by the regional climate. Plants on the north coast of NSW commonly flower within one year after germination. The germination pattern of seedlings shows no strong seasonality, but seedling emergence occurs more often after rainfall. Plants generally emerge, flower and set seed within one year, especially after fire.

Bitou bush flowers mainly between April and July, with a second smaller peak of flowering in November/December, particularly in the northern parts of its distribution (Edwards *et al.* in press). However, flowering can occur throughout the year in ideal conditions albeit at lower densities. Seed fall is greatest between June and September with a second annual flush occurring in December (Edwards *et al.* in press, Gosper 2004).

Mycorrhiza

Vesicular-arbuscular mycorrhizal fungi occur on the roots of bitou bush (Copeland 1983), however, infection rates are low and possibly seasonal. Improved mineral nutrition, particularly in relation to nitrogen and phosphorus often results from mycorrhizal associations (Smith and Read 1997). This association could therefore improve the growth of bitou bush on soils of low nutrient status and enhance its growth efficiency.

Reproduction

Floral biology

The flowers of *C. monilifera* are protandrous, with the seeds usually produced by allogamy. The ray florets are female and fertile, while the disk florets are pseudohermaphrodite with abortive ovaries. A large number of insect species visit *C. monilifera* flowers and bees have been observed as pollination agents, but do not appear to be essential for pollination.

Seed production and dispersal

Seed production

Boneseed There is one seed in each boneseed fruit, up to eight seeds per inflorescence (Adair and Ainsworth 2000) and up to 50 000 seeds $plant^{-1}$ $year^{-1}$. Viable seed production can be between 800–3000 m^{-2} (Lane 1976, Weiss 1984).

Bitou bush There is one seed in each bitou bush fruit, up to 13 seeds per inflorescence, and up to 48 000 seeds $plant^{-1}$ $year^{-1}$, with an average of 3500–5000 viable seeds m^{-2} (Weiss 1983, 1984, Thomas *et al.* 2006). However, high fruit production will not always follow high inflorescence production (Gosper 2004). More recent measures of seed density in the soil are an order of magnitude lower than previous estimates (K. French personal communication), suggesting that the seed feeding biological control agents (see below) may be having an impact. Not all of the seeds in the soil seed bank germinate under field conditions (Mason *et al.* 2007) suggesting a dormancy period.

Dispersal

Boneseed Prior to desiccation of the fruit, the fleshy pericarp is attractive to a wide range of vectors e.g. rabbits, foxes, emus and many other species of bird (Dodkin and Gilmore 1984, Meek 1998, Weiss *et al.* 1998). Boneseed seeds have been observed in the scats of several native mammals including Bennett's wallaby, brushtail possum, and quolls suggesting that these animals play a role in boneseed dispersal. Stock such as cattle and sheep consume the foliage of boneseed (Scurr 2006a,b) and may also spread the seeds. Birds and, less importantly, ants can also act as dispersers of putamina on the soil surface. To a lesser extent, putamina are dispersed via dumping of garden refuse. In the past, boneseed was used as a garden ornamental, however the sale and movement of the plant is now prohibited under all Australian states' legislation except in Queensland (Brougham *et al.* 2006). Thus escape from gardens is less likely in the future.

Bitou bush The fleshy pericarp of bitou bush is attractive to a range of seed dispersal vectors including rabbits, foxes, emus and other birds (Dodkin and Gilmore 1984, Meek 1998, Gosper 1999). Foxes swallow whole fruits and bitou bush seeds have been observed germinating from fox scats (Meek 1998). There is a wide variety of avian dispersal vectors of bitou bush. Seventeen species of bird utilized bitou bush fruit, and it was the most utilized plant species of all native and exotic plant species observed in a coastal dune community in NSW (Gosper 1999). Dispersal of seeds by ocean currents is believed to play an important role in the spread of bitou bush in Queensland (Batianoff 1997). Seeds are also dispersed via human activity such as dumping of garden refuse.

Physiology of seeds and germination

Seed longevity is directly related to depth of burial in the soil profile. Seed survival is greatest at depths >2 cm. Seedlings emerge from seeds buried at 1–5 (–8) cm (Noble and Weiss 1989). Seed mortality due to fire decreases rapidly with depth from almost 100% on the surface to negligible numbers below about 4 cm (Noble and Weiss 1989).

Boneseed Greater than 50% of boneseed seeds germinated in the laboratory at temperatures of between 9.5°C and 30.5°C, while the optimum rate of germination was determined at 21–25°C (Weiss 1983). The viability of seed after three years in the field was measured in a study that showed seed viability increases with depth of burial in the soil profile, and on average was 13% (Weiss 1984). The viability of laboratory-stored seed over the same period was 42%. Germination of seeds in the field may be up to 150 times greater in burnt compared to unburnt areas (Lane and Shaw 1978). Similarly, the germination of boneseed markedly increased after exposing weathered seeds to 100°C for 30 seconds (Weiss *et al.* 1998).

Bitou bush The fruits of bitou bush contain moderate quantities of sugars and low quantities of protein and fat, relative to native fruits (Gosper 2004). These characteristics make fruit attractive to birds and foxes, and 50–70% of seeds can remain viable after ingestion by foxes, though not all of these will germinate (Meek 1998).

The germination response to temperature is similar to that of boneseed (Weiss 1983). Seeds remain viable for at least five years (Aveyard 1971); however, the actual persistence of seeds in the soil is currently unknown. After three years, seeds buried in the field have comparatively low viability (2% on average) compared to laboratory-stored seed (24%) (Weiss 1984). Laboratory and field based trials are currently underway to test the viability, germination characteristics, seed dormancy and persistence of both subspecies (K. French and H. Cherry personal communication).

Aveyard (1971) found that the germination levels of bitou bush were low (<50%) after exposure to field conditions such as fluctuating temperature and humidity. Similarly, Mason *et al*. (2007) found low levels of emergence (36%) in the field. Weiss (1983) found there was faster and higher total germination once the pericarp was removed or the seeds were weathered. Germination also occurred at lower osmotic potentials (corresponding to lower soil moistures) if the pericarp was removed (Weiss 1983).

Vegetative reproduction

Vegetative reproduction can occur in both subspecies by layering when stems come into contact with the soil. Layering typically occurs in sandy dune soils where stems are more likely to be covered. With bitou bush, this leads to the development of sand dune 'hummocks' as sand builds up around layered stems (Figure 7).

Hybrids

Hybridization between the subspecies present in Australia is thought to occur, but has not yet been documented. However, an apparent hybrid with intermediate leaf shape and margins, number of ray florets, bush shape and fruit shape has been observed at Avalon in NSW and at Frankston, Victoria. A tendency towards intermediate types has also been observed at Mollymook, NSW (M. Gray personal communication), north of Port Stephens (P. Downey personal observation) and at Wollongong (K. French personal observation).

Population dynamics

Studies on the population dynamics of the two subspecies of *C. monilifera* in Australia are heavily skewed towards bitou bush. In South Africa, *C. monilifera* is locally abundant, and often the dominant member of plant communities in or near coastal situations (Milton 1980, Neser and Morris 1984). The population dynamics of both boneseed and bitou bush may be affected by global climate change as changes to temperature and precipitation regimes may influence fecundity, recruitment and competitive ability (Gallagher *et al*. 2008).

Boneseed Information on the population dynamics of boneseed in Australia is lacking, though Melland (2006) diagrammatically presented boneseed infestation rates under different habitat condition types, relative to fire and integrated control activities. The results presented in the study suggest boneseed can be suppressed using a combination of fire, herbicide control and direct seeding of native grasses. Seed densities in good quality native vegetation may change from <500 seeds m^{-2} to zero seeds m^{-2} on average two years after a fire and subsequent integrated control activities. In severely degraded native vegetation, the original seed resource may be between 2000 and 19 000 seeds m^{-2}, but can be reduced to 230 seeds m^{-2} within 2.5 years after a fire, if integrated control activities are applied (Melland 2006).

Fire alters the age structure and density of boneseed populations by killing plants and seeds as well as stimulating germination (Melland 2006). Seedling densities can reach 2300 m^{-2} after fire (Weiss 1983). The fast growth of boneseed leads to a competitive advantage over many native species. In the You Yangs Regional Park, Victoria many middle strata native plant species have been entirely displaced by the establishment of dense boneseed populations after fire. The mature acacias that normally form the canopy are now starting to senesce. At 20 years after the fire, acacia seedlings appear to be unable to compete with mature boneseed shrubs, which may result in the acacias being lost from the system (Bray 2006).

Bitou bush The population dynamics of bitou bush in Australia were such that seed bank reserves were thought not to be limiting population growth and expansion (Figure 8) (Weiss 1983). However, the success of biological control agents may be changing this relationship. Seeds may be present even where bitou bush plants are sparse, suggesting that either biological control is reducing the sheer number of germinable seeds, or that above-ground dynamics may govern germination and suppress bitou bush invasion in natural ecosystems (Mason *et al*. 2007).

Fire can alter the situation by killing seeds in the litter and topsoil and stimulating germination of the remaining soil seedbank. Resulting seedling densities can be as high as 1100 m^{-2} (Weiss 1983). Bitou bush plants can be killed by fire but some plants will resprout if the fire is of low intensity (e.g. a control burn) (Thomas *et al.* 2006). While disturbance, especially by fire, promotes seedling emergence, germination can still occur in undisturbed situations.

Faster root growth by bitou bush compared with native species ensures faster uptake of available soil water, resulting in a competitive advantage by bitou bush seedlings (Weiss and Noble 1984a). The large leaf surface area of bitou bush also enables higher light absorption than by many native species. Consequently, seed production of *Acacia longifolia* subsp. *sophorae* is reduced when growing in proximity with bitou bush (Weiss and Noble 1984b). Competition for phosphorus between seedlings of bitou bush and natives also occurs (Copeland 1984).

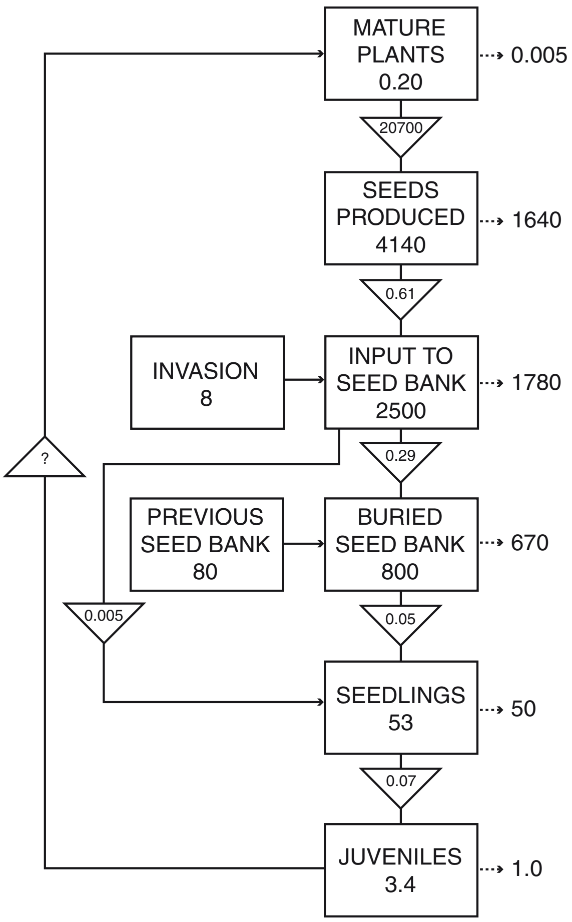

Figure 8. Diagrammatic life table for bitou bush, based on a population in an unburnt area at Moruya, NSW. Values for each phase (in rectangles) are given on a $m^{-2}y^{-1}$ basis. Interphase values (in triangles) are fractions surviving between successive phases (except for the top triangle which is number of seeds per plant). Dotted lines represent losses from each phase (from Weiss 1983).

Bitou bush invasions appear to affect ecosystem processes including nutrient cycling and decomposition rates. For example, it takes between 0.9 and 1.3 years for 99% of bitou bush litter (i.e. dead leaves on the ground) to decay while it takes between 3.1 to 4.4 years for the same percentage of native litter to decay (Lindsay and French 2004a). This rapid decay can be accelerated by leaf litter invertebrates which may in turn speed up nutrient cycling (Lindsay and French 2004a).

Importance

Detrimental

Both subspecies of *C. monilifera* were collectively listed as one of the 20 Weeds of National Significance, due to their ability to invade and displace native plant communities (Thorp and Lynch 2000). The threat of *C. monilifera* to biodiversity is high, with over 200 native species identified as being at risk from the invasion of both subspecies (DEC 2006, ARMCANZ *et al.* 2000). Both subspecies can invade a diverse range of native habitats including forests, woodlands, riparian areas and coastal sand dunes, and threaten native plant species. In addition, infestations can affect the aesthetics and integrity of the native flora and associated fauna, as well as prevent efficient utilization of and access to these natural areas. The economic cost of managing bitou bush to save plant species and ecological communities at risk in NSW was estimated at $2.845 million in the 2005–06 financial year (DEC 2006), a financial cost outweighed by the benefits to conservation equivalent to a $2.56 return on every dollar spent (Sinden *et al.* 2008). The effect on the environment is also high as bitou bush invasions can alter a range of ecological processes (see French *et al*. 2008).

Biodiversity at risk

The threat of *C. monilifera* (both bitou bush and boneseed) to native species was recognized when it was listed as a key threatening process (KTP) in NSW (see NSW SC 1999). This determination identified three plant and several bird species as potentially at risk. The Weeds of National Significance strategy for *C. monilifera* subsequently identified three more plant species in NSW, one species in Victoria and 12 in Tasmania, two endangered ecological communities and six other significant areas in Australia as being at risk (see ARMCANZ *et al.* 2000). A further 150 plant species, three plant populations and 26 ecological communities were identified as at risk from *C. monilifera* in NSW during the development of a threat abatement plan (TAP) for *C. monilifera* in that state (DEC 2006). A further 28 are suspected to be at risk, but were not assessed fully at the time (DEC 2006). Approximately 65% of the species at risk are not listed under the schedules of the threatened legislation either in NSW or nationally.

All of the species identified in the TAP are at risk from bitou bush. However, boneseed also poses a threat to about 15 of them as well as several ecological communities. As outlined above, a further 14 species are known to be at risk nationally solely from boneseed (ARMCANZ *et al*. 2000). From initial examinations of the biodiversity at risk from boneseed in Victoria and Tasmania, a substantial number of species may be at risk (P. Downey and H. Cherry unpublished data – see Downey 2006). Information from field studies has also contributed to the number of species identified as being at risk (e.g. Mason and French 2007, French *et al*. 2008).

Boneseed infestations reduce the diversity of both above-ground vegetation and the soil seedbank (Thomas *et al.* 2005). The mechanisms by which bitou bush threatens native species include alterations to microclimatic conditions (Lindsay and French 2004a, Ens 2007), allelopathic compounds that affect seedling establishment (Vranjic *et al.* 2000a, Ens 2007), lower light transmittance (Ens 2007), litter decomposition rates (Lindsay and French 2004a) and nutrient recycling rates (Lindsay and French 2005). A summary of this is presented by French *et al.* (2008). Such information is critical for *C. monilifera* management, biodiversity conservation outcomes and the long-term success of control programs.

Beneficial

Boneseed It was initially introduced for ornamental purposes due to its shrubby habit, green foliage and bright yellow flowers (but it is now banned from sale in most Australian states, due to its ability to escape from cultivation and invade bushland). Boneseed is grazed by sheep and cattle as well as native pademelons (Scurr 2006a,b). Sheep appear to have a stronger preference for boneseed than do cattle. While cattle prefer native grasses to boneseed they will eat boneseed plants. Grazing and trampling by sheep and cattle can significantly damage boneseed plants.

Bitou bush It was widely planted in NSW due to its ability to stabilize sand dunes and act as a pioneer species, however it is now banned from sale in Australia due to its ability to invade native bushland after such deliberate plantings. It is widely utilized by birds as a food source (Gosper 1999) and can be valuable especially in winter when fruits of other species are less abundant.

Legislation

Importation of all six subspecies of *C. monilifera* is now illegal in Australia. Boneseed and bitou bush are both declared weeds in all Australian states and territories except Queensland where boneseed is not yet declared. While they are classified differently under the various legislation, most legislation prohibits sale and movement of any part of the plant (see Brougham *et al*. 2006).

In NSW both bitou bush and boneseed are listed collectively as a key threatening process under the NSW *Threatened Species Conservation Act 1995* (NSW SC 1999).

A threat abatement plan to ameliorate the threat posed by both subspecies to native species in NSW was recently approved under the Act (DEC 2006).

Weed management

Non-aerial herbicide use

Various herbicides have been tested for use on *C. monilifera* and several are registered for use (Brougham *et al*. 2006). The most commonly used herbicides are formulations of glyphosate or metsulfuron methyl applied using cut and paint, or foliar spray application.

Some formulations of glyphosate contain a polyoxethylene amine (POEA) surfactant that may be toxic to some frogs (Bidwell and Gorrie 1995, Mann and Bidwell 1999). Only formulations of glyphosate containing non-POEA surfactants are registered for use in aquatic situations (NRA 1996). Consideration should also be given to not using these formulations in any terrestrial situations that are a potential habitat for frogs, particularly those frog species listed under the threatened species legislation, and which are known to utilize bitou bush as habitat (see DEC 2005).

Examination of the impact of glyphosate application for the control of bitou bush on leaf litter invertebrates in the field showed no significant direct or indirect effect on invertebrate abundance or community structure (Lindsay and French 2004b). Similar results have been found for metsulfuron methyl by French and Buckley (unpublished data). However, glyphosate causes mortality of seedlings and damage to mature plants of the endangered shrub, *Pimelea spicata* R.Br (Matarczyk *et al.* 2002) and other native plants.

Aerial spraying of herbicide

Bitou bush Aerial boom spraying of herbicide is used to treat large extensive infestations of bitou bush in NSW (Toth and Winkler 2008). This technique was developed following initial trials using six different herbicides, varying rates, season of application and assessments of the impacts on a range of native species. Low rates of glyphosate (e.g. 2 L ha^{-1}) and metsulfuron methyl (e.g. 30 g L^{-1}) used in winter resulted in significant mortality of bitou bush with minimal non-target impact to native species (Toth *et al*. 1996, Toth 1997). Best practice guidelines have been developed for aerial boom spraying of bitou bush in NSW (Broese van Groenou and Downey 2006). Aerial spraying can be more cost-effective than ground-based application, and is suitable for inaccessible areas and large infestations. However, recent examination of this technique shows that the impacts to native plant communities may be greater than suggested during initial trials (Matarczyk *et al.* 2002, Mason and French 2007). In addition, the success of aerial boom spraying is dependent on having resources to treat subsequent recruitment.

The NSW National Parks and Wildlife Service has also developed an aerial spot spray unit, using a modified spray rig mounted in a helicopter and a modified hose and nozzle assembly suspended below. This technique uses ground based foliar rates to apply herbicide selectively to isolated plants or small infestations in areas that are otherwise difficult to access (e.g. cliff faces).

Aerial seeding of native species has been used during the aerial boom spraying programs. However, the results are variable and dependent on weather (e.g. scarified seeds require rain within several days to a few weeks after herbicide application in order to be effective).

Manual and mechanical removal

Boneseed Manual removal of boneseed without herbicide can be achieved for seedlings through to small adults. The cut and paint technique is useful for larger plants; however, herbicide needs to be applied immediately to the cut stem (Brougham *et al*. 2006). This technique can be very valuable in treating boneseed recruitment following the initial control of an infestation. Several case studies illustrating the success of manual removal of boneseed are presented in Brougham *et al*. (2006).

After manually removing mature boneseed plants, there can be a large increase in boneseed seedling emergence as well as the possible reduction in native species germination due to soil disturbance (Thomas *et al.* 2000). The effect of stacking the uprooted boneseed plants on the soil surface has not been shown to significantly affect the germination of either boneseed or native species, provided light can penetrate to the soil surface (Thomas *et al.* 2000).

Mechanical pulling can be used to clear large plants from degraded areas, pasture and grazing lands. It is possible to remove very large plants with the root mass intact using a compact excavator or tractor with a modified claw attachment. The claw grips boneseed plants around the stem close to the ground, and the mechanical arm is lifted to pull the plant out of the ground (Brougham *et al*. 2006). Due to the shallow lateral root system, pulling large plants can lead to soil disturbance as the root system is extensive which may promote the germination of either boneseed or other weed species.

Mechanical grooming and slashing can be used to prevent boneseed from flowering. The cut stems typically resprout and thus require regular treatment. This technique is not an option in natural areas (Brougham *et al*. 2006).

Bitou bush Manual removal of bitou bush can be achieved using the same techniques as those described for boneseed and is also valuable in treating bitou bush recruitment following the initial control.

Mechanical removal, however, is not typically used or recommended to control bitou bush in part because the majority of infestations occur in natural areas or on sand dunes. Mechanical removal of bitou bush with large machinery on sand dunes is likely to lead to significant erosion and is thus not recommended.

Fire

Boneseed Fire results in the death of boneseed adults (Lane and Shaw 1978) and seeds, especially during intense fires. The effectiveness of fire in the control of boneseed is dependent on the density of boneseed and the quantity (or biomass) and spatial variation of the native vegetation present. Burning boneseed is effective only if there is sufficient fine sized fuel (<6 mm in diameter) at ground level to carry the flames. These fuel loads can occur either naturally, where native grasses and forbs are present amongst boneseed plants, or can be achieved artificially by slashing the vegetation and allowing it to dry on the ground prior to burning. Slashing boneseed plants also can aid the continuity of burning across an infestation, especially where there are monocultures of boneseed (Melland 2006, Melland and Preston 2008).

Fire can significantly deplete the soil seed bank, through a combination of seed mortality and heat stimulated germination. The results vary depending on the fire dynamics and the spatial pattern of the seed bank (Melland 2006). It is not feasible to expect a uniform, high intensity burn to cover extensive areas and thus cause uniform emergence of seedlings and boneseed plant mortality.

It is not necessary to use chemical control within 12 months of a burn because recruitment may still be occurring and natural levels of seedling mortality are high. In addition, well established plants will be easier to detect (Melland 2006).

Other post-fire control methods include sowing seeds of native species and manual removal of boneseed plants. While sowing native grasses post-fire suppresses boneseed seedlings, it also reduces the diversity of native species (Melland 2006). Hand removal is effective, but is dependent on the density of boneseed plants present. As outlined above, manual control does not need to occur within the first 12 months, but the timing is ultimately determined by the growth and flowering pattern of the boneseed plants present. An integrated control program should be tailored to specific sites, as some plants have been observed to flower within 12 months after fire (Melland 2006).

Bitou bush Fire can be used to control bitou bush, but nearly 30% of mature plants regenerate and post-fire seedling germination can be as dense as 1100 m^{-2} (Weiss 1983). Seeds buried 3 cm or deeper in the soil may be stimulated to germinate with fire (Vranjic *et al.* 2000b).

The control of bitou bush after fire in Bundjalung National Park on the NSW North Coast incorporated ground based herbicide application and aerial spraying for five consecutive years. This approach has led to a positive response from the native species and a significant reduction in bitou bush plants and seeds (Thomas *et al*. 2006). The success of this approach has been largely due to the co-ordination and support of many stakeholders in the field and long term persistence.

Post-fire control may also involve direct seeding with monocotyledonous species such as *Lomandra longifolia* Labill. as this plant has the potential to reduce invasion by bitou bush seedlings (see Weiss and Noble 1984b, Vranjic 1997).

Natural enemies

In South Africa, 113 phytophagous arthropods, three fungi and a mycoplasm have been found associated with *C. monilifera* with a total of 46 organisms, mostly insects, having potential as biological control agents (Scott and Adair 1990). A biological control program which identified 19 possible agents for detailed host specificity testing was established in Australia in 1987 (Downey *et al.* 2007). Of these 10 have been approved for release in Australia on *C. monilifera*, one rejected (bitou leaf beetle (*Ageniosa electoralis* (Vogel)) (Adair and Scott 1993) and one is currently subject to host specificity assessment (boneseed rust fungus (*Endophyllum osteospermi* (Doidge) comb. nov.)) (Morley and Morin 2008). Downey *et al*. (2007) undertook a full review of the *C. monilifera* biological control program in Australia from its inception until 2005, thus only an abbreviated summary with updated information is presented below.

Boneseed Six insect species have been released for boneseed, but despite repeated and often large releases, none of these agents has established in the field. Biotic resistance by indigenous invertebrates is suspected as being a key factor in preventing the establishment of the foliage-feeding agents in south-eastern Australia (Downey *et al.* 2007).

The three foliage-feeding agents that failed to establish on boneseed are the leaf beetles, *Chrysolina picturata* Clark (blotched boneseed leaf beetle), *Chrysolina scotti* Daccordi (black boneseed leaf beetle) and *Chrysolina* sp. 2 (painted boneseed leaf beetle). High egg mortality and predation of larvae by arboreal-dwelling invertebrates, particularly ants and spiders, contributed significantly to the failure of these insects to establish on *C. monilifera* in Australia (Meggs 1995, Ireson *et al.* 2002, R. Adair personal observation).

The reasons for the failure of the other three agents (e.g. bitou tip moth (*Comostolopsis germana* Prout), *Chrysanthemoides* leaf roller moth (*Tortrix* sp.), and lacy-winged seed fly (*Mesoclanis magnipalpis* Bezzi)) to establish on boneseed are not as clear and include predation pressure and poor climatic matching between the insects' origins in South Africa and release locations in Australia (see Adair and Edwards 1996).

For the lacy-winged seed fly poor host-agent compatibility is implicated because all collections in South Africa originated from *C. monilifera* subsp. *pisifera* or *C. monilifera* subsp. *rotundata.* The lacey-winged seed fly may need to alternate between hosts throughout the year but there are only two subspecies of *C. monilifera* in Australia. Recent attempts to establish this insect in southern NSW on bitou bush also appear to have failed, although further release and evaluation attempts are warranted (see Morley and Morin 2008).

The leaf buckle mite, *Aceria* sp., is one of several potential agents currently being investigated for the control of boneseed in Australia (Morley and Morin 2008). This eriophyiid mite feeds on developing *C. monilifera* leaves, inducing the formation of hairy, white to brown erinea that disrupt normal leaf and shoot development (Adair 1997). The leaf buckle mite was approved for release from quarantine in 2005. However, due to the presence of more than one eriophyiid species occurring with the erinea, cultures need to be initiated from single females of confirmed identification, which has delayed the release program. Targeted releases of the leaf buckle mite on boneseed infestations are expected in late 2007.

The systemic rust fungus *E. osteospermi* shows considerable promise as a biological control agent for boneseed and potentially bitou bush (Adair and Scott 1989). Once the fungus is established within the host, the infection is retained until the death of the infected branches (Morin 1997). However, several technical difficulties need to be resolved in order to complete host-testing and safety evaluation, and possible release of this fungus in Australia (see Morley and Morin (2008) for further discussion).

Several potential agents for boneseed remain untested, but could be considered in future programs. These include the tip-wilt Gelechiidae (Lepidoptera) that causes distal stems to collapse, the lesser seed fly *Mesoclanis dubia* Bezzi that feeds in the fruits of boneseed, and a gall-forming Cecidomyiidae (*Lasioptera* sp.) that causes damage to inflorescence stems and peduncles (Downey *et al.* 2007).

Bitou bush A total of six species of insects have been released on bitou bush in Australia, four of which have established. The bitou tip moth (*C. germana*) and bitou seed fly (*Mesoclanis polana* Munro) are now widely established in NSW and two other agents, the bitou tortoise beetle (*Cassida* sp.) and *Chrysanthemoides* leaf roller ('*Tortrix*' sp.) are currently surviving in low numbers close to their initial release sites (Downey *et al.* 2007). The two failed agents are both foliage-feeding beetles (the black boneseed beetle (*C. scotti*) and the painted boneseed beetle (*Chrysolina* sp. 2)); both were released on bitou bush as part of the boneseed release program.

The bitou tip moth is having a significant impact on the flowering and seed production of bitou bush (Holtkamp 2002). However, the presence of two Hymenopteran parasitoids, *Diadegma* sp. and *Brachymeria* sp., may reduce the impact of tip moth populations, as up to 50% of the bitou tip moth larvae can be parasitized (Holtkamp 1993).

The bitou seed fly was released on bitou bush at 11 sites on the NSW north and central coasts between 1996 and 1998. Within two years of the initial release, it was found to be widely distributed, and now occurs from Fraser Island in Queensland to Tathra in southern NSW – a total distribution of over 1200 km (Edwards *et al.* 1999). Long-term monitoring of seed production indicates high and persistent levels of seed reduction (58–86%) has occurred in northern NSW populations, with considerably lower impact on seed production (6–11%) in southern temperate regions (Edwards *et al.* in press). In contrast, only modest reductions (23–31%) in seed production were observed between 2001–2002 at five sites between Iluka in northern NSW and Moruya near the southern limit of the NSW distribution of this weed (Stuart *et al.* 2002).

Post-release larval mortality studies for the *Chrysanthemoides* leaf roller moth indicated that generalist predators such as ants and spiders caused 98% mortality of larvae, and dune infestations of bitou bush were more prone to predator activity than headland infestations (Strakosch 2004, Swirepik *et al.* 2004). Releases of the leaf roller moth in NSW are now being concentrated on headlands sites.

The *Chrysanthemoides* leaf roller moth is now the focus of a NSW Weed Warriors program. This innovative school education program engages students, weed officers, land managers and community groups to rear, release and monitor biological control agents. Web-based and multimedia teaching resources are also being incorporated into this program to enable school students to learn about weed science principles and weed impacts to biodiversity and the environment (Schembri *et al.* 2008).

There is currently limited scope for new biological control agents for bitou bush. The cerambycid tip wilt beetle *Obereopsis pseudocapensis* has potential as an agent for *C. monilifera* (Adair and Edwards 1996, Neser and Morris 1984). While preliminary host specificity testing has occurred, further testing and an impact evaluation is still needed for this insect (Downey *et al*. 2007).

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