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SPECIAL

**National Bitou Bush and Boneseed
Forum proceedings**

R.G. and F.J. Richardson

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Published and edited by
R.G. and F.J. Richardson
PO Box 42
Meredith, Victoria 3333, Australia.
Email: richardson@weedinfo.com.au
www.weedinfo.com.au
ABN 20 556 029 011

Advisory panel
Dr. W.T. Parsons B.Agr.Sc. Ph.D.
2 Clendon Close
Mt. Eliza, Victoria 3930

Dr. J.T. Swarbrick B.Sc. Dip Agric. Sci. Dip.
Trop. Agric. Ph.D. Cert. Tert. Ed.
15 Katoomba Crescent
Toowoomba, Queensland 4350

Assistant Editors
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University of Sydney
PO Box 883
Orange, New South Wales 2800

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B.Sc. Agr. Dip. Ed. Ph.D.
Department of Plant Pathology and
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University of Sydney
New South Wales 2006

Dr. E.S. Delfosse B.Sc. M.Sc. Ph.D.
USDA Agricultural Research Service
5601 Sunnyside Avenue
Beltsville MD 20705-5139, USA

Dr. V.E. Edge B.Sc. Ph.D.
10 Witonga Crescent
Baulkham Hills, New South Wales 2153

Professor R.J. Field B.Sc. Ph.D.
Plant Science Department
Lincoln College
PO Box 84
Canterbury, New Zealand

Dr. P.R. Merriman B.Sc. D.I.C. Ph.D. M.I.
Institute for Horticultural Development
Private Bag 15
South Eastern Mail Centre
Victoria 3176

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Review

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

P.W. Weiss^A, R.J. Adair^B, P.B. Edwards^C, M.A. Winkler^D and P.O. Downey^D

^A 17 Rubbo Crescent, Weston, Australian Capital Territory 2611, Australia.

^B Department of Primary Industries, PO Box 48, Frankston, Victoria 3199, Australia.

^C PO Box 865, Maleny, Queensland 4552, Australia.

^D Pest Management Unit, Parks and Wildlife Group, Department of Environment and Climate Change, PO Box 1967, Hurstville, New South Wales 1481, Australia.

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 involucre 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 involucre 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).

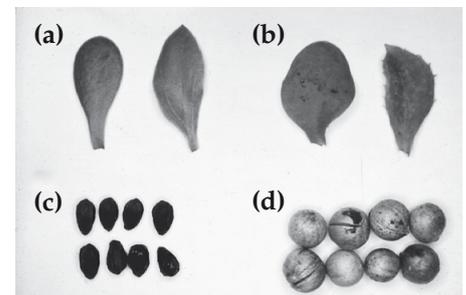


Figure 2. Leaves and putamina of *Chrysanthemoides monilifera* showing bitou bush leaves (a) with cotyledon (left) and first true leaf (right), boneseed leaves (b) with cotyledon (left) and first true leaf (right), putamina of bitou bush (c) and boneseed (d).

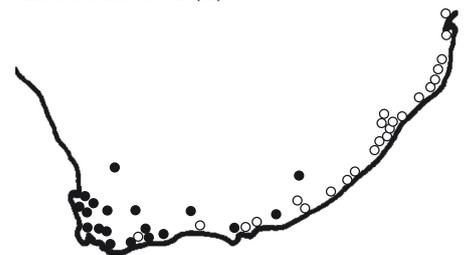


Figure 3. Distribution of boneseed (●) and bitou bush (○) in South Africa (from Norlindh 1943, Naser and Morris 1984).

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).

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

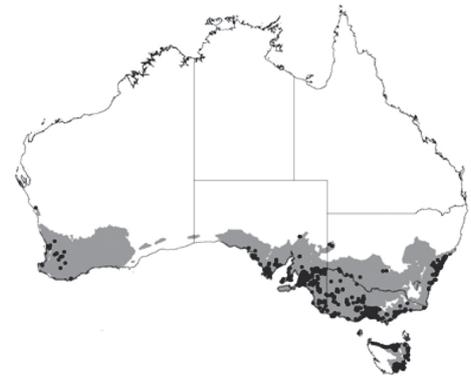


Figure 4a. Current (●) and potential distribution (grey shading) of boneseed in Australia – BIOCLIM analysis (Clare O'Brien 2006, Department of Environment and Climate Change, NSW).



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).

canopy-feeding generalists and understory 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 CO₂ m⁻²s⁻¹ under field and glasshouse conditions, respectively. The corresponding transpiration rates are from 1.8 to 5.4 mmol H₂O m⁻²s⁻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.

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



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

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 pseudo-hermaphrodite 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, brush-tail 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, Nester 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).

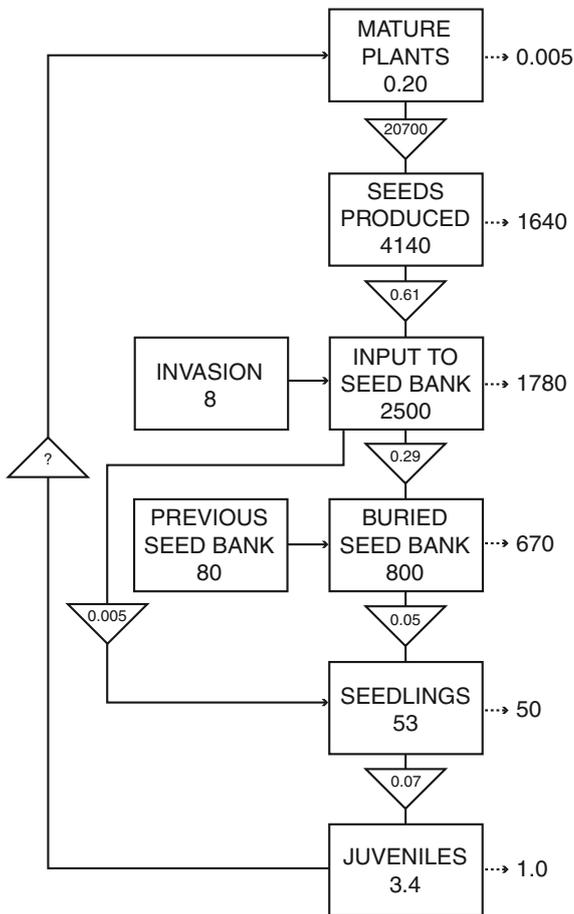


Figure 8. Diagrammatic life table for bitou bush, based on a population in an unburnt area at Moruya, NSW. Values for each phase (in rectangles) are given on a $m^{-2}y^{-1}$ basis. Interphase values (in triangles) are fractions surviving between successive phases (except for the top triangle which is 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 mycoplasma 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 (*Ageniosia 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 (*Comptosia 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 lacy-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 eriophyid 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 eriophyid 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, Naser 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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National Bitou Bush and Boneseed Forum

Proceedings of a forum held at the Mercure Hotel, Geelong, Victoria on 28 August 2007.

Editors: Hillary Cherry, Paul Downey, Peter Tucker and Marion Winkler

Keynote address: Research on bitou bush and boneseed – a work in progress

R.H. Groves, CSIRO Plant Industry, GPO Box 1600, Canberra, Australian Capital Territory 2601, Australia.

Summary

In this overview of research on the two environmental weeds bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) and boneseed (*C.m.* subsp. *monilifera* (L.) Norl.), I list some of the more significant milestones in previous research as I perceive them before assessing the effectiveness of some present research. Throughout, I emphasize the importance of understanding the ecology of these two subspecies in southern Africa (their region of origin), especially as it relates to their management in southern Australia using biological agents. Further quantification of the impacts of bitou bush and boneseed in reducing native biodiversity will be necessary information for the future, especially for boneseed. For more effective management of the weeds, it will be necessary to continue to exclude entry to Australia and New Zealand of the other four subspecies of *Chrysanthemoides monilifera* known from southern Africa. An optimal combination of agents for biological control of boneseed in southern Australia and New Zealand is also called for, as is the smarter re-vegetation of areas on which bitou bush and boneseed have been weakened by on-going management. The positive roles of bitou bush and boneseed in stabilizing dunes and in providing early winter food for some migrating native birds will become more significant as these re-vegetation programs progress. Other impacts, either positive or neutral, on different groups of species and ecological processes must also be addressed before an integrated management system can be formulated to further reduce the negative impacts on coastal ecosystems of these two weeds of Australasian significance.

Introduction

Within the family Compositae (Asteraceae), the genus *Chrysanthemoides* is closely related to *Osteospermum sens. strict.*

Norlindh (1943) treated Linnaeus' taxon *Osteospermum moniliferum* of 1753 as *Chrysanthemoides monilifera*, a polymorphous species occurring widely in southern Africa; he delimited five geographic races of the species (which he termed subspecies) that predominate in respective regions of southern Africa, such that *C.m.* subsp. *rotundata* occurs naturally along the eastern coast of South Africa from about Port Elizabeth north to Lourenco Marques in Mozambique, and *C. monilifera sens. strict.* is confined naturally to the southwestern Cape. These are the only two subspecies of *Chrysanthemoides monilifera* known to be present in Australia (Gray 1976), called bitou bush and boneseed respectively. In New Zealand only boneseed occurs, as far as is known (Webb *et al.* 1988).

Bitou bush is thought to have been introduced accidentally to Australia in ship's ballast from eastern South Africa to Stockton, near Newcastle (Gray 1976), from whence it was spread naturally (by birds) and was spread deliberately for erosion control of sand dunes (Barr 1965). Bitou bush now occurs locally also in southern Queensland and at several sites in Victoria. The date of introduction of boneseed to Australia is unknown, though it was recorded as present in Sydney in 1852 (Gray 1976), presumably introduced deliberately as a garden plant. The first record for boneseed in Victoria is 1858 for the Melbourne area, also for a garden plant (Parsons 1973). The species now occurs widely in Victoria, South Australia, Tasmania and locally in New South Wales (NSW) and southwest Western Australia. Boneseed's mode of introduction to Auckland, New Zealand in 1870 (Webb *et al.* 1988) is not known, but was presumably also deliberate for horticulture.

Wherever they occur in conserved areas of natural vegetation, both subspecies are regarded as major weeds and are declared noxious because of their deleterious effects on biodiversity. They are not, however, regarded as weeds of grazing or cultivated

land. In Australia, both subspecies now have the added status of being Weeds of National Significance (Thorp and Lynch 2000).

In this paper firstly I shall nominate some milestones as I perceive them in past taxonomic and ecological research on bitou bush and boneseed, before reviewing briefly and somewhat selectively present progress on the ecology and management of these two environmental weeds. I will conclude by suggesting some areas for research and management that I see as especially desirable for the more effective conservation of coastal ecosystems in which these weeds presently occur.

Some milestones in past research

Norlindh's taxonomic paper published in 1943 was certainly a milestone in delineating the taxa, especially in relation to interpreting subsequent Australian efforts at biological control (Table 1). Munro (1950) described the herbivory of seed flies in the genus *Mesoclanis* on *Chrysanthemoides* flowers and fruits in South Africa; his taxonomic paper was one reason for Naser and Morris's later (1985) and cautious optimism for a future program on biological control of these two weeds, an optimism that has been borne out subsequently, at last for bitou bush (see later).

In 1974, the Australian Weeds Committee considered a proposal for initiating research on the biological control of four weeds of South African origin, including the environmental weeds bitou bush and boneseed and bridal creeper (*Asparagus asparagoides* (L.) Druce). Whilst that committee accepted the cases for the two agricultural weeds, viz. oxalis (*O. pes-caprae* L.) and spiny emex (*Emex australis* Steinh.), the majority of members did not support the cases for initiating a search for potential biological control agents of either *Chrysanthemoides* or *Asparagus*. Soon after (September 1974–March 1975), when I was on sabbatical leave in South Africa, I did however check herbarium specimens of each plant species in both Pretoria and Cape Town and accumulate some information on their biological variation and their ecology. It was not until 1984, however, that the NSW Department of Agriculture and the NSW National Parks and Wildlife Service jointly sponsored a conference on bitou bush and boneseed and significant progress began to be made

Table 1. Some significant milestones in previous research on *Chrysanthemoides monilifera* – a personal interpretation.

Date	Milestone	Reference
1943	Taxonomy and distribution pattern in S. Africa	Norlindh (1943)
1950	Identification of seed-eating flies in S. Africa	Munro (1950)
1974	Meeting of the Australian Weeds Committee	
1976	Taxonomy and distribution pattern in Australia	Gray (1976)
1983	Ph.D. thesis on bitou bush/ <i>Acacia</i> relationships	Weiss (1983)
1984	National Conference held at Port Macquarie	Love and Dyason (1985)
1986/7	CONCOM Working Group established	
1989	<i>Comostolopsis germana</i> release	Scott and Adair (1990)
1995	CRC for Weed Management Systems established	
1996	<i>Mesoclanis polana</i> release	Edwards (personal communication)
2003+	Impacts of bitou bush on biodiversity defined	Gosper (2003), DEC (2006), Coutts-Smith and Downey (2006), French (2008)

nationally (Love and Dyason 1985). For that conference held at Port Macquarie, the widespread occurrence of bitou bush on the NSW coast was mapped (Love 1985), the effectiveness of different management methods (fire use; Lane 1985) and herbicide application (Love 1985) for both subspecies were reviewed, and the chances for biological control by insects and fungal pathogens were considered by two South African scientists (Neser and Morris 1985). I rate the proceedings of that conference as an especially significant milestone.

As a direct consequence of the Port Macquarie conference, I was asked to prepare a budget for a biological control program for bitou bush and boneseed, a proposal which was ultimately accepted by the then Council of Nature Conservation Ministers (CONCOM, later to become ANZECC). A CONCOM Working Group was established soon thereafter in 1986/7 which oversaw both the gathering of funding from the various State agencies, Environment Australia and CSIRO, and its expenditure on a survey of potential agents and the ecology of the host plant subspecies in South Africa. The South African laboratory was based firstly at Rhodes University in Grahamstown for research on *Emex australis*, but soon moved to the University of Cape Town where it started surveys on *Chrysanthemoides* in 1987. The field release in Australia of the bitou tip moth (*Comostolopsis germana* Prout) as early as 1989 and of the seed fly *Mesoclanis polana* Munro in 1996 were notable early results of the South African program in terms of the subsequent effectiveness of biological control of bitou bush. Both reduced seeding of the weed. Three other agents (including *Chrysolina scotti* Daccordi) were introduced and field-released also in 1989 in Australia for control of boneseed; other agents were considered and some released subsequently (e.g. the species of *Cassida* now established around Sydney; Scott and Adair 1990) but

none, as yet, seems to have been effective in limiting seeding or plant populations of boneseed.

The Co-operative Research Centre (CRC) for Weed Management Systems was established in July 1995 and significant additional funding for research and management began to be provided for these two major weeds through the CRC's program for Natural Ecosystems (Program 3). Several more agents were tested and released, including the defoliator *Tortrix* sp., and best practice management guides were produced for each subspecies to help field managers and coastal re-vegetation teams. Attempts at closer integration of the different individual control methods were made, both for bitou bush (J. Vranjic personal communication) and for boneseed (R. Melland personal communication).

More recent research in NSW has focused on the impacts of bitou bush on different aspects of biodiversity; this approach has been productive in terms of defining the number of plant and animal species at risk, some plant and animal populations and the number of plant communities threatened by weed invasion. Recent research has also emphasized the beneficial role of *C. monilifera* fruits in providing food for native birds, especially migrating ones such as the swift parrot (*Lathamus discolor*), at a time in early winter when the native coastal species have yet to fruit (see Gosper 2003, DEC 2006, Coutts-Smith and Downey 2006, French 2008, for detail). Research on this topic provides a sound basis for defining the impact of bitou bush on biodiversity, although its extension to other regions and to the congeneric boneseed is still required.

Taxonomy, distribution and ecology in southern Africa

The natural distribution of *C.m.* subsp. *rotundata* and of *C. monilifera sens. strict.* (Figure 1) shows that the two subspecies

do not overlap in their distribution compared with some of the other four subspecies (Norlindh 1943). Bitou bush is strictly coastal in the predominantly summer-rainfall region of eastern South Africa, except for a few populations inland of Durban (towards Pietermaritzburg), whilst boneseed occurs in predominantly winter-rainfall areas of the western Cape coast and inland to an altitude of about 1000 m. Boneseed in South Africa is found mainly on mountainsides (cf. bitou bush's preference for coastal sands); bitou bush in its native range seems less able to tolerate shade from an overstorey than does boneseed (personal observation). The geographic separation in natural distribution of the two subspecies facilitated searches for potential biological control agents appropriate to each subspecies. The ecological differences between the two subspecies in southern Africa seem to apply almost equally to their present distribution patterns in southeastern Australia.

Norlindh (1943) described hybrid material between several of the subspecies in South Africa. In eastern Australia, hybrids between the two subspecies are known to occur (P. Weiss personal communication, R. Adair personal communication).

Impacts of bitou bush and boneseed in Australia

The negative impacts of bitou bush on a range of native plant and animal species and natural plant communities is now documented for NSW (DEC 2006, Coutts-Smith and Downey 2006, French 2008). Many such species (at least 34, of which plant species such as *Thesium australe* R.Br and *Zieria prostrata* J.A.Armstr. are two notable instances), populations (of at least two plants and one animal) and communities (at least five, of which the Eastern Suburbs Banksia Scrub and the littoral rainforest at Iluka are of especial significance) are known to be endangered or threatened from bitou bush invasion (Table 6.4, Coutts-Smith and Downey 2006). So great is this overall negative impact that bitou bush invasion was listed as a Key Threatening Process by the NSW government and a Threat Abatement Plan finalized recently (DEC 2006).

T. Mullett (personal communication) showed for an invaded coastal heathland at Hat Head National Park in northern NSW that plant species abundance declines by as much as 75% as vegetative cover of bitou bush increases (Figure 2); this result is for above-ground vegetation. The extent of decline is similar for community cover-abundance scores along the same transect. The diversity of species represented in the soil seed pool was largely unaffected, however, by bitou bush cover levels (Figure 2). (The latter result should give hope to re-vegetation teams active in this region.)

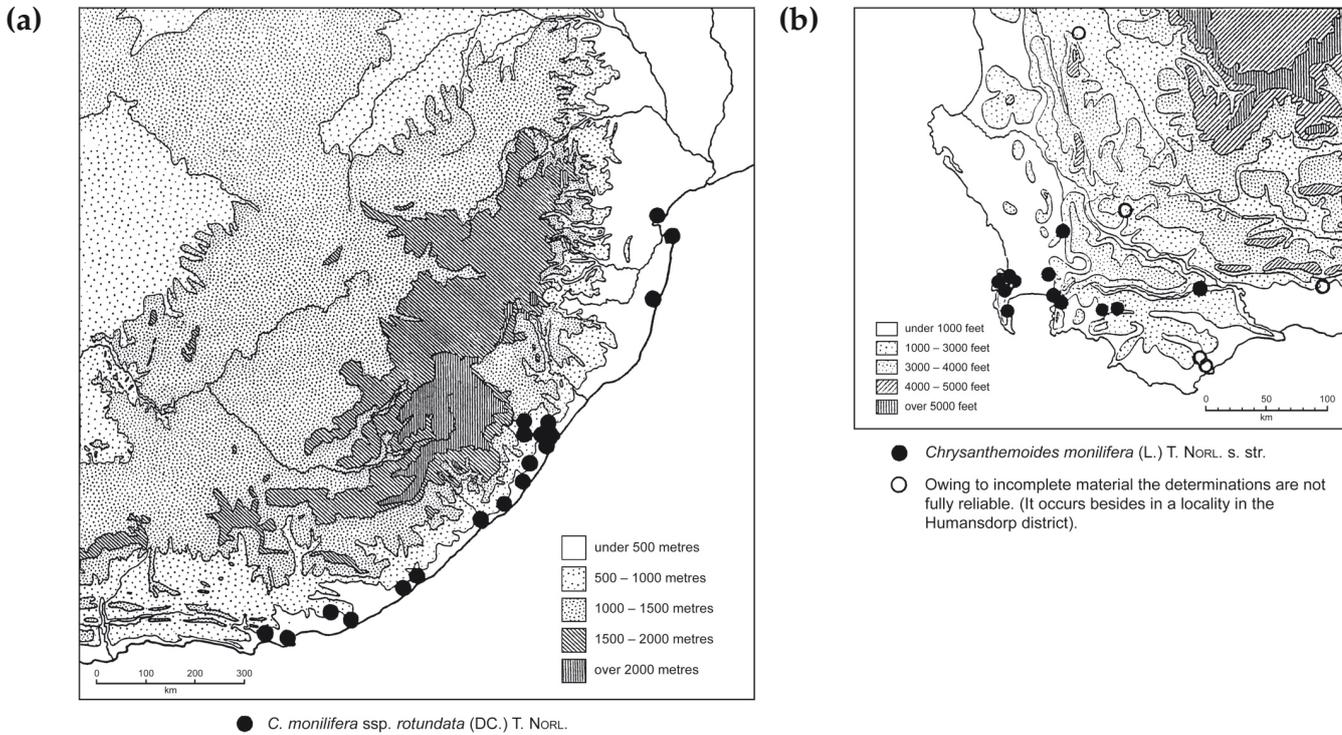


Figure 1. Distribution of the two subspecies of *Chrysanthemoides monilifera* in southern Africa as mapped by Norlindh (1943) from herbarium specimens: (a) *C.m. subsp. rotundata*; (b) *C. monilifera sens. stricta*. (Redrawn from Norlindh 1943).

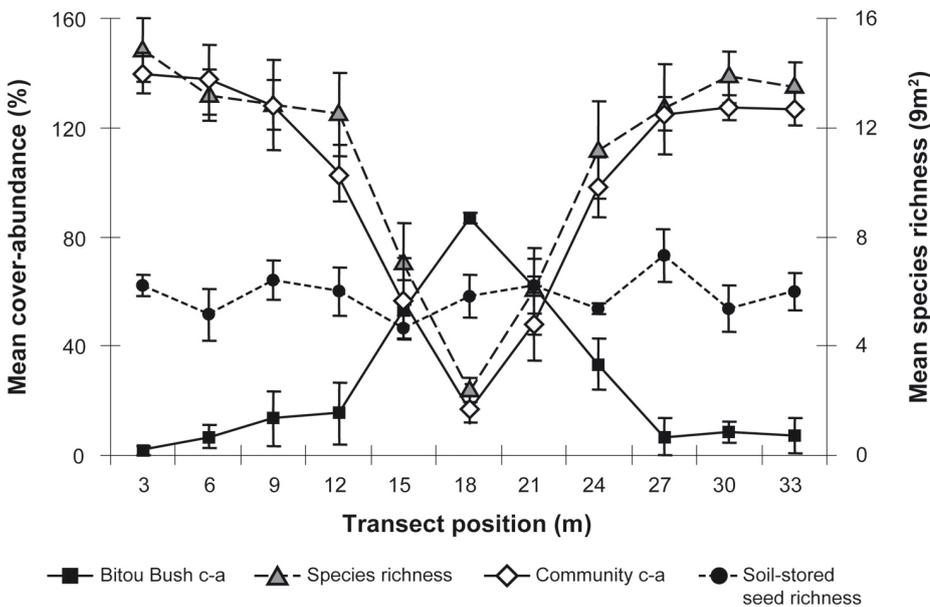


Figure 2. Impacts of bitou bush invasion on three measures of native plant diversity as measured by mean cover-abundance (%) for (a) individual species, (b) community and (c) soil-stored seed, along a 33 m transect in coastal heath at Hat Head National Park, NSW (Mullett personal communication).

One negative impact of bitou bush on coastal ecosystems is its ability to alter dune morphology (Heyligers 1985) from the dune shaping by native species such as *Spinifex sericeus* R.Br and *Acacia longifolia* subsp. *sophorae* (Labill.) Court.

On the other hand, and one reason for its earlier deliberate planting along the NSW coastline, bitou bush can effectively stabilize dune systems already eroded as a result of cattle grazing and human usage – a one-time positive impact on coastal

ecosystems (Barr 1965). Bitou bush negatively impacts habitat opportunities for a range of animals, especially reptiles, as well as providing cover and food for pest animals, such as foxes. Bitou bush can provide food for introduced birds and thus impact negatively on native bird abundance (Gosper 2003). Food supplies for both resident and migratory frugivorous native birds can be limiting in non-invaded coastal ecosystems in early winter. Gosper (2003) showed a positive impact of bitou bush in that the early winter fruiting season of bitou bush in invaded vegetation can fill a food niche for such birds until the fruit supply from native species, such as *Elaeocarpus* spp., becomes available later in the winter and early spring. This positive impact on native bird diversity is of especial value to the annual migration pattern of the endangered swift parrot as it moves north from southern Tasmania in early winter.

In summary, bitou bush impacts overwhelmingly negatively on the biodiversity of the coastal ecosystems it has invaded, but it also has some little-recognized positive impacts on coastal geomorphology and some groups of native animals. Results on the impacts of boneseed on biodiversity are few for southern Australia or for New Zealand but presumably they are generally similar to those for bitou bush. For instance, McAlpine and Timmins (2002) identified boneseed as posing a threat to native seedling recruitment in New Zealand.

Present management of vegetation invaded by *Chrysanthemoides*

Methods of weed management range from the regional exclusion of entry of plant material (quarantine) through noxious weeds legislation to hand-pulling of seedlings, removal of mature plants by mechanical, physical (fire), chemical or biological means, to active re-vegetation of invaded sites by planting of competitive native species and promoting the germination of native soil-stored seed. The most effective management systems seem to be combinations of at least some of these different methods integrated with the biology of both the invasive species and its native associates (Groves 1989). I next wish to touch on five components of the overall present management system.

1. Past and present management of their respective quarantine services have kept the other four subspecies of *C. monilifera* out of both Australia and New Zealand and have kept bitou bush out of New Zealand to date. That is a major achievement because these other four subspecies have the potential to occupy regions different from the coastal ones invaded at present by bitou bush or boneseed. For instance, *C. m. subsp. canescens* occupies montane regions (between 1500–2000 m) along the eastern escarpment of the Drakensberg in South Africa (Norlindh 1943) and probably has a similar potential should it ever be found in Australasia.
2. *Chrysanthemoides monilifera* can still be seen as a cultivated plant in home gardens (Groves personal observation) and as a hedging plant in a caravan park (Weiss personal communication), despite the species being declared a noxious weed in most regions. Such occurrences may act as foci for future infestations and, though fortunately rare now, vigilance in detection of new occurrences is still required.
3. Aerial application of herbicides to coastal vegetation invaded by bitou bush is now widespread and, if timed to take place in early winter when the major native plant species are not growing, can be successful in reducing weed dominance (Toth *et al.* 2008). Some small herbs in the understorey, including orchids, may still be adversely affected by such treatment, however.
4. Biological control of bitou bush has been relatively successful in NSW in reducing the growth of established plants and, presumably, in reducing seed output and its incorporation into the soil seed pool.
5. Some local community programs have been very successful at maintaining coastal vegetation weed-free in the medium term, e.g. that at Diamond Head in northern NSW which has been

going for 27 years (Dodkin personal communication, Mardell 2008) and that at Iluka going for 11 years (J. Thomas personal communication). These two examples and some others show what can be achieved through local group dedication to the task and effective facilitation by local agency staff. Some regional programs, such as that on the NSW south coast (Thompson and Pomery 2008), involve co-ordination of effort and funding across several shires (Shoalhaven, Eurobodalla and Bega) and a pooling of regional resources, an approach that seems to be more productive than individual smaller-scale programs. In all such instances, however, a low level of continued hand-pulling effort is and always will be required to remove newly emergent plants, the seed for which has been brought in by birds which have fed in vegetation that still has some fruiting plants present.

Present management are most effective in situations where different methods of control have been combined with the release of several biological control agents and medium-term programs of native species re-vegetation to limit re-infestation by bitou bush. In the next section, I wish to point to several aspects of overall management that may be even more effective in the future.

Towards more effective management

Quarantine in both Australia and New Zealand has been effective in excluding the four other subspecies of *C. monilifera* (and also the congener *C. incana*) known from South Africa. From the distribution maps published by Norlindh in 1943, it seems that *C. m. subsp. pisifera*, with its preference for sandy soils (Adair personal communication), may have the widest natural ecological range in the Cape Province. Both countries should be on the alert to prevent entry of this taxon and thereby prevent replication of what is a major problem in biodiversity management. The task of keeping *C. m. subsp. rotundata* out of the North Island of New Zealand is an equally formidable challenge for quarantine managers of that region.

Much research effort and funding has gone in to biological control programs for the two subspecies of *C. monilifera* (Downey *et al.* 2007). To date, only that for bitou bush has been effective, although the quantitative extent of reduction in plant population density seems not to have been measured. Whether a greater effort and more funds are required to bring about effective control of boneseed populations is unsure at this time. It is especially disappointing that field releases of *Chrysolina* spp. and '*Tortrix* sp.' have not matched their observed behaviour in South Africa. This behavioural difference needs further

investigation, if biological control of boneseed is to be as seemingly effective as that for bitou bush in NSW. Perhaps the eventual release of *Tortrix* sp. in New Zealand, with its depauperate ant fauna relative to Australia, will be helpful in understanding some reasons behind the hitherto unsuccessful releases of insects for boneseed control.

I have already mentioned the effective regional partnerships formed to integrate management on the NSW south coast (Thompson and Pomery 2008). Land managers in other regions may well benefit from an increased level of co-operation in the sharing of funding opportunities and in co-ordinating weed management systems. Increased regional co-operation throughout southern Australia would mimic the already high level of co-operation between research scientists both within Australia and internationally, involving South Africa, Australia and New Zealand.

Finally, I wish to comment on the future effectiveness of re-vegetation programs for both weeds from three points of view. The first aspect is the choice of species to use in re-vegetation. It was intuitively sound to first use the native analogue of *Chrysanthemoides*, viz. *Acacia longifolia* subsp. *sophorae* to re-vegetate areas from which the weed had been removed. After all, Weiss (1983) had earlier shown that the two species did compete directly for resources, both in the field and in glasshouse experiments. Results of subsequent glasshouse research (J. Vranjic unpublished data) show, however, that in the short term it was the herbaceous components of the original plant community, such as *Themeda australis* (R.Br) Stapf and *Lomandra longifolia* Labill., which were more effective in limiting the early growth of seedlings of *C. m. subsp. rotundata* than either *Acacia longifolia* or the slower-growing *Banksia integrifolia* L.. This result from glasshouse research had been quantified earlier in the field by Weiss and Noble (1984), who recorded fewer seedlings of *C. m. subsp. rotundata* occurring in the presence of *L. longifolia*. They concluded that the tussock-forming habit of *L. longifolia* hindered *Chrysanthemoides* invasion. These combined results suggest that it may be insufficient to rely solely on *Acacia* seedlings to prevent further invasion (or re-invasion) by *Chrysanthemoides* and that an early ground cover of herbaceous plants may be a necessary ingredient in future re-vegetation programs. If such an herbaceous component can be included after fire or mechanical removal, or even after herbicide application, so much the better it would seem, and especially to prevent initial surface sand erosion.

A second requirement for future re-vegetation programs is to consider including fruit-bearing plants to provide food for native birds, along the lines advocated by Gosper and Vivian-Smith recently (CRC

web site). Coastal species such as *Enchylaea tomentosa* R.Br and *Rhagodia candolleana* Moq. may provide fruit of high food quality that otherwise would not be available to frugivorous native birds. Given the high incidence of fleshy fruits on several major weeds in addition to those of *Chrysanthemoides*, this recommendation would seem to be applicable to re-vegetation programs in general.

Bitou bush in South African coastal vegetation often occurs as a single species with only bare sand between the bushes. Boneseed, on the other hand, is usually a dominant in fynbos-type vegetation in which many other species co-occur. If re-vegetation programs are not effective for whatever reason, it seems evident that ecologically similar species occurring in the same communities in South Africa may invade vegetation from which *Chrysanthemoides* has been removed or controlled. I think especially of introduced species such as *Polygala myrtifolia* L. and *Psoralea pinnata* L., both of South African origin, both are common in coastal gardens and, furthermore, both of which are already major environmental weeds in parts of southern Australia and New Zealand. I do not wish to see a future situation in which *Chrysanthemoides* populations may well be limited by present management, only to find the sites invaded by yet another environmental weed of South African origin.

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Current status and management of boneseed in New Zealand

Keith Briden, New Zealand Department of Conservation, PO Box 13049, Christchurch 8141, New Zealand.

Summary

Boneseed, *Chrysanthemoides monilifera* subsp. *monilifera* (L.) T.Norl., was first recorded in New Zealand in 1870. After a relatively long lag phase, it was increasingly recognized as an invasive weed during the 1990s. Boneseed is now widespread on drier east coast sites of New Zealand and is a serious threat to coastal ecosystems. It is declared an 'unwanted organism' under the *New Zealand Biosecurity Act 1993* which means it is banned from promotion, sale, propagation and distribution. New Zealand has a strategic approach to weed control and uses surveillance and a weed-led approach to find and eradicate new infestations, and a site-led approach to manage high value sites where boneseed has become a widespread weed. A range of methods are used in New Zealand to control boneseed, including manual, herbicide, mechanical, and biological control. Boneseed is an ideal weed for control by community Weedbuster¹ groups.

Spread and distribution of boneseed in New Zealand

Boneseed was first recorded in Auckland in 1870 (Webb *et al.* 1988). It is a highly invasive plant originating from South Africa and is weedy in Australia, New Zealand, France and the USA (Weiss *et al.* 2008). It appears to have had a reasonably long lag phase. Records from the Auckland Museum Herbarium and the Allan Herbarium in Christchurch show a steady increase in abundance and distribution from the 1970s to present.

The New Zealand Department of Conservation (DoC) funding for all environmental weed species has increased steadily from NZ\$1 million in 1994 to NZ\$14 million in 2006. This increase in funding has

allowed more monitoring and control of weeds like boneseed, and this has resulted in an increased awareness of the impacts of boneseed and the need for its control. Local authorities have also increased the amount of funds spent on environmental weed control in recent years. Specific weed awareness programs such as Weedbusters have been enabled by the local and central government initiatives.

Boneseed is now distributed at many sites on the east coast of New Zealand from Northland in the North Island down to the Otago Peninsula in the South Island. Infestations occur on the west coast of the North Island near Wanganui and from Wellington to the Kapiti coast (Figure 1). Boneseed has been used as an ornamental garden plant and the worst infestations are found near the main population centres such as Auckland, Wellington and Christchurch. Lesser infestations are now common around some smaller coastal settlements. Boneseed has now spread to native coastal ecosystems and is a serious threat to conservation values. Ecosystems affected by boneseed include; dune systems, rocky coastlines, cliffs, estuaries, coastal shrublands, and offshore islands. Offshore islands are particularly important to New Zealand's conservation effort because many are pest free and contain threatened fauna and flora. The closely related bitou bush (*C. monilifera* subsp. *rotundata* (DC.) T.Norl) does not occur in New Zealand.

Legislation

The *New Zealand Biosecurity Act 1993* is the main statute governing biosecurity activities. The purpose of the Biosecurity Act is to enable 'the exclusion, eradication and effective management of pests and unwanted organisms'. Boneseed is classified as an unwanted organism under the Act. This means that it is illegal to sell, propagate, distribute or promote boneseed in New Zealand.

The *Hazardous Substances and New Organisms Act 1996* (HSNO Act) enables the New Zealand Environmental Risk Management Authority to make decisions on applications for all hazardous substances and new organisms, which includes new plants and herbicides being imported into New Zealand. As boneseed is already declared an unwanted organism, this prohibits the importation of the other five subspecies of *Chrysanthemoides monilifera* into New Zealand.

The HSNO Act also governs herbicide use and registration. It requires persons applying herbicides to be approved handlers if (1) they are commercial operators, (2) the herbicide is toxic to humans, or (3) the herbicide is toxic to the environment. For boneseed, suitable herbicides are registered that are not toxic to humans or the environment. Such herbicides can be used by land managers and volunteers, like Weedbusters groups, without the need for them to become approved handlers.

Registered herbicides in New Zealand do not often carry specific label information related to controlling specific environmental weeds. HSNO legislation allows off label use of herbicides when the weed targeted is not a food crop or the herbicide used does not find its way indirectly into food. This pragmatic approach allows a range of readily available herbicides to be used at various application rates to control boneseed in New Zealand.

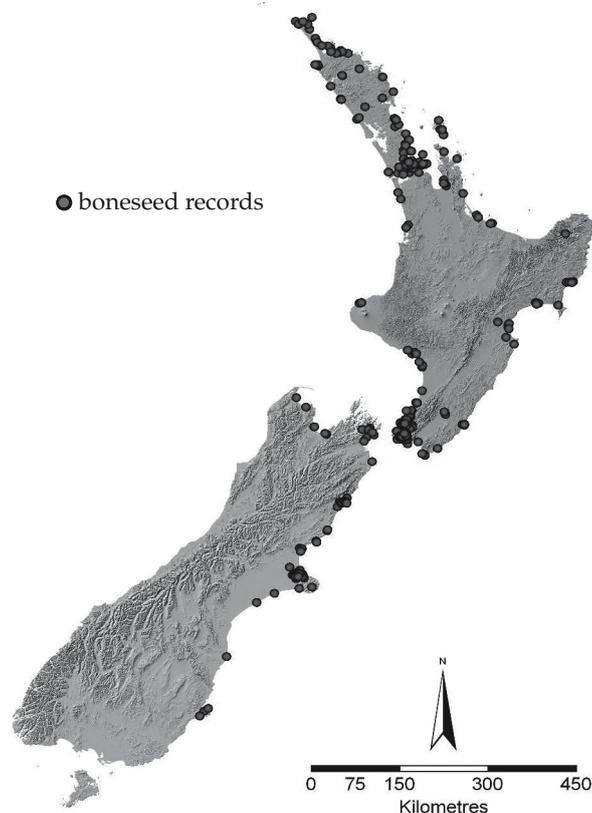


Figure 1. Distribution of boneseed (*Chrysanthemoides monilifera*) records, 2007.

Footnote

¹ Weedbusters New Zealand is a community awareness and education program modeled on the successful Australian Weedbusters initiative. www.weedbusters.org.nz provides information for the community on over 130 weed species they are likely to encounter. Information and images are provided for boneseed as well as control methods including herbicide formulations.

DoC has a legal mandate to protect natural values from environmental weeds, including boneseed. The main two pieces of legislation are the *Conservation Act 1987*, and the *National Parks Act 1980*. Regional Councils may prepare a Regional Pest Management Strategy under the *Biosecurity Act 1993*. If a weed species is included in its strategy, a Regional Council is then able to respond to that weed species within its boundaries.

Control strategies

A range of strategies are used in New Zealand to manage weed infestations including surveillance, weed-led control, site-led control, and biological control. DoC has developed a weed quality management system that includes a strategic weed policy, standard operating procedures, and a range of supporting tools to assist weed work. A quality approach to weed work enables effective and efficient use of scarce resources.

Surveillance is used to locate new infestations of boneseed in geographical areas where boneseed is not known to occur or occurs in very low numbers. Weed-led and site-led control strategies are defined in the DoC's Strategic Plan for Managing Invasive Weeds (Owen 1998). Weed-led programs aim to minimize the potential impacts of invasive weeds by managing priority weed species on land of any tenure before they become a major problem. The objective of weed-led control is to eradicate or contain new infestations. This strategy is used in parts of New Zealand where boneseed is not widespread and can be eradicated or contained. Site-led weed programs aim to protect the natural values of priority sites from weeds that are already widespread in an area. For example, boneseed is controlled at rare sand-dune systems in New Zealand to protect threatened plants and lizards.

A biological control program in New Zealand targeting boneseed is currently being undertaken by Landcare Research. The first biocontrol agent trialled is the boneseed leaf roller moth (*Tortrix* s.l. sp. *chrysanthemoides*). It was released in 2007 at Waiheke Island near Auckland and there are plans for additional releases of the leaf roller moth in 2008. Landcare Research is optimistic the boneseed leaf roller moth will have a greater chance to establish in New Zealand than it has in Australia because there is less likelihood of ant predation on the caterpillar stage (L. Hayes personal communication). Work on a second agent, a rust fungus *Endophyllum osteospermi* (Doidge) comb. nov., is also in progress.

Control methods

The main methods used to control boneseed in New Zealand are manual, chemi-

cal, and mechanical. In many instances, combinations of these methods are used. Once a site is cleared of boneseed, restoration and planting with native species can be carried out to reduce boneseed reinvasion. This paper covers a sample of best practice control methods, including those suitable for volunteer Weedbusters.

In New Zealand, manual control involves pulling boneseed seedlings and small plants by hand. Herbicides are used where a seed bank has established and high numbers of seedlings make manual control time consuming and expensive. In a Christchurch study, an area of 25 year old boneseed was cleared, opening up a site that had a considerable seed bank. After autumn rains, seedlings germinated at rates of up to 720 seedlings m⁻². The herbicide glyphosate 360 g L⁻¹ was applied at 10 mL L⁻¹ of water. This resulted in 100% control of boneseed seedlings, as well as 100% kill of all grasses. Use of the selective herbicide clopyralid 300 g L⁻¹ applied at 5 mL L⁻¹ of water also resulted in 100% control of boneseed seedlings, while retaining or improving the grass cover (Briden and Popay 2004).

Once boneseed plants are too large to be hand-pulled they are cut at ground level using a pruning saw. In New Zealand boneseed often recovers with multiple stems coppicing from the cut stump. To avoid this a herbicide must be applied to the cut stump immediately after cutting. Two suitable herbicide methods are (1) apply a 10% solution of glyphosate 360 g L⁻¹ to the cut stump, or (2) apply a gel herbicide containing picloram at 50 g kg⁻¹ (e.g. 'Vigilant® Gel'). Herbicide gels are easy to apply and can be used by volunteers in New Zealand without requiring approved handler certification.

Mature boneseed plants are also foliar sprayed with a range of herbicides. A suitable formulation using knapsack sprayers is to apply glyphosate 360 g L⁻¹ solution at 5 mL L⁻¹ of water when thorough coverage of foliage is possible, or 10 mL L⁻¹ of water where thorough coverage is not possible. Herbicides are also applied by approved handlers using motorized spray units and by aerial application using helicopters. Abseiling has also been used to gain access for herbicide control of boneseed at sites containing boneseed on cliff edges.

Mechanical shredding has recently been trialled by the Christchurch City Council in sand dunes north of Christchurch city (R. Chambers personal communication). A mobile mulcher was mounted on a small 'Positrack' machine with low impact rubber tracks. The machine moved through the undulating dune terrain with ease and caused minimal environmental impact. It was able to cut down and mulch entire boneseed plants, some of which were 3–4 metres in height.

Grazing can be used to suppress boneseed, but if stock is removed boneseed can rapidly recover. Stock movement may also aid the spread of weed seeds via sheep wool. A New Zealand study showed sheep were able to spread broom (*Cytisus scoparius* (L.) Link) seeds to new sites because the seeds had become entangled in their wool (Ledgard 2003).

Community control of boneseed

Boneseed is an ideal weed for the community to control. This is supported by the following observations made by the author, who has been controlling boneseed on a coastal headland near Christchurch since 2001;

1. Boneseed invades coastal sites that are often highly valued by the community, thus inspiring control actions,
2. Infestations often occur near population centres close to where potential volunteers live,
3. Boneseed is easy to control (seedlings and small plants can easily be hand pulled),
4. Boneseed usually has a single stem which is easy to cut and apply herbicide to,
5. Common and safe herbicides can be used to treat cut stems or spray mature plants without the need for volunteers to obtain approved handlers' certification,
6. Boneseed does not have prickles or spines and is non toxic,
7. In New Zealand there are no snakes or biting ants to deter volunteers,
8. Few New Zealand native plants have conspicuous yellow flowers which makes boneseed easy to find and identify as a weed,
9. Government agencies support community control of boneseed by providing funding, herbicides and tools,
10. Weedbusters' can see the results of their work because large areas can be quickly controlled and,
11. The effort required can decrease over time. Most effort is required in the first 1–3 years with initial boneseed removal and dealing with new seedlings. After 5–6 years of control, the seed bank is much reduced and ongoing maintenance takes little effort.

Summary

Boneseed is a weed that can be easily controlled to prevent impacts on biodiversity. Control programs will require; legislation, a strategic approach, raised awareness, knowledge sharing, funding, and interagency and community coordination.

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Future directions for bitou bush and boneseed management in Australia

Paul O. Downey^A, Hillary Cherry^A, Andrew Crane^B, Dennis Gannaway^C, Margaret MacDonald^D, Clyde McGaw^E, Tom Morley^F, David Roberts^G, Bruce Thom^H, Peter Tucker^I and Ian Turnbull^J

^A Pest Management Unit, Parks and Wildlife Group, Department of Environment and Climate Change, PO Box 1967, Hurstville, New South Wales 1481, Australia.

^B Department of Primary Industries and Water, 134 Macquarie Street, Hobart, Tasmania 7000, Australia.

^C Department of Water, Land and Biodiversity Conservation, GPO Box 2834, Adelaide, South Australia 5064, Australia.

^D Anglesea and Aireys Inlets Society for the protection of flora and fauna (ANGAIR Inc.), PO Box 12, Anglesea, Victoria 3230, Australia.

^E Biosecurity Queensland, PO Box 864, Ipswich, Queensland 4305, Australia.

^F Department of Primary Industries, PO Box 48, Frankston, Victoria 3199, Australia.

^G You Yangs Regional Park, Parks Victoria, Branch Road, Lara, Victoria 3212, Australia.

^H University of Sydney, New South Wales 2006, Australia.

^I Trees for Life, 5 May Terrace, Brooklyn Park, South Australia 5032, Australia.

^J Bellingen Shire Council, PO Box 117, Bellingen, New South Wales 2454, Australia.

In August 2007, a national bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) and boneseed (subsp. *monilifera* (L.) T.Norl.) forum was held in Geelong, Victoria, as part of the bitou bush and boneseed Weeds of National Significance (WoNS) program. The forum summarized the latest research and management of these two weeds. Approximately 70 people from throughout southern Australia and New Zealand attended the forum. Participants included community members, government agency staff, students, scientists, private contractors and non-government organization representatives. In addition to the forum talks and posters (also presented in this journal edition), a facilitated session was held to establish the future directions of the bitou bush and boneseed WoNS program in Australia.

Two national bitou bush and boneseed forums were held previously, with the last one being a decade ago (see Love and Dyason 1985, Holtkamp *et al.* 1997). In the intervening period, a significant amount of information has been published or collated, particularly for bitou bush. This is reflected in the recent revision to the Biology of Australian Weeds paper (see Weiss *et al.* 2008 – this edition). The WoNS program, supported by Australian Government funds, has assisted with the production of a large amount of this information, in part through the appointment of a dedicated bitou bush and boneseed coordinator and a national education and awareness campaign (see Holland Clift *et al.* 2006). Also, the increased understanding of both weeds has shown that the subspecies differ in ecological niches, distribution, impact and management techniques, and this has reinforced the need to separate

management and research efforts for each subspecies.

Here we present a summary of the outcomes of the facilitated forum session aimed at establishing future directions of the national bitou bush and boneseed WoNS program. The forum participants were asked to list the: (i) key management issues for bitou bush and boneseed and (ii) main areas where they would like to see action in the future.

(i) *Key issues.* There were eight key points as determined by forum participants being (in no order of priority), participants:

1. were impressed by the large number of people and organizations involved in the management of bitou bush and boneseed in Australia;
2. realized that individuals are not working alone and there is a well-established network to tap into;



Australian Government

Defeating the Weed Menace

**National
BITOU BUSH & BONESEED
management group**

Table 1. List of future priorities actions for the National Bitou Bush and Boneseed WoNS Program.

No.	Priority Action	Number of votes [#]
1	Continue the public education program and national coordination	52 (18%)
2	Develop holistic approaches to weed management for bitou bush and boneseed (i.e. involving all weed species)	44 (15%)
3	Secure and maintain long-term funding (across all levels)	41 (14%)
4	Increase community participation and capacity building (especially with private landholders and agencies) as well as supporting 'champions'	38 (13%)
5	Continued research into improving control techniques and integration of them into management strategies (including biological control and fire) along with research into ecology/biology	35 (12%)
6	Establish better site management protocols post-control (including revegetation)	26 (9%)
7	Identify assets at risk (e.g. habitats, sites, species; particularly for boneseed)	22 (8%)
8	Development of best practice guidelines	17 (6%)
9	Establish containment and exclusion zones (at a range of scales – i.e. local to national)	10 (4%)

[#]Percentages of all the votes cast, total number was 285 votes or 57 people who voted (each with 5 votes).

3. recognized that there is high value in a coordinated approach, as has occurred for bitou bush in New South Wales;
4. expressed the opinion that long-term commitment and persistence to bitou bush and boneseed management is critical;
5. recognized a need for improved knowledge transfer;
6. acknowledged that management of bitou bush and boneseed must be holistic and incorporate secondary weed control;
7. expressed the opinion that containment and eradication programs are essential and;
8. recognized the importance of post-control management (e.g., restoration) for bitou bush and boneseed infested sites.

(ii) *Main areas for action in the future.* The ideas listed by individuals were assessed, refined, and condensed by other members of the forum to produce suggestions for action. All participants then voted for their five most preferred actions. The suggestions and votes were then combined to provide a priority list of future actions (Table 1). These nine broad actions incorporated a number of more specific actions. Where those specific actions were deemed to be important we included reference to them in brackets (see Table 1).

These nine priority actions illustrate support for the continuation of the national program. With the exception of actions 2 and 6, they are similar to actions outlined in the National Bitou Bush and Boneseed WoNS Strategy (see ARMCANZ *et al.* 2000). This suggests that the national strategy, while several years old, is still relevant and that achieving many of these actions requires a long-term commitment. The role of the National Coordinator has contributed significantly towards actions 1, 4, 5, 8 and 9 over the past few years

and such progress could not have been achieved without this dedicated full-time position or significant Australian Government funding for the WoNS program, particularly the 'Defeating the Weeds Menace' initiative.

Priority actions 2 and 6, however, reflect a change in management direction from the National Strategy in that they address broader management of sites over the long-term with respect to other weed species and post-control recovery of sites. There are several factors that may have contributed to this change in focus over the past seven years, being: (i) the benefit of 20+ years of control and refinement of management techniques, particularly for bitou bush; (ii) the production of the NSW Bitou Bush Threat Abatement Plan (DEC 2006), which has moved the focus from control *per se* to control directed at conservation of threatened species and; (iii) education programs aimed at holistic weed management, partly administered through the WoNS program.

Given the significant achievements of the bitou bush and boneseed programs over the past decade (e.g. most of the recommendations outlined by Groves (1997) have been achieved, as well as significant progress towards actions in the National Bitou Bush and Boneseed Strategy), this forum was a good opportunity to reflect on these achievements and establish future directions. The key outcomes of the forum and priority actions identified by forum participants reflect the widespread community support for the program. In addition, it is anticipated that the outcomes of this forum (including these proceedings) will help to maintain future commitment to bitou bush and boneseed management in Australia.

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Management implications of recent research into the effect of bitou bush invasion

Kris French^A, Emilie Ens^A, Carl R. Gosper^{A,B}, Elizabeth Lindsay^{A,C}, Tanya Mason^A, Ben Owers^{A,D} and Natalie Sullivan^A

^AInstitute for Conservation Biology and Law, University of Wollongong, Wollongong, New South Wales 2522, Australia.

^BCurrent address: WA Department of Environment and Conservation and CSIRO Sustainable Ecosystems, Private Mail Bag 5, PO Wembley, Western Australia 6913, Australia.

^CCurrent address: CSIRO Entomology, Black Mountain Laboratories, Canberra, PO Box 1700, Canberra, ACT 2601, Australia

^DCurrent address: NSW Department of Environment and Climate Change, 43 Bridge Street, Hurstville, New South Wales 2220, Australia.

Summary

We review recent research into the impact of bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) Norl.) on coastal ecosystems which suggest this weed is having widespread impacts on ecosystem services, flora and fauna. Increased decomposition rates and altered nutrient cycling accompany changes in plant community structure and composition. Changes in invaded habitats influence invertebrate and bird assemblages. We summarize research that shows that the establishment phase of seedlings is the key phase where bitou bush out competes native species through both resource and interference competition mechanisms. Control of bitou bush at sites by hand spraying and/or hand pulling, and aerial spraying alone do not restore all species that were in uninvaded coastal communities, although these management techniques can reduce seed availability of bitou bush. We suggest that destruction of bitou bush seedlings should be specifically targeted in weed management strategies and that long term management plans are developed to ensure control of secondary weeds that are at risk of invading after bitou bush control. These activities should include using fire to encourage native seed germination and to potentially remove volatile allelopathic chemicals in the soil. Management strategies should also include replanting schemes to increase species richness of all plant structural groups to build ecosystem resilience.

Introduction

The invasion of coastal communities by the African shrub *Chrysanthemoides monilifera* subsp. *rotundata* (DC.) Norl., bitou bush, has persisted despite widespread control efforts including the release of biocontrol agents, extensive herbicide programs and regeneration activities of state agencies, local governments and volunteers. Research

initially fell behind control efforts by not providing deeper insights into the biology and ecology of invasion to help focus control efforts and to understand the impacts of management. Thus, the impacts of bitou bush on biodiversity, the mechanisms of invasion and the efficacy of different management actions were not well understood and guidelines for bitou bush control were without a sound scientific base.

Research has been continuing for over a decade to fill some of these gaps. The aim of this paper is to briefly review research on the impacts of bitou bush (summarized in Table 1) on native ecosystems and the implications for management. We restrict ourselves to reviewing the contributions from published scientific literature or current research efforts rather than management and policy documents to facilitate the incorporation of scientific findings into management. We outline the evidence for each study, although details of research methodology are avoided for brevity. We divide the findings into two broad sections. Initially, we investigate the impacts of bitou bush on all aspects of the ecosystems they invade. Secondly, we summarize studies that have investigated how different control activities influence habitats invaded by bitou bush. We then present the management implications of this research with some suggestions for new management strategies to increase the efficacy of current management efforts.

The impacts of bitou bush

1. Bitou bush changes ecosystem properties and processes

Bitou bush invasion changes the characteristics of coastal ecosystems. In Australia, the invaded habitat is darker, cooler and moister than non-invaded habitat at ground level (Lindsay and French 2004a, Ens 2007). The leaf litter layer is reduced as a result of faster decomposition of bitou bush leaves (Lindsay and French 2004a)

and a lower biomass of leaves falling in invaded habitats (Lindsay and French 2005). Consequently, nutrients are released into the soil more quickly in invaded habitats, resulting in fewer nutrients being stored in the litter layer (Lindsay and French 2005). At present we do not understand if the higher soil nutrient load in invaded sites is eventually leached out of the soil or if it is re-absorbed by plants, however, current research is investigating these possibilities.

Habitats dominated by bitou bush have substantially different patterns of fleshy fruit production to uninvaded ecosystems as bitou bush produces large quantities of fruit during early winter when native fruits are scarce (Gosper 2004a). At least 18 species of birds consume bitou bush fruits, most of which are likely to disperse the seeds (Gosper 2004b). While it would be predicted that bitou bush infestations would affect dispersal of native fruits, Gosper *et al.* (2006) showed that native fruit removal is unaffected by either invasion or broad scale spraying of bitou bush.

2. Bitou bush affects fauna

Despite less litter in bitou bush invaded habitats, the abundance and richness of litter invertebrates are not adversely affected by bitou bush invasion (French and Eardley 1997, Lindsay and French 2004b). However, there is a change in the composition of the invertebrate assemblage due to the cooler, moister environment of invaded sites. Some invertebrate groups are more abundant, particularly moisture-loving species, such as springtails, millipedes, amphipods, slaters, earthworms and pseudoscorpions (French and Eardley 1997, Lindsay and French 2004b). Some groups are less abundant (ants, earwigs, spiders, centipedes and native cockroaches) or less diverse (beetles) in invaded sites (Lindsay and French 2004b). The implications of these changes in food webs are not understood, although the increase in species involved in decomposition may be one aspect causing the changes in observed increases in decomposition rates. Similarly, epigeic and arboreal invertebrates did not differ between bitou bush invaded and native habitats, although there was evidence that the Heteroptera responded to the more mesic conditions in invaded habitats (Wilkie *et al.* 2007).

Furthermore, the effect of invasion of bitou bush on the bird assemblage is variable. Those birds that rely most heavily on plant material for food resources, such as some nectarivores and frugivores, are less abundant in invaded habitats, suggesting that these habitats provided inadequate resources for such birds (French and Zubovic 1997, Gosper 2004b). However for canopy foraging species and some insectivores, few changes were evident (French and Zubovic 1997, Gosper 2004b).

Table 1. Brief summary of impacts of bitou bush on coastal communities.

Environmental characteristic	Effect of bitou bush invasion	References
Ecosystem	Cooler, moister and darker micro-habitat Leaf litter decomposition rates increased Nutrient cycling changed Changed patterns of fleshy fruit availability Seed dispersal interactions appear unaffected	Lindsay and French 2004a Lindsay and French 2004a Lindsay and French 2005 Gosper 2004a Gosper <i>et al.</i> 2006
Fauna	Invertebrate composition changed with an increase in moisture-loving species (millipedes, amphipods, earthworms, pseudoscorpions and isopods) Lower beetle diversity and abundance of ants, earwigs, centipedes and native cockroaches Epigaeic and arboreal invertebrates largely unaffected Fewer plant feeding birds Some bird species avoid bitou bush and predominantly use remnant native shrubs in invaded areas	French and Eardley 1997, Lindsay and French 2004b French and Eardley 1997, Lindsay and French 2004b Wilkie <i>et al.</i> 2007 French and Zubovic 1997, Gosper 2004b Owers 1999
Flora	Threatened species impacted A range of other species become rare or locally extinct leading to lower occurrence along the coast Native seedlings outgrown by bitou bush Native seedling growth suppressed by soil-based chemicals under bitou bush plants Moderate effects of bitou invasion on seed bank dynamics	Coutts-Smith and Downey 2006 Mason and French 2007, unpublished data Weiss and Noble 1984, unpublished. data Ens 2007 Mason <i>et al.</i> 2007, unpublished data

We investigated behaviour of little wattlebirds (*Anthochaera chrysoptera*), New Holland honeyeaters (*Phylidomyris novaehollandiae*), silvereyes (*Zosterops lateralis*) and superb fairywrens (*Malurus cyaneus*) and found few changes in the proportion of time these species spent undertaking different behaviours in invaded and uninvaded habitats (Owers 1999). However, in invaded habitats (where bitou bush cover is over 80%), three of these species were observed using native plants preferentially. Superb fairywrens used bitou bush more than the other three species studied, but not as often as would be predicted from availability of bitou bush (Figure 1). With a reduction in abundance of native plants in invaded habitats, the reliance of nectarivores on native plants provides a potential explanation of why this group is less abundant in bitou bush invaded habitats. This study, however, showed that at least some species are using bitou bush as habitat.

3. Bitou bush invasion is associated with a lower abundance of many native plant species

While bitou bush is listed within New South Wales (NSW) legislation as affecting 46 threatened species (Coutts-Smith and Downey 2006), recent surveys have found that the threat is much greater than just those listed species. In surveys along the coast of NSW, we recorded many plant species in lower abundance

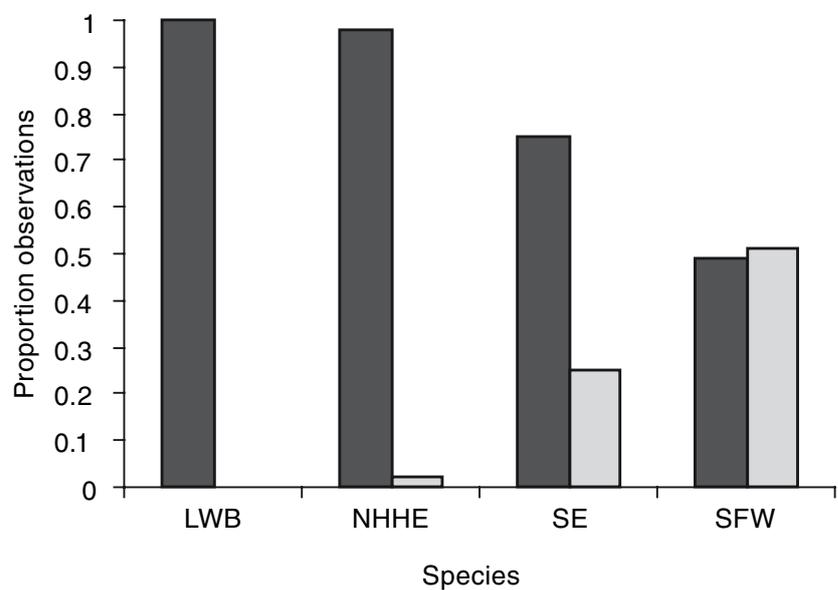


Figure 1. Proportion of observations of four species of birds in native (solid bars) and bitou bush (open bars) plants in bitou bush invaded habitats. LWB = little wattlebird; NHHE = New Holland honeyeater; SE = silvereye; SFW = superb fairywren.

or occurrence in fore dune habitats, suggesting a range of species are at risk from widespread bitou bush invasion (Mason and French 2007a, K. French unpublished data). For example three widespread species *Spinifex sericeus* R.Br, *Carpobrotus*

glaucescens (Haw.) Schwantes, and *Acacia longifolia* subsp. *sophorae* (Labill.) Court) have a lower abundance and occurrence in invaded sites along the NSW coastline (Mason and French 2007a). All life forms are represented in the inventory of species

that have lower abundance or occurrence and this confirms the importance of regeneration using of a wide range of species across all structural layers following bitou bush management. Research is continuing to investigate the species identified here in the context of the NSW Threat Abatement Plan for bitou bush (DEC 2006).

4. *Bitou bush changes the diversity of weed and native seeds and seedlings.*

Seeds of bitou bush in invaded habitats are abundant although there appears to be a reduction since early studies by Weiss (1984). In a recent study on the central coast of NSW we have found 570 viable seeds m^{-2} in invaded habitats (K. French unpublished data). Similar densities have been found at sites in the Illawarra. Interestingly, we have not found the high seed densities measured by Weiss (1984; 2000–3000 viable seeds m^{-2}). Furthermore, viability of seeds in the soil seedbank on the central coast of NSW was only 23% with many seeds empty (K. French unpublished data). This suggests that the activity of released biocontrol agents may be effective in reducing seed production and viability, although this needs to be confirmed. Similar reductions in density of seeds in invaded areas have been measured on the north coast of NSW (Royce Holtkamp personal communication). At this stage we are cautious in concluding that biocontrol is influencing the spread of bitou bush, as a reduction in bitou bush seed densities in the soil seedbank may not result in a reduction in the number of bitou bush plants establishing if seeds are in surplus. Longevity of bitou seeds in the seedbank is also not well understood and should be a priority for future work.

In hind dunes, bitou bush seed in soil seed banks were more abundant in invaded compared to uninvaded sites (Mason *et al.* 2007b). Densities of bitou bush seeds in the soil in native areas, less than 20 m from the edge of bitou bush invaded areas, contained only two viable seeds m^{-2} (K. French unpublished data). Comparisons of species richness of seeds of most native life forms in the seed banks did not differ between invaded and uninvaded sites, although seeds of native tree species were less abundant in invaded sites and there was a trend of increased weed species richness in both invaded and managed compared to uninvaded sites (Mason *et al.* 2007b). In both fore and hind dunes, we have found dramatic differences between the above ground native species composition and the species that germinated from the seedbank, indicating that reliance on the seedbank may not return communities to preinvasion species richness (Mason *et al.* 2007b).

The addition of native seed to areas that have been invaded does not result in improved establishment of native species

following control. In a recent study we cleared patches of bitou bush and native vegetation in fore dune areas on the central coast and a portion of patches received an addition of native seeds. We found that adding native seeds did not increase native species regeneration in patches. There was a flush of germination of native species in both cleared and uncleared patches, and in both native and invaded patches. This flush of germination of native species was far lower than the numbers of bitou bush seed germinating in invaded sites. However, most native and exotic seedlings in all patches died following very hot weather over summer so that only the native sites continued to host native seedlings.

5. *Bitou bush seedlings gain a competitive advantage through rapid germination and growth rates*

Research suggests that bitou bush acts to displace native species at the establishment stage in their life cycle, rather than influencing mortality of adult plants. Two lines of evidence support this. Firstly, flower production, growth rates and photosynthetic stress indices for adult plants of three native species, *Monotoca elliptica* (Sm.) R.Br., *Correa alba* Andrews and *Lomandra longifolia* Labill., did not differ between invaded and non-invaded bitou bush habitats (Ens and French 2008) indicating few impacts on established plants. Secondly, Weiss and Noble (1984b) found that bitou bush seedlings grew faster than coastal wattle seedlings and suggested that this was a mechanism of displacement. Recently, in glasshouse experiments, bitou bush seedlings increased in biomass more rapidly and reduced the biomass of *Banksia integrifolia* L.f. and *Ficinia nodosa* (Rottb.) Goetgh. *et al.* (synom. *Isolepis nodosa*). This effect was greater than the effect of the native species on bitou bush seedlings or the effect of intraspecific competition (K. French unpublished data). Similarly, in artificially cleared plots in bitou bush invaded habitat, more bitou bush seeds germinated and grew more quickly than native seeds, suggesting that both seedling numbers and speed of growth would give bitou bush a competitive advantage (K. French, unpublished data). Therefore, faster growth rates may promote the invasive potential of bitou bush especially at the seedling stage.

6. *Bitou bush exudes chemicals or changes soil processes that influence the growth of seedlings*

One other mechanism may be used by bitou bush plants to increase their competitive advantage in habitats. Vranjic *et al.* (2000) found the presence of litter or soil from beneath bitou bush could influence growth of the dominant shrub *Acacia longifolia* subsp. *sophorae*, which suggests

chemical interference within the soil/litter layers may facilitate invasion by bitou bush. In recent research extending these findings, it was found that bitou bush actively inhibits the seedling growth of a range of species apparently through releasing toxic compounds from the roots into the soil (Ens 2007). While extracts from *A. longifolia* subsp. *sophorae* roots and soil near roots also inhibited the growth of native seedlings, the novelty of the chemicals exuded by bitou bush appeared to affect a wider range of native species (Ens 2007). Interestingly seedlings of coastal wattle, the dominant species in fore dune communities, were affected by this interference mechanism, potentially providing an effective mechanism to enhance invasion of coastal habitats.

7. *Management regimes differ in their impacts on coastal biota*

Management of bitou bush can also pose a disturbance that affects native plant species. In fore dune communities, on-ground management by groups such as bush regenerators improved native species recovery more than the use of non-targeted aerial spraying (Mason and French 2007). Both techniques reduced the number of bitou bush seeds in the seedbank (Mason *et al.* 2007). Interestingly, more weed species were associated with sites where groups had been working on weed control activities, perhaps as a result of the increased soil disturbance and importation of weed propagules on workers' tools and clothing (Mason and French 2007).

Comparisons between native sites, sites that have been sprayed, and sites that have received a spray-burn-spray treatment suggests that the inclusion of prescribed fire has some benefits for native regeneration (Prattis 2004). However, in addition to an increase in native species established after spray-burn spray treatments, there was also an increase in the richness of weed species. Both these studies suggest an increased risk of secondary weed invasion as a result of bitou bush management, which is of concern.

Herbicide spraying over winter using glyphosate and metsulfuron methyl is an important mechanism of bitou bush control, however, we have identified a number of native plant species that are in lower abundance in areas that have been sprayed (Mason and French 2007) and have observed a range of native species that are killed by spray (personal observation). Thomas *et al.* (2006) also confirmed reductions of a number of species following spraying. Matarczyk *et al.* (2002) found significant impacts of spraying of glyphosate on an endangered plant species, *Pimelea spicata*, highlighting the conservation risks of using herbicide to control weed invasions on non-target species.

It is also possible that non-target organisms such as invertebrates may be affected by herbicides, particularly as some consume dead plant material in the litter layer. We investigated the effects on soil and litter invertebrates in bitou bush invaded habitats following spraying with both glyphosate (Lindsay and French 2004c) and metsulfuron methyl (French and Buckley 2008) and found no direct impact of herbicide spray on litter invertebrates. Species may be indirectly affected by the use of these herbicides through the alteration of habitat structure as bitou bush dies. For example, frugivorous birds were less abundant following herbicide treatment of bitou bush, presumably responding to the dramatic decline in fruit availability (Gosper 2004b).

The release of biocontrol agents can influence ecosystem structure through impacting on plant herbivore interactions. Willis and Memmott (2005) showed that the tephritid fly, *Mesoclanis polana*, which was released as a biocontrol agent for bitou bush, influences native food webs. *M. polana* reduces the number of species involved in interactions amongst plants, native seed feeders and their parasitoids in spring through increasing the abundance of native parasitoids.

Management implications

Given the range of impacts bitou bush has on ecosystem function and native species, efforts to continue mitigating the impacts of bitou bush are clearly justified. The key challenge is not so much how bitou bush can be controlled (the methods available are probably better than for most weeds), but rather on how the negative effects of bitou bush and management can be mitigated and particularly how functioning ecosystems can be restored.

Preventing spread of bitou bush

The mechanism for invasion appears to be largely the occupation of vacant spaces by bitou bush seedlings, rather than competition against native plants that have already established. This suggests that effective control may be better achieved through changing the probabilities of space occupation at this early stage. Only small numbers of viable bitou bush seeds were identified in the soil seedbanks of native areas adjacent to infestations, suggesting that seed dispersal of even a few metres is a rare event and potentially controllable in early stages. Our knowledge of dispersal patterns of frugivores suggests that this localized dispersal will be supplemented by long distance dispersal events associated with animal movements resulting in distant patches of bitou bush forming. Thus control near the invasion front will need to be complemented by searches into native vegetation to locate new patches of bitou bush seedlings. Given that the

establishment of bitou bush seedlings in these native areas is likely to be high relative to establishment of native seedlings and given the rapid growth rate of bitou bush, any seedlings that do germinate have a high likelihood of forming a new weed patch.

The research summarized here suggests that management is likely to be most cost effective and successful at the germination and establishment phase. Herbicide application or hand pulling of new bitou bush seedlings within 20–30 m of invasion boundaries, followed by searches for seedlings deeper into nearby native areas, is likely to be significant in controlling spread. Furthermore, removing seedlings and young juveniles will be helpful as soil-based allelopathic chemicals are unlikely to have accumulated, allowing natural rates of establishment of native species after weed control.

Weed removal activities

The change in focus to managing bitou bush seedlings rather than adults should extend to weed removal techniques. Our results suggest that both aerial spraying and more intensive hand pulling and weeding at particular sites are not effective in allowing regeneration of many native species. Further management actions are necessary by managers, particularly following aerial spraying. Two actions appear to be necessary; burning of sites to encourage native regeneration and planting those native species that remain absent.

As burning enhances germination of the soil seedbank and increases species richness of seedlings, it is likely that burning following weed control activities will help in returning vegetation to preinvasion structure, however, it is not adequate without additional actions to ensure establishment of native species absent from the seedbank. While spray-burn spray treatments have advantages over just spraying, we suggest that the second spraying treatment is replaced by hand pulling or spot spraying bitou bush seedlings. Repeat spraying is likely to reverse many of the benefits of burning and many seedlings will suffer mortality. Many native species, particularly seedlings, are susceptible to glyphosate and while Toth *et al.* (1996) have shown limited susceptibility for seven species, a wide range of native species are impacted by spraying (Thomas *et al.* 2006, K. French and T. Mason personal observation). Furthermore, allelopathic chemicals exuded by bitou bush which build up in the soil and root mass as bitou bush grows, are likely to persist in the soil following spraying, influencing germination of native species. Early removal of bitou bush seedlings may reduce the quantity of allelopathic chemicals and reduce the stress placed on already germinated native seedlings.

Having resources available for bitou bush control after bushfire events may be crucial given the competitive ability of bitou bush seedlings. Given that coastal fires will occur, bitou bush management could be directed to a fast-response force in post-fire areas to remove newly emerged bitou bush seedlings and providing less competitive opportunities for native seedlings. Missing these opportunities may have substantial future costs (Thomas *et al.* 2006).

The loss of native plant species and the reduced capacity of native seedbanks to facilitate regeneration at sites poses difficulties for returning invaded areas to functioning healthy coastal communities. Research results provide a strong argument to supplement current control activities with planting of targeted native species and to ensure removal of secondary weeds that increase in abundance after bitou bush control. Native species chosen for revegetation planting should include all components of the vegetation community (forbs, grasses, shrubs, trees) to rebuild habitat complexity and ecosystem resilience. Replanting schemes that only focus on larger shrubs and trees will be inadequate to restore ground layer richness, which is one of the most affected strata in weed invasion (T. Mason and K. French unpublished data).

This approach suggests the need to set long-term management plans and funding schemes (for a minimum of five years), as control of bitou bush alone is not sufficient. Follow up work must be done to successfully restore coastal vegetation communities. Evaluation of communities needs to be undertaken with a clear understanding of the desired outcome. This suggests the need to develop a list of native species that should be present, perhaps based on nearby surveys of uninvaded vegetation. Revegetation with all strata rather than only larger shrubs and trees is imperative in the evaluation process. Thus funding should incorporate evaluation of sites, requisitioning and purchasing of seedling stock of missing species, planting of these into the areas and monitoring to ensure establishment. Such activities could equally be applied to current projects to assist complete ecosystem restoration. Nurseries must be encouraged to propagate an extensive range of species, not the current minimal set available.

Overall, these results represent a significant change in the way that bitou bush should be managed. Further research to establish the effectiveness of current biocontrol agents will help in predicting future invasion potential. While the management changes we suggest are more costly in the short term, they will reduce long-term costs by avoiding the need for broader replanting of more species in the future and they are likely to produce a

better biodiversity outcome. Incorporating research alongside these new approaches to management will provide an evaluation strategy of the activities to help improve future protocols.

Acknowledgments

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Progress on boneseed (*Chrysanthemoides monilifera* subsp. *monilifera* (L.) Norlindh) biological control: the boneseed leaf buckle mite *Aceria* (Keifer) sp., the lacy-winged seed fly *Mesoclanis magnipalpis* Bezzi and the boneseed rust *Endophyllum osteospermi* (Doidge) A.R.Wood

T.B. Morley^A and L. Morin^B

^A Department of Primary Industries, PO Box 48, Frankston, Victoria 3199, Australia.

^B CSIRO Entomology, GPO Box 1700, Canberra, ACT 2601, Australia.

Introduction

So far six exotic organisms have been released in Australia as potential biological control agents for the environmental weed boneseed (*Chrysanthemoides monilifera* subsp. *monilifera* (L.) Norlindh (Asteraceae)). None of these has established on boneseed although one, the bitou tip moth (*Comstolopsis germana* Prout (Lepidoptera: Geometridae)) has colonized all of the major infestations of the closely-related invasive species bitou bush (*C. monilifera* subsp. *rotundata* (DC.) Norlindh). Currently three organisms are under investigation for possible use as biological control agents for boneseed. They are the boneseed leaf buckle mite (*Aceria* (Keifer) sp. (Acari: Eriophyidae)) (BLBM), the lacy-winged seed fly (*Mesoclanis magnipalpis* Bezzi (Diptera: Tephritidae)) (LWSF) and the rust fungus (*Endophyllum osteospermi* (Doidge) A.R.Wood) that induces witches' brooms. They are all endemic natural enemies of boneseed in South Africa and each has the potential to suppress boneseed vigour and/or seed production.

Boneseed Leaf Buckle mite

Characteristics

The BLBM (Figure 1) is vermiform (worm-like), about 0.15 mm long and its preferred host is boneseed (Morley 2004). The BLBM induces formation of leaf galls known as erinea. Erinea are composed of abnormally dense patches of hair-like structures that resemble felt. Initially erinea are white but turn brown within a few weeks. Erinea may develop anywhere on a leaf, have irregular shapes and size and may range from one to several hundred square millimetres. Erineum formation is induced by BLBM feeding at shoot meristems and commences before a leaf becomes visible. Erineum growth interrupts the normal expansion of affected leaves, resulting in leaf disfigurements ranging from small dimples to gross distortion of mature leaves. The BLBM feeds and breeds in erinea until overcrowding or erineum deterioration

stimulates dispersal. Dispersive mites can walk to adjacent uncolonized shoot tips or can be wind-dispersed to other boneseed plants.

Introduction to Australia

Following host specificity testing in South Africa in 2002 that showed the BLBM would be safe to introduce to Australia (Morley 2004), the mite was imported into quarantine at the Department of Primary Industries – Frankston, Victoria in 2006 and was due for field release in Spring 2007. In collaboration with local land managers, community groups and researchers, releases are planned for core boneseed infestations in Victoria, South Australia and Tasmania and may be extended to New South Wales in the future. There are no plans to release in Western Australia as very few boneseed infestations are present and State law requires eradication of plants when found.

Chrysanthemoides seed flies

Three *Mesoclanis* spp. have been considered for biological control of boneseed and bitou bush in Australia (Edwards and Brown 1997; Naser and Morris 1985). These flies lay their eggs into *Chrysanthemoides* flowerheads and the larvae can destroy substantial proportions of developing ovules, thus suppressing seed production. When introduced to Australia in 1996, the bitou seed fly (*Mesoclanis polana* Munro) (BSF) rapidly colonized almost the entire range of bitou bush (Edwards *et al.* 1999). However, in South Africa the BSF does not utilize boneseed and prevails at latitudes much closer to the equator than the more southerly bitou bush infestations in Australia. The BSF was therefore considered unlikely to effectively suppress seed production of Australian boneseed or the more southerly bitou bush infestations, and this appears to be true (Robin Adair personal communication and Morley unpublished observations). Conversely, in South Africa the lacy-winged seed fly (LWSF) (Figure 2) utilizes a range of *C. monilifera* subspecies (Munro 1950, Edwards and Brown 1997) including boneseed, bitou bush (most prosperously at latitudes similar to southerly Australian bitou bush infestations (Edwards and Brown 1997)), subsp.



Figure 2. Lacy-winged seed fly *Mesoclanis magnipalpis*.

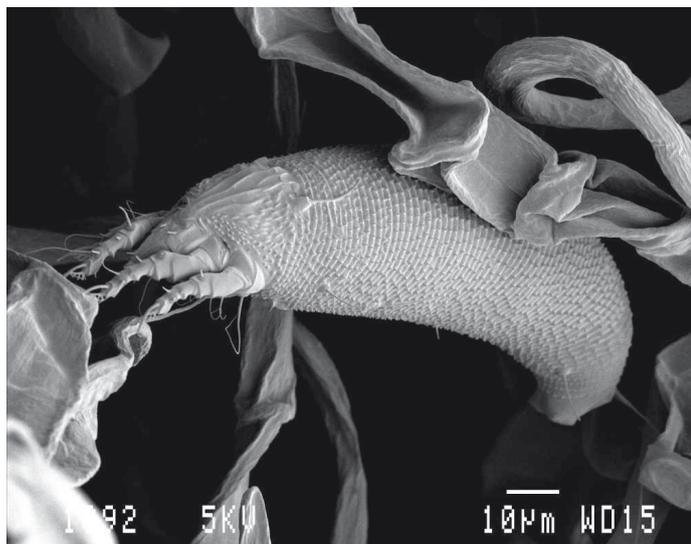


Figure 1. Boneseed leaf buckle mite *Aceria* sp. (Courtesy Charnie Craemer, Plant Protection Research Institute, Pretoria, and Alan Hall, University of Pretoria, South Africa).

pisifera (L.) Norlindh and *Chrysanthemoides incana* (Burm.f.) Norlindh. Thus the LWSF seemed a good candidate biological control agent.

Failure of LWSF to establish

Boneseed

Attempts to establish the LWSF in Australia have been in progress for nearly a decade. It was first released on boneseed in 1998 and also in 1999, 2000 and 2005. These efforts involved LWSF reared from imported *C. monilifera* subsp. *pisifera* fruit using a special AQIS-approved direct release protocol to ensure the released individuals were free of pests and diseases. Releases were made in the You Yangs, on the Mornington Peninsula and at Frankston, Victoria. The LWSF did not establish but on three occasions offspring were recovered in the same season as the release (Aline Bruzzese and Robin Adair personal communications, Morley unpublished data). This confirmed the apparent suitability of boneseed as a host for LWSF ex *C.m. pisifera*. The reason for establishment failure is not known but it appears that LWSF ex *C.m. pisifera* is not able to survive between the end of boneseed's fruiting season in early summer and the beginning of the next flowering season in late winter. In South Africa, LWSF ex *C.m. pisifera* might not be constrained in this way either because the interval between *C.m. pisifera* fruiting and flowering is sufficiently short or there are alternative *Chrysanthemoides* hosts whose flowerheads are suitable and available at critical times. Importation and release of the LWSF ex *C.m. monilifera* has been previously considered but not attempted largely because boneseed's relatively short flowering season combined with the logistic and mandatory delays of passage through Australian quarantine make this option difficult. Populations of LWSF on *C.m. monilifera* are also often difficult to find in South Africa (Robin Adair personal communication). Notwithstanding these difficulties, in light of the failure of LWSF ex *C.m. subsp. pisifera* to establish on boneseed in Australia it might now be worthwhile investigating the introduction of LWSF ex *C.m. monilifera* in case it exists as a biotype specifically adapted to tolerate boneseed's flowerhead phenology.

Bitou bush

In 2005, the LWSF ex *C.m. pisifera* was also released on bitou bush on the New South Wales south coast. This was done with the view that LWSF could be redistributed from these release sites to boneseed infestations in Victoria, South Australia and Tasmania, in much larger numbers than it is practical to import, thereby perhaps enhancing the possibility of establishment on boneseed. However, the LWSF has not been recovered from bitou bush post-release (although sampling of release

sites has yielded nearly 4000 BSF (Morley unpublished data)). The reason for this outcome is not known but the following speculations seem plausible:

- 1) LWSF is present but in such low numbers that it has not yet been detected. If this is the case then further sampling should eventually detect it.
- 2) There are distinct biotypes of LWSF in South Africa that have particular *Chrysanthemoides* preferences and LWSF ex *C.m. pisifera* is a biotype not suited to the bitou bush populations found in Australia. Intraspecific variation of *Mesoclanis* has not been studied but based on the experience described above and an observation by Munro (1950), biotypism seems a real possibility. Munro (1950) observed that flies of a collection of *M. magnipalpis* ex *C. incana* were 'larger than usual'. Importation of LWSF ex *C.m. rotundata* at a latitude comparable to Australia's southerly infestations (e.g. St Francis Bay, South Africa, where large populations of LWSF can be found (Edwards and Brown 1997)) would address the biotype theory. This could perhaps improve the chance of establishment on bitou bush and is the next most obvious strategy to try.
- 3) Competition with the BSF has prevented or impeded LWSF establishment. If this is the reason for failure of the LWSF to establish on bitou bush, then it might be overcome by releasing larger numbers and/or using other techniques to promote establishment (e.g. exclusion of BSF from bitou bush at release points).

Boneseed rust

The South African rust fungus *E. osteospermi* is a microcyclic species only recorded on a small group of related plants of the genera *Chrysanthemoides* and *Osteospermum* (Calenduleae: Asteraceae) in South Africa (Doidge 1926, Morris 1982, Wood 1998, Wood and Crous 2005b). It is thought to have considerable potential for the biological control of boneseed, and to a lesser extent bitou bush, in Australia (Morin 1997). Although the disease has been recorded on a few occasions on bitou bush in South Africa, this was only at the southernmost part of the plant's range (Wood and Crous 2005b). Consequently, while the rust may attack bitou bush in the southern part of its New South Wales range,

should it be released in Australia, it is not expected to have a significant impact on most Australian bitou bush populations. Climate modelling has shown that the rust would likely have its greatest impact in Tasmania and southern Victoria (Wood *et al.* 2004).

Infection

E. osteospermi systemically infects its hosts via immature foliage and stems. After 1–2 years, infected plants develop witches' broom branches with multiple swollen stems, short internodes and smaller and slightly chlorotic leaves (Wood 2002, Wood and Crous 2005a) (Figure 3). The rust produces fruiting bodies on leaves of witches' brooms when conditions are conducive, generally in winter to late spring (Wood 2002).

Impacts

The rust has been shown to have a significant impact on boneseed populations in South Africa, reducing growth and reproduction and in some instances killing plants (Wood 2002, Wood and Crous 2005a). Deformed infected branches of diseased plants produced far fewer buds, flowers and fruits than branches of healthy plants and usually die within 1–4 years. The rust also has an indirect effect on the

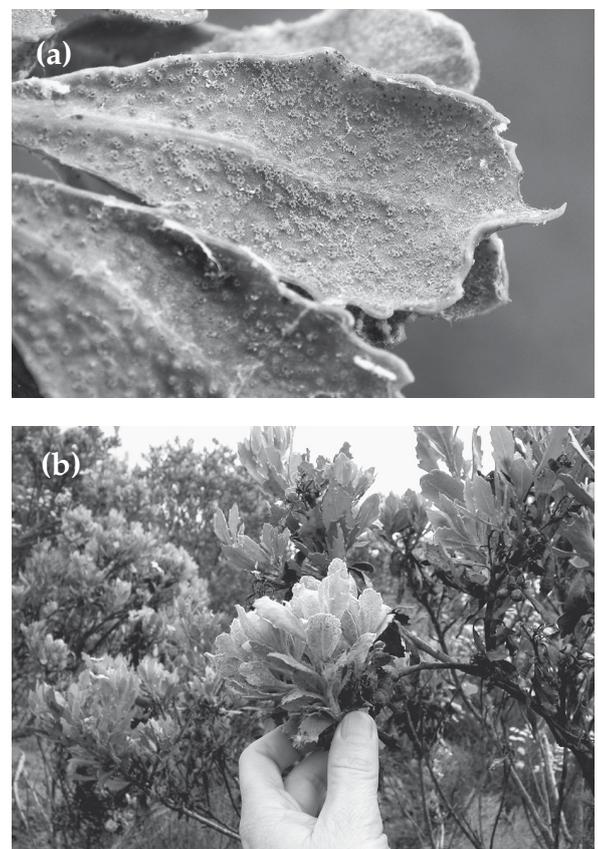


Figure 3. Boneseed rust, *Endophyllum osteospermi*; (a) fruiting bodies on leaves and (b) witches' brooms caused by the rust infection.

growth and reproduction of non-infected branches of diseased plants. Field measurements showed that the production of flowers and fruits on non-infected branches decreased as the severity of the disease on plants increased (Wood 2002, Wood and Crous 2005a). The systemic nature of *E. osteospermi* is a desirable characteristic for biological control purposes, as once the fungus is established within the host, the infection is retained until the death of infected branches (Morin 1997).

Risk assessment

Because of the nature of the rust, which develops visible symptoms only 1–2 years after infection of its host, an initial series of host-specificity tests were performed on detached leaves of test plant species. This was done to determine, using microscopy techniques, whether the rust was capable of penetrating epidermal cells of non-target plant species (as it successfully does on its host *C. monilifera*) (Wood 2006). Successful penetration was observed on boneseed and its close relative species tested within the Calenduleae tribe, but also on four other species outside the Calenduleae. Additional tests were carried out on leaves still attached to plants of some of the non-target plant species as well as the target weed species boneseed and bitou bush, to confirm accuracy of results obtained with detached leaves (Wood 2006). Since penetration of epidermal cells does not necessarily imply that the infection process will continue and be successful, more tests on whole plants of the species where penetration occurred in initial tests are currently underway to determine if the fungus is capable of colonizing tissue of these species. Results from these additional tests will provide the necessary information to fully assess the risk of significant impact on these non-target species should the rust be released in Australia.

If permission is granted to release *E. osteospermi* in Australia, an acceptable approach for its release from quarantine will have to be negotiated with AQIS and Biosecurity Australia. Because of the rust's long generation time, it will not be possible to maintain infected plants in quarantine until spores are produced and therefore an alternative strategy will be required (e.g. surface decontamination of infected plants before transfer from quarantine facility to ordinary glasshouse to provide optimal sporulation conditions; or direct release of spores collected in South Africa).

Summary

BLBM was due for release in Australia in Spring 2007. Further attempts to establish LWSF on: 1) bitou bush in Australia with collections ex *C.m. rotundata* from St Francis Bay, South Africa and 2) boneseed in Australia with collections ex *C.m. monilifera* in South Africa would be worthwhile. The boneseed rust has a significant impact on *C.m. monilifera* populations in South Africa. Substantial progress on risk assessment has been made and if approval for release is granted then an importation strategy that accommodates the rust's unusually long life cycle will need to be negotiated with AQIS and Biosecurity Australia.

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The role of fire in integrated management of boneseed (*Chrysanthemoides monilifera* subsp. *monilifera*)

Rachel Melland and Christopher Preston, CRC for Australian Weed Management and School of Agriculture, Food and Wine, University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia.

Summary

Boneseed, *Chrysanthemoides monilifera* subsp. *monilifera* (DC.) T.Norl. (Asteraceae) is a South African shrub that is invasive in Australian temperate ecosystems. Fire can be a useful boneseed management tool, as it can kill existing plants and deplete the soil seed bank. When used as part of an integrated approach (e.g. fire followed by herbicide treatment and/or hand-pulling of surviving plants), it is possible to eliminate boneseed, especially where the seed bank is less than 1000 seeds per m² (i.e., lightly-invaded, intact ecosystems). However, where seed banks are larger (i.e., heavily-infested, degraded ecosystems) this integrated approach may only lead to a reduction of boneseed population, albeit up to 99%, 30 months after the fire.

Introduction

Boneseed is an aggressive, invasive shrub originating from South Africa. It was brought to Australia as a garden ornamental in the 1850s and has since invaded many vegetation types in temperate Australia (Weiss *et al.* 2008). Currently boneseed has not reached its full potential distribution in Australia and continues to spread into new areas (Weiss *et al.* 2008). As boneseed can reduce the density and diversity of native plant species (Thomas *et al.* 2005) and it has the potential to cover vast tracts of land, its control should be an important conservation goal in Australia. In the past, attempts to control boneseed used various techniques in isolation; however, none resulted in landscape scale control. Fire has been used to control various weed species at a landscape scale, including bitou bush (*C. monilifera* subsp. *rotundata* (DC.) T.Norl.: see Downey 1999), and its use in the control of boneseed is warranted. This paper discusses the role of fire as part of integrated control of boneseed in temperate Australian ecosystems.

Fire and weed management

Fire works in three main ways to control weed infestations; 1) killing existing adult plants; 2) providing physical access to the site for follow-up control; and 3) depleting the soil seed bank through seed mortality and/or stimulated germination (Downey 1999). Fire can be particularly beneficial for long-term control of weeds if it is directed

at reducing the seed bank (see Lonsdale and Miller 1993); however, the resultant germination must be controlled before the weed species flowers for effective management (Downey 2000). In addition, fire can be most effective if used in the early stages of invasion (see Grice 1997).

Boneseed fire studies

Fire can play a pivotal role in boneseed management in native ecosystems in Australia (Melland 2007). Boneseed seeds are both stimulated to germinate and killed by heat. For example, boneseed germination was markedly increased after exposing seeds to 100°C for 30 seconds (Lane and Shaw 1978), while mortality occurs in bitou bush seeds at about 220°C (Downey 1999).

An experiment conducted at two sites in Victoria, the You Yangs Regional Park and Arthur's Seat State Park, examined the role of controlled burns in boneseed management (Melland 2007). In these experiments, fire was most effective for controlling boneseed when there was abundant fine sized fuels (e.g. <6 mm in diameter) at ground level. These fine fuels enable the fire to carry through the boneseed infestation. Fuel at the ground level helps to heat the soil, which in turn leads to seed bank depletion. Where fine fuels are not present or in low quantities at the ground level, the slashing of boneseed plants several weeks prior to burning can be used as a substitute.

At Arthur's Seat, where boneseed had been previously slashed and so fine fuel was abundant, temperatures of 300°C were achieved consistently at the soil surface during the fire. This resulted in the soil surface being heated to over 100°C for more than five minutes, and more than 82% mortality of the boneseed seed bank. The boneseed seed bank continued to decline with time since the fire, and eventually reached zero after 30 months (Melland 2007). At the You Yangs, in areas where standing boneseed populations had no understorey (i.e. no fine fuels), the fire burnt more quickly and at lower temperatures. In these areas, fire temperatures rarely reached 300°C at ground level and soil surface temperatures only remained above 100°C for about two minutes. This resulted in a boneseed seed bank mortality of less than 72% where fine fuels were

not abundant. There was substantial boneseed germination from the remaining seed bank at both sites after the fires.

The use of fire for boneseed management may be influenced by a number of variables, including previous fire frequency, the existing vegetation structure, soil moisture, fire intensity and boneseed seed bank soil profile (i.e. the number and depth of boneseed seeds in the soil). Too frequent fires may limit the ability of the native ecosystem to recover. As fire results in considerable and rapid germination of boneseed seedlings, follow up control must be conducted.

The use of physical and chemical controls for boneseed control following fire

Following fire, physical and chemical weed control methods can be implemented as part of an integrated program to optimize the impact on the target weed species. Here we looked at hand removal (or hand pulling) of seedlings and herbicide foliar spray following the fires at the You Yangs and Arthur's Seat. Hand-pulling of boneseed seedlings following a fire was more effective and took less time than in unburned areas, which when combined with a depleted seed bank may reduce the time needed to eliminate boneseed from an area by hand pulling from decades to less than three years. For hand-pulling to be effective, all flowering plants must be removed each year to prevent new seed addition to the seed bank.

Several herbicides are registered for use on boneseed in Australia (Brougham *et al.* 2006), including glyphosate and metsulfuron-methyl. Herbicides were best applied to the fast-growing boneseed seedlings that had emerged before the native seedlings following the fire. In addition, application of metsulfuron-methyl at 6 g ha⁻¹ a.i. and glyphosate at 360 g ha⁻¹ a.i. to boneseed seedlings 12 (-17) months after fire was found to reduce boneseed numbers by 87%; however, while glyphosate killed native species, native grasses and some native seedlings survived application of metsulfuron-methyl (Melland 2007).

Integrated boneseed management

Based on the results of this work, we propose an integrated approach to boneseed management using fire. In vegetation that remains rich in native plant species and has a low boneseed density following fire, hand-pulling or chemical control are likely to eventually eradicate boneseed, provided sufficient labour is available. Where boneseed has been established for some time (i.e. dense infestations), it is unlikely these labour-intensive practices will be successful because of the large soil seed bank that accumulates under boneseed stands. The seed bank may reach 20 000 seed per m²

(Melland 2007) and will contribute new seedlings for some time, even after fire.

Lightly-invaded, intact ecosystems

Where boneseed infestations are limited, including a limited soil seed bank (i.e. 1000 seeds per m² or less) and the native vegetation is relatively intact, particularly at the ground level, fire and intensive hand pulling can lead to localized eradication of boneseed. Alternatively, the application of metsulfuron-methyl within a few months after the fire (once boneseed seedlings have emerged), or at 12 months (before flowering), followed by hand-pulling of any subsequent germination can also be effective.

Heavily-infested, degraded ecosystems

In dense boneseed infestations with large seed banks (i.e. >1000 seeds per m²) and low densities of native species, slashing of boneseed plants prior to burning is essential to provide sufficient fine fuel to carry an effective fire. Following fire in such a situation, effective follow-up control of seedlings is best achieved with metsulfuron-methyl or glyphosate application within 12 months of the fire (preferably in the first spring) and prior to the first boneseed plants flowering and setting seed. Hand-pulling of seedlings without prior herbicide application is ineffective due to the high density and subsequent emergence of boneseed seedlings from the seed bank following the fire. This integrated approach did not lead to the localized eradication of boneseed. However, it did lead to the removal of adult plants and more than 99% depletion of the seed bank after 30 months.

Post fire site management

The disturbance created by a fire may leave a site open to invasion by other weed species. Where there are few native species remaining following boneseed invasion and subsequent management, revegetation should be undertaken to ensure secondary weed invasion does not occur. In such circumstances, it may be appropriate

to undertake boneseed control (including fire) and revegetation in a mosaic pattern that will eventually produce an ecosystem with a range of age structures and densities of native species. In addition, such a mosaic pattern will allow native species, which may be intolerant of control methods, to recolonize from neighbouring areas. Also this mosaic approach may help to ensure that sufficient resources are available to tackle a site after fire, particularly where fire has been used over a large area.

Conclusion

Integrated management that incorporates fire allows the control of persistent stands of boneseed that cannot be successfully managed by treating individual plants or using single control techniques alone. The advantages of fire are a large reduction in the soil seed bank, rapid emergence of much of the rest of the seed bank and ease of access for follow-up management. Fire alone, however, did not eradicate boneseed, but when used in an integrated fashion using herbicide treatment and hand-pulling of seedlings, localized eradication was achieved. The effectiveness of herbicide treatments depended on timing of application, as well as the size of the original boneseed seed bank. Where the original seed bank of boneseed is large, herbicides had to be applied later to achieve the best result. Using a variety of follow-up control methods in a mosaic pattern, including revegetation where necessary, could provide additional benefits where boneseed invasion has caused significant degradation of the ecosystem.

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Economic evaluation of the management of bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) to conserve native plant communities in New South Wales

Jack Sinden^{A,B}, Paul O. Downey^C, Susan M. Hester^{A,B} and Oscar Cacho^{A,B}

^A School of Business Economics and Public Policy, University of New England, Armidale, New South Wales 2351, Australia.

^B CRC for Australian Weed Management.

^C Pest Management Unit, Parks and Wildlife Group, NSW Department of Environment and Climate Change, PO Box 1967, Hurstville, New South Wales 1481, Australia.

Summary

The bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) Threat Abatement Plan (TAP) aims to reduce the impacts of bitou bush on biodiversity in New South Wales. This is the first weed TAP in Australia and so its effectiveness in conserving threatened biodiversity, as well as its cost of implementation, must be examined to determine if this new approach should be adopted as a template for managing the biodiversity impacts of other major weed species. We therefore consider the question 'is the TAP a good investment in relation to protecting biodiversity'? We combine the costs of implementing the TAP with conservative, published estimates of the benefits of protecting biodiversity, to calculate the benefit-cost ratios of the investment. The ratios indicate that the benefits of the TAP exceed the costs under a wide range of economic conditions. While this result supports the approach, the cost of implementation should be analysed over the five years relative to the biodiversity outcomes in order to determine the *ex post* benefit of the TAP.

Introduction

Bitou bush arrived in Australia from South Africa about 1908 and has now spread to 80% of coastal New South Wales (DEC 2006). In 1999, the weed was listed as a key threatening process under the NSW *Threatened Species Conservation Act 1995* and in accordance with the Act, a Threat Abatement Plan was prepared to reduce, abate or ameliorate the threat of bitou bush on coastal biodiversity (DEC 2006). The cost of implementing the TAP in 2005–06 was estimated to be \$2.85m, a cost that should continue over the five years of the plan's implementation. Is this cost a good investment in relation to the biodiversity that is protected? The objectives of this paper are therefore to (i) assess the economic desirability of the TAP, and (ii) further develop the method for these kinds of evaluation.

Methods

The steps for evaluating the TAP follow the standard procedures of benefit-cost analysis (see Sinden and Thampapillai (1999), for further details).

(a) Define the problem and the management strategy

The problem is the threat posed by bitou bush to native plant communities in New South Wales. The TAP is a management strategy to address the problem, which aims to protect 158 plant species and 28 ecological communities at over 300 sites along the entire New South Wales coastline. The TAP comprises various actions including on-ground control, monitoring the response of bitou bush and native species to control, and co-ordination of on-site and between-site management to implement the plan. The analysis must answer the question, 'do the benefits of the TAP exceed the costs'? The benefit is the value gained from the protection of biodiversity from bitou bush, and the costs are the resources invested to achieve this benefit.

(b) Define the nature and value of the costs

The costs include cash expenditure, external grants, and in-kind contributions, so the total cost is defined as:

$$\text{Total cost} = \text{cash expenditures} + \text{external grants} + \text{in-kind costs} \quad (1)$$

The external grants are income from other state and Commonwealth agencies such as the National Heritage Trust. The in-kind costs include volunteer labour costed as the number of volunteer hours multiplied by an hourly wage rate, government agency and other staff time and the associated on-costs (e.g. office space, phones, computers, and vehicles).

The total cost of implementing the TAP in 2005–06 was \$2 845 500, which is estimated to remain at a similar level for each of the five years of the TAP (DEC 2006). The

costs of all on-ground activities, including direct control, monitoring, and preparation of site-specific plans, was \$2 489 000 for each year. These costs span many of the 169 priority sites in the TAP.

The costs include expenditure by the Department of Environment and Climate Change, Department of Lands, five coastal Catchment Management Authorities, the Lord Howe Island Board, numerous coastal councils and the University of Wollongong. Approximately 40 different agencies are involved in implementing the TAP. The costs include on-ground control activities, and the support activities of planning, monitoring of priority sites, training volunteers, and direct co-ordination.

(c) Define the nature of the benefits

There are two kinds of benefit derived from the TAP, namely (i) the increase in amenity from the improved access to the beaches (and the associated social values), and (ii) the increase in environmental services from the extra biodiversity that is protected. To identify the increase in environmental and social services due to the TAP, consider an area where native species are being protected for their biodiversity benefits. With the TAP we assume that the full set of current environmental and related social services will continue for the foreseeable future at the current level with a service flow of *AB* in Figure 1. If the TAP is not implemented however, the environmental services will decline following a trend such as *AC* or *AD*. Therefore the increase in benefits of full implementation of the TAP can be identified as the area *ABC* or *ABTD*, following the shape of the curve *AC* or *AD*, respectively.

Partial implementation of the TAP would lead to a decline in environmental services, giving a flow between *AB* and *AC*, rather than *AB* itself. The curve *AC* could also represent the optimal service flow without implementation. The actual service flow for *AC* in Figure 1 is based on the value of *X* in the final year, which is determined by the level of implementation and assumptions about the rate of decline of services.

(d) Measure the gain in quantity of benefits

To measure the increase in the quantity of benefits, such as *ABC*, we need to know the shape of the curve (*AC*) and the quantity of services at the end of the time horizon (*X* in Figure 1). These two data needs, and their uncertainties, can be addressed through simulations that incorporate probability distributions for the shape of the curve and the value of *X*.

The shape of *AC* can be modelled through a range of mathematical functions. The rectangular hyperbola function conveniently allows the shape and the end-point *X* to be varied to model either

of the curves AC or AD in Figure 1, or any similar curve. We start by calculating the loss in benefits without the TAP, which would be EF at time t . Using the function, this loss in year t (L_t) is defined as:

$$L_t = (q^* t) / (1 + ((q/m) - 1) * t) \quad (2)$$

where q and m are parameters that are changed to vary the shape of the curve. The time t is coded as a proportion of 1.0, so year 2 becomes 0.1 for a 20-year time horizon. The model assumes that the weed spreads over an equal proportion of the site each year and completely covers the site by the end of the time period T .

We now standardize the service level at the start of year 1 to 1.0 and the level in the final year T to X . The actual service level (S) that remains in year t (S_t) is equal to $(1 - L_t)$. So the standardized value of the service flow (S^*) in each year t is derived as:

$$S_t^* = ((1 - L_t) + X) / ((1 - L_0) + X) \quad (3)$$

where L_0 is the loss in year 0 which is the start of year 1. The service output S^* in year t has now been standardized to 1.0 at the start of year 1 and to a final level X . The standardized loss in year t (L_t^*) is therefore:

$$L_t^* = (1 - S_t^*) \quad (4)$$

The total gain in quantity of benefits over all the years to T is the total loss that is avoided, so:

$$\text{Total gain in quantity of benefits} = \sum_{t=1}^T L_t^* \quad (5)$$

The total gain from equation (5) is a measure of the total quantity of extra services that are due to the investment in implementing the TAP and is indexed to the value of 1.0 at the start of year one. It therefore measures area ABC for curve AC, area ABTD for curve AD, or the similar area for any other similar curve.

The total value of the gain per site can be calculated by multiplying the total gain from equation (5) by the value of the benefit (BN) for one unit of the gain:

$$\text{Total gain in value of benefits} = \left(\sum_{t=1}^T L_t^* \right) \cdot BN \quad (6)$$

The monetary value for the total gain in benefit due to the implementation of the TAP, as defined in Equation (6), is derived from the rectangular hyperbola function of Equation (2) in which q , m and X can be varied. For convenience, m will be always be set at 1. If q exceeds 1 as in AC and AD in Figure 1, the changes in annual

Quantity of services (S_t)

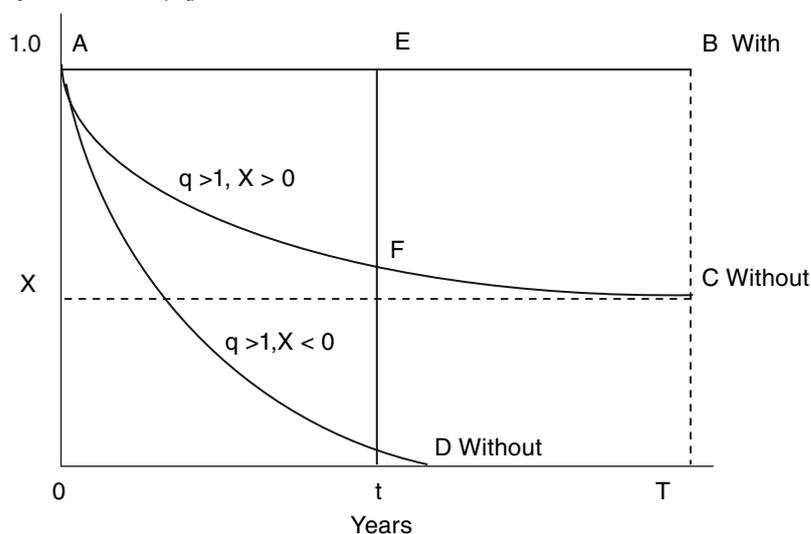


Figure 1. Flow of biodiversity services, with and without the management of bitou bush.

biodiversity losses or impacts are initially high but decrease with time. This trend models the later stages of a weed invasion, as argued by van Wilgen *et al.* (2004). If $q = 1$, AC is a linear trend that models an invasion where there is an equal loss of biodiversity services each year. If q is less than 1, there are small losses at first and then losses increase at an increasing rate each year as might occur in the early stages of a weed invasion without control (see van Wilgen *et al.* 2004). The decreasing trend in annual biodiversity losses seems most appropriate to the current stage of the invasion of bitou bush because of the long time it has been present as a weed, and so q should exceed 1.0.

(e) Value the increase in benefits

The value of a unit of the benefits (BN) must now be determined in order to apply Equation (6). The issues of valuing biodiversity are well discussed in the literature (see Sinden and Thampapillai 1999, for example) and thus a defensible monetary value for the flow of environmental services can be derived from the literature for the present problem. For example, Sinden and Griffith (2007) derived the value for biodiversity services from similar sites that were protected from 35 weeds in Australia. They analysed the way the costs of control varied with characteristics of the weed invasions, and determined that the costs of control increased when the number of sites threatened by a weed increased. The increase in cost for an extra site is a measure of the benefit of protecting the extra site – because costs would only be increased if the benefits increased at least as much. Their value for the benefit was \$5,864 per site per year. Following economic theory, and the likely constraints

on the budgets for control of each of the 35 weeds, this value represents the minimum level for the benefit. This value is used here to determine a range of values for the unit of benefit BN .

(f) Calculate the benefit-cost ratios

The gains and losses can readily be compared with the following benefit-cost ratio (BCR).

$$BCR = \frac{\text{Present value of the flow of annual benefits for all sites for } T \text{ years}}{\text{Present value of the flow of the TAP costs for 5 years}} \quad (7)$$

A present value is the value today of a flow of future benefits, or costs, discounted at an appropriate rate. This analysis is undertaken from the viewpoint of the community, as opposed to that of the private firm, so a discount rate of 5% is appropriate and year one is taken as 2005–2006.

When the BCR exceeds 1.0, benefits exceed costs, when it equals 1.0 benefits equal costs, and when it is less than 1.0, costs exceed benefits. A BCR of 2.4, for example, reflects \$2.40 worth of benefits for every dollar invested.

While the costs are given for each of the five years of the TAP, the benefits will vary with the shape of curve AC (as defined by q), the final service level X , and the unit value of benefits BN . These variations can be incorporated, and the ratios calculated, in a simulation using the @RISK software (Palisade Corporation 2002). This simulation follows five steps.

- (i) Define the data for each variable. The costs are \$2 845 000 in total, and \$2 489 000 for just the on-ground control costs, for

each of the first five years of the TAP. The time horizon is set arbitrarily at 20 and 50 years to reflect the short-term and long-term nature of the biodiversity benefits, and the discount rate is given at 5%. To account for the uncertainty of the shape of the curve AC , q and X are defined by probability distributions. The variable BN is also defined through a probability distribution to allow for any residual, perceived uncertainty in the monetary value of the biodiversity benefit. The triangular distribution is an appropriate, yet simple, distribution to apply because it is defined by just three values, namely, the minimum, most likely and maximum levels of each variable.

(ii) A specific value is selected for each variable in the calculation. Costs are either \$2 845 000 or \$2 489 000, the time horizon is 20 or 50 years, and the rate is 5%. For simplicity the value for m is always fixed at 1.0. We derive a value for each of the remaining variables (q , X and BN) in each calculation by sampling from their respective probability distributions (Table 1).

(iii) A benefit-cost ratio. The benefit-cost ratio is calculated from the set of values derived in the previous step.

(iv) Create a range of ratios. The third step (iii) is repeated many times (500 in this case) to give a range of ratios, which illustrates the degree of variability in the model and calculations.

(v) Produce results. The results are then derived from the range of ratios determined in step (iv). The results include the mean benefit-cost ratio, standard deviations, and the minimum and maximum ratios.

The TAP covers more than 300 sites, which vary in terms of (i) the number of native plant species at risk and the number of individuals of each plant species, (ii) the vulnerability of these native plants and plant communities to bitou bush invasion, (iii) the ability to achieve effective control of bitou bush, and (iv) the other threats that are present. The variety of native plants remaining at a given site in a given year is a function of all these factors, and provides the flow of biodiversity services.

This variation was explicitly modelled and tested though the changes in q and X in the simulation to allow for differences in the composition of plant communities at each site. The values adopted for these two variables followed the available knowledge. Further information on the levels of service reduction at T would help to refine estimates of X , and data

Table 1. Values to define the triangular probability distributions.

Parameters	Values		
	Minimum	Most likely	Maximum
q , gives curve like AC or AD	5	15	20
X , is the final service level	-0.10 ^A	0.01 ^B	0.10 ^B
BN , is the value of site benefit	\$5261 (-10%)	\$5864	\$8769 (+50%)

^A A negative value for X models curve AD that cuts the horizontal axis. The minimum value of -0.10 sets D at 16 years which is assumed to be the earliest time at any site when all biodiversity services would have been lost without the TAP. The sensitivity of the benefit-cost ratios to this subjective judgment on the time is analysed below.

^B These two positive values for X indicate that the final service levels in year T are 1% and 10% respectively of the original level.

on the likelihood and timing of complete extinction of the services would help to refine q . In this way we tested the importance of these particular data.

Results

The simulation produced a minimum benefit-cost ratio of 1.82, and a maximum of 3.56. Further, 90% of the ratios fell between 2.08 and 3.15, with 95% of them exceeding 2.0. The mean ratios for the two time periods and the two kinds of cost are shown in Table 2, with the standard deviations in parentheses.

The most relevant scenario comprises the total costs and a 50-year benefit flow because these attributes best model the implementation of the TAP across its range of actions and reflect the long-term benefits of these management activities. This scenario has a mean BCR of 2.56. Thus, for every dollar invested in the implementation of the TAP yields \$2.56 in return. So the annual benefit from the TAP, or its total annual economic worth, is \$7.28m ($2.56 \times \$2.845m$). The benefits from the TAP therefore appear to exceed the costs under a wide variety of economic conditions.

The simulations provided correlations between the benefit-cost ratios and the values of the variables used to calculate them. The correlations were 88.5% between benefit value BN and the ratio, 37.6% between q and the ratio, and 31.5% between final service value X and the ratio. So the variations in the ratio depend largely on the variations of the biodiversity benefit BN rather than the shape parameter q , or the final service level X . The values for the benefit BN are taken from conservative, published, estimates derived for a similar problem in similar circumstances (Sinden and Griffith 2007).

The initial function of Equation (2) makes the restrictive assumption that the weed spreads across each site at a constant proportion of the area each year. The simulation of steps (i) to (v) allow for specified variations in the effects of each amount of spread on the output of environmental

Table 2. Benefit-cost ratios to assess the desirability of implementing the Bitou Bush Threat Abatement Plan.

Years of benefit flow (time)	Benefit-cost ratios for	
	On-ground TAP costs	Total TAP costs
20	2.22 (0.28)	1.94 (0.25)
50	2.92 (0.38)	2.56 (0.33)

services, and so mitigates the effect of this assumption.

Discussion

A benefit-cost analysis assesses the contribution of a project to the increase in economic welfare, or the contribution of a problem to the loss in welfare. For example, Sinden *et al.* (2005) measured the loss in welfare in agriculture in Australia due to weed invasions. Benefit-cost analysis measures welfare as the sum of consumers and producers surplus, as set out in Sinden *et al.* (2005). If the changes in quantities of goods and services are large, we must measure the surpluses. But if the changes are relatively small in the context of the nation as a whole, as in the present analysis, welfare is equivalent to the monetary value of benefits minus the monetary value of costs.

This analysis is based on well-documented costs, a range of estimates for the benefits, and a simulation that allows for variations in the loss of the quantity of biodiversity services over time. The basic procedures, and the method for valuing the benefits, are well established (see Sinden and Thampapillai (1999), for example). The simulation addresses the uncertainty in the estimation of the loss of services in a comprehensive manner and indicates that the implementation of the TAP is economically desirable over a wide range of conditions.

The bitou bush TAP establishes a protocol for delivering biodiversity conservation through weed control (Downey 2007).

The economic evaluation is based on the 2005–06 cost of implementation, which we have assumed to be constant over the five years of the TAP. But the actual costs may vary over the years. The process for monitoring the TAP includes measuring the actual costs, thus the actual expenditures can be determined in future and the analysis can be repeated as a standard *ex post* assessment. Irrespective of these uncertainties, the Threat Abatement Plan appears to be a cost-effective strategy for protecting biodiversity and a sound investment. Given that this is the first such strategy for a weed species in Australia, such strategies should therefore be considered for other weed species that pose significant threats to biodiversity because they deliver weed control targeted at biodiversity conservation in a cost effective manner.

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Projecting the impact of climate change on bitou bush and boneseed distributions in Australia

Rachael V. Gallagher^A, Linda J. Beaumont^A, Paul O. Downey^B, Lesley Hughes^A and Michelle R. Leishman^A

^ADepartment of Biological Sciences, Macquarie University, North Ryde, New South Wales 2109, Australia.

^BParks and Wildlife Division, NSW Department of Environment and Climate Change, Hurstville, New South Wales 2220, Australia.

Summary

Global climate change will have significant implications for the management of invasive species in Australia and throughout the world. Changes to temperature and precipitation regimes may influence the fecundity, recruitment and competitive ability of invasive species leading to expansions or contractions of species distributions. Using point localities derived from the Global Biodiversity Information Facility (GBIF), and NSW National Parks and Wildlife Service survey data we have

modelled projections of the potential future bioclimatic ranges of the widespread weeds bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) Norl.) and boneseed (*Chrysanthemoides monilifera* subsp. *monilifera* (L.) Norl.) within Australia. Uncertainty exists in estimates of future climate, due to differences in projections derived from alternate climate models. Also, the severity of climate change will depend on emissions scenarios that will be influenced by human population levels, socio-economic conditions and

technological changes. To address some of the uncertainty surrounding future climate, we projected species distributions onto scenarios derived from two climate models (CSIRO MK2 and NCAR) and two emissions scenarios (A1f and B1) for the year 2030. Through investigating the potential for climate change to alter the distribution of bitou bush and boneseed, managers can make informed decisions when developing strategies with a long term perspective.

Bitou bush and boneseed eradication and containment in Australia

Hillary Cherry^A, Lyn Willsher^B and Barry Whyte^B

^A National Coordinator Bitou Bush and Boneseed, Pest Management Unit, NSW Department of Environment and Climate Change, PO Box 1967, Hurstville, NSW 1641, Australia

^B Biosecurity Queensland, Department of Primary Industries and Fisheries.

Introduction

Bitou bush and boneseed (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl. and *C. monilifera* subsp. *monilifera* (L.) T.Norl., respectively) are highly invasive environmental weeds that pose a serious threat to Australia's natural ecosystems and biota. Bitou bush threatens coastal plant communities in New South Wales (NSW), eastern Victoria and south-east Queensland (Qld), while boneseed threatens inland and coastal native plant communities across NSW, South Australia (SA), Tasmania, Victoria, and Western Australia (WA). Over 200 plant species and ecological communities in Australia are negatively impacted by these weeds (ARMCANZ *et al.* 2000, DEC 2006) and over 15% (approx. 120 million ha) of Australia is susceptible to invasion (see maps in Weiss *et al.* 2008).

In 2000, the National Bitou Bush and Boneseed Strategic Plan (ARMCANZ *et al.* 2000) was approved as part of the Commonwealth's Weeds of National Significance initiative. A key goal of this plan is to prevent the spread of bitou bush and boneseed in Australia. A national program sponsored by the Australian Government and the affected states has resulted in the development of national containment and eradication zones that prevent the spread of bitou bush and boneseed. This paper presents an overview of these bitou bush and boneseed containment and eradication programs.

Bitou bush containment

Queensland eradication and surveillance

By the early 1980s, bitou bush had infested approximately 700 ha of the south-east Qld coast, with the potential to invade as far north as Yeppoon. Land managers recognized this threat: bitou bush was declared noxious under Qld legislation and became the target of an eradication campaign. This led to one of the longest running bitou bush control programs in Australia. Control work began in 1982 on the major infestations and a decade later just small infestations remained. By 2007, infestations were reduced to only scattered individual plants, which are under annual control. However the initial areas

still require annual searching to prevent reinvasion, thus the cost of controlling individual plants and searching for them has increased dramatically over the years.

In the late 1990s, aerial surveys were introduced to the eradication program as a means of monitoring progress and surveying infestations. Aerial surveys are now carried out every three years. Under the current treatment program, all known bitou bush infestations are physically surveyed and treated annually. When the eradication project commenced, 90% of plants found were adults, which were treated with herbicide, now the majority are seedlings that are manually removed.

This eradication and surveillance program is a joint effort between Qld Department Primary Industries and Fisheries, Qld Environmental Protection Agency, the relevant Qld local government authorities and Tweed Shire Council in NSW, as the project also includes maintaining a bitou bush-free buffer zone along the NSW/Qld border. The combined input from key stakeholders to maintain this program is estimated at approximately \$80 000 annually. Given that bitou bush could invade extensive areas of coastal Qld, the investment to date has resulted in significant savings by eliminating the need to manage this weed over a wider area (either now or into the future).

Because the area of land to be surveyed annually is large and the probability of reinvasion from extensive infestations in neighbouring NSW is high, it is likely that this program will need to continue for many years to come. Although Qld is aiming at eradication, long-term surveillance and follow-up control will be necessary to ensure this eradication goal is achieved. Now that all major bitou bush infestations have been eliminated in Qld, sustained support for the program is critical to continue protecting the state from the impacts and costs associated with bitou bush reinvasion.

Northern NSW bitou bush containment line

In 1995, a bitou bush containment line and buffer zone was established along the Tweed River at the NSW/Qld border,

thereby preventing the northward movement of bitou bush seeds into Qld. This project also aims to move the containment line south over time. The containment line supports the Qld eradication program (see above), as well as regional efforts to reduce the extent of bitou bush infestations in northern NSW. The containment line and buffer zone are jointly maintained by the Qld Department of Primary Industries and Fisheries and the Tweed Bitou Bush Steering Committee, in conjunction with other relevant stakeholders including the North Coast Weeds Advisory Committee (see Jamieson and Luxton 2008). The highly coordinated, regional approach ensures efficient management and has enabled the groups to obtain critical funding, including state and federal government grants. These funds have also been used to tackle other coastal weeds in the region in a holistic manner.

Southern NSW bitou bush containment line

In 2002, the South Coast Bitou Bush Task Force (SCBBTF), together with relevant stakeholders, prepared the South Coast Bitou Bush Management Plan, which identified the need for a national southern bitou bush containment line at Tuross Head, NSW (for further detail, see Thompson and Pomery 2008). The location of the containment line was decided upon after the SCBBTF mapped all bitou bush infestations and selected priority control and containment areas.

Since the inception of the Plan, the Task Force has been working together to stop the southward spread of bitou bush. Bitou bush infestations in southern NSW, below and above the containment line, have been significantly reduced. This has resulted in the northern movement of the containment line by over 100 km in just over five years. In the Eurobodalla Shire alone, bitou bush infestations were removed from over 2700 hectares of coastline and the beaches were returned to a native landscape.

In addition, an annual education, inspection and enforcement strategy for bitou bush was put in place across the south coast. Inspections carried out on public and private land since 2002 have led to over 420 private landholders controlling bitou bush on their land. North of the containment line, the SCBBTF is working to protect a number of Endangered Ecological Communities threatened by bitou bush. While south of the containment line, bitou bush is now under control and no longer represents a threat to biodiversity over the 350 km of coastline from Sussex Inlet to the Victorian border. The SCBBTF is also working with Victorian stakeholders to eradicate bitou bush from north-eastern Victoria.

The success of this program is due to a coordinated regional approach and

the overwhelming contribution of the community. Landcare and Coastcare groups have dedicated thousands of hours towards controlling this weed and restoring the beaches to their original condition

Boneseed eradication and containment

Western Australian eradication program

Boneseed in WA is currently restricted to 35 small (i.e. average of <1 ha) isolated populations. These small populations, however, have the potential to expand across the entire southwest of the state, an area of approximately 37 Mha. Thus, eradication of boneseed in WA is seen as a national priority.

A boneseed eradication program for WA began in 2007, led by the National Boneseed Coordinator in conjunction with the Department of Agriculture and Food WA, five affected Natural Resource Management (NRM) regions, local government and the community. Initially, a WA Boneseed Eradication Strategy was developed to engage the relevant stakeholders and ensure long-term commitment as well as establish an action plan for new incursions. All infestations were mapped and assessed. In addition, an intensive 'Boneseed Blitz' awareness campaign was undertaken during the flowering season to raise awareness and encourage the public to report infestations.

Following workshops held throughout southwest WA in May 2007, stakeholders committed to the strategy and to ongoing eradication at known boneseed sites. The eradication strategy is now being implemented with strong state and regional support, and all known population of boneseed are currently under control. A range of land managers and community members are currently engaged in development of individual site plans and long-term control and monitoring at each of the known sites. Successful implementation of this strategy, together with the National Boneseed Containment Line established in western South Australia (see below), will help to protect some of Australia's most biologically diverse ecosystems from the threat of boneseed.

Containment and control outlier infestations in Tasmania

Large areas of Tasmania remain boneseed-free, however they are still susceptible to invasion. Eliminating key outlier infestations and containing core infestations will prevent further spread into areas currently free of boneseed. In June 2007, the Australian Government's Defeating the Weed Menace Program and Tasmanian State and NRM bodies provided support for the strategic control of outlying boneseed infestations across Tasmania. The National Boneseed Coordinator, together with

representatives from the three NRM regions, state agencies and non-government organizations, developed the Tasmania-wide project and formed the Tasmanian Boneseed Steering Committee. The committee identified priority outlier infestations for boneseed control throughout Tasmania and engaged contractors to undertake initial control works. The program is unique because it provides for initial boneseed control but also engages property managers and private landowners in follow-up control on their land for three subsequent years.

This project supports the work of 16 local government municipalities that have eradication of boneseed as a principle management objective under the Tasmanian *Weed Management Act 1999*, as well as supporting the Cradle Coast NRM program to eliminate boneseed from that region (see Taylor 2008). The program also supports the control of strategic boneseed infestations in remote areas where there is no local capacity, as these infestations are equally important from a strategic viewpoint. Community groups strongly support this program by continuing to contain and reduce core infestations. Thus, the Tasmanian program builds on current boneseed containment efforts by eliminating priority outlier populations, empowering landowners to prevent reinvasion, increasing community awareness and supporting the hard work of community volunteers.

National western boneseed containment line

With the exception of isolated populations in WA, the western edge of boneseed infestation in Australia is on the Eyre Peninsula, SA. However, only scattered populations occur on the Eyre and Yorke Peninsulas. A partnership between the Eyre Peninsula, and the Northern and Yorke NRM regions and the Australian Government's Defeating the Weed Menace Program was initiated to prevent further westward spread of boneseed in Australia, through the establishment of a western containment line. Land managers are coordinating and implementing on-ground works to control all of the 190 ha of boneseed west of this containment line (see Sheridan and Agnew 2008). In addition, this project aims to control key outlier populations across the Northern and Yorke NRM region as well as core infestations around Adelaide, to prevent further westward spread. The NRM bodies have committed to a 10-year boneseed containment and control program, including enacting community awareness campaigns to inform the public on the threat of boneseed in their regions. This program also strongly supports the WA Boneseed Eradication Program by reducing the possibility of westward spread.

National eastern boneseed containment

Revised potential distribution mapping of boneseed in 2005 indicated that a small number of existing populations could affect the majority of the Riverina region in NSW, if left uncontrolled. Following an awareness campaign based on the revised maps, the Eastern and Western Riverina Noxious Weeds Advisory Groups in southern NSW recognized boneseed as an emerging threat to their regions. The National Boneseed Coordinator is working with the NSW Department of Primary Industries and these regional advisory groups to develop a boneseed management strategy, including containment zones and a more stringent legislative listing for boneseed in the region under the NSW *Noxious Weeds Act 1993*. The goal of this strategy is to prevent further spread from current infestations, with the ultimate aim of eradicating boneseed from the region. While the establishment of a boneseed containment line at the NSW-Victoria border has not yet been achieved, the growing commitment to the problem is leading to a greater focus on boneseed in the area. The National Coordinator will continue to garner support for this program from a range of stakeholders in Victoria, the Australian Capital Territory and adjoining regions in NSW.

Conclusion

Raising awareness of the boneseed and bitou bush problem is a critical component of establishing nationally significant containment and eradication initiatives. The National Bitou Bush and Boneseed Program developed regionally-focused awareness materials such as posters, flyers and banners, which are freely available on the web (see www.weeds.org.au/WoNS/bitoubush) and from the National Coordinator (contact details above). These awareness materials are based on sound management information and research results. The National Bitou Bush and Boneseed Program will continue to support management efforts for these weeds and encourage research to improve our ability to control them. For example, information on seed longevity for both bitou bush and boneseed is unknown. In 2008, researchers will begin a 10-year seed longevity study and undertake a recently developed accelerated seed ageing test (Long 2007) for bitou bush and boneseed. These studies will provide insight into the length of time required to manage the seedbank, information which is critical to the success of eradication programs.

The programs outlined above highlight the success and significance of national eradication and containment programs, especially for managing widespread weeds that have yet to reach their full potential.

Acknowledgments

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Assessing the recovery of native plant species following bitou bush control – the need for monitoring

Scott A. King^{A,B} and Paul O. Downey^A

^A Pest Management Unit, Parks and Wildlife Group, Department of Environment and Climate Change (NSW), PO Box 1967, Hurstville, New South Wales 1481, Australia.

^B Current address: Monitoring, Evaluation and Reporting Unit, Scientific Services Division, Department of Environment and Climate Change (NSW), PO Box 1967, Hurstville, New South Wales 1481, Australia.

Introduction

Weeds are acknowledged as a significant threat to the environment (WRI *et al.* 1992), but successful abatement of the weed threat has been hampered by a lack of information on the species at risk and inclusion of this information into weed management strategies (Downey 2008). This problem of lack of information persists because few people monitor weed control programs, and those that do rarely feed data into broader analyses. Monitoring is therefore vital for reporting on wide-scale trends and the success of individual control programs. However, designing a monitoring program is difficult because simple, clear guidelines for assessing the response of weed control on biodiversity are lacking. For example, which species should be monitored and what methods are the most appropriate?

We surveyed weed managers to determine the extent of monitoring being undertaken for the invasive plant, bitou bush (*Chrysanthemoides monilifera* subsp.

rotundata (DC.) T.Norl.), and the response of native species follow bitou bush control. The results support similar surveys of pest animal control programs in Australia (see Reddiex *et al.* 2006), albeit on a smaller scale, in that while biodiversity conservation is a stated aim, few people collect and analyse data to assess the success of control programs at protecting or promoting the recovery of native species. To rectify this problem we have developed standard monitoring guidelines, an outline of which we also present here.

Survey of monitoring programs

To determine the level of monitoring being undertaken for bitou bush control programs in New South Wales (NSW) and the nature of such programs, we surveyed over 70 land managers involved in control programs in early 2007. Of the 52 respondents, 85% said they undertook some form of monitoring. However, of the almost 90% of respondents who stated that an

aim of their control program was biodiversity conservation, only 61% monitored the response of native plants to bitou bush control. Further, because the majority of these data were collected using photo-points (75%) or maps (64%), there are difficulties with determining specific species responses. Less than half these respondents collected data that could determine such responses as measured by density or estimated cover, with 43% using quadrats and 29% using species counts.

Surprisingly, just over a third of respondents used standard data sheets to record data in the field. But when asked if they would like to see standard data sheets developed, 84% answered yes. When asked about standard monitoring guidelines, 71% said they would like to see them developed, and none said they wouldn't.

Questions on data storage revealed that over one-third of respondents did not store their data electronically, while 44%

stored their data in a spreadsheet and 21% in a database. This trend carried through to data analysis, with 39% not undertaking any form of analysis. Of those who did analyse data, 72% performed simple analyses such as calculating percentages, but only eight percent graphed their data, and only four percent did statistical analysis.

The most commonly cited reasons for not undertaking more monitoring were: a lack of time (80%), funds (64%), guidance (44%) and expertise (28%). Given the importance of monitoring in assessing the outcomes of management programs, these results suggest that many bitou bush control programs may need to be restructured to accommodate monitoring programs, especially once monitoring guidelines become available (see below).

Standard monitoring guidelines

The survey revealed clear support for further assistance with monitoring and the development of monitoring guidelines. In response, and to assist with implementing the NSW Bitou Bush Threat Abatement Plan (Bitou TAP; DEC 2006), a monitoring manual is being developed (King *et al.* 2008). These guidelines are not restricted to monitoring the response of bitou bush following control, but also cover other weed species and the response of priority native species and ecological communities to bitou bush control. Lastly, the guidelines include information on monitoring the investment of time and resources stakeholders commit to controlling bitou bush and protecting native species.

The Bitou TAP monitoring guidelines are structured using a three tiered approach, with options of techniques ranging from simple qualitative mapping through to robust research studies. Site managers select the techniques most suitable to their needs and resources as well as the aims of their management program. Techniques described in the guidelines include mapping, photo-point monitoring, qualitative observations, population censuses, and estimates and measurements of cover and density. The guidelines also contain a series of data sheets for the different techniques to simplify data collection in the field. Lastly, the guidelines explain how to analyse and present the results of a monitoring program.

In the first instance, these guidelines will be used to establish monitoring programs at many of the 169 priority Bitou TAP sites along the coast of NSW. The benefit of using standard monitoring guidelines is that we can centrally compile results from every site to provide a state-wide analysis and overview of the Bitou TAP, including the control of bitou bush, the response of the native species at risk and the cost of implementing such actions. Copies of the Bitou TAP monitoring guidelines can be downloaded from DECC (2007). It is anticipated that the Bitou TAP monitoring guidelines can be adapted for use in monitoring other weed control programs for biodiversity conservation.

Acknowledgments

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The Cradle Coast boneseed incentive program

Greg Taylor, Cradle Coast Natural Resource Management Authority,
PO Box 338, Burnie, Tasmania 7320, Australia.

Summary

The Cradle Coast Natural Resource Management (CCNRM) region is located in northwest Tasmania and covers approximately one third of the state. Boneseed (*Chrysanthemoides monilifera* subsp. *monilifera* (DC.) T.Norl.) is an emerging weed threat in the region and has been recorded at around fifteen sites along the northern coastline and on King Island. Community groups have successfully controlled boneseed at many sites in the region however other sites have had no control.

In 2006, CCNRM initiated a strategic approach to controlling boneseed in the

region. An incentive program was developed to provide financial support and technical advice to landowners. This program enabled boneseed control at eleven sites with a total area of 34.3 ha treated. An area of approximately 60 hectares remains to be surveyed and controlled, and boneseed is known to be present at various densities throughout this area.

In 2007, CCNRM worked together with the other two Tasmanian NRM Regions (Northern and Southern NRM) and the National Boneseed Coordinator to develop a funding application to address outlying boneseed populations in Tasmania. This

application received successful funding from the Australian Government's Defeating the Weed Menace program and will enable the CCNRM region to complete the initial boneseed control programs initiated in 2006, as well as initiate the remaining programs outlined in CCNRM's boneseed strategy.

All on-ground works are governed by a contract, which obliges landowners to continue controlling boneseed on their land for a total of three years. Landowners are supported in this work by ongoing assistance and guidance from CCNRM, and in some cases by local government. All boneseed control sites are mapped, with data stored on a central database. This database is used to generate letters to landowners, providing timely annual reminders for boneseed follow up control. Successful implementation of this program will help deliver on the Tasmanian Boneseed Strategy and will ensure that significant progress is achieved towards the eradication of boneseed in the CCNRM region.

Community weed education initiatives in New South Wales: getting school children involved

Alyssa Schembri^A, Royce Holtkamp^B, Hillary Cherry^C, Julie Haeusler^D and Jane West^D

^A NSW Department of Primary Industries, Orange Agricultural Institute, Forest Road, Orange, New South Wales 2800, Australia.

^B NSW Department of Primary Industries; ^C National Bitou Bush and Boneseed Coordinator, NSW Department of Environment and Climate Change; ^D NSW Department of Education and Training, Centre for Learning Innovation.

In these days of mounting cutbacks, funding the successful introduction and deployment of weed biological control agents has become increasingly difficult. One of the most successful strategies for achieving deployment success has been coordinating the involvement of community interest groups. Input from these groups has varied from assistance with site selection to rearing and releasing agents as well as monitoring the impact of agents at selected sites.

Weed Warriors

The latest initiative in community based biological control projects is Weed Warriors, a national program designed for schools that aims to increase awareness and actively involve students in the management of local weed issues. The

program is funded nationally by the Natural Heritage Trust and the Cooperative Research Centre for Australian Weed Management, with State agencies and Natural Resource Management regions contributing on a local level. Students work closely with local weed officers, land managers and community groups to implement a biological control program for a regional priority weed. This program has recently been introduced to schools in New South Wales with bitou bush (*Chrysanthemoides monilifera* spp. *rotundata* (DC.) Norl.) as a primary target weed and the *Tortrix* sp. leaf rolling moth as the agent.

Weed resources for schools

In addition to the Weed Warriors program, the NSW Department of Education and Training is developing *Weeds: Educate to*

Eradicate. This school education program is being created in partnership with education experts, land managers and weed scientists. The program, which is funded through the Australian Government's Defeating the Weed Menace initiative, uses integrated classroom learning tools to increase weed awareness among young Australians (i.e. upper primary and lower secondary students). Interactive teaching resources, including web-based and multimedia materials, are being developed. One such resource is entitled *Weeds Attack!*, which is a series of computer-based modules that will lead students through a range of educational challenges while teaching them about the impact of weeds. These resources will be incorporated with existing weed education programs such as Weed Warriors to provide a complete

package for teachers to educate students about the impacts of weeds, while fulfilling curriculum requirements.

The program is initially being developed around the 20 Weeds of National Significance (using bitou bush in the first iteration) and resources will include agricultural and environmental weed information. The resources will conform to national curriculum standards to allow national adoption. Students will inves-

tigate the impacts of weeds on a global scale and learn about weed science principles and weed impacts to biodiversity and the environment. They will also work with local weed managers and community groups, as part of the Weed Warriors program, to implement a biological control program for a locally significant weed, thus empowering students to apply effective weed control measures in their local community.

Weeds: Educate to Eradicate is an innovative approach to raising weed awareness among young Australians by educating students using integrated learning tools. The partnership developed in the program will provide expertise for state-wide implementation and the capacity to foster national expansion of the project.

Bitou bush aerial spraying in New South Wales – what have we learned?

John Toth^A and Marion A. Winkler^B

^AManagement of Environmental Weeds Pty Ltd, PO Box 330, Mona Vale, New South Wales 1660, Australia.

^BPest Management Unit, Department of Environment and Climate Change, PO Box 1967, Hurstville, New South Wales 1481, Australia.

Summary

Developing the aerial boom spraying methodology

Bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) is a significant environmental weed in coastal New South Wales (NSW). Control of extensive infestations of bitou bush within native vegetation can be undertaken using aerial herbicide application. Aerial spraying to control bitou bush proved to be a suitable control option following herbicide studies on native plant species which showed they were tolerant to the aerial application at very low rates during winter months (Toth *et al.* 1993). This technique was developed following ground based herbicide trials carried out in the late 1980s near Jervis Bay, NSW, in which six herbicides were initially trialled for the control of bitou bush. At the same time, a permit was granted to deliberately apply the same herbicides to seven native plant species, being *Acacia longifolia* subsp. *sophorae* (Labill.) Court, *Banksia integrifolia* L.f., *Casuarina glauca* Sieber ex Spreng., *Leptospermum laevigatum* (Gaertn.) F.Muell., *Leucopogon parviflorus* (Andrews) Lindl., *Monotoca elliptica* (Sm.) R.Br. and *Lomandra longifolia* Labill., to determine their response to off-target damage associated with bitou bush control. The results showed that only herbicides containing glyphosate or metsulfuron methyl as the only active ingredient were effective for controlling bitou bush (Toth *et al.* 1996). In addition, the effect of low rates of glyphosate on the native species produced no measurable damage, and low rates of metsulfuron methyl resulted in only

ephemeral damage to *L. laevigatum* and *L. parviflorus*. Hence these two herbicides proved sufficiently selective for bitou bush (Toth *et al.* 1993).

A subsequent trial was undertaken to examine the seasonal sensitivity of bitou bush to glyphosate and metsulfuron methyl. These herbicides were also trialled to determine an effective application rate for bitou bush control amongst native species. The two-year trial indicated that bitou bush is at least twice as sensitive to glyphosate in winter than during summer, especially following peak winter flowering (Toth 1997). There was no apparent trend with metsulfuron methyl. Effective bitou bush control during the winter was also achieved with very low rates of both herbicides. Similar seasonal and rate trials were subsequently carried out on five of the native plant species, being *A. longifolia* subsp. *sophorae*, *B. integrifolia*, *L. laevigatum*, *L. parviflorus* and *L. longifolia* to examine if there was also a seasonal and application rate tolerance. The results showed a seasonal tolerance of these native plants to low rates of herbicides applied during winter. However, seedlings of *A. longifolia* subsp. *sophorae* showed some sensitivity to glyphosate (Toth *et al.* 1996). The combined results indicated that low rates of glyphosate and metsulfuron methyl applied during winter not only controlled bitou bush, but were unlikely to result in significant off-target damage to native plant species.

Independently, Anderson (1989) trialled aerial boom spraying of bitou bush at 8 L ha⁻¹ of glyphosate [four times the

current rate] at South Stradbroke Island which showed control was selective for bitou bush with little damage to native species. However subsequent examination showed that three species may be adversely impacted (see Toth *et al.* 1996); further analysis of these three species following control at 2 L ha⁻¹ shows that such impacts are likely to be reduced at the lower application rates currently used.

A series of herbicide trials were then carried out using aerial boom spraying in NSW in which very low rates of glyphosate (2 L ha⁻¹ of Roundup® (36 g L⁻¹ glyphosate)) and metsulfuron methyl (30g L⁻¹ of Brushoff® (600 g kg⁻¹ metsulfuron methyl)) were applied to bitou bush infestations. These results supported the original ground based trials described above.

Penetrants were also trialled during the ground based herbicide applications for glyphosate and metsulfuron methyl. The addition of Pulse® (1020 g L⁻¹ polyether modified polysiloxane) had a negative effect on *L. laevigatum* in that it led to a greater degree of leaf burn. Based on this result Pulse® has not been recommended for use in the aerial spraying of bitou bush (Toth *et al.* 1996).

A further trial in 1997 examined the potential use of Roundup Bioactive® (36 g L⁻¹ glyphosate) for aerial spraying of bitou bush, however, the results indicated that Roundup Bioactive is more phytotoxic to the following five native plant species *Scaevola calendulacea* (Andrews) Druce, *Carpobrotus glaucescens* (Haw.) Schwantes, *Myoporum boninense* Koidz. and *Correa alba*

Andrews, than either Roundup® or Brush-off® (Toth unpublished data). As no other herbicide was used in this trial the results do not necessarily translate to other generic brands of glyphosate or metsulfuron methyl.

Using aerial boom spraying to control bitou bush in New South Wales

Aerial boom spraying (hereafter aerial spraying) to control bitou bush has been undertaken along the NSW coastline between Narooma and Tweed Heads since 1992. However, it was not until 2006 that best practice guidelines were developed (Broese van Groenou and Downey 2006). The guidelines, which are a checklist of events in chronological order, highlight the complexity of aerial spraying for weeds, especially in natural ecosystems, and the degree of coordination and knowledge needed to undertake aerial spraying. These guidelines are now used widely when planning and undertaking aerial spraying of bitou bush in NSW.

The outcome of 15 years of aerial spraying to control bitou bush in New South Wales has revealed that while large areas can be treated effectively, follow-up control is essential to managing bitou bush recruitment, as well as secondary weed invasion, after each aerial spraying operation. And, more importantly, that aerial spraying should only be undertaken when resources are available to undertake such follow-up control work.

Where areas are being aerially sprayed on a regular basis (i.e. annually), the use of one application of metsulfuron methyl may help to prevent any possibility of herbicide resistance to glyphosate developing in bitou bush. Repetitive use of metsulfuron methyl in annual applications is not recommended at this stage because of the residual effects of metsulfuron methyl and comparatively less information available on its impact to native species.

To assist with revegetation, aerial direct seeding during aerial spraying operations has also been employed in some areas. The results of these aerial seeding trials are inconclusive due to the influence from a number of external factors. For example, success when using scarified seeds is dependent on rain within several days of the application. However if rain does not occur, seed viability can decrease dramatically.

Aerial spraying has proved to be efficient and cost effective for broad-acre control of bitou bush in NSW compared to ground based herbicide application, especially over large areas and in areas that are otherwise inaccessible (e.g. coastal cliffs).

Developing an aerial spot spraying methodology

In the past few years, another method of aerial control has been developed for

bitou bush. The technique, known as aerial spot spraying, uses ground based spraying equipment mounted onto a helicopter. This spray rig has a modified nozzle within a metal conical casing which is lowered from the helicopter directly over the targeted plants. The herbicide can therefore be applied to individual or isolated bitou bush plants within native vegetation or in inaccessible areas (e.g. cliff faces). This technique has been used widely over the past few years and is now contributing to the aerial management of bitou bush in NSW. It must be noted that this techniques uses ground based application rates of herbicide and not the low herbicide rates used in aerial boom spraying.

Assessing the impact of aerial spraying on native species

In addition to the seven native species originally tested for herbicide sensitivity (see above), further information has been gathered over the past 15 years on the herbicide sensitivity of other plant species (native and weeds). This observational data has been collected on the response of 220 plant species (weeds and natives) to glyphosate and 83 to metsulfuron methyl to date (see Broese van Groenou and Downey 2006). However information is still needed for many native plant species, particularly in relation to their response to metsulfuron methyl. It should be noted that these data are based on results from basic formulations of glyphosate (i.e. Roundup® – 36 g L⁻¹ glyphosate) and metsulfuron methyl (Brushoff® – 600 g kg⁻¹ metsulfuron methyl) only. Thus, further research is needed into other formulations, as extrapolations to such formulations are not warranted based on the trials with penetrants (see above).

The effect of aerial spraying on rare and endangered species is of particular significance, for example research by Matarczyk *et al.* (2002) found that spray drift from ground-based applications of glyphosate can adversely impact populations of *Pimelea spicata* R.Br., an endangered species in NSW. It is therefore important to take a precautionary approach and locate rare and threatened species on each site prior to aerial spraying, so that these areas can be appropriately protected from any potential adverse impacts (see Broese van Groenou and Downey 2006). These species can either be excluded from the aerial spraying area with suitable buffers demarcated, or in some instances covered, for example with hessian (see Broese van Groenou and Downey 2006).

Mason and French (2007) discovered that while aerial spraying reduced the diversity of weeds in the areas treated for bitou bush control, the native species assemblage did not necessarily return to non-invaded site conditions. This result suggests that native plant

community restoration will not necessarily occur naturally following aerial spraying, and direct seeding or planting of native species may be required. Also, they found that aerially sprayed sites had lower native species diversity than sites where on-ground bitou bush management occurred. However, there were several compounding factors not accounted for in this study and, thus, further investigation into the possible impacts of aerial spraying on native species is still needed. In particular some plant groups, like orchids, should be targeted for such studies (P. Flower personal communication).

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Implementing the Bitou Bush Threat Abatement Plan across different land tenures: challenges and successes

Nicole L. Strehling^A, Neil Rendell^B, Scott A. King^{C,D} and Paul O. Downey^C

^A Northern Rivers Catchment Management Authority, Level 3, 49 Victoria St, Grafton, New South Wales 2460, Australia.

^B Southern Rivers Catchment Management Authority, PO Box 3095, Wollongong, New South Wales 2500, Australia.

^C Pest Management Unit, Department of Environment and Climate Change, PO Box 1967, Hurstville, New South Wales 1481, Australia.

^D Present address: Monitoring, Evaluation and Reporting Unit, Scientific Services Division, Department of Environment and Climate Change, PO Box 1967, Hurstville, New South Wales 1481, Australia.

Summary

Threats to biodiversity are not constrained by land tenure. The serious threat posed by bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) to native plant communities in New South Wales is the shared responsibility of most coastal councils, the Department of Environment and Climate Change, the Department of Lands, numerous private land holders and public trusts, as well as indigenous people, volunteers and community groups. The five coastal Catchment Management Authorities also have an essential role in engaging land managers in threat abatement, and supporting on-ground control through delivery of additional resources. The successful abatement of this wide-scale threat will require the active cooperation of all affected parties.

The NSW Bitou Bush Threat Abatement Plan (TAP) has prioritized 169 sites for bitou bush control, independent of land tenure. These sites encompass 38 different land tenures, leading to many challenges in implementing the plan, three of which are discussed here: (i) incorporating new ideas into existing control programs; (ii) providing information to stakeholders to implement the TAP, and; (iii) ensuring the TAP objectives are achieved on the ground.

A range of measures were developed to ensure the involvement of as many land managers as possible. These measures will help to coordinate threat abatement across all land tenures and encourage long term maintenance of on-ground biodiversity outcomes at priority sites.

Introduction

Landscape-scale threats to biodiversity are rarely constrained by land boundaries or ownership. Thus broad-scale threat abatement strategies must gain the support and cooperation of a range of different land managers to succeed.

One such landscape-scale threat is the invasion of native plant communities by the weed bitou bush. Bitou bush poses a serious threat to coastal biodiversity; it has invaded over 80% of the New South Wales coastline (Thomas and Leys 2002), and the prospect of eradication is unlikely. The scale of the problem led to bitou bush being listed as a key threatening process under the NSW *Threatened Species Conservation Act 1995* (NSW SC 1999). In response to this listing, a bitou bush threat abatement plan (Bitou TAP) was prepared that identified the native species and ecological communities most at risk, and the specific sites at which control will have the greatest benefit to biodiversity, independent of land tenure (DEC 2006).

The Bitou TAP identified 169 priority sites for control, spanning 38 different land tenures and more than twice this number of site managers. The NSW Department of Environment and Climate Change (DECC) is responsible for approximately half of the priority sites, with the remainder being managed by the Department of Lands (DoL), coastal councils, private land holders and public trustees. Additional stakeholders include the contractors, indigenous people, volunteers and community groups, who undertake a significant proportion of the bitou bush control each year. Lastly, the implementation of the TAP is consistent with the regional natural resource management targets of the five coastal Catchment Management Authorities (CMAs), who with the Australian Government's Natural Heritage Trust (NHT), are contributing funds and supporting land managers to control bitou bush through the TAP. Thus, reducing the threat of bitou bush to native species is heavily dependent on a collaborative approach involving all of these stakeholders. Here we present a discussion of the major challenges and hurdles encountered during the development of the TAP and

its initial implementation, with respect to engaging these stakeholders.

Challenges to implementing the Bitou TAP

The Bitou TAP is the first threat abatement plan for a weed in Australia. The TAP adopts a different approach to conventional weed strategies by prioritizing weed control to protect the biodiversity most at risk, as opposed to broad-scale weed control or eradication. This new approach has left many land managers cautious about implementing the TAP, and has resulted in a number of challenges. The main challenges have included: (i) incorporating new ideas/approaches into existing control programs; (ii) ensuring land managers have the information necessary to implement the TAP, and; (iii) ensuring the TAP objectives are achieved on the ground. Below we present a short discussion about each, and explain some of the strategies employed to address these challenges.

Incorporating new ideas

The principle aim of the TAP is to reduce, abate or ameliorate the threat posed by the invasion of bitou bush to threatened species, populations and ecological communities, or those species which may become threatened as a result of bitou bush invasion (DEC 2006). Few of the pre-existing bitou bush control programs at priority sites shared this objective. Many had eradication as the aim, and while others aimed to conserve biodiversity, the specific biodiversity at risk was not identified or monitored (see King and Downey 2008). Successful implementation of the TAP therefore, required a change in the approach of existing bitou bush control programs. To facilitate incorporation of new ideas, a site-specific management planning process and an incentive funding program were implemented.

Incentive funds, provided by NHT and delivered through the CMAs, offered land managers the resources to initiate implementation of the TAP at over 40 priorities sites. This encouraged land managers to gain practical experience and confidence in implementing the TAP on-ground, and provided CMAs the opportunity to guide and support land managers through the essential elements of implementing the TAP, while leveraging additional resources. It is hoped that the use of incentive funds to help land managers successfully implement the TAP at a limited number of priority sites will increase their understanding and acceptance of the TAP, and facilitate their implementation of the TAP at additional sites in future, and/or contribute to the priorities after these incentive funds end.

The requirement to prepare site-specific management plans using a standard proforma provided a structured mechanism

for landholders to document the TAP implementation process, helping them to systematically work through this new approach to weed control. This process was designed to ease the transition for land managers in adopting the new threat abatement approach to bitou bush control, specifically aimed at protecting biodiversity. During the approval process for these site-specific management plans, it became evident that many land managers were trying to fit their existing control programs into the TAP framework, rather than re-designing their programs to meet the key TAP objective of targeting bitou bush control to protect priority species. Surprisingly, some of these land managers had contributed significantly to the TAP development process. It is a challenge to alter pre-existing control programs that land managers consider to be successful. This resistance to change reflects the common belief that any weed control will automatically result in positive biodiversity outcomes. However, there is increasing evidence that this is not the case (D'Antonio and Meyerson 2002), and such views hamper successful threat abatement, and protection of those species most at risk (Downey 2008).

Information to support TAP implementation

While the TAP outlines the native plant species at risk from bitou bush invasion, priority sites for control, and a summary of control options, more information is needed to help land managers successfully implement the key objective of the TAP on the ground. A number of initiatives have been put in place, and were only made possible with the financial assistance of the NHT/Australian Government in partnership with the five coastal CMAs in New South Wales and the DECC. These initiatives include a full-time coordinator, a website, an identification guide to the native species at risk, monitoring guidelines and best practice management guidelines.

The NHT grant allowed employment of a full-time TAP coordinator to review site-specific management plans, administer a community education and awareness campaign, provide advice and support to all stakeholders, and undertake some of the monitoring programs.

The Bitou TAP website (DECC 2007) explains the background of the TAP, lists the priority species and sites, shows examples of completed site plans, and explains how people can get involved. The site also contains downloadable resources to help land managers implement the TAP, such as copies of the TAP, site plan pro forma, as well as links to current funding opportunities.

The NHT grant initially contained funds to train volunteers to work with threatened species. However, the limited

funds available would only have trained about 30 volunteers a year for three years. Feedback from land managers and volunteer groups revealed that many of them could not readily identify the uncommon priority species. Instead of the limited training, a field guide to the native species at risk was produced. This will increase the capacity of all stakeholders to save the species most at risk of extinction by teaching them what these species look like and where to find them. The guide contains descriptions and photos or illustrations of all the native plants and vegetation communities threatened by bitou bush as outlined in the TAP (Hamilton *et al.* 2008). The guide is available free to all stakeholders, with a PDF version available on the TAP website.

A recent survey highlighted the need to guide land managers with respect to monitoring of their bitou bush control programs (King and Downey 2008). To assess the effectiveness of threat abatement through the TAP approach, monitoring information needs to be collected in a standard format from all priority sites. The bitou bush monitoring guidelines (see King *et al.* 2008) describe three levels of monitoring programs of varying complexity to suit the different resources and skills available to each land manager. All three monitoring options require the production of maps to show the extent of bitou bush, priority species, ecological communities, other weeds and control areas. However, each approach differs in the level of observation and measurement required, allowing land managers to select their preferred monitoring approach, based on their skills and resources.

Several best practice guidelines have been produced to assist land managers to maximize the efficiency of their on-ground control. Guidelines have been developed for aerial spraying of bitou bush (Broese van Groenou and Downey 2006), as well as a management manual for boneseed (*Chrysanthemoides monilifera* subsp. *monilifera* (L.) T.Norl.), the other invasive subspecies (Brougham *et al.* 2006). A management manual for bitou bush is currently being drafted and is due for publication in mid-2008. These guidelines are already available in hard and electronic format from the website (see DECC 2007).

Achieving objectives on the ground

The challenge of supporting land managers to deliver the objectives on the ground was addressed by the development of site-specific management plans (see DECC 2006, DECC 2007). These site plans are prepared utilizing a standard proforma, and require the approval of DECC. Site plans give land managers the opportunity to account for variations at each individual site to best meet the objectives of the TAP, and allow managers to develop a greater sense

of ownership over their priority site. An additional benefit is that these plans can be used to attract additional funding and demonstrate outcomes.

Each site-specific management plan also incorporates an essential monitoring and evaluation component to help ensure TAP objectives are achieved. This monitoring and evaluation of on-ground outcomes, undertaken in accordance with the bitou bush monitoring guidelines (King *et al.* 2008), will facilitate adaptive management and maximize effectiveness of control programs and recovery of priority entities.

DECC-approved site plans (i.e. that are consistent with the TAP) are issued with a generic Section 132C scientific licence for the Bitou TAP under the *National Parks and Wildlife Act 1974*. This licence authorizes land managers to control bitou bush near threatened species and ecological communities if the work is undertaken in accordance with the Bitou TAP and the conditions of the licence. This generic licence avoids the necessity of individual site managers having to apply for individual licences.

Delivery of initial incentive funds through a partnership between DECC and the CMAs has also helped to ensure objectives are achieved on-ground. The CMAs have staged the payment of incentive funds, and linked payment to implementation of site-specific management plans. This encourages close liaison between each CMA and land manager throughout the life of the project, and allows provision of early advice and support if problems are encountered. Land managers should be able to apply the practical experience and understanding of TAP implementation gained through this initial funding to other sites in future.

The TAP should increase the ability of land managers to access future funding opportunities. The TAP sets out a strategic approach to control of bitou bush for biodiversity outcomes that is based on best available knowledge and is consistent with the regional priorities of the coastal CMAs. This makes it a valuable tool to guide investment in weed control in an environment where the need far exceeds the limited resources available. Projects that implement the TAP should therefore receive favourable consideration for future funding opportunities. This will help to facilitate implementation at all sites and ensure that resources are available to maintain biodiversity outcomes beyond the term of the site plans.

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National western boneseed containment: a line in the sand on the Eyre and Yorke Peninsulas, South Australia

Peter Sheridan^A and Deb Agnew^B

^AEyre Peninsula Natural Resources Management Board, PO Box 2916, Port Lincoln, South Australia 5606, Australia.

^BYorke Peninsula Group, Northern and Yorke Natural Resources Management Board.

Boneseed (*Chrysanthemoides monilifera* subsp. *monilifera* (L.) T.Norl.) appears to have been a popular although isolated garden plant on the Eyre and Yorke Peninsulas, where it has since escaped and established wild populations. Infestations in the Eyre and Yorke regions are the western most in South Australia and despite being recorded in twenty nine locations, currently impact an area of less than 190 ha of bushland. Boneseed is growing in northern mallee areas with rainfall as low as 200mm and in areas of up to 500mm of rainfall in blue gum, *Eucalyptus petiolaris* (Boland) Rule, and sugar gum, *E. cladocalyx* F.Muell, country in the south.

The first recording of boneseed on Eyre Peninsula was in 1985, where it was recognized growing in an old township and on an adjacent rail reserve. The majority of boneseed infestations on the Eyre and Yorke Peninsulas occur in native vegetation on roadsides, on public reserves and on private property. Commonly escaped from gardens, this weed is spread by animals, wind or water. Birds, including emus (*Dromaius novaehollandia*) and animals such as foxes (*Vulpes vulpes* L.) are contributing to the spread of the seed.

The majority of boneseed control in the Eyre and Yorke regions is carried out annually by hand pulling of plants in bushland areas, with some targeted spraying in areas of prolific germination. In January 2005, bushfires completely burned a major boneseed infestation on southern Eyre Peninsula. The high fuel load at this blue gum site, estimated at 5–7 tonnes per hectare, meant the native vegetation burned much longer and hotter than surrounding areas. All mature boneseed plants were killed and seeds were presumed destroyed by the intense fire. However, boneseed seedlings appeared along the edge of Pirlaworta Creek 10 months later.

Heightened community awareness of the threat of boneseed and increased support for control is an important goal of the Eyre and Yorke Peninsula Natural Resources Management (NRM) Boards. In 2007, all 190 ha of boneseed are targeted for initial control. The control of all standing plants and the elimination of existing seed sources on Eyre and Yorke Peninsulas will be a major achievement over the next ten years. Work towards this goal will be possible through a project funded by the Australian Government's Defeating the Weed Menace Program in 2007/2008.

A ten year Boneseed Management Plan is being developed for both NRM regions with the aim of developing a national Western Boneseed Containment Line. All boneseed plants west of the containment zone will be destroyed. Landholders will be engaged to apply follow-up control over the ten year period and the NRM Boards will be responsible for long-term coordination of continued control. Officers of the NRM Boards will ensure that all landholders, those with boneseed infestations and those adjoining these infestations, are aware of the plant and will undertake annual inspections of suspect areas and eradicate any plants found. It is anticipated the Western Boneseed Containment Line will protect the western regions of South Australia and all of Western Australia by eliminating the seed source and preventing further spread.

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Manning Coastcare Group – a case study

Daintry Gerrand^A, Jim Love^B and Warwick Dyson^C

^A ID Landscape Management Pty Ltd, 120 Wharf Road, Johns River, New South Wales 2443, Australia.

^B Seascapes Planning Services.

^C Warwick Dyson Environmental Services.

Summary

Manning Coastcare Group (MCCG) won the Australian Government National Coastcare Award in 2006. The Award recognized the scale of achievement and systematic approach to planning and on-ground works targeting bitou bush (*Chrysanthemoides monilifera* spp. *rotundata* (DC.) Norl.) control and 'coastal corridor' restoration.

As a community organization, we have recognized the need to take a holistic approach on a regional scale. Our goal was to achieve restoration of the coastal corridor and maintenance of biodiversity as opposed to conserving a small number of specific sites. Our key members have practical common sense and tertiary training in environmental management and education and a strong desire to achieve productive on-ground works. We looked objectively at the site history and scale of weed infestations and then prioritized weed species and allocated work priorities according to the funds and resources available.

The Group formed in 1995 and started work in 1996 on eight Littoral Rainforest sites along the Manning coastline in conjunction with Greater Taree City Council. In 1998, MCCG received 'Coastcare' funding to undertake a baseline study of environmental weeds at 51 sites along the coast ('Coastline Survey of Asparagaceae and other Environmental Weeds' (Williams and Gerrand 1998a)) and funding from the New South Wales (NSW) Environmental Trust to undertake the development of eight Littoral Rainforest Action Plans (Williams and Gerrand 1998b). In 1999, the Greater Taree City Council Local Government Authority 'Bitou Bush

Control Strategy' was prepared (Williams and Gerrand 1999). This strategy and the previous studies facilitated prioritization of weeds and development of further funding applications.

Since 1996, MCCG has received over \$624 500 in grant funds from the National Landcare Program, Coastcare, NSW Environmental Trusts, Envirofund, Greater Taree City Council and the Hunter Central Rivers Catchment Management Authority (CMA). The Group now targets prioritized weeds over some 200 hectares of coastal corridor under funding from the Hunter Central Rivers Catchment Management Authority.

Conservation of biodiversity within the coastal corridor has been a central focus for MCCG with activities covering some 80% of the 40 kilometre coastline. Specialist contract regenerators are used in sensitive environments such as the 'endangered ecological communities' of Littoral Rainforest and Themeda Grasslands and where spraying of bitou bush is required. These contractors are locally based and have developed invaluable specialized knowledge on weed control techniques and local conditions.

Manning Coastcare Group has also concentrated on developing skills and providing social and employment opportunities for the local community. The Group has developed a mechanism for harnessing community contribution on a regular basis through an 'over 50s volunteer worker' program in association with Centrelink, the Australian Government human services agency. Over 30 local residents contribute 15 hours per week every week of the year under this scheme. When this

in-kind contribution is coupled with the Groups other voluntary time, MCCG has contributed over \$3 566 510 of in-kind labour since 1996.

The Group also works closely with Greater Taree City Council Noxious Weeds Division and the NSW Department of Lands on the application of aerial spraying of bitou bush along the coastal corridor to complement the more site specific works around sensitive Littoral Rainforest environments. Monthly meetings are conducted with alternate meetings held in the field to review works on various sites.

MCCG is currently undertaking a 10 year review of weed status along the coastal corridor as a basis for a monitoring program and comprehensive evaluation of progress. Funding has been provided by Hunter Central Rivers CMA, which intends to use the project as a 'model' in monitoring and evaluation for land managers and community groups.

In times of increasing population pressures along the coastal fringe and climate change predictions, the sustainability of our natural ecosystems as well as our local social networks is a very important part of building the resilience of our local environment. Manning Coastcare Group is expanding its programs to integrate changes in community profiles and shifts in government welfare arrangements for the unemployed, while continuing its commitment to maintaining biodiversity within the coastal corridor.

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Coordinated regeneration programs in coastal vegetation on the Tomaree Peninsula – a decade of bitou bush control

Melissa Schroder^A, Geoffrey James^A and Anthony Marchment^B

^A Parks and Wildlife Group, Department of Environment and Climate Change, Locked Bag 99, Nelson Bay, New South Wales 2317, Australia.

^B Port Stephens Council, PO Box 2324, Raymond Terrace, New South Wales 2324, Australia.

Abstract

Coordinated weed control programs focussing on the weed bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) Norl.) have been undertaken on the Tomaree Peninsula on the mid-north coast of New South Wales (NSW) since the development of a co-operative control plan in 1997. The Port Stephens Bitou Bush Management Plan was developed by the Port Stephens Coastal Weed Action Group with members from Port Stephens Council, NSW National Parks and Wildlife Service (now the Department of Environment and Climate Change), Department of Land and Water Conservation (now Department of Lands) and various community bush regeneration groups. The Plan has taken a cross-tenure approach to the prioritization of control programs. This has ensured success and enabled the implementation of strategic coordinated programs that utilize consistent control methodology. The programs are committed to the protection of significant native vegetation communities and promotion of natural regeneration.

Bitou bush infests over 1600 ha of the 10 000 ha Tomaree Peninsula. Distribution and density mapping was first undertaken in 1997 using aerial photography and ground truthing. Density was mapped at the shrub layer level in four categories; high >50%, medium 10–50%, light 1–10% and scattered <1%. This information assisted in the establishment

of priorities. Mapping was replicated in 2007. After ten years of coordinated bitou bush control, comparisons indicate a significant reduction in the density of bitou bush. This includes a 17% reduction in high density infestations, 44% reduction in medium infestations and a 36.7% reduction in light infestations. Whilst the density of the weed has been reduced, the distribution has increased by 3.5% in the ten year period. This reflects reinvasion from infestations outside of the Tomaree Peninsula and illustrates the difficulties in controlling dispersal mechanisms such as birds and ocean currents.

Programs are prioritized to control bitou bush at locations where significant vegetation communities, such as endangered ecological communities and threatened plant species occur. Observational data collected throughout the control program has provided important information on the ecosystem resilience of coastal vegetation communities following the control of bitou bush. Ecosystem resilience was lower in fore dune and hind dune vegetation with high density (>50%) bitou bush infestations. These areas require revegetation to stabilize dunes and reduce secondary weed invasion. Coastal vegetation communities (such as coastal heath and forest on clay soils) demonstrated higher ecosystem resilience and were able to recover from light, medium and high density bitou bush invasion over the ten year

period. This information has informed the selection of future bitou bush control sites and facilitated better site management.

Despite the success of bitou bush control, secondary weed incursions, including weeds previously not widely recorded in NSW such as *Asystasia gangetica* (L.) T. Anderson, *Crithmum maritimum* L., *Eryngium maritimum* L. and *Tetragonia decumbens* Mill, have established in sites where bitou bush infestations were treated. These sites occur in proximity to urban townships, where refuse dumping and bird dispersal remain two key vectors for secondary weeds. Dispersal by ocean currents has also been linked to at least two new secondary weed incursions. Some of these secondary weeds are more difficult and expensive to control than bitou bush, thus increasing original follow-up cost predictions. Regardless, once a program has commenced, the commitment to continue follow-up of all weed species is integral. This includes continuing to support community engagement as a component of the programs. Active community support has contributed greatly to the success of holistic weed control at a number of sites.

Ignoring boundaries and developing priorities across land tenure has increased the success of coordinated bitou bush (and other weed) control. Undertaking programs cooperatively is the most effective way to deal with landscape weed invasion. This program is an example of what can be achieved when different land managers and community groups can develop and implement strategies together and forge a commitment for consistent follow-up. Given the continual dispersal of bitou bush (and other weeds) and the constant risk of reinvasion, long-term control will continue to be an ongoing part of managing coastal vegetation communities on the Tomaree Peninsula.

Acknowledgments

We thank all of the community groups who have dedicated their time and energy towards removing weeds across the Tomaree Peninsula.

Biodiversity, fire and bitou bush management on the mid-north coast headlands of New South Wales: a study in progress

Michael Dodkin, Parks and Wildlife Group, Department Environment and Climate Change, PO Box 61 Port Macquarie, New South Wales 2444, Australia.

Introduction

In New South Wales (NSW), increased urban settlement and land tenure changes have led to a reduction in fire frequency in coastal areas and seen many coastal headlands given protected status (e.g. added to national park estate). As a result, coastal headlands have become important recreational and conservation sites. Managing weeds, fire and biodiversity in conservation areas requires an integrated approach. The decision making processes for integrating these management issues on protected headlands is difficult, especially in the absence of baseline information. Bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) is the main weed of coastal headlands in NSW and poses a significant threat to biodiversity (i.e. it is listed as key threatening process under the NSW *Threatened Species Conservation Act 1995*). Fire is a known management tool to control this weed. In an attempt to provide baseline data to assist in the management of bitou bush for biodiversity conservation, we have undertaken a pilot study to review vegetation history and other historical information from ten coastal headlands in northern NSW using aerial photographs taken between 1940 and 2006. The focus of the review is to determine the historical integration of weed, fire and biodiversity management on these headlands and understand how past management decisions, in addition to geomorphology and coastal evolution have shaped the current vegetation. This may allow us to learn from past decisions to assist future management.

Ten study sites

The ten headlands are reserved for conservation and public use and are located between the Macleay River and the Wallis Lakes region in northern NSW. Eight headlands occur in national park estate, while two are managed by local government (Kempsey and Port Macquarie-Hastings Councils). We used air photo interpretation to infer past coastlines from the surface expression of soil landscapes. These headlands were once offshore islands and are now joined to the mainland due to deposition of sediments during Pleistocene and Holocene interglacials. This earlier separation from the mainland may have contributed to a high degree of endemism on these headlands. The headlands contain endangered Themeda (*Themeda australis* (R.Br.) Stapf.) Grassland and Littoral Rainforest communities, in addition to many significant plant species, all of which are threatened by bitou bush invasion.

Interpreting aerial photos

Stereoscopic air photo interpretation was used to determine vegetation data, which was then arranged in GIS layers to enable spatial, temporal and qualitative comparisons. Vegetation attributes, including plant species and community types, cover classes of *Themeda* and bitou bush, as well as tree, shrub and rock cover, were determined from aerial photos. The study also identifies the geological history of each headland and assesses the soil landscapes, thus enabling the documentation of physiography (physical features), soils and natural hazards (e.g. erosion/landslip

risks). This information on natural hazards can be used when making decisions regarding site restoration, weed and fire management and infrastructure development (e.g. walking tracks, viewing platforms). The air photo interpretation and GIS mapping has been verified by selective field sampling. Land managers were also surveyed and asked to provide the history of bitou bush control at each headland.

What have we found so far?

This study began in 2003 and is ongoing. To date, we have identified and mapped high priority ecological communities, such as Littoral Rainforests and Themeda Grasslands, and documented 67 plant species of regional or state-wide conservation significance. We have determined geomorphologic history, recreational usage, vegetation condition, the status of bitou bush and other weeds and management history (including weed control and fire history) across the ten headlands. We are now in the process of analysing this information to see what past management techniques were most successful (in light of current biodiversity) and to determine the most effective integration of herbicides, bush regeneration and fire to suppress bitou bush and other weeds and promote native vegetation. It is anticipated that selective burning on headlands will be undertaken to protect, and potentially enhance, biodiversity. The aim is to promote re-establishment of Themeda Grasslands while protecting Littoral Rainforest and suppressing weed invasion. The interpretation of historical information from aerial photos may be applicable in other landscapes that require this type of rigor for appropriate management of biodiversity values.

Acknowledgments

Collaborators on this study include Bryce Laut, Fire Management Officer, DECC; Brenton Marchant, Senior Technical Officer (GIS), DECC; Michael Eddie, Senior Soil Surveyor, DECC; Bob Wilson, Air Photo Interpretation; Stephen Griffith, Consulting Botanist; and Alex Floyd, Consulting Botanist (rainforest).

A history of boneseed control in the You Yangs Regional Park, Victoria

David Roberts, You Yangs Regional Park, Parks Victoria, Branch Road, Lara, Victoria 3212, Australia.

Introduction

The You Yangs is a 2000 ha regional park situated between Victoria's two largest cities – Melbourne and Geelong, and is home to one of the countries densest boneseed (*Chrysanthemoides monilifera* subsp. *monilifera* (DC.) T.Norl.) infestations. Boneseed was thought to have been planted in the park as an erosion control measure in the late 1940s, but exact introduction details are unknown. Boneseed quickly established in the park, initially taking a strong hold on the low fertile granite slopes and progressively spreading to the open woodland in the foothills. By 1963, the District Forester reported approximately 30% of the park or 650 ha (1600 acres) having moderate to heavy infestations of boneseed, particularly in the steep rocky country. The current boneseed infestation covers more than 1300 ha of the 2000 ha park and dominates the landscape, particularly in the rocky granite hills.

The dense boneseed infestation has had devastating consequences for the native flora and fauna within the You Yangs. Much of the native middle and lower story flora has been lost in infested areas and replaced with a monoculture of boneseed. The competition provided by boneseed has inhibited regeneration of eucalypt seedlings, particularly *Eucalyptus leucoxylon* F.Muell., *E. polyanthemos* Schauer, *E. macrorhyncha* F.Muell. ex Benth. and *E. sideroxylon* Woolls, which has long term effects on canopy trees and reliant fauna species. The volume of dormant boneseed seeds present in the soil (2000–19 000 seeds m⁻²; Brougham *et al.* 2006), means that any treatment or disturbance of mature boneseed plants results in vigorous boneseed recolonization, which effectively out-competes native species.

The success of boneseed management in the You Yangs Regional Park has been influenced by a number of factors including sufficient funding, appropriate resources, continuity of staff, community engagement, wildfire events, technology advancements, research and changes in land use and public expectation. The control of boneseed over a 50 year period has relied on local strategies and a combination of control methods.

Control strategies

Boneseed control strategies implemented across the park have included all the recognized techniques: manual control,

chemical control, mechanical control, the use of fire regimes and biological control. No single method has been successful in controlling boneseed, however an integrated approach using a combination of several of these techniques has provided the most productive and sustained results.

Manual control

The history of manual boneseed control in the park can be traced back to 1958, when the Bird Observers Club identified boneseed as a significant threat to the natural bushland due to its rapid spread and initiated an annual 'boneseed pulling' working bee. Over a period of 25 years, this group along with the Geelong Field Naturalists Club successfully controlled boneseed over an area of 120 ha. Other volunteer groups including many schools, service clubs and the Guides and Scouts organizations, still contribute frequently to the manual removal of boneseed through the 'Adopt a Block' initiative, which invites community groups to undertake boneseed control in a specific area of the park, where they are recognized for their efforts with signage. Revegetation following the manual control of boneseed has resulted in over 26 000 native trees and shrubs being planted in treated areas.

Chemical control

Current chemical programs for boneseed focus on areas where known significant natural values are present, in particular areas of brittle greenhood (*Pterostylis truncata* Fitzg.) colonies, a threatened orchid species present in large numbers within the park. Glyphosate is widely used along roadsides and around key visitor areas to control a range of weed species including boneseed, bridal creeper (*Asparagus asparagoides* (L.) Druce) and capeweed (*Arctotheca calendula* (L.) Levyns). Chemical control was also applied as a broad acre aerial application following a significant wildfire in 1985, however the program ceased due to high costs.

Mechanical control

Slashers, groomers, brush cutters and heavy machinery have been used as a knock down approach for the control of boneseed in the park. These techniques have been restricted to the large infestations where there is an absence of the native shrub layer and a monoculture of boneseed. Mechanical approaches provide

access into thick infestations for follow up chemical control and have worked well as part of an integrated program. Initially it was hoped mulching of the boneseed would result in suitable fuel to conduct large scale burning of mature plants, however this was not achieved because plants were mulched too finely by the slashers.

Biological control

Six biological agents have been introduced into the You Yangs to control boneseed since the early 1990s. The advent of biological controls provided great hope and enthusiasm to land managers and volunteer groups. Unfortunately, the agents have provided little control for boneseed due to a number of factors including predation of the agents by native fauna and environmental conditions such as drought and extremes in temperature. Although not yet successful at controlling boneseed, a real benefit of the biological control programs is the positive messages surrounding integrated pest management and the education value to local schools and environment groups visiting the park.

Where to from here?

Parks Victoria has continued working with the challenge of large scale management programs for the control of boneseed. Twelve priority management zones were established across the park in 1999 to focus control efforts and limited resources on protecting the threatened brittle greenhood orchid and areas of known significant natural values. Weed control strategies produced by Parks Victoria and The University of Ballarat for boneseed and bridal creeper at the You Yangs Regional Park led to the development of these zones (Miller and Eales 1999).

Future management of boneseed in the You Yangs will involve a combination of methods as described above, with a greater emphasis on the role that fire can play in the landscape. As the community develops a greater acceptance of fuel reduction burning and a greater understanding of the benefits of ecological burning on public land, the opportunity to integrate fire management techniques with chemical and manual control of boneseed may be a cost-effective management option for the You Yangs into the future.

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The Zen of controlling bitou bush in Crowdy Bay National Park

Cathy Mardell, Parks and Wildlife Group, Department of Environment and Climate Change, PO Box 5657, Port Macquarie, New South Wales 2444, Australia.

Introduction

The bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) control program on Diamond Head in Crowdy Bay National Park, New South Wales, began 27 years ago when the ranger for the park approached the local group of the National Parks Association (NPA) to help tackle the bitou bush problem. The project was a positive practical contribution at a time when the group was very active in raising community awareness about local environmental issues. At the time, the National Parks and Wildlife Service (NPWS) District Manager remonstrated that the project was only 'justifiable if feasible results are attainable'. Results of the project to date have shown that efforts have been well invested, and prove that consistently coordinated management over many years can produce positive control outcomes over wide areas. Projects such as this one that aim to remove weeds from large scale areas are time consuming, challenging, and costly but also produce positive results with persistence and a degree of flexibility in the application of the techniques

History of bitou bush control at Crowdy Bay National Park

Invasive weed control, like meditation, is a practice that only reaps true results with constant practice. For the first nineteen years, groups of twenty or so volunteers, together with NPWS officers met twice per year and carefully hand pulled or cut and poisoned bitou bush over the length and breadth of Diamond Head. The gatherings or Bitou Bashes, as they are known, continue today and, on average, groups of 25 people meet to work for six hours during autumn and winter each year. NPWS staff attend the Bitou Bash Days and bring tools, herbicide and refreshments and assist with the work. Contractors and NPWS staff also ground-spray infestations too large for the volunteers to successfully attack. The sprayed areas continue to be meticulously followed up by volunteers or contract bush regenerators to remove re-sprouting bitou seedlings.

Toward the end of the first 19 years, it became obvious that it was impossible to control plants in inaccessible areas on the cliff face of the headland. Abseiling was trialled as a means to access out-of-reach areas, however it proved to be time

consuming and inefficient. Serendipitously then, a new method of treatment delivery using a helicopter fitted out with agricultural boom spraying equipment arrived on the scene around 1998. Using low concentrations of glyphosate to kill bitou bush in the cooler months without adversely affecting the dormant remnant native vegetation proved to be extremely successful (see Toth *et al.* 1996). Vast areas of hitherto unreachable bitou bush were killed and good native recruitment occurred in the sprayed areas. It must be noted however that follow-up work on ground in these areas is impossible given the terrain. In these instances, the few remaining plants are controlled using aerial spot spraying.

The development of aerial spraying methods expanded in 2000 to include the valuable technique of aerial spot spraying. This method uses ground based spraying equipment mounted in a helicopter. The herbicide can therefore be applied via a cone-shaped nozzle which is lowered from the helicopter to spray individual bitou bush plants (Toth and Winkler 2008). When there are only a few individual plants, boom spraying is not efficient and can result in an unacceptable level of non target kill. The aerial spot spray method has thus become an important tool enabling the treatment of very discrete areas or individual plants where ground spraying is not feasible. To date, aerial spot spraying has been employed on inaccessible areas on the headland to continue control as bitou bush plants decrease in number.

Expanding the program

With the strong support provided by aerial spraying, the program was able to further expand to join the bitou bush-controlled headlands of Diamond Head north to Perpendicular Point in Kattang Nature Reserve, along the sweeping expanse of Dunbogan Beach. The Friends of Kattang Nature Reserve had been working since 1995 to achieve a bitou bush-free status on the headland at Perpendicular Point, with great success. At this stage the project expanded to include co-operation from Port Macquarie-Hastings Council, as a 3.7 km portion of the 8.3 km beach was managed by Council.

Aerial spraying began along the length of Dunbogan Beach in the winter of 2002. The results were outstanding, however,

soon after all adult plants were controlled, the seed bed germinated prolifically. It was obvious broad-scale spraying would be an ongoing event until the seed bank was exhausted. Hand weeding continued by the volunteers at the twice yearly Bitou Bash to ensure vigilance in headland areas. Volunteer work also expanded to include new infestations discovered behind the fore-dune, particularly in the significant littoral rainforest along Dunbogan Beach. Larger infestations that were inaccessible to helicopter spraying (due to canopy cover) were treated by NPWS and contract bush regenerators. Backpack herbicide spraying was extremely time-consuming for these widespread infestations and a technique was developed that used quad bikes and a tank trailer, where it was possible to navigate through the bush. But heavily vegetated areas without access tracks limited the usefulness of this approach.

Challenges

Although aerial spraying has been an excellent addition to the program, there are a number of variables that can negatively affect implementation. Inclement weather anywhere along the coast can affect all other regions. There is a limited window of time during the year when aerial spraying can occur and there are very few suitable helicopters and applicators. If weather prevents spraying in one area, the applicators will move to another in an effort to complete spraying within the limited seasonal window. The aerial spraying program takes place along the length of the NSW coast, thus delays have a domino effect down the coastline. Problematic too are the more local effects of poor weather, as calm and clear conditions are needed on the day (see Broese van Groenou and Downey 2006). Logistics are also complex, requiring much forward planning and the co-operation of 20 or more participants from Council, Landcare, NPA volunteers and NPWS. Timing of aerial spraying is also a key factor in gaining control and ensuring the efficacy of the program. Anecdotal, bitou bush has begun flowering earlier over the last couple of seasons. As a result, the majority of plants have flowered and seeded by the time aerial spraying occurs. This may set the program back significantly if the seed bank is increased.

Monitoring of the aerial spraying program was introduced in 1999 to track the changes to health and condition of native plants. Selection of monitoring sites was problematic at first, as the much of the sprayed area is on steep and inaccessible headlands. However, suitable sites were established and monitoring protocols were refined over time to a single-page template, which is efficient and easy to use. Results from the surveyed sites have been positive, with very few losses of non target plants.

The value of volunteers in bitou bush control

In 2007, it was determined that aerial spraying was no longer viable for Dunbogan beach as there were not enough bitou bush plants for it to be efficient. A contractor was engaged to ground-spray the remaining plants on the foredune and hind dune, and the excellent results have been followed up by volunteers on Bitou Bash days. Vigilance at this stage is critical to maintaining areas where aerial spraying and ground control has been completed.

The NPA community group provides ongoing labour support on Bitou Bash days and, importantly, has attracted ongoing grant funding. To date, eight Envirofund grants totalling \$93 850 (with the 9th application of \$32 000 pending) have contributed significantly to the project. The NPWS contribution since 1998 including budget funding and in kind contributions is in excess of \$200 000.

Conclusion

The Crowdy Bay National Park bitou bush control program has demonstrated many successes over the last 27 years. The program continues to expand, and in the last two years has incorporated significant areas around Crowdy Beach. Dedicated community volunteers have made much of these successes possible and, overall, the program has shown to be feasible and efficient. In addition to the extensive aerial spraying and ground control campaigns, over 224 000 individual bitou bush plants have been hand-removed over the course of the project by volunteers. These amazing efforts continue to prevent further bitou bush invasion and protect these valuable coastal areas.

Acknowledgments

I thank the numerous volunteers who helped to control bitou bush at Diamond Head and Perpendicular point over the years. Also the NSW NPWS for maintain-

ing long-term commitment to bitou bush control at these sites. Lastly, Mike Dodkin (NPWS) for his efforts in coordinating the project over the last 28 years.

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Management of bitou bush on the New South Wales north coast

Iain Jamieson^{A,C} and Reece Luxton^{B,C}

^AFar North Coast Weeds, PO Box 230, Lismore, New South Wales 2480, Australia.

^BClarence Valley Council, Locked Bag 23, Grafton, New South Wales 2460, Australia.

^CNorth Coast Weeds Advisory Committee.

Introduction

The North Coast Weeds Advisory Committee (NCWAC) is an advisory and coordinating body for weed management covering 290 kilometres of coastline stretching from the Queensland border to the Shire of Nambucca in the south and encompassing the Tweed, Byron, Ballina, Richmond Valley, Clarence Valley, Coffs Harbour, Bellingen and Nambucca Councils. The committee helps to promote best practice weed management and assists in the implementation and co-ordination of effective on-ground weed management programs. The committee's management of the noxious weed bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) Norl.) is carried out by a variety of organizations and funding is obtained from a diverse range of sources. This paper presents an overview of the success of this program.

The North Coast Weeds Advisory Committee

The NCWAC has representatives from five Local Control Authorities (LCAs), who are responsible for the administering of the NSW *Noxious Weed Act 1993* on free hold and Council managed lands. The success of the NCWAC program is due to the co-operative effort between these LCAs and other committee members including the NSW Department of Primary Industries, Department of Environment and Climate Change, Department of Lands, the Queensland Department of Primary Industries and Fisheries and the Northern Rivers Catchment Management Authority. The committee also cooperates with a number of local land managers, including community groups, Aboriginal Land Councils and private property owners. The committee meets quarterly and sponsors an annual weed forum that brings

together key stakeholders and members of the community to share the latest weed research and management information. A dedicated project and planning officer organizes NCWAC events and assists with the development of strategies and funding applications. The part-time project officer position is funded by matching contributions from the five participating LCAs and NSW Department of Primary Industries, at a total cost of approx \$32 000 per year.

Bitou bush management

Bitou bush was gazetted as a noxious weed across all NSW North Coast LCAs in 1998, and the NCWAC took immediate action. The committee formed the North Coast Bitou Bush Taskforce in 1999 and appointed a project officer to develop a regional bitou bush strategy, which was completed in 2001. A bitou bush regional control plan was adopted in 2002. Since

then, the area of bitou bush infestations managed by committee members has substantially increased through the involvement of a number of stakeholders.

The programs developed under the regional strategy are a cooperative approach between NCWAC and its members and include projects such as those undertaken by the NSW Department of Environment and Climate Change in Bundjalung and Yuraygir National Parks, where over 650 hectares of bitou bush are under active management. This work is supported by bitou bush control on adjoining lands by Clarence Valley Council to the south and Far North Coast Weeds in the north. The North Coast Bitou Bush Taskforce also assists with co-ordinated regional aerial control programs, which target up to 800 ha of bitou bush infestations annually.

Highlights of the NCWAC program include the formation of the Tweed Bitou Bush Steering Committee in 2002, which currently manages 500 ha of various land tenure for bitou bush and other coastal weeds. The Committee maintains the northern bitou bush containment line at the Tweed River, which aims to prevent bitou bush from re-infesting south-eastern Queensland.

The NCWAC also supports biological control efforts for bitou bush. The bitou tip moth (*Comosotolopsis germana* Prout)

and the bitou seed fly (*Mesoclanis polana* Munro) were first released in the Clarence Valley to control bitou bush in 1992 and 1996, respectively. NCWAC members are working with the national Weed Warriors program to mentor school children and help them rear and release bitou bush leaf-rolling moths (*Tortrix* sp) over the next few years. NCWAC utilizes integrated management programs where possible.

In the Clarence Valley, a consistent control program over the last decade has resulted in 18 sites under council management being reduced from heavy to light bitou bush infestations. Over 90% of the coastline in Coffs Harbour Council is under active bitou bush management, with over 30 different community groups involved. Bitou bush is also being managed on over 80% of the Bellingen Shire and Nambucca Shire coastlines.

The advent of the NSW Bitou Bush Threat Abatement Plans (TAP; DEC 2006) has also increased bitou bush management efforts. The Northern Rivers Catchment Management Authority has provided funding for bitou bush control at 24 priority sites in the NCWAC region. The implementation of the TAP has allowed for site specific management plans to be developed which will assist in monitoring and evaluation.

A consistent and coordinated approach has contributed to the successful management of bitou bush on the NSW north coast. The NCWAC operates under a strategic framework that continues to foster cooperative management programs. Current efforts of mapping the distribution of bitou bush in early 2008 will provide an effective measurement of success against baseline mapping conducted in 2001.

Continued sharing of information through the committee has highlighted the need for a multi species as opposed to single species approach to control over the years. Recently, the committee's landscape approach to bitou bush management has evolved into the development of a regional plan that calls for holistic management of all coastal weeds, with special emphasis on the secondary weeds that invade after bitou bush control. This holistic approach will better enable NCWAC members to further protect the natural landscapes on the NSW north coast.

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New South Wales south coast bitou bush and boneseed control program

Kerry Thompson^A and David Pomery^B

^AShoalhaven City Council, PO Box 42, Nowra, New South Wales 2541, Australia.

^BIllawarra District Noxious Weeds Authority, PO Box 148, Kiama, New South Wales 2533, Australia.

Introduction

Coordinated weed control programs focusing on the weeds bitou bush and boneseed (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) (Norl.) and *C. monilifera* subsp. *monilifera* (L.) Norl., respectively) have been undertaken along the south coast of New South Wales (NSW) since the development of a regional weed control plan in 2002 (Broese van Groenou and Wolfenden 2001). Previously, only fragmented control was undertaken by individual stakeholders. Bitou bush has invaded approximately 9400 ha or 38% of the NSW south coast coastline from Wollongong to Bega (see DEC 2006). It is a major component of the vegetation north of Sussex Inlet (where the National Bitou Bush Southern Containment Line has been established) but is less abundant to the south. The National Southern Containment Line delineates the geographical location where the southern spread of bitou bush is being contained (Figure 1).

The full extent of boneseed on the south coast is not yet fully known. The majority of infestations appear to be in the Wollongong region just south of Sydney, although scattered infestations are also found further south through to Bega.

Rare and threatened plant species on the south coast such as *Pimelea spicata* R.Br, *Cynanchum elegans* (Benth) Domin. and *Thesium australe* R.Br. are particularly at

risk from bitou bush invasion (DEC 2006). On the far south coast the habitat of the white footed dunnart, *Sminthopsis leucopus* Thomas, is also threatened by bitou bush infestations.

After only five years of coordinated programs there has been a significant reduction in the density of bitou bush and boneseed throughout the entire south coast region. However, as with any weed control program, there is still much to be done and new challenges to overcome. This paper describes the development and implementation of coordinated regional activities to control bitou bush and boneseed along the NSW south coast and includes a case study of the Southern Rivers Catchment Management Authority (SR-CMA) Coastal Land Restoration Project.

South Coast Bitou Bush and Boneseed Taskforce

Background

Bitou bush was first declared a noxious weed in Shoalhaven City Council in 1993 when the NSW *Noxious Weeds Act 1993* was established. It was later declared noxious in all remaining south coast councils in 1999, when boneseed was also added to the list. In NSW, noxious weeds are declared on a Local Control Authority (LCA) or council basis hence the listings may vary in different council areas. No formal regional action had been undertaken to address the bitou bush or boneseed problem prior to 1999.

In 2000, the Southern Tablelands and South Coast Noxious Plants Committee established a taskforce to deal with bitou bush and boneseed in the region. The establishment of the South Coast Bitou Bush and Boneseed Taskforce (SCBBBT) was supported by funding from the Regional Weed Action Program run by the NSW Noxious Weeds Advisory Committee. The SCBBBT comprises regional weed experts from local and state government agencies and the community. The initial role of the taskforce was to have direct input into the development of the bitou bush and boneseed management strategies, and oversee the implementation of these strategies into the future. All members of the Taskforce had input into the development of the management strategies through

progressive workshops and advisory recommendations.

In 2002 the SCBBBT developed the South Coast Regional Bitou Bush Strategy (Broese van Groenou and Wolfenden 2002), and five year Management Plan (SCBBBT 2002). This regional plan placed emphasis on and encouraged a coordinated approach to bitou bush and boneseed management and control by all stakeholders throughout the region. An updated plan has recently been prepared (SCBBBT 2007) and endorsed by all stakeholders for a further five years until 2012. This plan also includes regional priority sites for control of bitou bush for biodiversity conservation, as identified in the NSW Bitou Bush Threat Abatement Plan (DEC 2006).

Taskforce Objectives

The role of the Taskforce is now well established and includes:

- i. the implementation, review and updating of the regional Bitou Bush and Boneseed Strategy and Management Plan;
- ii. the implementation of public awareness programs, and
- iii. provision of a coordination role and funding body for regional weeds projects (see case study below for further discussion).

The existence of the SCBBBT also ensures integrated planning between all stakeholders to overcome agency boundaries, implementation of best practice management techniques for comprehensive on-ground control works and the ability to maximize funding opportunities through coordinated efforts. Education and extension programs are also promoted and supported.

Major achievements of the Taskforce

Coordinated management has resulted in the National Southern Containment Line being moved 100 km north from Tuross Heads to Sussex Inlet in only five years.

All bitou bush populations south of the containment line are being controlled continuously, as per the regional, state and national management plan initiatives, with the specific objective of preventing seed production each year. North of the containment line, bitou bush is being controlled strategically with the aim of controlling all new and light infestations by 2009, and containing all medium and core infestations by 2012, so that there is no increase in size or spread of infestations. Boneseed is being eradicated from the region wherever it occurs.

As an ongoing initiative of the SCBBBT, a school bitou bush resource kit was produced in consultation with the NSW Department of Education, Illawarra Environmental Education Field Studies Centre. The kit, designed for primary and secondary students, has an investigative

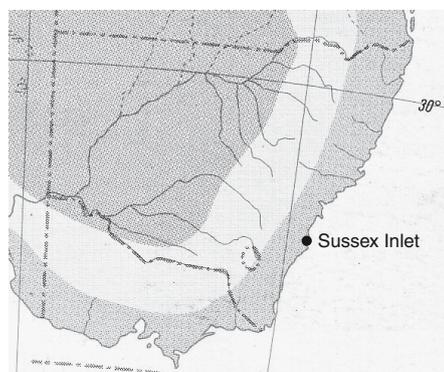


Figure 1. National bitou bush Southern Containment Line at Sussex Inlet, approximately 200 km south of Sydney.

approach with an emphasis on bitou bush and its impacts on the environment. Under funding from the Australian Government's Defeating the Weed Menace program, this initiative has now been adopted at a State level and is being further developed with the NSW Department of Education to create integrated classroom learning tools to increase weed awareness (Schembri *et al.* 2008). The program, which will be known as *Weeds Attack!*, will use bitou bush as a prototype. It will also include lessons about the other Weeds of National Significance and will conform to national curriculum standards to allow national adoption.

Southern Rivers Case Study

The SCBBBT currently manages the SRC-MA Coastal Land Restoration and Bitou Bush Control Project, one of many programs running simultaneously but complementary to other local projects throughout the South Coast region. The aim of the project is to implement the Bitou Bush and Boneseed Management Plan using a co-operative regional approach across the whole of Southern Rivers CMA region (over 600km of coastline). Six local Government agencies cooperate with four State agencies, two facilitator groups and a variety of community groups, contractors and landholders.

Diverse links and associations are forged between these numerous agencies and community groups to effectively implement on-ground works. This cooperation is a key component to successful control of bitou bush over such an expansive geographic area. The adoption of diverse best practice management for each specific site throughout the project area ensures maximum effectiveness of weed control. The project builds on existing weed control and environmental revegetation works in all areas, thus strengthening local efforts and networks.

An innovative approach to support existing programs has been the integration of the NSW Department of Corrective Services into the project. Community Service Order (CSO) clients complete on-ground weed control at three suitable sites within the Illawarra. CSO clients undertake primary and secondary control of bitou bush and other weeds at each site, thereby extending the control efforts of agencies and community groups. The work carried out by the CSO clients involves an

integrated approach using physical and hand weeding methods to support chemical and biological approaches. The end result has been a reduction in infestation levels of bitou bush at each site that in turn has prevented the weed from spreading to less infested areas. The addition of this agency with a 'non environmental' focus is a good example of 'thinking outside the square' when seeking partnerships in environmental management.

Within the Shoalhaven, Eurobodalla and Bega Valley council areas where CSO clients are less able to meet local requirements, a project officer or the Noxious Weeds Officer has been appointed to work with community groups and contractors at a total of 15 sites. These managers coordinate and implement on-ground control of bitou bush at each site and in so doing ensure the National Bitou Bush Southern Containment Line is maintained.

Through the partnerships forged in this project, a significant impact on bitou bush and boneseed infestations has been achieved across the project area since the program's inception in 2004. The major achievements to date include:

- i. 2700 ha of bitou bush and boneseed controlled,
- ii. 35 ha revegetated after control,
- iii. 4340 native trees planted,
- iv. 40 ha of other environmental weeds treated that co-occurred or re-invaded after bitou bush control,
- v. Over 20 000 hours by CSO teams on the project and,
- vi. 3546 volunteer hours worked.

The volunteer hours have been accrued by environmental 'Care' groups working throughout the project area. In any one year, the project has 24 volunteer groups involved in weed control and revegetation efforts. These volunteers are a fundamental component of the integrated on-ground works and offer a significant contribution to the overall success of the project.

Summary

The expansive spread of pest plants into the natural environment demands that the management of these weeds be a combined effort between all stakeholders utilizing integrated control techniques. This regional coordination of bitou bush and boneseed management along the entire coastal fringe of southern NSW has contributed significantly to successful control

of these noxious weed species. The SRC-MA land restoration project is a prime example of forging strong partnerships between people from many agencies and different facets of the community who are all focused on combating a serious weed invasion, whilst aiming to attain long term biodiversity outcomes throughout the coastal zone.

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