The Impact of Boneseed (*Chrysanthemoides moniifera* spp. *monilifera*) Invasion on Biodiversity:

Sandford, Tasmania 2009

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EXECUTIVE SUMMARY

1. Ninety sites were surveyed across Tasmania, South Australia and Victoria. There were 45 sites invaded by boneseed and 45 native sites. In 20 x 20m quadrats species richness was measured. Samples of the seed bank from 3 invaded and 3 native sites were collected in each state and germinated in the glasshouse. Comparisons were made between species richness of invaded and native sites and between species richness in above ground vegetation and the seed bank.

2. Boneseed reduces biodiversity. There is a 25% reduction in species richness of natives and a doubling of exotic species in invaded sites. Herbs, shrubs and trees show reduced richness in invaded sites, while graminoids, ferns and vines appear unaffected. No change in species composition was evident between invaded and uninvaded sites, suggesting that the reduction in species richness has not included a significant replacement of species: rather a loss of species present at sites. Only in the inland sites in Victoria was there a change in species composition of the herb layer.

3. The seedbank was vastly different in composition from the above ground vegetation and was similar across all sites within each state, despite being collected from different vegetation types and in invaded and native areas. Very few shrubs and trees germinated in the seed bank trial with herbs and grasses dominating both in richness and abundance.

4. The species composition of the seed bank was affected by invasion in Victoria and South Australia, but not in Tasmania, suggesting that invasion does influence the capacity of the seed bank to restore vegetation. More importantly however, the capacity of all sites to regenerate effectively from the seed bank is limited and in order to ensure the conservation of biodiversity into the future, monitoring of species richness at sites, particularly those where management of boneseed has occurred, will be needed to ensure management can facilitate the establishment of missing species.

ACKNOWLEDGEMENTS

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The survey work in the three states and the glasshouse experiment was greatly facilitated by Natalie Sullivan.

Para Wirra (South Australia), 2009

INTRODUCTION

Environmental weeds have been shown to pose considerable threat to the environment, lowering species diversity (WRI *et al*. 1992, Gooden *et al*. 2009, Mason et al. 2009) by displacing native species through above and below ground competition (Walck *et al.* 1999). Environmental weeds can threaten and destabilize functional complexity and biodiversity (Adair and Groves, 1998) posing a real challenge to environmental managers (Williams and West, 2000).

Ideally, identifying broad patterns of species loss would be an important step for management. If specific native species or plant functional types can be identified as 'at risk' from invasion, then management can be focused and more economical to conserve these species. Mason *et al.* (2009) identified negative impacts of both graminoid and woody invaders on species richness with smaller herbaceous and perennial species particularly impacted. In eastern Australia, bitou bush (*Chrysanthemoides monilifera* spp*. rotundata*) has been extensively studied and the impacts of invasion on plant richness have been quantified in a range of habitats (Mason and French 2008). For bitou, the grass and herb layer appears particularly affected, although in the hind dunes the canopy species were also affected. The impact of the closely related subspecies, boneseed (*Chrysanthemoides monilifera* spp*. monilifera*) has not been investigated despite serious infestations in Victoria, South Australia and Tasmania.

BONESEED

Boneseed (*Chrysanthemoides monilifera* subsp. *monilifera*) (Asteraceae) was introduced to Australia from South Africa (Scurr et al. 2008). A perennial shrub of between 1 – 3 m height, with toothed, stiff, semi-succulent leaves and bright yellow flowers boneseed can be found in 5 southern states of Australia, i.e. in the south of NSW, Victoria, South Australia, Western Australia, and Tasmania. It was first grown as garden plant and recorded in the Sydney region in 1852, Melboune in 1858, Adelaide in 1892 and Tasmania in 1931 (Weiss *et al*. 2008). In the You Yangs and parts of coastal Victoria boneseed could have been planted for soil stabilization, as in the case of its close relative, bitou bush, along the NSW coast (Garnet 1965).

Both subspecies are listed amongst the 20 Weeds of National Significance in Australia. Several studies conducted in Australia showed that boneseed is capable of invading native vegetation communities and displacing the species present thereby reducing biodiversity (Weiss et al. 1988, Thomas et al. 2000).

Due to the vast scale of boneseed invasion which includes serious infestations intermingled with scattered low density infestations, two management approaches, eradication and containment, have been used to prevent further spread. Eradication is used where boneseed only covers relatively small areas and there are sufficient resources for follow-up control whereas the containment strategy has been used in areas of vast weed infestations. In the latter strategy further spread of boneseed from the dense infestations is prevented by controlling scattered plants at the edge of infestations with an aim to eventually start reducing the core infestation from the outside (Brougham et al., 2006).

It is clear that the most important issue for removing the effect of boneseed invasion is the continued management of the site following initial control methods. Such management should include a restoration programme to help re-establish initial native vegetation which is likely to prevent re-infestation in the future. Research on bitou bush in fore- and hind-dune situations has shown that in most cases restoration efforts have to include targeted replanting focusing on species missing from sites post-invasion (Mason and French, 2008, French 2010).

In order to enable resource managers to establish long-term management plans it is important to gain information on which species might be missing from invaded sites which are present in uninvaded sites of the same plant community. Furthermore, an insight into the soil seed bank will provide further evidence of presence and absence of these species as an abundance of native seeds in the seed bank might be able to reduce the impact of invasive species in the long term (McAlpine et al. 2008, Chazdon, 2003)

AIMS OF THIS STUDY

Our aim was, therefore, to initially establish whether there was a distinct range of species at risk due to boneseed invasion, i.e. which species present at boneseed uninvaded sites were missing from boneseed invaded sites of the same vegetation type and/or location? Secondly, we aimed to determine whether these species were present in the soil seed bank of these sites. Establishing the species which are absent from invaded sites and identifying whether these are also absent from the soil seed bank, would enable us to develop tailored management plans to maintain biodiversity in specific ecosystems.

By conducting the study across a whole range of states in Australia we also attempted to establish possible differences across the core area of infestation of boneseed.

METHODS

STUDY AREA

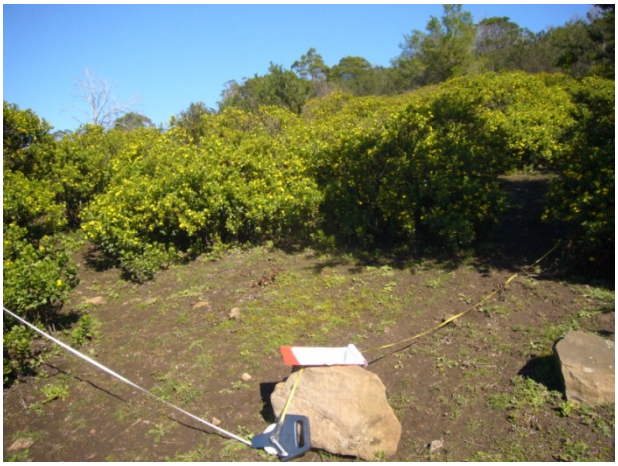
Altogether, 90 sites were selected in three different states, i.e. Victoria (28 sites), South Australia (32 sites) and Tasmania (30 sites) choosing an equal amount of boneseed invaded and boneseed uninvaded sites in each state (Details in Appendix 1). Wherever possible an attempt was made to group invaded sites with uninvaded sites of the same vegetation type and similar location.

SAMPLING STANDING VEGETATION

The sampling of standing vegetation took place between May and October 2009. Invaded sites were selected according to boneseed foliage cover, i.e. we selected plots with a boneseed cover abundance of 5 to 7 on the modified Braun/Blanquet cover abundance scale for the invaded sites and a cover abundance of 0 to 2 for the uninvaded sites (Table 1). Some sites of invasion below 50 % were selected to establish possible threshold levels of infestation. Within these areas the plots were selected at random.

The plots consisted of a 20 x 20 m quadrat in which we estimated and recorded the cover abundance of all species according to a modified Braun/Blanquet cover abundance scale. Some environmental variables such as other groundcover, soils and disturbance history were also recorded as well as GPS points, direction of slope and current land use. Information as to the disturbance history and current land use was obtained by land owners or specific rangers in the Parks and National Parks.

Plants were identified and recorded on site if known to the field researchers. Where species could not immediately be identified, specimen samples were collected and pressed recording site details and a letter code and were sent to the respective local herbarium, i.e. the National Herbarium of Victoria in Melbourne, the State Herbarium of South Australia in Adelaide and the Tasmanian Herbarium in Hobart. Some of the samples were taken to NSW and identified by the Janet Cosh Herbarium at the University of Wollongong.



Penna (Tasmania) 2009

Table 1. Modified Braun/Blanquet cover abundance values used for surveying vegetation.

Braun/Blanquet value	Vegetation abundance
1	one/few individuals & <5 % cover
2	uncommon & < 5 % cover
3	common & < 5 % cover
4	from very abundant < 5 % to 5 – 20 % cover
5	20 – 50 % cover
6	50 – 75 % cover
7	75 – 100 % cover

ANALYSIS

We conducted two-factor ANOVAs on species richness of native plants and exotic plants in invaded and uninvaded sites. The native species were then divided into functional groups; herbs, shrubs, trees, graminoids, ferns and vines and ANOVA used to identify differences in species richness of functional groups between invaded and uninvaded sites.

To distinguish patterns between states or locations we undertook an ordination on the Bray Curtis dissimilarities between sites, based on cover abundance values. On the basis of this we divided the sites into 5 regions: South Australia, Inland Tasmania, Coastal Tasmania, Inland Victoria, Coastal Victoria. Using PERMANOVA, we determined differences between regions and invasion category.

SEED BANK STUDY

We collected soil samples from 6 sites in each state, 3 boneseed invaded and 3 uninvaded sites. These sites were 20 x 50 m plots in which the standing vegetation had been recorded. One hundred soil cores were obtained from each of the 6 sites by inserting a soil corer with a diameter of 63 mm and a depth of 49 mm fully into the ground and collecting the soil core in a canvas sack. The soil corer dimensions and number of core samples were the same as had been optimized and used in a study by Mason, French and Russell (2007). The canvas sacks with the soil cores were transported to the University of Wollongong. Upon arrival in Wollongong the soil cores were mixed, sieved, and spread equally onto between 16 and 19 seed trays per site which had been filled to ¼ with river sand to avoid soil and seeds being flushed out through the bottom of the tray. The seed trays were also lined with a fine mesh for the same purpose. Four

control seed trays containing sand only were set up for the 3 states each to account for glasshouse contaminants. The seed trays were then distributed at random in the glasshouses.

Smoke water can encourage germination in many seeds (deLange and Boucher 1990, Roche et al 1997, Mason et al 2007). Once the trays were set up they were watered on four consecutive days with a mix of smoke water and tap water, i.e. one part of smoke water to nine parts of tap water. The smoke water was produced following the method of Dixon et al. (1995). Leaves and debris were gathered from sites that were sampled to ensure that each state had its own specific smoke water. The leaves and debris were burnt in a little incinerator with two pipes connected to it, i.e. one for the air influx and the other one for the out-going smoky air. The second pipe with the out-going smoky air was then connected to a water drum and the water drum had another pipe connected to it where the air was vacuumed out of the water drum. Thus an airflow which sent smoky air from the incinerator through the water drum was achieved. After the four days of smoke water treatment the trays were watered by automatic sprinkler system twice a day for 4 minutes.

Seedlings were counted and labeled as they emerged. Each different seedling type was given a label with date and data was entered into a recording sheet which showed the site number, tray replicate, label lettering, species name or description and the date when it was recorded. As species became more distinct they were pricked out and two samples each were potted on for exact identification. Identification was undertaken at the Janet Cosh Herbarium or state herbaria with the aid of specimen samples taken from the region in the standing vegetation sites. Recordings were made in two week intervals until germination ceased. After 6 to 12 months the seed germination trial was finished for each of the states and all plants were identified to at least genera level. Identification of seedlings proved sometimes extremely difficult due to the lack of seedling identification guides and the fact that even after one year certain plants that had been grown on had still not flowered.

ANALYSIS

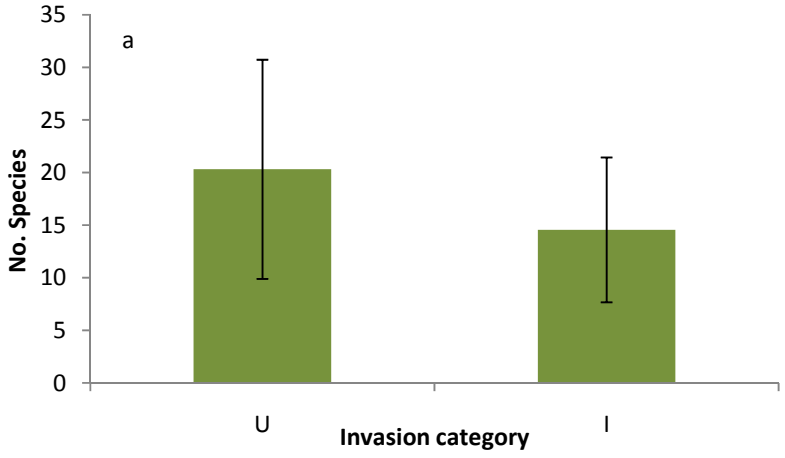
We conducted two-factor ANOVAs on species richness of native plants and exotic plants in invaded and uninvaded sites comparing the seed bank and the standing vegetation. To distinguish patterns with each state we undertook an ordination on the Bray Curtis dissimilarities between the seed bank and standing vegetation for sites that were invaded and native, based on presence absence values. Using PERMANOVA, we determined differences in the composition of the seed bank and the standing vegetation, and invasion category.

RESULTS AND DISCUSSION

STANDING VEGETATION

SPECIES RICHNESS

Invaded areas had lower species richness of native plants ($F_{1,88}$=9.52, p = 0.003) and higher exotic species richness ($F_{1,88}$=13.795, p > 0.001) than native (uninvaded) sites (Figure 1). Herbs and shrubs were the dominant component of sites and, together with trees, were more speciose in native than invaded sites (Figure 2, Table 2). Ferns and vines were poorly represented at all sites and together with graminoid species, were not more speciose in one habitat over the other.



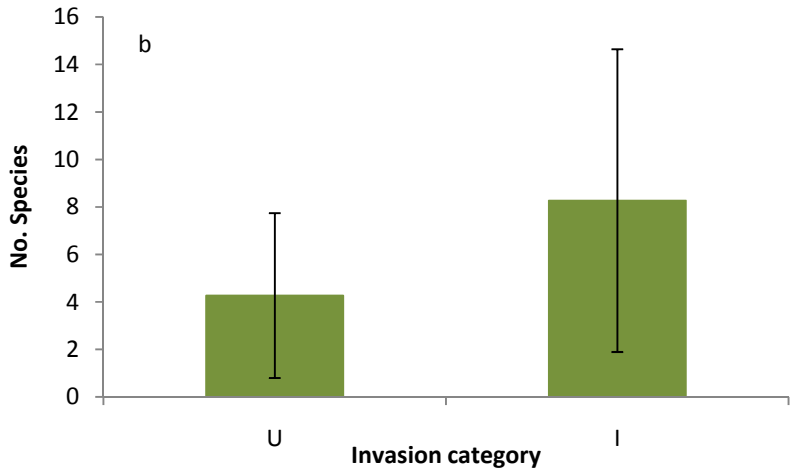


Figure 1. a) Native and b) exotic species richness in uninvaded (U) and invaded (I) plots in South Australia, Victoria and Tasmania.

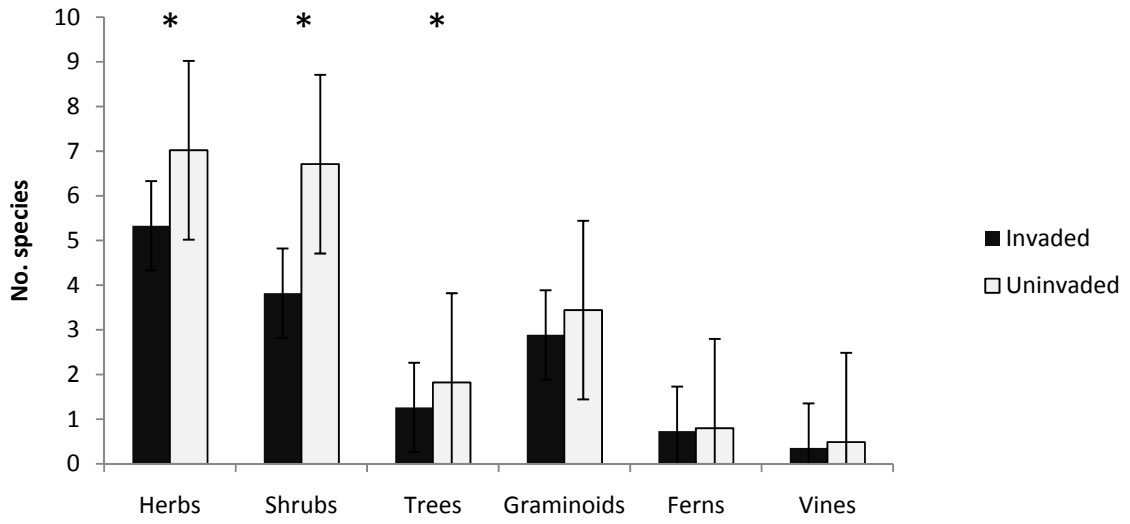


Figure 2. Average number of species in different functional groups in uninvaded and invaded plots. Asterisks identify where significant differences lay (see also Table 3). Values are means and SD.

Uninvaded Para Wirra (SA) and invaded You Yangs (VIC)

Table 2. Results of ANOVAs for differences in species richness between invaded and uninvaded habitats for different functional groups.

	herbs	shrubs	trees	graminoids	ferns	vines
Average invaded	5.333	3.822	1.267	2.889	0.733	0.356
uninvaded	7.022	6.711	1.822	3.444	0.800	0.489
F	3.636	12.24	4.45	1.66	0.232	1.38
p	**0.0598**	**0.0007**	**0.0378**	0.201	0.632	0.244

SPECIES COMPOSITION

Analysis of differences in species composition identified 5 clear regions (Figure 3). South Australian sites grouped separately from other states, while Victorian sites were split into two clear groups: a largely coastal set of sites and an inland cluster. Similarly Tasmanian sites were split into a largely coastal cluster and an inland cluster.

When functional groups were analysed separately, each region remained significantly different in composition from all other regions (Table 3). No difference in functional groups was identified between invaded and uninvaded areas except in the herb layer in inland Victoria. (Table 3).

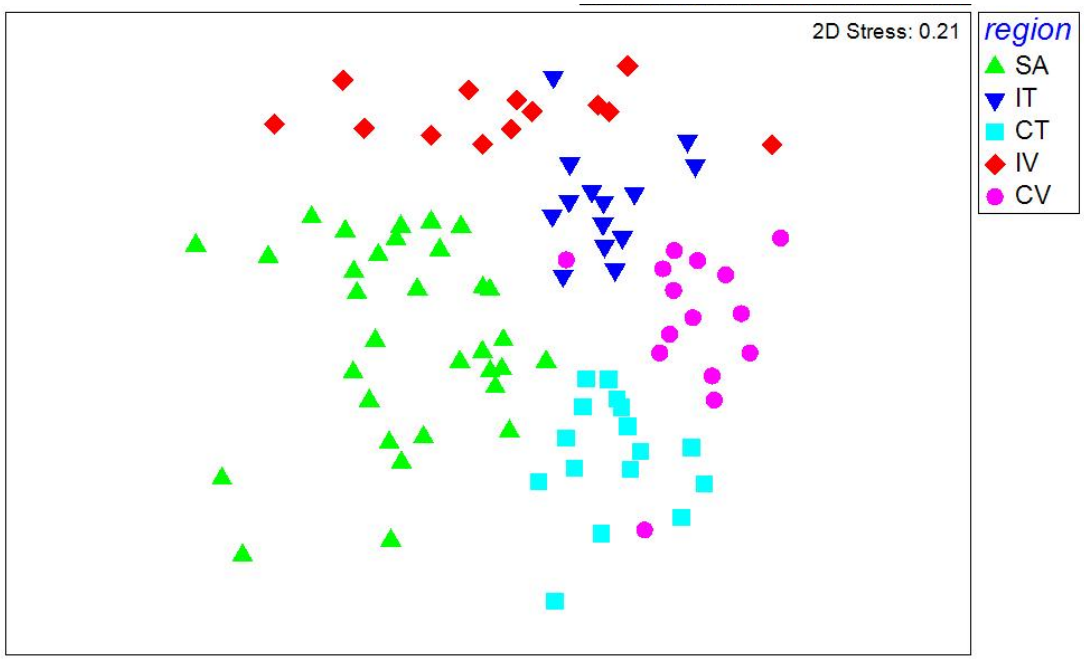


Figure 3. Ordination (nMDS) of sites based on Bray Curtis indices of similarity or native species composition using a modified Braun/Blanquet cover abundance scale. Five clear regions are identified. SA – Sth. Australia, IT – Inland Tasmania, CT – Coastal Tasmania, IV – Inland Victoria, CV – Coastal Victoria.

Table 3. Probabilities of PERMANOVA analysis of differences in composition of functional groups showing each main factor in the model and the interaction term. Bold indicates significantly different.

Functional group	Region	Weed	Region x weed	Notes
Trees	**0.001**	0.38	0.082	All regions differ
Shrubs	**0.001**	0.44	0.415	All regions differ
Graminoids	**0.001**	0.14	0.377	All regions differ
Herbs	**0.001**	0.123	**0.001**	Only in inland Victoria is there a difference in composition between invaded and native areas.

SEED BANK

SPECIES RICHNESS

States differed in the differences in the seed bank between native and invaded sites (Table 4). In South Australia, there were no differences with invasion category in the seed bank despite differences in the above ground vegetation. Greater exotic species richness was found in the seed bank relative to the standing vegetation and in invaded compared to native sites. This indicates greater risk of invasion following boneseed management and a depauperate native community could develop from the seed bank after disturbance or removal of boneseed.

In Victoria the seed bank had greater native species richness than the vegetation, suggesting a greater capacity for regeneration at sites following weed removal. However exotic species richness was also greater in the seed bank, placing greater risk of secondary invasion following management or other disturbances. There were no differences in species richness of the seed bank, nor differences with invasion category in Tasmania for either native or exotic species.

Table 4. Probability values for the analysis of changes in species richness between the seed bank and the standing vegetation in invaded and native sites in South Australia, Victoria and Tasmania.

	Factor	Natives		Exotics	
South Australia	Invasion	**0.0004**		**0.0017**	invaded>native
	Seed/ vege	**0.0011**		**0.0056**	Seed bank> vege
	Invasion * seed/vege	**0.0003**	SR only greater in uninvaded vegetation	0.8107	
Victoria	Invasion	**0.0189**	native>invaded	0.7437	
	Seed vs vege	**<0.001**	Seed bank> vege	**<0.0001**	Seed bank> vege
	Invasion * seed/vege	0.6222		0.4184	
Tasmania	Invasion	0.6682		0.8200	
	Seed vs vege	0.4857		0.5180	
	Invasion * seed/vege	0.8916		0.8200	

SPECIES COMPOSITION

In all states, the species composition of the seed bank at the sites clustered closely together but differed strongly from the standing vegetation (Figure 4). In Tasmania, there was no difference in composition in invaded and uninvaded sites, however composition varied between invaded and uninvaded sites in both above ground vegetation and the seed bank in Victoria and South Australia (Table 5).

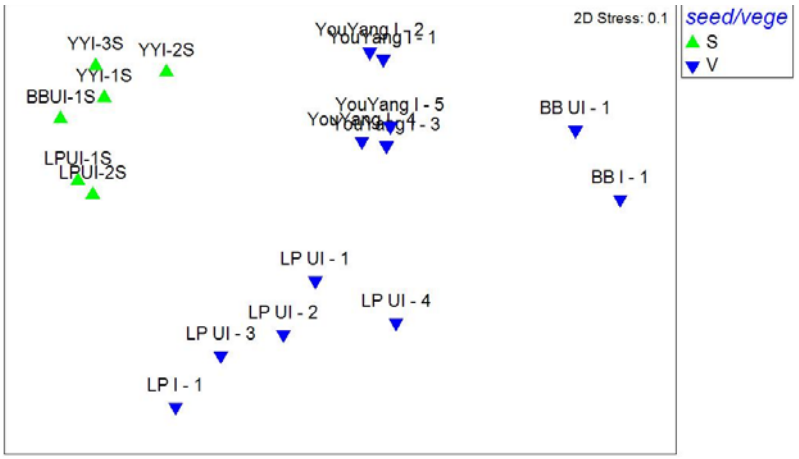
A similar result was found for exotic vegetation with differences occurring between the above ground vegetation and the seed bank in all states but no differences amongst invasion category. We investigated whether exotic vegetation was similar between states using PERMANOVA but all states had a different exotic vegetation composition in both their seed banks and above ground vegetation.

Table 5. Probabilities values for each state for PERMANOVA results testing differences in composition between invasion category (invaded vs uninvaded) and between seed/vege (seed bank vs above ground vegetation).

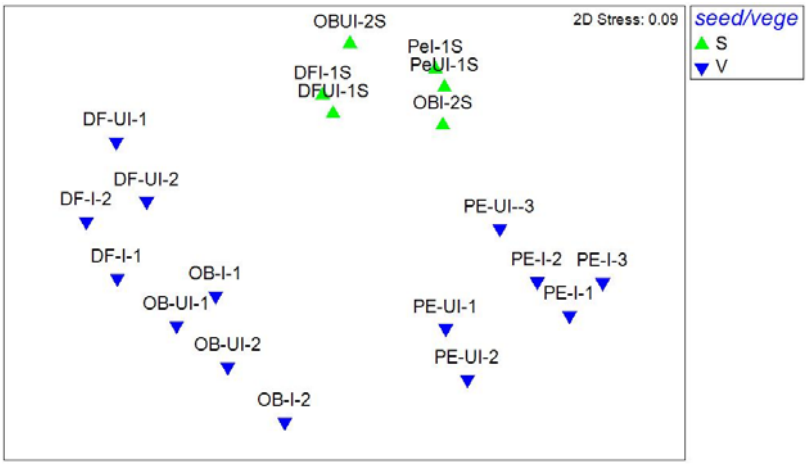
	Factor	Probability
Victoria	Invasion	**0.014**
	Seed/vege	**0.001**
	Invasion * Seed/vege	0.281
South Australia	Invasion	**0.049**
	Seed/vege	**0.001**
	Invasion * Seed/vege	0.165
Tasmania	Invasion	0.890
	Seed/vege	**0.001**
	Invasion * Seed/vege	0.935

Of species that germinated in the glasshouse, most were herbs or graminoids (Figure 5). Very few shrub, tree or fern species were present. No differences were found between invaded and uninvaded sites. Herbaceous seedlings and grass seedlings dominated the germinants, suggesting that even those species of shrub, tree or vine that germinated were in low numbers (Figure 6).

Victoria



Tasmania



South Australia

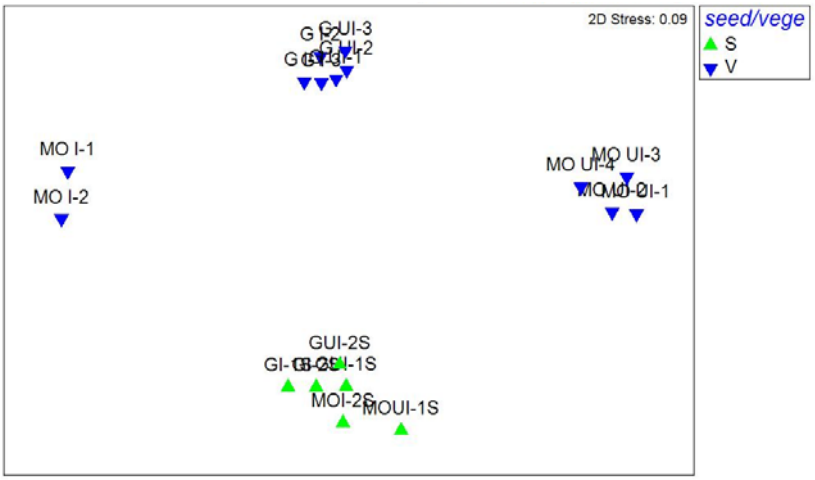


Figure 4. Ordination of differences in species composition between the seed bank and standing vegetation for invaded and native sites in all states.

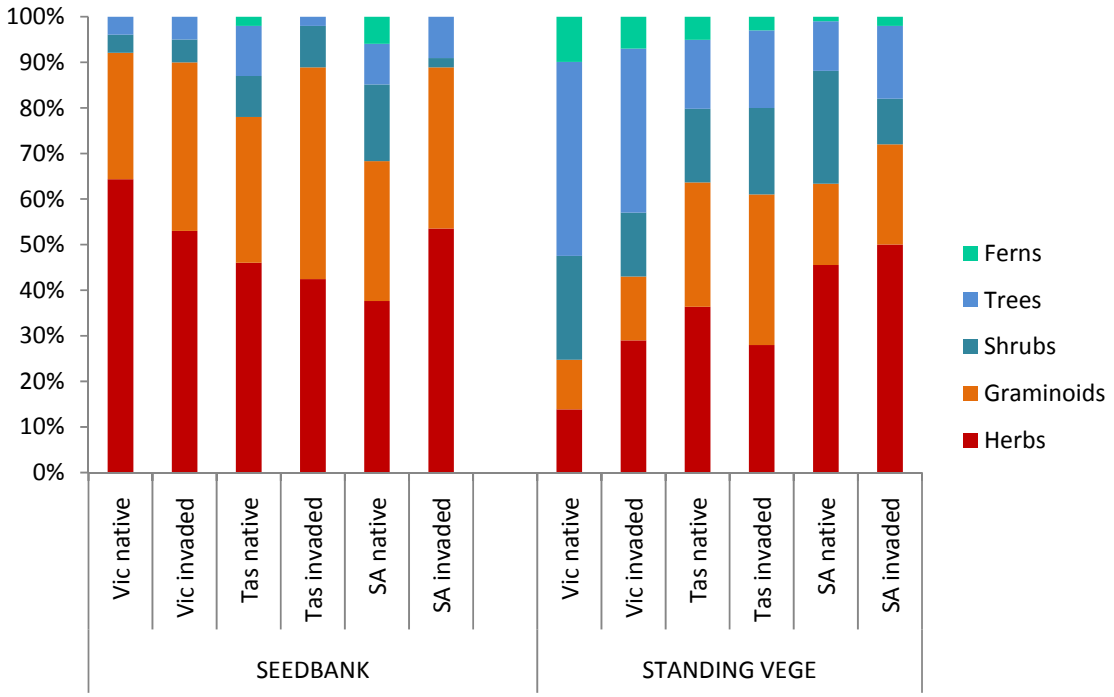


Figure 5. The percentage of species belonging to different functional groups in the seed bank trials compared to the standing vegetation.

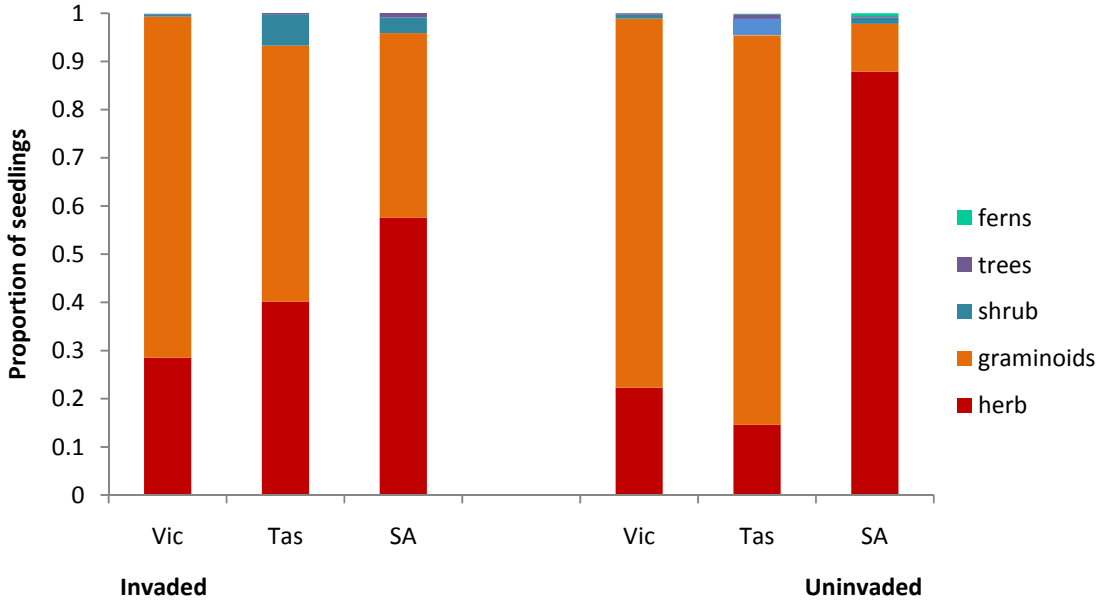


Figure 6 The proportion of seedlings of different functional groups in the seed bank trials from invaded and uninvaded areas.

For local areas where enough invaded and uninvaded sites were surveyed we identified which species were missing from invaded sites, and for comparison those species in invaded sites that were missing from native sites (Table 6). In most local areas, the species were distributed amongst all functional groups and there were more species missing from invaded sites than native sites. Furthermore, the species listed here are highly variable from one area to the next indicating the random nature of the species losses.

Table 6. Native species present in uninvaded sites only and in invaded sites only across different local areas where adequate sites were undertaken.

State/Location	Vegetation type	Natives present in uninvaded sites only	Natives present in invaded sites only
VICTORIA **Anglesea, Lorne and Wye River (8 sites)**	**Trees**	*Acacia mucronata* *Acacia stricta* *Allocasuarina littoralis* *Eucalyptus botryoides* *Eucalyptus cypellocarpa* *Eucalyptus saligna* *Banksia marginata*	*Acacia paradoxa* *Eucalyptus globulus*
	Woody/shrubs	*Billardiera brachyantha* *Billardiera macrantha* *Coprosma quadrifida* *Coronidium scorpioides* *Epacris impressa* *Gonocarpus tetragynus* *Notelaea ligustrina* *Olearia erubescens* *Persoonia juniperina* *Pimelea flava* *Pultenaea forsythiana* *Spyridium parvifolium* *Tetratheca ciliata* *Myoporum insulare*	*Pultenaea daphnoides*
	Herbs	*Clematis aristata* *Drosera aberrans* *Hydrocotyle hirta* *Myosotis australis* *Wahlenbergia gracilis*	*Acaena sp.* *Chrysocephalum semipapposum* *Desmodium gunnii* *Euchiton collinus* *Geranium sp.* *Glycine clandestine* *Solanum laciniatum* *Solenogyne gunnii* *Veronica calycina*
	Graminoids	*Austrostipa sp.* *Joycea pallid* *Microlaena stipoides* *Tetrarrhenia juncea*	
	Ferns	*Adiantum aethiopicum*	

SOUTH AUSTRALIA **Para Wirra (10 sites)**	**Trees**	*Acacia myrtifolia* *Acacia paradoxa* *Allocasuarina muelleriana* *Eucalyptus fasciculosa* *Eucalyptus goniocalyx* *Exocarpus cupressiformis* *Xanthorrhoea quadrangulata*	*Acacia acinacea* *Acacia calamifolia*
	Woody/shrubs	*Acrotriche depressa* *Astroloma conostephioides* *Bossiaea prostrate* *Calytrix tetragona* *Callitris preissii* *Correa reflexa* *Daviesia brevifolia* *Dodonaea viscose* *Eutaxia microphylla* *Gonocarpus mezianus* *Grevillea lavandulacea* *Hakea carinata* *Hakea rostrata* *Hibbertia crinita* *Hibbertia sericea* *Hybanthus floribundus* *Leptospermum myrsinoides* *Opercularia turpis* *Pimelea stricta* *Pittosporum phylliraeoides* *Platylobium obtusangulum dispar* *Prostanthera behriana* *Spyridium parviflorum* *Tetratheca pilosa*	*Amyema miquelii* *Astroloma humifusum* *Hymenanthera dentata* *Olearia ramulosa* *Pimelea linifolia* *Vittadinia blackii* *Vittadinia gracilis*
	Herbs	*Acianthus pusillus* *Buchardia umbellate* *Bulbine bulbosa* *Caladenia sp.* *Cassytha glabella forma* *Chamaescilla corymbosa* *Corybas dilatata* *Corybas sp.* *Cyrtostylis sp.* *Drosera glanduligera* *Glossodia major* *Hydrocotyle callicarpa* *Levenhookia pusilla* *Microseris lanceolata* *Pterostylis sanguine* *Thelymitra pauciflora* *Thelymitra rubra* *Tricoryne elatior*	*Convololus remotus* *Convolvolus erubescens* *Crassula sieberiana* *Dichondra repens* *Galium sp.* *Geranium solanderi* *Hydrocotyle laxiflora* *Plantago sp.* *Pterostylis robusta* *Rumex brownie* *Senecio quadridentatus* *Senecio tenuiflorus* *Solenogyne dominii* *Thelymitra nuda*
	Graminoids	*Lepidosperma semiteres* *Lepidosperma viscidum* *Lomandra collina* *Lomandra multiflora* *Lomandra soraria* *Poa clelandii* *Poa labillardieri* *Schoenus apogon*	*Austrodanthonia longifolia* *Austrodanthonia scabra* *Austrostipa setacea* *Echinopogon ovatus* *Elymus scaber* *Lomandra densiflora* *Lomandra nana* *Microlaena stipoides*

SOUTH AUSTRALIA Greenways and Naracoorte (8 sites)	**Trees**	*Banksia marginata* *Eucalyptus fasciculosa*	*Eucalyptus obliqua* *Melaleuca lanceolata*
	Woody/shrubs	*Bossiaea prostrata* *Brachyloma ciliatum* *Bursaria spinosa* *Helichrysum apiculatum* *Hibbertia villifera* *Leptospermum myrsinoides* *Leucopogon rufus*	*Astroloma conostephioides* *Goodia lotifolia* *Hibbertia crinite*
	Herbs	*Ajuga australis* *Arthropodium sp.* *Buchardia umbellata* *Caesia vittata* *Caladenia carnea* *Caladenia latifolia* *Crassula peduncularis* *Daucus glochidiatus* *Geranium retrorsum* *Glossodia major* *Pelargonium littorale* *Phyllangium sulcatum* *Senecio picridioides* *Stylidium graminifolium* *Thysanotus patersonii*	*Corybas dilatata* *Dianella revolute*
	Graminoids	*Lepidosperma carphoides* *Poa sp.*	*Austrostipa setacea*
TASMANIA Gordon's Hill, Penna, and Sandford (14 sites)	**Trees**		*Eucalyptus pulchella*
	Woody/shrubs	*Gonocarpus tetragynus* *Pimelea humilis*	*Correa alba*
	Herbs	*Acaena novae-zelandiae or ovina* *Asperula sp.* *Bulbine glauca* *Galium sp.* *Geranium solanderi* *Lepidium sp.* *Senecio linearifolius* *Wahlenbergia sp.* *Wurmbea dioica*	*Crassula helmsii* *Gnaphalium sp.* *Plantago varia* *Silene gallica* *Xanthosia dissecta*
	Graminoids	*Carex breviculmis* *Juncus bassianus* *Poa poiformis* *Tetrarrhena (prob. T. distrenophylla)* *Themeda triandra*	*Danthonia geniculata*
	Ferns	Cheilanthes austrotenuifolium	
TASMANIA O'Possum Bay, Bicheno, and Deriot (12 sites)	**Trees**	*Acacia dealbata* *Acacia terminalis* *Pittosporum undulatum* *Polyscias sp.*	*Acacia floribunda* *Acacia myrtifolia* *Acacia suaveolens* *Allocasuarina verticillata* *Eucalyptus viminalis*

Woody/shrubs	*Bossiaea cinerea* *Gonocarpus tetragynus* *Hibbertia acicularis* *Hibbertia impetrifolia* *Indigofera australis* *Leucopogon collinus* *Leucopogon parviflorus* *Opercularia*	*Bursaria spinosa* *Leptomeria drupacea* *Olearia ramulosa* *Olearia stellulata* *Pomaderris elliptica* *Pultenaea daphnoides* *Tetragonia tetragonoides*
Herbs	*Drosera* *Geranium solanderi* *Goodenia* *Goodenia lunata*	Acaena novae-zelandiae or ovina *Chiloglottis* *Dianella tasmanica* *Einadia nutans* *Galium australe* *Gnaphalium* *Hydrocotyle* *Senecio glomeratus* *Solanum sp.*
Graminoids	*Austrodanthonia setacea* *Poa labillardierei* *Themeda triandra*	*Austrostipa flavescens* *Austrostipa rudis* *Carex sp.* *Deyeuxia monticola* *Gahnia grandis* *Juncus pallidus* *Lepidosperma gladiatum* *Microlaena stipoides* Themeda australis

EFFECTS OF BONESEED INVASION

Our results confirm that boneseed reduces biodiversity. There is a 25 % reduction in native species richness in invaded sites. Furthermore, herbs, shrubs and trees are more negatively affected, while graminoids, ferns and vines are less affected. Ferns and vines are rare within all vegetation types and therefore hard to identify changes in richness with invasion. However, grasses are very speciose in many habitats but seem to persist despite invasion. No change in species composition was evident between invaded and uninvaded sites, suggesting that the reduction in species richness has not resulted from a consistent loss of particular species or a small set of growth forms. Instead species loss has been relatively erratic, although the more dominant shrubs, trees and herbs are where losses have mostly occurred. Species that are lost from invaded areas are not predictable.

These results suggest a particular approach for the management of invaded sites for biodiversity conservation. Rather than focus on specific species at risk, management needs to monitor species recovery following weed control and manage the return of all plant functional

types. Guidelines for undertaking this process have been trialled along the south coast of NSW for sites managed for bitou bush (French 2010). This approach is promising, providing a time line and mechanism for determining species needing to be actively replanted at sites.

Exotic species were more abundant in invaded sites, posing a risk by continuing to replace native species within invaded sites but also indicating an increased risk of secondary invasion following any control measures to remove boneseed. Prioritisation of exotic species may be needed to focus management on removing the most problematic species.

The seedbank is unlikely to be the dominant mechanism of restoration of sites. The seed bank was vastly different in composition from the above ground vegetation and was similar across all sites within each state, despite being collected from different vegetation types and in invaded and native areas. Very few shrubs and trees germinated in the seed bank trial with herbs and grasses dominating both in richness and abundance. While this may be a result of an inability to break dormancy cues of some species, it is more likely to be a deficit of seeds in the seed bank for the bulk of the species.

The species composition of the seed bank was affected by invasion in Victoria and South Australia, but not in Tasmania, suggesting that invasion does influence the capacity of the seed bank to restore vegetation. More importantly however, the capacity of all sites to regenerate effectively from the seed bank is limited and in order to ensure the conservation of biodiversity into the future, monitoring of species richness at sites, particularly those where management of boneseed has occurred, will be needed to ensure management can facilitate the establishment of missing species.

This project took a broadscale geographical approach to identifying the impacts of boneseed. Further surveys within each region are likely to confirm the patterns we identified here and elucidate more details about biodiversity losses. Rebuilding resilient natural communities and ensuring that biodiversity at the regional scale is maintained is a major management issue for the future.

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Appendix 1. Sites surveyed with details of land tenure, history, vegetation communities and invasion of boneseed.

VICTORIA	.	No. sites	Habitat and history	Infestation
Victorian Vulcanic Plain	**You Yangs Regional Park**	5	Granite based soils with low rainfall. Little indigenous veg. survived European settlement. Low species diversity with a range of exotic plants, timber plantations and revegetation projects. Long pastoral history. Regional Park with strong visitor pressure. Sites comprise two former quarry sites with lots of disturbance and no boneseed treatment, one untouched site with no treatment and two boneseed leaf buckle might release sites. **Dry open forest** dominated by *Acacia mearnsii, Acacia pycnantha*, ground layer of *Austrodanthonia geniculata* and *Cheilanthes sieberi, Microlaena stipoides, Einadia nutans* and *Oxalis exilis*	All plots surveyed had a boneseed cover of 75 - 100% Bushfire of 1985 distroyed most groundcover and shrubs in the park.
	Granite Rocks	2	Granite based soils. Former local tip – very disturbed soil. Clusters of boneseed infestations throughout the site which are, however, controlled by hand pulling. Now private property under covenant of Trust of Nature. **Dry open forest** dominated by *Eucalyptus rubida* and *Eucalyptus macrorhyncha* in the canopy layer and *Lomandra filiformis, Prosanthera nivea, Dianella admixta* and *Austrostipa* in the ground layer.	Two uninvaded plots, no boneseed present but disturbed site
	Batesford	2	Granite based soils. Private property (78 Ha) surrounded by agricultural fields. Most of the land protected under Covenant of Trust of Nature. The place has not been burnt for a long time. Granite based woodland with strong affinity to YouYangs and Granite Rocks. **Dry open forest** dominated in both sites by *Cassinia aculeata* and *C. arcuata* and in the uninvaded plot only by *Allocasuarina verticillata*, *Eucalyptus leucoxylon* and *Cheilanthes sieberi.*	One invaded plot with boneseed cover of 75 - 100% and one adjacent uninvaded plot of just a few individuals both on disturbed ground Private property under Covenant Trust of Nature
Gipsland Plain	**Lysterfield Park**	5	Granite based soils. Park since 1940's former farmland. Lysterfield Lake served as fresh water supply for Mornington Peninsula. In the invaded plot boneseed has regenerated after initial control measures. Site LPUI-2 had a wildfire in 2003. Other sites untreated – no boneseed problem. The 4 uninvaded sites were in **damp sclerophyll forest**, and **heathy woodlands** with *Eucalyptus oblique, E. ovata* and *E. radiata* dominated the canopy layer and *Allium triquetrum, Geranium sp., Dichondra repens* and *Hypochaeris* , *Oxalis* species and *Lomandra longifolia* as ground cover. The invaded site was in **dry open forest** with scattered rocks. Dominant species were *Eucalyptus radiate* over *Oxalis* sp., *D. repens*, *L. longifolia and Lepidosperma laterale.*	One invaded plot with boneseed cover of 75 - 100%. The uninvaded plots had 0 to a few boneseed plants (just in one plot)

VICTORIA continued	.	No. sites	Habitat and history	Infestation
	Arthur's Seat	2	Granite based soils. Arthur's Seat State Park rises above the Mornington Peninsula up to a height of 305 metres (summit). The state park was declared 1988 to "protect bushland left relatively untouched by human intervention". The 1998 Management Plan does not mention any specific measures taken to deal with the boneseed problem. Our invaded plots were consequently heavily invaded. The uninvaded plot is located in **damp sclerophyll forest** dominated by *E. ovata* and *E. radiata* in the canopy layer with *Pteridium esculentum (75 – 100% cover), Cassytha melantha Goodenia ovate, Gahnia radula,* and *Oxalis sp.* underneath. The invaded site is **dry sclerophyll forest** dominated by *Allocasuarina verticillata* and *Eucalyptus viminalis* in the canopy layer and *Anthoxanthum odoratum, Austrodanthonia sp., Microlaena stipoides,* and *Oxalis sp.*underneath the canopy.	One uninvaded site and one invaded site with boneseed cover of 75 - 100% Uninvaded plot had 0 boneseed
Midlands	**Maldon**	4	All sites on Council land and former grazing land, now high pressure of kangaroo grazing. The two uninvaded sites are on Malden Heritage Reserve land. Boneseed control is undertaken. The two uninvaded sites are in **dry open forest** dominated by *Eucalyptus microcarpa* or *E. goniocalyx* respectively, the shrub layer and ground layer by *Cheilanthes austrotenuifolia* and *Gonocarpus elatus* as well as *Austrodanthonia and Austrostipa sp., Lomandra filiformis and Oxalis sp.* The two invaded plots are **former pasture land** with only the occasional tree, i.e. *Acacia implexa as well as Austrostipa and Erodium sp., Avena barbata, Cheilanthes austrotenuifolia, and Themeda triandra in the understorey.*	The two invaded sites have a boneseed cover of between 50-75 % and 75 – 100% respectively.
Otway Range	**Anglesea**	4	All sites are on Crown land (Reserve land). The sites were situated in the Anglesea Heath area with a mining area and the village of Anglesea close by. Extraction of brown coal since the 1960's. plots situated on **wet/damp sclerophyll forest** dominated by *Eucalyptus ovata*, as well as *Acacia longifolia* and *Acacia verticillata* and an understorey of *Cassinia aculeate*, *Cassytha melantha, Dianella admixta, Goodenia ovata*, and *Leptospermum continentale*	Two invaded sites had a boneseed cover of 75 - 100%. In one of the two uninvaded sites boneseed was uncommon & cover < 5 % (edge invasion) while in the other one there were only one/few individuals.

VICTORIA continued	.	No. sites	Habitat and history	Infestation
	Lorne	3	The invaded plot was south of Lorne on a hill site sloping away from the sea. Reserve land managed by Parks/Council. Controlled burns to manage boneseed in vicinity of site. The two uninvaded sites were also on National Park reserve land with visitor pressure due to campsite nearby. **wet/damp sclerophyll forest** dominated by *Eucalyptus obliqua* and *E. viminalis* and understorey of *Olearia lirata, Pteridium esculentum* and *Poa labillardierei*	One invaded site with boneseed cover of 50 - 75 %. Two uninvaded site no boneseed present
	Wye River	1	The Wye River site is in a park reserve managed by parks. Boneseed managed by hand pulling **wet/damp sclerophyll forest** dominated by *Eucalyptus viminalis, E. obliqua, E. globulus* and understorey of *Acacia paradoxa* and ground layer of *Lepidosperma laterale* and *Poa labillardierei*	One invaded plot with boneseed cover of 50 - 75 %
SOUTH AUSTRALIA				
	Cleland Conservation Park	3	The park has a history of sheep grazing, timber production, mining and was not bought by the government until 1945. Last fire disturbance in 1983. **Blue gum forest** dominated by *Eucalyptus leucoxylon, E. obliqua*, and *Acacia pycnantha*, and a ground cover of *Senecio, Erhardta, Arthropodium* and *Microlaena*	Three invaded sites, two of which with boneseed cover of 75 - 100 % one site with cover 20 - 50 %
	Manning Reserve	3	45 ha reserved owned by Field Naturalist Society of South Australia. Disturbance due to kangaroo grazing and visitor pressure. Last fire disturbance not known. Boneseed infestations are managed by hand pulling and cut and swab by volunteers. Some work is carried out by contractor labour paid for by Heritage Agreement. **heath and heathy woodland vegetation** dominated by *Acacia myrtifolia, Eucalyptus fasciculosa* and *E. albopurpurea, as well as Hibbertia* and *Leptospermum sp., Olearia axillaris, Astroloma conostephioides*, *Calytrix tetragonia* and *Xanthorrhoea semiplana*	Three uninvaded sites, two of which have some boneseed but uncommon & < 5 % cover.
Yorke District	**Innes NP**	2	History of agriculture and grazing. The 9232 ha park at the southern tip of Yorke Peninsula was first pronounced in 1970. Boneseed is controlled by hand pulling. Sites very close (approx. 10 m apart) to each other. **shrubland** dominated by *Acacia microcarpa, Acacia* sp. 'Winged', *Acacia leiophylla* and *Acacia cupularis* plus a high cover of *Leucopogon parviflorus* in both plots	One invaded and one uninvaded plot. Invaded plot with boneseed cover of 20 - 50 %, uninvaded plot with boneseed uncommon & < 5 %

SOUTH AUSTRALIA continued	.	No. sites	Habitat and history	Infestation
	Para Wirra Recreation Park	10	1409 ha of parkland first proclaimed National Park in 1962 then renamed 1972 as recreation park. Most of park covered in eucalypts, especially Long-leaf Box, Pink Gum, Blue Gum and Golden Wattles and scattered native pines, underneath the trees yaccas and heaths. Boneseed is mainly managed by cut and paste and removal/hand pulling. **low open woodland** dominant species were *Eucalyptus leucoxylon, E. fasciculosa* and *Acacia pycnantha* and a dense cover of *Hibbertia exutiacies* underneath some plots could be more closely described as **closed scrub** with dominant species *Eucalyptus odorata*, *Allocasuarina muelleriana* and *Hibbertia* and *Hakia carinata*	Six invaded plots of four with boneseed cover of 20 - 50 %, one with cover of 50 - 75 % and one with cover of 75 - 100 %. Of the uninvaded sites only one had a cover of one/few individuals & < 5 % cover. The others had no boneseed present
	Greenways Heritage Agreement Site	6	Heritage Agreement site relative narrow strip of land surrounded by agricultural fields Before the time this survey was conducted boneseed was managed by controlling only outlying populations away from majorly infested area by hand pulling and cut and paste. However, in the 2007 draft of a fire management plan a prescribed burn was suggested and it is not known whether the plan has gone ahead. **low open forest** dominant species *Eucalyptus obliqua, Acacia longifolia* and below *Xanthorroea australis, Austrodanthonia clelandii* and *A. geniculata*, as well as *Leucopogon parviflorus* and *Pimelea humilis*	Three invaded sites , two of which with a boneseed cover of 50 - 75 % and one with boneseed cover of 75 - 100 % The three uninvaded sites had no boneseed present in the plot.
	Naracoorte Nature Reserve	2	One plot situated next to a quarry, one plot near a football field close to habitation both sites heavily disturbed. The two plots are approx. 1 km apart. **Woodland** dominated by *Eucalyptus baxteri, Acacia longifolia, Acacia mearnsii,* and *Acacia paradoxa,* underneath grows predominantly *Pteridium esculentum* and some *Dodonaea viscosa*	One invaded plot with boneseed density of 50 - 75 % . One uninvaded plot with no boneseed present.
	Morialta Conservation Park	6	Part of the Greater Mount Lofty Parklands-Yurrebilla. Boneseed control is undertaken by volunteers using hand pulling and cut and paste techniques. **heathy open woodland (boneseed uninfested sites)** dominated by *Eucalyptus obliqua*, some *Acacia myrtifolia*, understory of *Buchardia umbellate, Gonocarpus tetragyna, Hakea rostrata, Hibbertia crinita, Isopogon* and *Ixodia* **Open Woodland (boneseed infested sites)** dominated by *Eucalyptus leucoxylon* with ground layer of *Austrodanthonia clelandii* and *Bromus madritensis.*	Two invaded sites with boneseed density of 20 - 50 %. Four uninvaded sites two of which with one/few individuals % < 5 % cove. The other two with no boneseed present.

TASMANIA		No. sites	Habitat and history	Infestation
	Gordons Hill Parks and Wildlife Reserve	4	Reserve land on a hill site. Boneseed control currently undertaken by volunteer groups using cut and paste and remove and hand pull methods on the last remaining sizeable patches of infestation. Wildfire events between 2000 and 2003. Disturbance due to recreation area and wallaby grazing. Described as **open eucalypt woodland** most sites dominated by *Allocasuarina verticillata* with some *Acacia mearnsii, Bursaria spinosa, Cheilanthes austrotenuifolia, Lepidosperma laterale, Bulbine glauca* and *Cerastium*	Boneseed invaded sites with a cover of between 50 - 75 % and 75 - 100 %. Two uninfested plots one without any boneseed present, the other one with boneseed uncommon & < 5 %.
	Penna Private	6	former pasture now left for conservation. Disturbance wallaby grazing. All sites on same hillside above farm buildings. Boneseed control was undertaken by owner using primarily hand pulling and cut and paste techniques. **Pasture and shrubland** dominated by *Bursaria spinosa* in the shrub layer and *Senecio* and *Danthonia geniculata* and *Crassula sieberiana* in the ground layer	Three invaded plots with boneseed cover of between 50 - 75 % (two) and 75 - 100 % (one plot). Uninvaded plot with one plot boneseed uncommon & <5 %, one plot with one/few individuals & < 5% and one plot without boneseed.
	Sandford Private	4	**SF-I 1 and SF-UI 1 pasture land now left for conservation** dominated by *Austrostipa semibarbata, Dichondra repens*, and weeds such as *Plantago lanceolata, Hypochaeris sp.,* and *Marrubium vulgare*. Little difference between infested and uninfested plot. Some release of boneseed leaf buckle mite on the property. Currently no other measures undertaken to control boneseed. **SF-I2 and SF-UI2 Casuarina "sketchy" woodland** dominated by A*llocasuarina verticillata, Astroloma humifusum, Dianella revoluta*, and *Einadia hastata*	Two invaded sites, one with boneseed cover of 20 - 50 % and one of 50 - 75 %. One uninvaded site with no boneseed present and one with one/few individuals & < 5% cover.
	Dodges Ferry	4	All four sites are **foredune and hinddunes** plant communities. Boneseed leaf buckle mite has been released in the area and hand pulling and cut and paste was undertaken by volunteers in the past. The sites are dominated by *Banksia marginata* and *Acacia longifolia* with *Lomandra longifolia* and *Leucopogon parviflorus* as well as *Rhagodia candolleana* or *Pteridium esculentum* forming the ground layer	Two invaded plots with 20 - 50 % and 50 - 75 % boneseed cover, respectively. Two uninvaded plots, one without boneseed and the other one with boneseed uncommon &<5 %

TASMANIA		No. sites	Habitat and history	Infestation
	O'Possum Bay	4	The sites are situated on fore- and hinddune land. OBI-1 one of the invaded plots is on Crown land reserve and is a beach site (Foredune) community which has been managed by hand pulling boneseed for the last 5 years. The other sites are council land behind houses and are hinddune vegetation. No visible boneseed control undertaken. **Foredune (OB-I 1) and Hinddune (OB-I 2, OB-UI 1,2)** dominated by *Eucalyptus amygdalina, Lepidosperma concavum, Lomandra longifolia*, and *Pteridium esculentum*, with some *Acacia melanoxylon* and *Dodonea viscosa* and *Rhagodia candolleana*	Two invaded plots with boneseed over of between 20 and 50 % and between 50 and 75 % respectively. Two uninvaded plots without any boneseed present.
	Bicheno	6	Crown land sites. All sites on hill site area. Boneseed control measures are in place, however, need to be intensified as samples showed boneseed is present in all the plots. Further control measures have been planned. Hill site behind Bicheno a few 100 metres from ocean, **Eucalypt Open Woodland** dominated by *Eucalyptus amygdalina, E. pauciflora, Allocasuarina littoralis, Exocarpus cupressiformis, Lomandra longifolia, Lepidosperma laterale,* and *Pteridium esculentum*	Three invaded plots with boneseed over of between 20 and 50 % (two) and 5 and 20 % (one). Bonseed uninvaded sites with one/few individuals & <5 % (two sites) and one with boneseed uncommon & <5 %
	Deviot	2	Private land north of Launceston. Boneseed controlled in most of the north. But not yet on this plot of private land behind houses. **Eucalypt Open Woodland** dominated by *Eucalyptus amygdalina* (both plots), *E. viminalis* (only boneseed invaded plot), only uninfested plot: *Lepidosperma concavum, Lomandra longifolia, Pteridium esculentum* and *Cyrtostylis* and *Banksia marginata* (one only) In both invaded and uninvaded plots: *Epacris impressa*	One invaded plot with boneseed cover of 75 - 100 % and one uninvaded plot without any boneseed present.