# Weed eradication

Strategies, timeframes and costs

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*Helping Communities Helping Australia*
A Commonwealth Government Initiative

Australian Government
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# Executive summary

**Information on weed eradication programs was collected – eight were completed programs, four were being monitored, seven were ongoing, and one had failed.**

Information was collected on 20 weed eradication programs from Australia and overseas. This information included the cost or effort involved to conduct the eradication program, the area searched and the area treated, methods used, and a description of the weed infestation. Eradication programs close to expected completion were also included because there were so few completed eradication programs. The costs of uncompleted eradication programs were minimum values as further costs can be expected to complete these programs. The 20 case studies comprised eight completed eradication programs, four programs for which control is complete but where the site is still being monitored, seven sites with ongoing control, and one failed program.

**Most of the successful eradications had a net area less than 4 ha, and the ongoing programs were generally greater than 4 ha.**

Of the eight successful case studies, seven were for species with a net infestation area of less than 4 ha. For the ongoing and continuing eradications, net infestation areas were variable but generally higher, with half the monitored case studies and two-thirds of the ongoing case studies having net infestation areas greater than 4 ha. The failed eradication had the largest net area (3400 ha) of all the case studies. These results support the theory that a small net area of infestation increases the likelihood of a successful eradication.

**Cost was modelled as a function of other attributes, and a regression was fitted that estimated cost based on net infested area.**

The data set from the 19 complete or near-complete eradication programs were compiled for analysis. The analysis involved standardising the measurement of effort into an estimated cost in dollars for each eradication case study. Then regression was used to model the cost as a function of the other attributes, including the area of infestation, the number of sites, the distance between sites and the duration of the eradication program. A regression was fitted that enabled the cost of eradication to be estimated based on net area of infestation. Eradication costs increased sharply with increasing area of infestation. The regression estimated an average cost of $4270 for eradicating an infestation with a net area of 0.1 ha, $19,700 for an area of 1 ha, and $1,052,500 for an area of 400 ha. These results strongly support the theory that a small net area of infestation greatly reduces the cost of eradication.

**In some instances actual costs were higher than the estimated costs, as factors other than net area can increase eradication effort.**

Three of the 19 weeds we assessed had much higher costs than were predicted from the regression based on their area of infestation. Several factors could account for this. All three infestations had been present for a long time (53, 30 and 70 years) compared to the mean of all species (21 years). Two of the weeds had a high number of individual infestations (>800 and 90) compared to the mean of all species (59 infestations). The third weed had spread widely, and although the actual area of infestation was small, the maximum distance between infestations was 280 km (compared to the mean maximum distance of 98 km). Two of these weeds were aquatic species which have previously been found to require more effort to eradicate than terrestrial species.

**The estimated costs were compared to estimates from the Cunningham model which included additional factors to determine cost. Estimates from the Cunningham model were generally higher than estimates from our regression.**

The cost of eradication for each weed species estimated from our regression model was then compared to the cost of eradication estimated for these weeds from a model (the Cunningham model) previously developed from estimates given by weed experts for eradicating 15 hypothetical weed infestations. The Cunningham model includes four factors which were found to significantly influence estimated eradication cost: area of infestation, number of infestations, ease of access to sites, and propagule longevity. The comparison between the models showed that the estimates of eradication costs from the Cunningham model were, on average, several times higher than the estimates from our model based on actual eradication case studies. The results from the case studies do not suggest that the additional factors included in the Cunningham model are not important. Our sample size was too small to enable us to test the significance of these factors adequately. Also, some of our costs used in the regression only included the number of work hours spent on a program. This is likely to underestimate total costs, which could be expected to include costs for equipment, herbicides, and other items. Costs of eradication are most likely to be somewhere between those estimated by the Cunningham model and by our regression.

**Field surveys of ten agricultural sleeper weeds were conducted – net areas of infestation were generally small.**

Field surveys were conducted to determine the geographical distribution of ten agricultural sleeper weeds identified in a previous study as potential targets for eradication. These ten weeds were selected because of their potential wide distribution in Australia and their potential impact on agriculture (benefit of eradication), as well as the feasibility and potential cost of their eradication. The ten weeds selected all had high benefit:cost ratios for eradication relative to other weeds that were assessed. Twelve field surveys for these ten sleeper weeds were completed. Five of these weeds were characterized by a relatively high number of small infestations. Net areas of infestation were small (under 10 ha) except for one weed. The field surveys for three of the weeds could not locate them at previously known sites. These sites will be inspected in the future to determine if the infestations have been eradicated.

**Eradication costs of the ten sleeper weeds were estimated using both the Cunningham model and our regression.**

The costs of eradicating the seven agricultural weeds for which field surveys had determined the net area of infestation, were calculated using both our regression model and the Cunningham model. Our regression gave cost estimates between $5300 and $66,700 for all the weeds except for the one with the largest infestation area (34.2 ha) for which eradication was estimated to cost $214,400. The Cunningham model estimated higher costs between $23,500 and $553,000, and the weed which infested the greatest area was not found to be the most expensive, because the additional factors included in this model also contributed to the estimated cost.

**Other factors relating to site condition and management can influence the cost and success of weed eradication.**

Other factors that influence cost and success of weed eradication or control programs may include weed management strategy, accessibility of sites, terrain and vegetation where the infestation occurs, knowledge of infestations, environmental sensitivities, treatment type (for example, spraying from planes or boats, hand-pulling, different chemical costs), cooperation of landholders, and social factors. One species cost almost nine times less to eradicate than the cost estimated from our regression model. The fact that such a large infestation area was eradicated for a comparatively small cost was mainly due to knowledge of all infestation sites. This species was intentionally planted on salt-affected land for forage and land rehabilitation, and because sites were known, they could be targeted directly without the need for extensive searching.

**Biological attributes of a weed will also affect the effort required to eradicate it.**

Biological attributes may provide information on the persistence of a species, and therefore, the feasibility and cost to eradicate it. For example, species that produce abundant seeds and a large persistent seed bank, and species that can reproduce from stem or leaf fragments may have vigorous and rapid reproduction. Although the correlation was not strong, our case study data showed eradication programs tended to run for a longer duration for more persistent species. Unfortunately, many of biological attributes of the weeds in this study were poorly known, so their affect on eradication feasibility and cost could not be assessed.

**Eradication of many surveyed sleeper weeds could probably be achieved**

Eradication could be achievable for many of the sleeper weeds surveyed, and the models predict that the cost of eradication is in the range of $5300 to $550,000 per weed.

# Contents

# 1. Introduction

Eradication of a weed species is an appealing option because it completely removes the detrimental effects of the weed as well as the high cost of continuing control (Bomford and O'Brien 1995). Eradication is defined as the complete and permanent removal of all wild populations from a defined area by a time-limited campaign (Bomford and O'Brien 1995). It is important that an eradication campaign is 'time-limited', that is, eradication needs to be achieved by a fixed date otherwise it is really continuing control (Bomford and O'Brien 1995). Eradication of a newly introduced pest is seen as a favourable option if the pest will: a) increase the cost of production or reduce the volume or value of production, b) pose health risks, c) cause extensive environmental damage, d) lead to quarantines and export restrictions, and e) increase the use of chemicals and other expensive controls (Myers *et al*. 1998). However, controlling an invader at a density sufficiently low that it is tolerable is usually seen as the appropriate response (Simberloff 2003). Often a management plan is specifically aimed at eradication of a species, but the methods are the same as those that would be used to reduce a population to an economically or ecologically acceptable level (Simberloff 1997).

Eradication of a species is assumed to be successful when the infestation area has been free from any individuals for the known life of the seedbank. This can be difficult to define as the life of a seed in the seedbank can only be an estimate, and often nothing is known about the seedbank (Wotherspoon and Wotherspoon 2002). The main difficulty in eradicating terrestrial plants is that seeds can remain viable in the soil for up to a century (Simberloff 1997). Furthermore, for eradication to be successful the area should be sufficiently isolated so that recolonisation is unlikely to occur (Myers *et al*. 1998).

Bomford and O'Brien (1995) determined six criteria for assessing whether eradication is technically possible and preferable to continuing control. These criteria were established for vertebrate pests but also apply to any other pest eradication. The six criteria are: 1) rate of removal exceeds rate of increase at all population densities; 2) immigration is zero; 3) all reproductive individuals must be at risk; 4) target species can be detected at low densities; 5) discounted benefit-cost analysis favours eradication over control; and 6) there must be a suitable socio-political environment. The first three criteria are essential for achieving eradication, and the last three are seen as desirable and determine whether eradication is preferred to continuing control.

Attempting to eradicate populations that are restricted in distribution is usually much more cost-effective than long-term control and may have a high probability of success, particularly if potential invasives are treated during their establishment or 'lag phase' (Soria *et al*. 2002). Sleeper weeds are in the 'lag phase' of establishment, before rapid proliferation and spread occurs. Sleeper weeds are similar to recent incursions, but differ in that they have been present as naturalized populations for some time but have been prevented from spreading by some environmental constraint. Examples of sleeper weeds in Australia include pampas grass (*Cortaderia selloana*), a sleeper weed for decades before becoming a major weed in the 1970s (Rawlings 1994), and giant sensitive plant (*Mimosa pigra*), which was introduced to Darwin in the late 1800s and was a minor weed until the 1970s (Lonsdale *et al*. 1989).

The primary aim of this project was to collate information from case histories of weed eradications (local, regional, or national, both in Australia and overseas) to support the development of eradication plans for weeds. Information on strategies, timeframes and costs for previous weed eradications were used to develop practical information on how to implement eradication programs. The case study information, together with field survey data, was used to assess the feasibility and cost of the eradication of 10 priority sleeper weeds in

Australia, previously identified in Cunningham *et al.* (2003). The results will be made available to States and other key interested parties to inform the development of weed eradication programs for agricultural sleeper weeds and other weed incursions at local or regional scales.

# 2. Method

## 2.1 Field assessment of sleeper weeds

Ten priority sleeper weeds were previously identified in Cunningham *et al*. (2003). These were determined based on their potential distribution in Australia and impact on agriculture, as well as the feasibility of eradication, and expressed as a benefit/cost ratio. Two of the sleeper weeds occur in two States and the rest occur in only one State/Territory. These weeds are:

*Asystasia gangetica* subspecies *micrantha* (New South Wales)

*Baccharis pingraea* (Victoria)

*Centaurea eriophora* (South Australia)

*Crupina vulgaris* (South Australia)

*Eleocharis parodii* (New South Wales)

*Nassella charruana* (Victoria)

*Oenanthe pimpinelloides* (South Australia and Victoria)

*Onopordum tauricum* (Victoria)

*Piptochaetium montevidense* (Victoria)

*Rorippa sylvestris* (South Australia and Tasmania)

Fieldwork to determine the current extent of these 10 weeds was managed through the Cooperative Research Centre for Australian Weed Management, and conducted by State agencies or independent consultants.

## 2.2 Eradication case study data collection

We collected information on successful and unsuccessful weed eradication programs from Australia and overseas. Sources were predominantly literature, the World Wide Web, and weed managers. This information included the cost or effort involved in carrying out the eradication program, methods used, and a description of the weed infestation and its distribution. We posted messages on two list-servers relating to weeds asking for suitable case studies. We emailed a survey to respondents which they completed and returned. Ideally only completed eradication programs were to be included, but these were so few, that eradication programs close to expected completion were also included. This is because sites where an infestation has been destroyed usually need to be monitored for many years due to longevity of the seedbank. Eradication programs were either on a local, regional or national scale, and populations were sufficiently isolated that reintroduction was unlikely.

Information on total cost of eradication programs was not always available. In some cases, the number of person days spent on a program was given and this was used to estimate labour cost. This cost was based on the mid-range salary of a technical field assistant plus an additional 23% for on-costs, totalling $196.85 per day (NSW agriculture rates). We consider this gives a conservative estimate, as it does not include other expenses such as herbicides, vehicle hire, travel allowance, and media campaigns. The costs given for uncompleted eradication programs (all after February 2001) are a minimum value as we can expect further costs to be incurred until their completion.

We also collected information on the biology of each case study weed. We intended to use these data in the main analysis so that the effect of biological attributes on eradication could be examined. However, information on the biology of each weed was often vague or unavailable. Instead, this information could more readily be incorporated into a scoresheet for eradication feasibility from Cunningham *et al.* (2003), where information is categorised more broadly and each weed given a score. Only the sections of the scoresheet that relate to persistence and control effort were used, as the other section relates to distribution and is therefore already covered in our other data collection and analysis.

## 2.3 Analysis

Data from the eradication programs were compiled for analysis. The analysis involved standardising the measurement of effort between the eradication attempts and then using regression to model the required effort (cost) as a function of other infestation attributes (e.g. net area of infestation, number of infestations, duration of eradication program). In this analysis, the uncompleted eradication programs were incorporated using standard techniques for censored data. Censored data in this context occurs when an eradication program is ongoing, and an imputed cost of eradication is given, which will be higher than the current presented value. The regression was fitted using Buckley-James distribution-free least squares which allows for right-censoring (Buckley and James 1979).

From the analysis of eradication case study data, a regression was fitted that enabled the cost of eradication to be estimated based on net area of infestation (see Section 3.2). The cost of eradication for each weed species estimated from this regression model was then compared to the cost of eradication estimated from the model of Cunningham *et al*. (2003). Cunningham *et al*.'s equation was developed from the responses of nine weed experts who each estimated the costs of achieving eradication of 15 hypothetical weed infestations. Cunningham *et al*. (2003) used a logistic regression analysis to measure the relative significance these experts attributed to 13 variables that potentially influence the cost of eradication. Four factors were found to significantly influence eradication cost: area of infestation, number of infestations, ease of access to sites, and propagule longevity. Other factors, such as tolerance to herbicide and time to seeding, did not have a significant influence on the experts' decisions and so were excluded from the model. In Cunningham *et al*.'s model eradication cost is calculated as:

$$\text{cost} = \exp\,[9.43 + (-0.5 \times A) + (-0.63 \times B) + (-0.36 \times C) + (-.042 \times D)] \times \$1000 \qquad (1)$$

where A is area category, B is number of infestations category, C is ease of access category, and D is propagule longevity category.

# 3. Results

## 3.1 Field survey of Australian agricultural sleeper weeds

Twelve field surveys for the 10 sleeper weeds (Section 2.1) were completed. Five of these weeds were characterized by a relatively high number of small infestations (*A. gangetica* ssp. *micrantha, C. eriophora, O. pimpinelloides* in S.A., *R. sylvestris* in both Tasmania and S.A.). In nine cases the total gross infested area[1] was less than 10 ha (Table 1). Net areas[2] were considerably smaller and only one infestation (*O. pimpinelloides* in S.A) had a net area greater than 10 ha.

Field surveys for *C. vulgaris*, *E. parodii* and *P. montevidense* could not locate these weeds at the previously known sites. *C. vulgaris* was known from an infestation growing in the Hope Valley Reservoir in Adelaide. The site will be resurveyed in October/November 2004 when the species is known to flower. *E. parodii* was previously found growing in irrigation ditches in rice fields in Tharbogang near Griffith, New South Wales. The rice field has since been converted to grow grapes and the irrigation ditches have been infilled and replaced with pipes. Field surveys searched the supply and drainage channels in the vicinity and to a wetland 20 km downstream for spread of this weed but found no plants. *P. montevidense* had previously been recorded at Cherry Lake in Altona, Victoria but during field surveys, no plants were found and the infestation appeared to have been buried under several metres of landfill. The Victorian Department of Primary Industries will inspect the site in the future to determine if the infestation has been eradicated.

In Tasmania *R. sylvestris* was previously known from five sites but could not be located at two of these sites – one was in a bulb nursery but was successfully controlled by herbicide application and droughting, whereas the other infestation was absent for unknown reasons. Due to the mode of spread of *R. sylvestris* in Tasmania (via wholesale bulb nurseries), it is likely that there may be further infestations of this weed in Tasmania. In South Australia *R. sylvestris* was recorded at Zadow's Landing and Mypolonga but the species was incorrectly identified. The species was later identified correctly as *R. palustris* which closely resembles *R. sylvestris*. *N. charruana* was previously known from nine sites in the Melbourne region. Field surveys recorded this weed at three of these sites (Cooper St. in Epping, Craigieburn grassland in the City of Whittlesea, and Edgars Rd in Thomastown); at another three sites the weed could not be located (Plenty Gorge Park in Yan Yean, O'Herns Rd in Epping North, and north of Cooper St. in Epping); and a further three sites were not surveyed but will be surveyed next year (Barry Rd in Thomastown, Wollert, and Old Lalor golf course). *O. pimpinelloides* was previously recorded at two sites in Victoria, but field surveys could not relocate it at one of the sites and it is believed that new housing developments may have covered the infestation.

## 3.2 Eradication case study data and analysis

Twenty weed eradication case studies (15 from Australia and five from overseas) were found with sufficient data for analysis (Table 2). Of these, eight were successfully completed eradications, four have not been declared eradicated as sites are still monitored but no re-

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[1] The area over which the weed is spread and must be searched.

[2] The area over which treatment must be applied.

emergence of the species has occurred, and seven still require some treatment although eradication is seen as a realistic goal in the near future. One case study was from a failed eradication attempt. The majority of case studies comprised eradication attempts at a local scale. Net infested areas ranged from 0.001 to 3300 ha, with most being <100 ha. This excludes the failed eradication case study which was 3400 ha. Number of infestations from completed or monitored/ongoing programs ranged from 1 to >800 with a maximum distance between infestations of approximately 850 km. Total cost of these eradications ranged from $200 to $2,000,000 over 1 to 39 years. Most eradication programs were commenced within one year of being reported to/by the authorities as being a weed problem or potential problem.

**Table 1**: Infestation details for agricultural sleeper weeds from field surveys.

| Species | Number of infestations | Gross area (ha) | Net area (ha) | Max. distance (km) | Ease of access to sites | Land use affected | Location |
|---|---|---|---|---|---|---|---|
| *Asyatasia gangetica* ssp. *micrantha* | 49 | 6.5 | 3.8 | 40 | High | Suburban gardens, roadsides | Port Stephens area, NSW. |
| *Baccharis pingraea* | 1 | 4 | 0.4 | 0 | High | Grazing | Near Maryborough, Victoria. |
| *Centaurea eriophora* | 40 | 8.5 | 4.1 | 4.5 | High | Roadsides, private land | Swan Reach, South Australia. |
| *Crupina vulgaris* | 0 | 0 | 0 | | High | Reserve | Not found at known site in the Hope Valley Reservoir, South Australia. |
| *Eleocharis parodii* | 0 | 0 | 0 | | High | Irrigation channel in cropping | Not found at known site in Tharbogang, NSW. |
| *Nassella charruana* | 5 | 50.02 | 6.004 | 10 | High | Suburban/rural roadsides, grassland | Three main sites in Melbourne region, Victoria. Not found at three other known sites; further three sites still to be surveyed. |
| *Oenanthe pimpinelloides* (S.A.) | 241 | 84.2 | 34.2 | 19 | Medium | Disturbed areas, paddocks, along watercourses | Finnis River catchment, South Australia. |
| *Oenanthe pimpinelloides* (Vic.) | 1 | 0.007 | 0.002 | 0 | High | Disturbed area | Kilcunda, Victoria. Not found at known site in Shepparton. |
| *Onopordum tauricum* | 3 | 10.073 | 0.52 | 350 | High | Grazing | Near Natimuk and Euroa, Victoria. |
| *Piptochaetium monteveidense* | 0 | 0 | 0 | | High | Grassland | Not found at known site at Cherry Lake in Altona, Victoria. |
| *Rorippa sylvestris* (Tas) | 19 | 1.4 | 0.1 | 40 | High | Wholesale nurseries | Three main sites - New Norfolk, Mountain River and Cradoc, Tasmania. Not found at other known sites in Kingston and Kettering. |
| *Rorippa sylvestris* (S.A.) | 17 | 0.0294 | 0.0113 | 2.1 | Medium to low | Watercourse | One main site at Aldgate Creek, South Australia. Incorrectly identified at Zadow’s Landing and Mypolonga. |

**Table 2.** Details of weed eradication case studies. [1] = Time taken from when the official report of the infestation was made, to the start of treatment of the eradication program; [2] = net area is the area on which treatment occurs; [3] = gross area is the area searched; [4] = maximum distance between discrete infestations.

| Species | Scale and description | Infestation age (yrs) | [1]Time to treatment (yrs) | [2]Net area (ha) | [3]Gross area (ha) | No. of sites | [4]Max. distance (km) | Program duration (yrs) | Total cost ($) | Result | Data source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Centaurea trichocephala* | Local: Abandoned pasture in Washington, USA | ? | 1 | <1 | <1 | 1 | 0 | 5 | 1380† | Completed | Mack and Lonsdale, 2002 |
| *Eupatorium serotinum* | Local/National: Disturbed area, Nerang, se Qld | ? | 1 | 0.5 | <5 | 2 | 1 | 18 | 9842† | Completed | Tomley and Panetta, 2002 |
| *Helenium amarum* | Local/National: Airfield & grazing, Lowood, se Qld | 10 | <1 | <50 | 50 | 2 | 1.6 | 39 | 72,835† | Completed | Tomley and Panetta, 2002 |
| *Hieracium pilosella* ssp. *nigrescens* | Local/National: Roadside, Midlands Hwy, s Tasmania | ? | <1 | 0.005 | <1 | 1 | 0 | 1 | 394‡ | Completed | Rudman and Goninon, 2002 |
| *Jatropha curcas* | Local: Planted, Mt Wells Battery, NT | >100 | <1 | 0.25 | ? | 1 | 0 | 5 | 4331† | Completed | Ian Miller, pers. comm. |
| *Pueraria phaseoloides* | Regional: Pasture, Santa Cruz Is., Galapagos Islands | 1 | <1 | 0.04 | <10 | 1 | 0 | 4.5 | 2953† | Completed | Soria *et al*., 2002 |
| *Salvinia molesta* | Local: Aquatic, Adelaide River, Northern Territory | <1 | 0.006 | 3.6 | <10 | 1 | 0 | 10 | 30,460 | Completed | Miller & Pickering, 1988; Ian Miller, pers. comm. |
| *Eichhornia crassipes** | Regional: Aquatic, Northern Territory | 0.6 | 0 | 2.354 | | 6 | 450 | 7 | 8800 | Completed | Ian Miller, pers. comm. |
| *Andropogon virginicus* | Local: Bush/residential, Woodburn, NSW | ? | <5 | 0.001 | 198 | 3 | 0.5 | 6 | 196† | Monitored | Tein McDonald, pers. comm. |
| *Bassia scoparia* | Regional/National: Sown on salt-affected lands, wheatbelt, WA | 3 | 3 | 3277 | ? | 52 | 850 | 8 | 494,581 | Monitored | Dodd & Randall, 2002; R. Randall, pers. comm. |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cenchrus echinatus* | Regional: Native grassland, Laysan Is., Hawaiian Islands, USA | >30 | 30 | 63.6 | 441 | 90 | 2.3 | 10 | 1,995,000 | Monitored | Flint & Rehkemper, 2002 |
| *Eichhornia crassipes** | Regional: Aquatic, Northern Territory | 2 | 0 | 2 | | 1 | 0 | 20 | >11,500 | Monitored | Ian Miller, pers. comm. |
| *Alternanthera philoxeroides* | Regional: Gardens and bushland, Melbourne suburbs, Vic | 53 | 1 | 1 | ? | >800 | <50 | 8 | 800,000 | Ongoing | Gunasekera & Bonila, 2001; Lalith Gunasekera, pers. comm. |
| *Citharexylum gentryi* | Regional: Agricultural Land, Santa Cruz Is., Galapagos Islands | 50 | 1 | 171 | >1200 | ? | ? | 2 | 141,338† | Ongoing | Soria *et al*., 2002 |
| *Cleome rutidosperma* | Regional: Suburbs and pastures, Darwin, NT | 10 | <1 | <10 | ? | 7 | 28 | 2 | 42,000 | Ongoing | Mitchell & Schmid, 2002 |
| *Hypochoeris radicata* | Local: Bush/residential, Woodburn, NSW | >18 | 18 | 15 | 198 | 12 | 0.5 | 8 | 9158† | Ongoing | Tein McDonald, pers. comm. |
| *Pasalum unvillei* | Local: Bush/residential, Woodburn, NSW | ? | ? | 1 | 198 | 12 | 0.5 | 15 | 2953† | Ongoing | Tein McDonald, pers. comm. |
| *Rubus glaucus* | Regional: NP forest, Santa Cruz Is., Galapagos Islands | 25 | <1 | 5 | 100 | ? | ? | 2 | 13,904† | Ongoing | Soria *et al*., 2002 |
| *Spartina angelica* | Regional: Estuaries, east and north coast Tasmania | 70 | 70 | 75 | 590 | 7 | 280 | 5 | >1,000,000 | Ongoing | Colin Shepherd, pers. comm. |
| *Chondrilla juncea* | Regional: Pasture/bush/roadside, wheatbelt WA | <10 | <10 | 3400 | 130,000 | >700 | ? | 28 | 56,000,000 †† | Failed | Pratt & Peirce, 2002; SWERP, 2002; R. Randall, pers. comm. |

* The monitored site of *Eichhornia crassipes* has been separated from the completed eradications of *Eichhornia crassipes* for analysis to make use of the additional data it provides.

† Total cost estimated from number of person days and the rate of $196.85 per day (technical field assistant salary plus on-costs).

‡ Cost was minimal as it was incorporated into road works, but is approximated as two person days of effort.

†† Total cost based on a conservative estimate, averaged at $2M per year from 1973 to 2002. NB Total budget for 2003/04 to control skeleton weed was $4.5M.

Analysis of the 19 case studies for which eradication was achieved or nearly achieved revealed a highly significant correlation between total cost of the eradication program and net area of infestation ($R^2 = 0.6613$, $p<0.001$) (Figure 1; raw data expressed as $\log_{10}$ values). Three species, *A. philoxeroides, C. echinatus* and *S. angelica* (A, B and C respectively on Figure 1) had high costs relative to their net area of infestation but several factors could account for this. All three infestations had been present for a long time (53, 30 and 70 years respectively) compared to the mean of all species (21 years). *A. philoxeroides* had a high number of individual infestations (>800) compared to the mean of all species (59 infestations). *C. echinatus* also had a relatively high number of infestations (90) as well as a high gross infested area (441 ha) compared to the mean gross infested area of all species (295 ha). The infestations of *S. angelica* were spread widely with a gross infested area of 590 ha over a maximum distance of 280 km (compared to the mean maximum distance of 98 km). The only species for which eradication failed (*Chondrilla juncea*) covered larger net and gross areas than any of the other 19 species and also had a large number of infestations (700). We can expect further costs to be incurred for *A. philoxeroides* and *S. angelica* since these eradication programs are not completed.

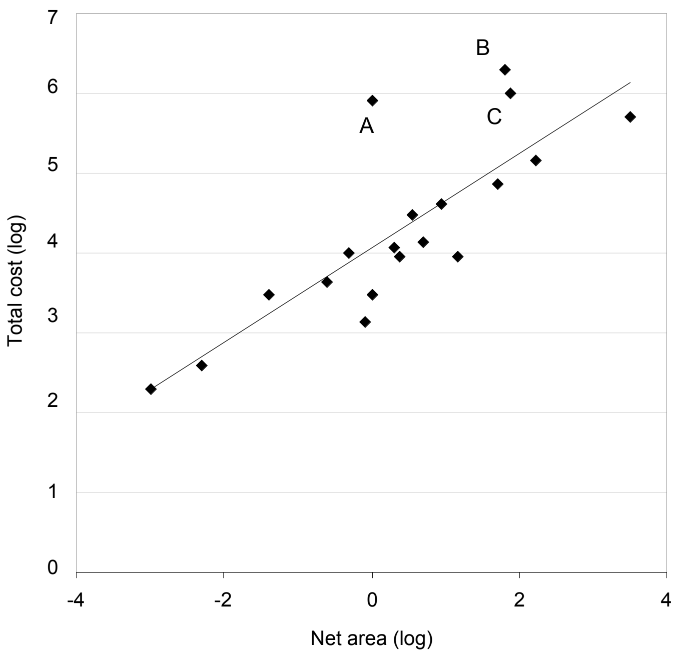


**Figure 1**: Relationship between the raw data of net area of infestation and total cost of eradication program expressed as the $\log_{10}$ of the values. Excludes failed eradication case study. Data points A, B and C are explained in the text.

As the data for the ongoing eradication programs are incomplete, the actual cost will be higher than the current recorded costs. This has been taken into account by using a Buckley-James least squares right censored regression model, which imputes for the costs yet to be incurred before fitting the regression line (Figure 2). The effect of this is clear in Figure 2, where the Buckley-James regression using the imputed data and the data from the successful (competed and monitored) programs is shown, along with a standard linear regression using only the data from the successful programs.

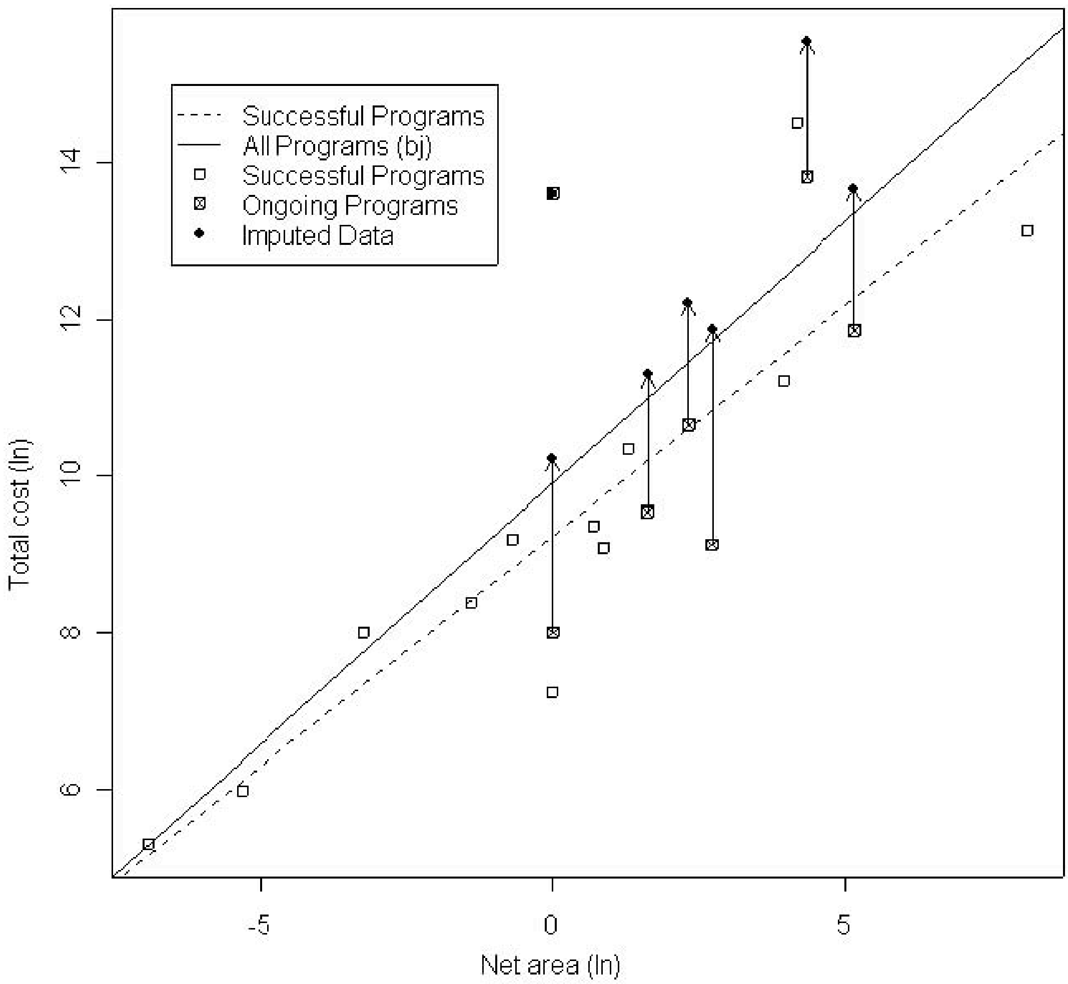


**Figure 2.** Plot showing data points and regression line from the imputed data and successful (completed and monitored) programs combined (solid line), as well as the regression line using only the data from the successful programs (dashed line). The arrows show the effect of the imputations. Values are expressed in $\log_{10}$.

The equation for the regression lines is:

ln(cost) = _ + _ ln(net area) (2)

and for the Buckley-James regression, _ = 9.8885267, _ = 0.6639676. _ is highly significant with a p-value of $9.072e^{-14}$.

Equation 2 can be rewritten as:

$$\text{cost} = e^{9.8885267} (\text{net area})^{0.6639676} \quad (3)$$

A comparison of estimated cost of all weeds (field surveyed sleeper weeds and eradication case study weeds) using this model (Equation 3) and that described in Cunningham *et al.* (Section 2.3, Equation 1) showed that the Cunningham *et al.* model generally estimated cost higher than cost estimated using our model from the case study data, and were several times greater than actual cost for most case study weeds. Cost estimated using our model from the case study data (Equation 3) is higher than the raw cost data (Table 3) for most data points since these points are below the Buckley-James regression line (Figure 2). The four data points that remained above this regression are, consequently, estimated at a lower cost than the raw data. These species are *A. philoxeroides, C. echinatus, P. phaseoloides,* and *S.*

*angelica* (*C. juncea* was also estimated at a lower cost but was not used in the analysis and does not appear in Figure 2).

Other attributes of weed infestations were plotted against cost (Figure 3). It can be seen from Figure 3 that most of the relationships between these attributes and cost show no distinct correlation. However, there appears to be a general increase in cost with increasing age of infestation (Figure 3A) and number of infestations (Figure 3B).

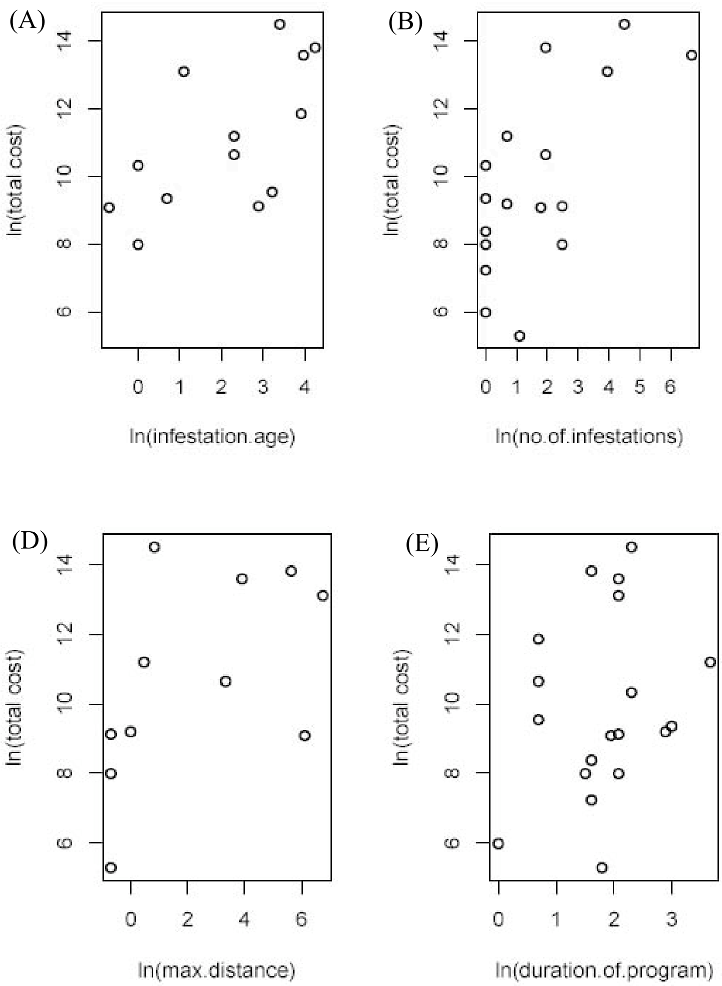


**Figure 3.** Relationships between cost and the infestation attributes of infestation age (A), number of infestations (B), gross infested area (C), maximum distance between infestations (D), and duration of the eradication program (E). These are plots of raw data ($log_{10}$ values) from completed and ongoing eradication programs without imputing the ongoing values using censored regression.

**Table 3.** Estimated eradication cost of nine sleeper weed sites for which field surveys have been conducted (Section 3.1), and for 20 eradication case study weeds (Section 3.2) based on the cost/area analysis of case study data from this project (Equation 3), and the method in Cunningham *et al*. (2003) (Equation 1). Actual cost to date for eradication case studies is also included for comparison. Status of weeds are FSW = field survey weed (agricultural sleeper weeds), O = ongoing, M = monitored, C = completed, and F = failed eradication programs. Ongoing eradication programs were used as censored data, therefore estimated costs of eradication are higher than the actual cost to date based on predicted future costs to complete the eradication programs.

| Species | Status | Cost ($) estimated from Equation 3* | Cost ($) estimated from Equation 1* | Actual cost ($) to date |
|---|---|---|---|---|
| *Asystasia gangetica* ssp. *micrantha* | FSW | 49,000 | 198,300 | - |
| *Baccharis pingraea* | FSW | 10,800 | 23,500 | - |
| *Centaurea eriophora* | FSW | 51,600 | 38,600 | - |
| *Nassella charruana* | FSW | 66,700 | 325,300 | - |
| *Oenanthe pimpinelloides* (S.A.) | FSW | 214,100 | 502,000 | - |
| *Oenanthe pimpinelloides* (Vic.) | FSW | 300 | | - |
| *Onopordum tauricum* | FSW | 12,900 | 175,000 | - |
| *Rorippa sylvestris* (Tas) | FSW | 4300 | 553,000 | - |
| *Rorippa sylvestris* (S.A.) | FSW | 1000 | | - |
| *Alternanthera philoxeroides* | O | 20,000 | 287,100 | 800,000 |
| *Andropogon virginicus* | M | 200 | 40,000 | 197 |
| *Bassia scoparia* | M | 4,570,100 | 589,900 | 494,581 |
| *Cenchrus echinatus* | M | 324,700 | 512,900 | 1,995,000 |
| *Centaurea trichocephala* | C | 20,000 | 56,800 | 1378 |
| *Chondrilla juncea* | F | 4,684,500 | 555,600 | 56,000,000 |
| *Citharexylum gentryi* | O | 630,400 | 589,900 | 141,338 |
| *Cleome rutidosperma* | O | 93,900 | 204,400 | 42,000 |
| *Eichhornia crassipes* | C | 35,600 | 287,100 | 8800 |
| *Eichhornia crassipes* 2 | M | 31,900 | 81,500 | >11,500 |
| *Eupatorium serotinum* | C | 12,600 | 64,700 | 9842 |
| *Helenium amarum* | C | 276,300 | 290,000 | 72,835 |
| *Hieracium pilosella* ssp *nigrescens* | C | 600 | 14,900 | 394 |
| *Hypochoeris radicata* | O | 123,200 | 473,400 | 9158 |
| *Jatropha curcas* | C | 7900 | 34,500 | 4331 |
| *Paspalum unvillei* | O | 20,000 | 124,000 | 2953 |
| *Pueraria phaseoloides* | C | 2300 | 14,900 | 2953 |
| *Rubus glaucus* | O | 59,000 | 411,600 | 13,904 |
| *Salvinia molesta* | C | 47,300 | 35,200 | 30,460 |
| *Spartina angelica* | O | 362,300 | 337,000 | >1,000,000 |

* estimated cost rounded to nearest $100

The Buckley-James regression showed eradication costs increase sharply with increasing area of infestation (Figure 4). The regression estimated an average cost of $4300 for eradicating a weed with a net infestation area of 0.1 ha, $19,700 for an area of 1 ha, and $1,052,500 for an area of 400 ha.

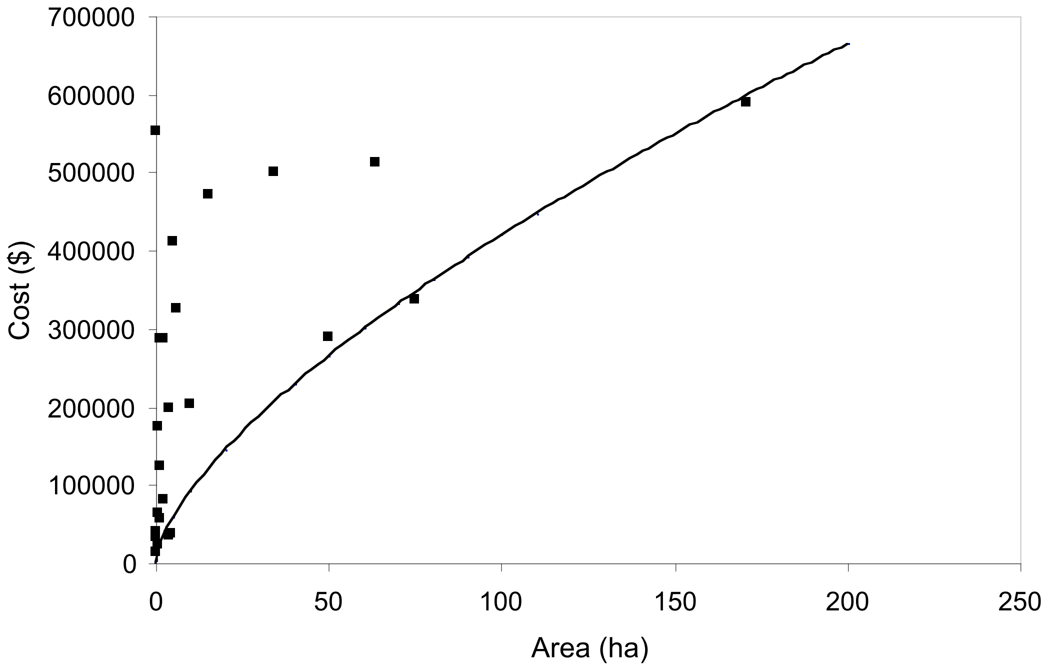


**Figure 4.** The Buckley-James regression (line) based on the infestation areas of the 19 case study weeds plotted for cost and area values. Data points (squares) are eradication costs estimated from the equation in Cunningham *et al.* (2003) for the 19 case study weeds and 10 field survey weeds. In addition to infestation area, cost estimates from the Cunningham *et al.* equation are also derived from number of infestations, ease of access to infestations, and seedbank longevity.

To explore the effect of a weed's biology and its persistence, scores from the BRS feasibility of eradication scoresheet (Cunningham *et al*. 2003) were plotted against program duration. Only the scores relating to control effort and propagating ability were used. Control effort categories were: period for which the plant is visible; distinctiveness of species; ease of access to infestations; and tolerance to herbicides or other treatments. Propagating ability categories were: time to maturity; number of propagules; dispersal distance; seedbank longevity; and type of vegetative reproduction if any. There was partial correlation between the biological attribute score and the duration of the eradication program (Figure 5). That is, the more persistent and weedy a species was (represented by a decreasing biological attribute score), the longer was the eradication program. However, this relationship is weak.

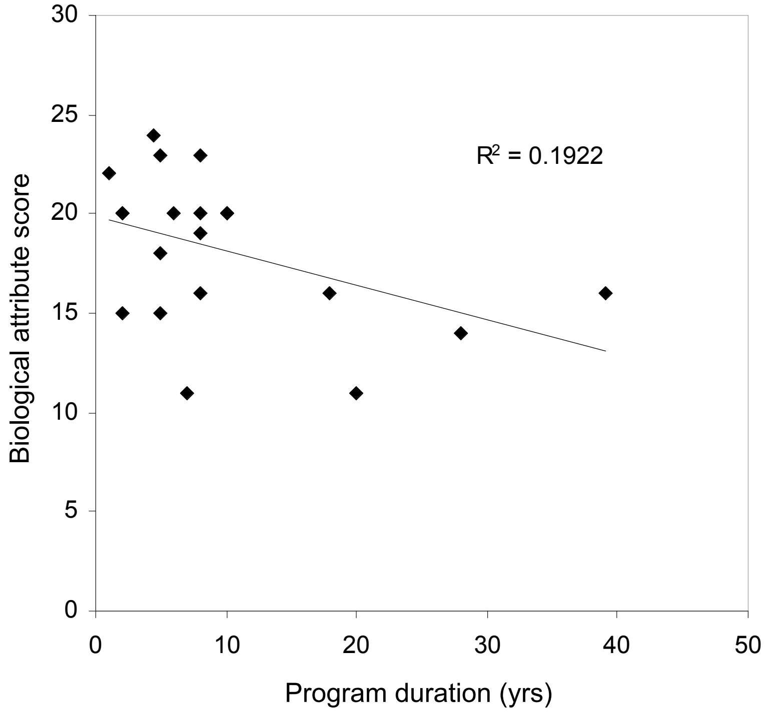


**Figure 5.** Biological attribute scores from the feasibility of eradication scoresheet in Cunningham *et al.* (2003) against program duration. Persistence and weediness of a species increases as the biological attribute score decreases.

# 4. Discussion

Of the eight successful case studies, seven were for species with a net infestation area of less than 4 ha. The eighth species, *H. amarum*, had an undefined net infestation area but it would be less than the gross infestation area of 50 ha. This is still well below the mean net area (194 ha) for all 19 species. For the ongoing and continuing eradications, net infestation areas were variable but generally higher, with half the monitored case studies and two-thirds of the ongoing case studies having net infestation areas greater than 4 ha. The failed eradication had the largest net area (3400 ha) of all the case studies (and new infestations were continually being found when the program was already in place). Generally the results support the theory that a small net area of infestation increases the likelihood of a successful eradication and reduces the cost. Previously identified criteria and principles to determine success of a weed eradication program (e.g. Groves and Panetta 2002; Panetta and Timmins 2004), state that total area of the population is a key criterion. Rejmánek and Pitcairn (2002) collated complete information on eradication effort for 18 exotic weed species in the State of California. They found that eradication of infestations smaller than one hectare (gross area) is usually possible, and that about _ of all infestations between 1 ha and 100 ha, and _ of infestations between 101 and 1000 ha have been eradicated.

Mack and Lonsdale (2002) describe the common features shared by examples of successful plant eradication programs – they usually involve very small plant populations and only one or a few infestations; detection is relatively early in the incursion and the decision to destroy the infestation(s) is swift; and repeated field operations reduce the species below levels of detection, even if complete eradication can not always be demonstrated. For all the completed eradication program case studies we found, the decision to eradicate was swift. All these programs were commenced within one year from the time that the species was recognised as being an undesirable weed or targeted for eradication (although in some cases, the weed had been present for longer).

Three species we assessed had high eradication costs relative to their net area of infestation. One species, *A. philoxeroides*, for which there is an ongoing eradication program, had both a high number of infestations and had been present for a long time. However, the small net area of infestation of this species (90% of the initial 1 ha has been destroyed) is likely to improve the chances of eradication being achieved. Another species, *C. echinatus* had a high number of infestations, and although the net area was initially 63.6 ha, the area that would need to be searched during site visits is almost seven times larger. *S. angelica* also had a gross area several times larger than the net area (nearly eight times) and had been present for a long time (70 years). These factors may have increased control costs of *C. echinatus* and *S. angelica.* Both *A. philoxeroides* and *S. angelica* are aquatic species, and aquatic species have been found to require more effort to eradicate than terrestrial species. Rejmánek and Pitcairn (2002) compared effort (work hours) and infestation area of eradicated weeds in California and found aquatic weed eradication is more demanding. However, in this project, the aquatic weed *E. crassipes,* appears to have been relatively inexpensive to eradicate compared to the estimated eradication costs, and *S. molesta*, also aquatic, was comparable to the estimated eradication costs.

Some eradication programs cost less to undertake compared to both estimated costs. This is expected for the ongoing eradication programs, as we do not know the final cost at completion. However, there is likely to be an underestimation for eradication program costs estimated from the number of person days. Although salary on-costs were included in the calculations, we could not include additional costs unless they were specified in the literature. These costs may include travel allowance, herbicides, vehicle and equipment hire, plus there could be costs for public awareness campaigns that would need to be done in addition to operational procedures. For the eradication of *B. scoparia*, Dodd and Randall (2002) determined that labour was estimated to be 65% of total costs. Therefore we could expect that additional expenses may be up to 52% extra on top of costs estimated from work hours.

The comparison between the models showed that the estimates of eradication costs from the Cunningham *et al.* (2003) model were, on average, several times higher than the estimates from our model based on actual eradication case studies. Our model was based solely on cost and net area, whereas the Cunningham *et al*. model included categories from a range of infestation and biological attributes. We could not test the significance of these attributes adequately in our analyses as our sample size was too small. In our equation, cost is assumed to reflect total effort involved but does not differentiate between any factors that may affect this (e.g. persistence, rate of spread). Cost of eradication of the sleeper weeds could be expected to fall between the estimates from the Cunningham *et al.* (2003) model and our estimates from the regression. Additional data would be useful to further test the effect of net area on cost.

Another source of potential error in our analysis could be in the use of the censored data. Censored data assumes that the eradication programs will be successful, and that they are time limited. Therefore cost has been extrapolated to an estimated completion time. However, costs yet to be incurred could be substantially greater than we have estimated. All too often, a weed species has been on the verge of eradication when the control effort has slackened, and the species has rebounded (Mack and Lonsdale 2002). Other studies have shown that costs per unit area in an eradication program will likely increase as population density declines (Zamora *et al*. 1989; Myers *et al*. 1998). As density falls, costs of finding and killing each remaining weed increases (Zamora *et al*. 1989), and in some cases, eradicating the last 1% of a target population can cost more than destroying the first 99% (Simberloff 2003). It will be interesting to follow the future costs for the ongoing eradication case studies from this project for this reason, that is, costs to date may be a fraction of the cost to completion.

Few eradication case studies have been reported, and even less that provided sufficient information for this project. Simberloff (1997) stated that there is no list of successful plant eradications in the USA or elsewhere, such as can be found for animal eradications. Mack and Lonsdale (2002) noted that successful plant eradication case histories could be assembled but it would make a small list indeed. Simberloff (2003) found that attempting to collate the literature on plant eradications is almost impossible as it is scattered and uncertain, and the use of the term 'eradication' is not consistent. We also attempted to collect information from failed eradication programs, as much could be learnt from them if they were documented more often (Simberloff 2003). The equation from Cunningham *et al*. (2003) was calculated from probability of eradication of 15 weeds with a range of profiles and is subject to the experience and knowledge of the individuals completing the surveys. Categories were developed around weeds with a relatively small distribution and may not be applicable for weeds with a larger distribution. For example, the highest category for number of infestations is 'number of infestations >3'. The score for this category was therefore the same for about half of the eradication case study weeds even though number of infestations ranged from 6 to >800.

Other factors that will influence cost and success of weed eradication or control programs may include weed management strategy, accessibility to sites, terrain and vegetation in which the infestation occurs, knowledge of infestations, environmental sensitivities, treatment type (e.g. spraying from planes or boats, hand-pulling, varying chemical costs), cooperation of landholders, and social implications. *Bassia scoparia* cost almost nine times less to eradicate compared to the cost estimated from the case study data (Equation 3). The fact that such a large infestation area was eradicated for a comparatively small cost was mainly due to knowledge of all infestation sites. *B. scoparia* was planted in the WA wheatbelt on salt-affected land for forage and land rehabilitation, and had naturalised at most sites within two years. Because sites were known, they could be targeted directly without the need to search further afield. The chance of a successful eradication is improved when new invasive weeds are detected and controlled early (Timmins and Braithwaite 2002).

Apart from infestation variables, biological attributes may provide information on the persistence of a species, and therefore, the ability and cost to control it. For example, *C. echinatus* produces abundant seed every year, and *A. philoxeroides* grows in both terrestrial and aquatic environments and will reproduce from a fragment of stem breaking away from the parent plant. Features such as these, which result in vigorous and rapid reproduction, are some of the properties likely to make a troublesome weed (Lamp and Collet 1989). Case study eradication programs tended to run for a longer duration, as the persistence of a species increased, although the correlation was not strong. This could be expected – a seedbank that persists in the soil for many years, a high number of seeds;,a species that is difficult to detect and kill, and other similar factors, will increase the time it takes to destroy all individuals in a population. The control methods and strategy should be developed for different infestation locations and different stages in the life cycle of the target species (Zamora *et al.* 1989).

Using biological attributes and infestation area, it is possible to determine the rate of spread of a weed infestation. Unfortunately, many biological attributes of the weeds throughout this project are unknown, particularly, the number of seeds produced per plant per year and the longevity of the seeds in the soil. Other factors such as dispersal distance of propagules could often only be guessed. Rate of spread is useful to know as eradication costs can be defined in terms of treatment area and rate of spread (Zamora *et al*. 1989). Cost generally increases because both the area to be surveyed and the population increases.

Results from the agricultural sleeper weed surveys suggest that while the total areas infested by these weeds may be relatively small, the number of individual infestations of some species could pose logistical problems should eradication be attempted (Cunningham *et al.* 2003, Panetta and Timmins 2004). Clearly the spatial distribution of the infested area will be critical – where individual infestations are in close proximity to each other, there is little additional time and effort involved in moving between infestations in order to treat them. Other factors come into play in determining eradication feasibility. These include the accessibility of the infestations (generally high for weeds in agricultural contexts), the tenure(s) of the land on which the infestations occur and potential seed longevity. With regard to the last two factors, *A. gangetica* ssp. *micrantha* poses some interesting problems, in that most of its infestations occur within private gardens and there is evidence that its seeds are relatively long-lived (Graham Prichard, pers. comm.).

There could also be problems in attempting to eradicate *R. sylvestris* from Tasmania, as it is believed that not all infestations are known. However, eradicating the known infestations is a realistic goal because the current infestations have remained stable over the last few years, and there is a great deal of support for its eradication by horticulturalists. Eradicating this species from South Australia poses other problems in that it infests a creek. There is the potential that *R. sylvestris* can spread rapidly at times of fast creek flow in autumn and winter when rhizomes can fragment and spread down stream. Eradication action for *R. sylvestris* in South Australia should therefore be swift as it currently infests a gross area of less than 300 $m^2$. Although there are a large number if infestations of *C. eriophora* in South Australia, they are fairly close together and appear to be in four main areas. Most infestations are small and total gross infested area is still considered a practical eradication goal. Infestations are either on the roadside or on cropping/grazing land and can be accessed easily. The infestation of *O. pimpinelloides* in Victoria appears to be a feasible eradication target as the single, small infestation is in an easily accessible site on a roadside, and the infestation does not appear to have increased in size since the first herbarium collection of it was made in 1996. The eradication of *O. pimpinelloides* in South Australia may be more difficult since the infested area is relatively large (although still less than 100 ha) and there are a large number of infestations. These infestations are fairly continuous, but occur along a river which poses a problem with spread since seeds are readily dispersed by water. In Victoria, the eradication of *B. pingraea* appears to be a realistic goal: the net area is small; access to the infestation and detection of the species is high; and the landholder has undertaken control measures so he should be favourable to eradication. *O. tauricum* in Victoria has been extensively controlled during the past 10 years with all infestations being reduced to small areas. It has been suggested that eradication can be achieved with continued time and effort each year. Access to most *O. tauricum* infestations is easy although one site is steep and rocky in places. There are further surveys to be conducted for *N. charruana*, and the total infested area in Victoria can then be determined (assuming all infestations are known). Depending on the size of the infestations yet to be surveyed, eradication of this species may be possible but eradication effort would need to be persistent as there is evidence that seeds may be long-lived (e.g. *N. trichotoma* seed can remain dormant in the soil for up to 15 years, Parsons and Cuthbertson 1992).

Eradication programs generally cost in the range of $200 to $2,000,000. Estimated annual cost of weeds in Australia is approximately $4 billion (Sinden *et al*. 2004). Therefore, eradication costs are small relative to the potential for harm, especially for species with a small infestation size. Lack of data is the main factor hindering our abilities to predict feasibility and cost of eradication and the consequences of delaying eradication attempts. Eradication could probably be achieved for many of the sleeper weeds surveyed and the models predict that the cost of eradication will be in the range of $5300 to $550,000 per weed.

# Recommendations

Much could be learnt from past successful and failed eradication programs, but lack of data prevents this to a large degree. Therefore, it is essential to collect and report these data for future eradication attempts. Essential data to collect for future eradication programs are:

- Area of infestation (gross and net)
- Number of infestations
- Number of work hours spent on the program
- Duration of eradication program
- Total cost of eradication program

It is also highly desirable to collect data from the eradication programs on:

- Maximum distance between infestations
- Age of the infestation
- Land use affected

Consideration should also be given on how best to ensure these data are collected, reported and stored for all current and future eradication attempts. For failed eradication attempts, any information on what caused it to fail and when or why the attempt was abandoned would be useful.

Our results suggest it should be possible to eradicate weed infestations with a net area less than 4 ha and a gross area less than 10 ha. Infestation with a gross area less than 100 ha may be possible depending on other factors. When agricultural sleeper weeds or new incursions meet these criteria, consideration should be given to eradicate them depending on their potential threat. Much larger net areas of infestation can be eradicated when all infestations are known and the decision to act is swift. These principles also apply to environmental weeds.

# Acknowledgements

Thank you to the people and agencies that conducted field surveys: Graham Prichard, Port Stephens Council, NSW; Penny Gillespie, David McLaren and many others, Department of Primary Industries, Victoria; Tasmanian Herbarium; John Wills, Mt Lofty Ranges Animal and Plant Control Board; Kym Haebich, Mid Murray Animal and Plant Control Board; Robin Coles, South Australian Research and Development Institute; Geoff Sainty, Sainty and Associates Pty Ltd. Thanks to Simon Barry from BRS for statistical advice, and to Simon Knapp from BRS who assisted with the statistical analysis. Thanks also to Dane Panetta for managing the sleeper weeds field surveys and for his valuable comments and suggestions.

# References


Bomford, M. and O'Brien, P. (1995) Eradication of Australia's vertebrate pests: a feasibility study. In (eds G.C. Grigg, P.T. Hale and D. Lunney) *Conservation Through Sustainable Use of Wildlife*. Centre for Conservation Biology, University of Queensland.

Buckley, J. and James, I. (1979) Linear regression with censored data. *Biometrics*, **66**: 429-436.

Cunningham, D.C., Woldendorp, G., Burgess, M.B. and Barry, S.C. (2003) *Prioritising sleeper weeds for eradication: Selection of species based on potential impacts on agriculture and feasibility of eradication*, Bureau of Rural Sciences, Canberra.

Dodd, J and Randall, R.P. (2002) Eradication of kochia (*Bassia scoparia* (L.) A.J. Scott, Chenopodiaceae) in Western Australia. In (eds. H. Spafford Jacob, J. Dodd and J.H. Moore) *13th Australian Weeds Conference: papers and proceedings, 8-13 September 2002*, *Sheradon Perth Hotel, Perth, WA*. Plant Protection Society of WA Inc., Perth, pp. 300-303.

Flint, E. and Rehkemper, C. (2002) Control and eradication of the introduced grass, *Cenchrus echinatus*, at Laysan Island, Central Pacific Ocean. In (eds. C.R. Veitch and M.N. Clout) *Turning the Tide: The Eradication of Invasive Species*, *Proceedings of the International Conference on Eradication of Island Invasives, Occasional Paper of the IUCN Species Survival Commission No. 27*. IUCN/SSC Invasive Species Specialist Group, Switzerland, UK, and New Zealand, pp. 381-388.

Groves, R.H. & Panetta, F.D. (2002). Some general principles for weed eradication programs. In (eds. H. Spafford Jacob, J. Dodd and J.H. Moore) *13th Australian Weeds Conference: papers and proceedings, 8-13 September 2002*, *Sheradon Perth Hotel, Perth, WA*. Plant Protection Society of WA Inc., Perth, pp. 307-310.

Gunasekera, L. and Bonila, J. (2001) Alligator weed: tasty vegetable in Australian backyards? *Journal of Aquatic Plant Management*, **39**: 17-20.

Lamp, C. and Collet, F. (1989) *Field Guide to Weeds in Australia*. Inkata Press, Melbourne.

Lonsdale, W.M., Miller, I.L. and Forno, I.W. (1989). The biology of Australian weeds 20. *Mimosa pigra* L. *Plant Protection Quarterly*, **4**: 119-131.

Mack, R.N. and Lonsdale, W.M. (2002) Eradicating invasive plants: Hard-won lessons for islands. In (eds. C.R. Veitch and M.N. Clout) *Turning the Tide: The Eradication of Invasive Species, Proceedings of the International Conference on Eradication of Island Invasives, Occasional Paper of the IUCN Species Survival Commission No. 27.* IUCN/SSC Invasive Species Specialist Group, Switzerland, UK, and New Zealand, pp. 164-172.

Miller, I.L. and Pickering, S.E. (1988) Eradication of salvinia (Salvinia molesta) from the Adelaide River, Northern Territory. *Plant Protection Quarterly*, **3**: 69-73.

Mitchell, A and Schmid, M. (2002) Case history of the eradication of fringed spider flower, Cleome rutidosperma DC. In (eds. H. Spafford Jacob, J. Dodd and J.H. Moore) *13th Australian Weeds Conference: papers and proceedings, 8-13 September 2002*, *Sheradon Perth Hotel, Perth, WA*. Plant Protection Society of WA Inc., Perth, pp. 297-299.

Myers, J.H., Savoie, A. and van Randen, E. (1998) Eradication and pest management. *Annual Review of Entomology*, **43**: 471-491.

Panetta, F.D. and Timmins, S.M. (2004) Evaluating the feasibility of eradication for terrestrial weed incursions. *Plant Protection Quarterly*, **19**: 5-11.

Parsons, W.T. and Cuthbertson, E.G. (1992) *Noxious Weeds of Australia*. Inkata Press, Melbourne.

Pratt, R. and Peirce, J. (2002) *Skeleton weed (Chondrilla juncea L.): Best practice management guidelines*. Bulletin 4557, August 2002. Department of Agriculture, Western Australia.

Rawling, J. (1994) Australia's environmental weeds – whose responsibility? *Landscape Australia*, **16**: 36-40, 58.

Rejmánek, M. and Pitcairn, M.J. (2002). When is eradication of exotic pest plants a realistic goal? In (eds C.R. Veitch and M.N. Clout) *Turning the Tide: The Eradication of Invasive Species, Proceedings of the International Conference on Eradication of Island Invasives, Occasional Paper of the IUCN Species Survival Commission No. 27*, IUCN/SSC Invasive Species Specialist Group, Switzerland, UK, and New Zealand, pp. 249-253.

Rudman, T. and Goninon, C. (2002) Eradication case history, *Hieracium pilosella* L. ssp. *nigrescens* (Fr.) Nägeli & Peter in Tasmania. In (eds. H. Spafford Jacob, J. Dodd and J.H. Moore) *13th Australian Weeds Conference: papers and proceedings, 8-13 September 2002*, *Sheradon Perth Hotel, Perth, WA*. Plant Protection Society of WA Inc., Perth, pp. 304-306.

Simberloff, D. (1997) Eradication. In (eds T.C. Brown, D.C. Schmitz and D. Simberloff) *Strangers in Paradise: Impact and Management of Nonindigenous Species in Florida*, Island Press, Washington D.C.

Simberloff, D. (2003) Eradication – preventing invasions at the outset. *Weed Science*, **51**: 247-253.

Sinden, J., Jones, R., Hester, S., Odom, D., Kalisch, C. James, R. and Cacho, O. (2004) *The Economic Impact of Weeds in Australia*. Technical Series no. 8, CRC for Australian Weed Management.

SWERP (2002) *Skeleton weed review 2002*. Skeleton Weed Eradication Review Panel (SWERP), Department of Agriculture, Western Australia, 26 July 2002.

Soria, M.C., Gardener, M.R. and Tye, A. (2002) Eradication of potentially invasive plants with limited distributions in the Galapagos Islands. In (eds. C.R. Veitch and M.N. Clout) *Turning the Tide: The Eradication of Invasive Species, Proceedings of the International Conference on Eradication of Island Invasives, Occasional Paper of the IUCN Species Survival Commission No. 27*. IUCN/SSC Invasive Species Specialist Group, Switzerland, UK, and New Zealand, pp. 287-292.

Timmins, S.M. and Braithwaite, H. (2002) Early detection of invasive weeds on islands. In (eds. C.R. Veitch and M.N. Clout) *Turning the Tide: The Eradication of Invasive Species, Proceedings of the International Conference on Eradication of Island Invasives, Occasional Paper of the IUCN Species Survival Commission No. 27*. IUCN/SSC Invasive Species Specialist Group, Switzerland, UK, and New Zealand, pp. 311-318.

Tomley, A.J and Panetta, F.D. (2002) Eradication of the exotic weeds *Helenium amarum* (Rafin) H.L. and *Eupatorium serotinum* Michx. from south-eastern Queensland. In (eds. H. Spafford Jacob, J. Dodd and J.H. Moore) *13th Australian Weeds Conference: papers and proceedings, 8-13 September 2002*, *Sheradon Perth Hotel, Perth, WA*. Plant Protection Society of WA Inc., Perth, pp. 293-296.

Wotherspoon, S.H. and Wotherspoon, J.A. (2002) The evolution and execution of a plan for invasive weed eradication and control, Rangitoto Island, Hauraki Gulf, New Zealand. In (eds. C.R. Veitch and M.N. Clout) *Turning the Tide: The Eradication of Invasive Species, Proceedings of the International Conference on Eradication of Island Invasives, Occasional Paper of the IUCN Species Survival Commission No. 27*. IUCN/SSC Invasive Species Specialist Group, Switzerland, UK, and New Zealand, pp. 381-388.

Zamora, D.L., Thill, D.C. and Eplee, R.E. (1989) An eradication plan for plant invasions. *Weed Technology*, **3**: 2-12.