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Eradication of Exotic Weeds in Australia: Comparing Effort and Expenditure

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Abstract

Weeds have many adverse impacts on agriculture and the environment and therefore are often targets of eradication attempts. Eradication attempts involve large commitments of labour and financial resources over significant periods of time. Using data from 12 Australian weed eradication attempts the authors compare work hours and expenditure on each attempt for various initial-infestation sizes. Analysis of a limited data set shows: (1) that while the eradication effort increases with the initial area of infestation, the effort applied per hectare actually decreases; (2) that application of a greater work effort was not the reason why completed eradications were successful; and (3) that the larger the initial infestation size, the smaller the amount of resources applied per hectare for eradication.

Key Words: weeds; eradication; work effort; expenditure; infestation size.

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Introduction

The number of exotic plant species introduced to Australia since the arrival of European settlement has been estimated at over 28,000 (Martin 2003), with over 2,700 of these plants documented as weeds (Lazarides et al. 1997). A large number of these weeds were originally introduced for horticultural purposes. Sixty-five percent of the plants that naturalised to become weeds between 1971 and 1995, had been introduced as ornamental plants for horticulture, 7% had been used in agriculture, and 2% were introduced as contaminant in seed, with the remaining introductions either from unknown or other sources (Groves 1998).

Quarantine authorities are constantly refining methods used to prevent the import of potentially weedy plants into Australia. The most recent way of assessing plants is through a Weed Risk Assessment (WRA) system, introduced in 1997. The WRA uses a question-based scoring system to determine a plant's weediness, asking the user to answer questions relating to the biogeography, undesirable attributes, and ecology of a proposed import (Pheloung 2001). Depending on the score, the recommendation is to accept, reject or further evaluate the plant. Despite the continual refinement of quarantine protocols to detect potentially invasive plant species before they enter Australia, exotic plants may well continue to naturalise and become weeds for some time due to the lag between the introduction of plants and recognition of their status as weeds. This lag could be as little as five years, or as much as 25 years or longer depending on the species (Groves 1998), so it may take many years before any benefits from tightening of quarantine protocols are experienced. Many of our future weed problems are present now in gardens, and are yet to make the transition to naturalised and then invasive species.

There are many impacts of weeds on agriculture and the environment. Some are beneficial, but most impacts are adverse. One tool for reducing the impact of weeds within Australia is weed control legislation. Each state and territory of Australia has legislation related to weed control which compels land occupiers to control and eradicate certain weeds, variously known as 'noxious', 'proclaimed' and 'declared' plants. Legislation also places restrictions on the movement and sale of plants and seeds, and so sets a framework for coordinated weed control within each state. Legislation differs between states and territories and in an attempt at a more strategic, coordinated and successful approach to weed control, the National Weed Strategy was released in 1997. The three goals of the Strategy are to prevent development of new weed problems; to reduce the impact of existing weed problems of national significance; and to provide the framework and capacity for ongoing management of weed problems of national significance (ARMCANZ et al. 1999).

One major outcome of the National Weeds Strategy has been the development of a list of ‘weeds of national significance’ or (WONS). The selection of the top 20 weeds was based on their relative invasiveness, potential for spread, and impact on the economy, the natural environment and society. The determination of WONS provides a framework for prioritising weed management at the state, regional and local levels, while still recognising that most weed problems will have to be dealt with through State and local government initiatives and by land managers themselves (Thorp and Lynch 2000).

In situations where new exotic plant incursions occur and are deemed to be eradicable, eradication programs are currently funded through a cost-sharing arrangement between the Commonwealth Government and the State and Territory Governments. The Commonwealth Government pays 50% of costs with the remainder paid by the affected state and territory governments depending on the gross value of production of their susceptible crops (Plant Health Australia, 2004). This agreement is currently being refined to include industry contributions to the cost of eradication, compensation to affected parties and consideration of the benefits and costs of the program. If a new weed is not deemed eradicable then it becomes a state, shire or local responsibility.

Eradication Issues

Eradication is a management goal for noxious weeds that is often prescribed but seldom achieved (Dodd, 1990). Eradication of a plant population implies deliberate management that leads to its extinction from a particular area, region or country (Groves and Panetta 2002). Eradication is technically feasible for both small and large infestations, but economically feasible for small infestations, especially for species that are known to be invasive elsewhere and are posing an economic threat to agriculture and natural ecosystems.

In view of the importance attached to weed eradication and the difficulties of achieving this goal, it is desirable to identify those weeds most likely to be eradicable (Dodd, 1990). In order to do this, it is appropriate (i) to evaluate whether eradication of a particular noxious weed can realistically be achieved; (ii) to identify the biological characteristics of the weed that most influence the success of an eradication program; and (iii) to identify the sort of data that should be collected on a regular basis to evaluate eradication programs.

Groves and Panetta (2002) suggested six main criteria that will determine success in weed eradication programs. They summarised these into two general principles Firstly, that weed eradication programs will be biologically and economically feasible if the known distribution of the weed is less than 100 ha, if it occurs at three or fewer locations, if the invaded sites are easily accessible and if the weed is readily detectable. The second principle is that if the weed has a period of seed viability in the soil greater than five years and / or continues to be traded by nurseries then the period required for eradication will be much longer. These two principles distinguish weeds that may be appropriate candidates for eradication from those that may be more appropriately considered as candidates for containment (Groves and Panetta 2002).

Using information on eradication effort for 53 infestations of 18 weeds for the State of California, Rejmanek and Pitcairn (2002) suggest that even infestations over 1000 hectares could be eradicated, but the eradication effort per hectare would need to be increased. It is important to note that the authors discuss infestations in terms of gross area and net area. The gross area is the area over which the weed is distributed, whereas the net area is the area to which treatment is applied. The net area is much smaller.

The task of eradication follows the “law of diminishing returns” since it will cost more and more to find and kill each additional plant as the population of the plant decreases (Pimentel et al. 1999). Further, while the last few plants are being sought, it is likely that previously treated land would become re-infested from buried and newly produced seeds, as has been documented for water hyacinth, in Queensland (Dodd, 1990).

When the goal of weed management changes from eradication to containment there may still be a real economic benefit. Containment strategies slow the spread of the weed and therefore reduce and delay the negative impacts on agricultural and natural ecosystems (Sharov and Liebhold 1998).

A basic principle of weed management is that prevention is the most cost-effective action, and avoids significant economic and environmental damage. Cost-effectiveness then declines as one moves through eradication, containment and damage mitigation through for example biocontrol (Sharov and Liebhold 1998). It should be noted, however, that this decline is mainly due to the weed becoming increasingly widespread, and hence having had greater impacts before intervention (Weed Management Society of South Australia, 2002).

Australian Eradication Campaigns

Over the last 70 years there have been many successful eradication programs at the state and local levels in Australia, including the eradication of perennial ragweed (*Ambrosia psilostachya*) from Victoria, nodding thistle (*Carduus nutans*) from Western Australia, South Australia and parts of Victoria, water hyacinth (*Eichhornia crassipes*) from South Australia, salvinia (*Salvinia molesta*) from parts of the Northern Territory, Queensland and parts of Victoria (Dodd 1990), seroty weed (*Eupatoriam seratinum*) and bitterweed (*Helenium amarum*) from Southern Queensland (Tomley and Panetta 2002), fringed spider flower (*Cleome rutidosperma*) from Queensland (Groves and Panetta 2002), kochia (*Bassia scoparia*) from Western Australia (Dodd and Randall 2002) and mouse ear hawkweed (*Hieracium pilosella*) from Tasmania (Rudman and Goninon 2002).

In addition, there are many eradication programs that have recently commenced and are still ongoing, including those for koster's curse (*Clidemia hirta*), siam weed (*Chromolaena odorata*), mile-a-minute (*Mikania micrantha*) and limnocharis (*Limnocharis flava*) from Queensland (Tomley and Panetta 2002), branched broomrape (*Orobanche ramosa*) in South Australia (Jupp et al. 2002), mesquite (*Prosopis* spp.) in Queensland, Mimosa (*Mimosa pigra*) in the Northern Territory and rubber vine (*Cryptostegia grandiflora*) in Queensland (Adamson et al. 2000). Skeleton weed (*Chondrilla juncea*), was the subject of a 30 year eradication campaign in Western Australia (Dodd 1996) but management has recently turned to containment.

Data from these programs, particularly for initial infestation sizes and eradication effort (number of person hours devoted to each site to date) could be usefully compared to draw conclusions about why some programs have been successful, while others are still ongoing. These sorts of comparisons were made by Rejmanek and Pitcairn (2002), in a study of 18 "A" rated weeds over 53 infestations in California, all of which were subject to eradication. The authors were able to obtain the following information for each weed infestation: (1) the size of infestation after delimitation (both gross and net area), (2) the date first found, (3) total number of surveillance and control visits to the infestation site to date, (4) the effort applied per infestation (number of person hours devoted to the site, including travel time to and from the site), and (5) current status of the infestation. Of the 53 infestations, eradication was ongoing for 29 of them and had been successful at the remaining 24 sites. The authors found that the mean eradication effort per infestation is consistently greater for ongoing projects than for eradicated infestations, and thus drew the conclusion that completed eradications were not successful because of the greater effort (Rejmanek and Pitcairn 2002). Their other important finding was that while the eradication effort increased with the area of infestation, the effort per hectare decreased at the same time, suggesting that it might be possible to eradicate large infestations, say over 1000ha, but the eradication effort would need to be greater.

To consider the conclusions of Rejmanek and Pitcairn (2002) in an Australian context, an attempt was made to collect the same data for Australian eradication campaigns. Unfortunately, data on eradication programs is not collected in a consistent manner across all states and Territories of Australia and rarely is information on work effort recorded on a per-infestation basis. Rather, where work effort is recorded, it is on the basis of the whole eradication program which may be made up of the eradication of many individual sites of weed infestation. Nevertheless, the information which was available has allowed some analysis to be undertaken and hence some conclusions to be drawn about eradication campaigns in Australia. A brief introduction to each weed and information available for its eradication is given below, followed by a comparison of results across all weeds.

Alligator weed (*Alternanthera philoxeroides)*

Alligator weed is a perennial plant, native to South America, that can grow on land and water under a wide range of conditions. It is listed as a weed of national significance because of the threat it poses to rivers, wetlands and irrigation systems. It was first detected in Australia in Newcastle in 1946 and has since spread to all states but only to a small portion of its potential range. A recent eradication program in Victoria has seen the number of new infestations recorded fall to very low levels. In this state it had been mistakenly grown as a vegetable throughout gardens of the Sri-Lankan community.

Seroty weed (*Eupatoriam seratinum*)

Seroty weed is a weed of the natural environment It was first discovered in 1962, growing beside the disused railway line at Nerang, 65 km south of Brisbane. The time and mode of introduction are unknown, but it appears to have the potential to spread rapidly. When first discovered in 1962 the infestation covered an area of 10 m^2, but by May 1963 this area had expanded to 230 m^2 (Tomley & Panetta 2003). By November 1963 the infestation had spread even further. The only satellite infestation was detected in 1970, when two plants were found on a roadside about 1 km from the main infestation. The plants in this latter infestation are more likely to have been transported by human activity than by wind, as no plants were ever found between these two locations. This infestation had spread to a total area of 0.5 ha before the eradication campaign started. It took 18 years for this population of seroty weed to be eradicated in 1980 (Tomley & Panetta 2003).

Bedstraw (*Galium tricornutum*)

Bedstraw originates in eastern Europe and is now a major weed of crops in parts of Victoria and South Australia. The weed is a declared plant in Western Australia, and until 2003 had not been found since 1968. A small but severe infestation of 100 hectares was found in the wheat belt of Western Australia in January 2003 and an eradication program commenced later that same year. Bedstraw plants produce up to 1000 seeds per year and these may survive in the soil for up to 5 years (Edward and Kingwell 2003). While the weed is easily controlled using herbicide it has the potential to cause large reductions in crop yields.

Fringed spider flower (*Cleome rutidosperma*)

Fringed spider flower is a weed of agricultural and natural environments. It was first found in Darwin, at Fort Hill Wharf in August 2000. A media campaign commenced to determine its distribution and four additional populations were found in and around Darwin later the same year. Combined, the weed infested a total area of 4.51 ha (Mitchell and Schmid 2003). An eradication campaign commenced shortly afterwards and is continuing. A further population was found on Berrimah Farm with a small satellite population of approximately 10 plants at Howard Springs, Darwin in February 2002. Of the five sites discovered in 2000, *Cleome rutidosperma* has been eliminated from one, due to the use of a long acting herbicide. This unfortunately was not an option at other sites (Mitchell and Schmid 2003).

Siam Weed (*chromolaena odorata*)

Siam weed was first discovered in Australia in 1994 on Tully River, south of Cairns in Queensland. It is a woody, climbing perennial shrub that grows up to 2 meters high and characteristically forms dense thickets. There are two forms of Siam weed in Australia genotype A is the most common type in north Queensland. Siam weed is a weed of Agriculture as well as natural environments. This infestation covers 11,300 ha of agricultural land and natural environment. The eradication campaign commenced in 1994 and it is expected to continue for a period of 16 years (Adamson et al. 2000).

Bitterweed *(Helenium amarum)*

Bitterweed, a weed of natural environments was first detected in 1953 at Lowood, 80 km west of Brisbane. It is thought to have been introduced by aircraft or associated equipment, since the infestation was in the general vicinity of an airfield that had been used by the United States Air Force during 1944-45 (Tomley & Panetta 2003). This weed ultimately spread over 50 ha, with a single satellite infestation establishing at 1.6 km from the main area. Records indicate that transportation of soil was responsible for this spread (Tomley & Panetta 2003**).**

Kochia (*Bassia scoparia*)

Kochia is an annual, native to eastern Europe and parts of western Asia, and was introduced into Western Australia in 1990 as seed for sowing on salt-affected soils to provide forage and a mechanism to rehabilitate salt-affected land. Kochia plants have a capacity for long-distance dispersal with dead, seed-laden plants breaking off at ground level and spreading by wind as 'tumbleweeds' (Dodd and Randall 2002). Once the weediness of this species was noted, an eradication program commenced in 1991, funded through State and Commonwealth funds. The eradication program is widely described as a success, with no kochia plants found since 2002, ten years after its introduction into Western Australia (Dodd and Randall 2002).

Mouse-ear hawkweed (*Hieracium pilosella*)

Mouse-ear hawkweed is a perennial herb native to Europe that was permitted to enter Australia prior to 1995 and had previously been detected in nurseries. The first recorded naturalisation of the plant was in January 2001 on agricultural land in the Tasmanian midlands. The infestation was small, 50 square metres, but density ranged from 40% to 80 % cover (Rudman and Goninon 2002). A state eradication program was initiated in 2001 and undertaken as part of road widening works in the area where the infestation was found. This joint programme lowered the cost of the eradication campaign. No additional mouse-ear hawkweed plants were found when the site was monitored during 2002 and monitoring will continue for several more years.

Branched broomrape (*Orobanche ramosa*)

Branched broomrape is a parasitic plant that attacks the roots of many broadleaved plants, including agricultural crops. It spends most of its time growing underground, only emerging from the ground and flowering for a few weeks each year. Branched broomrape is native to Europe, North Africa and the Middle East and was found and treated at several sites in South Australia during the 1990s. Surveys in 1999 detected a large number of infestations in the Murray Bridge totalling an area of 4800 hectares of land. A national program to eradicate branched broomrape commenced in 2001, funded through a cost-sharing arrangement between State and Federal authorities.

Salvinia (Salvinia molesta)

Salvinia is an aquatic weed that can choke waterways. It floats on still or slow-moving water and can grow rapidly to cover the entire water surface with a thick mat of vegetation. These shades out any submerged plant life and impedes oxygen exchange, making the water unsuitable for fish and other animals. In 1977 Salvinia was found growing in the upper reaches of the Adelaide River, in Northern Territory, and threatened to infest the entire system. The infestation was first located on the

Adelaide River on 10 January 1977, beside road bridge 120km south east of Darwin. This is approximately 240km upstream from the mouth of the river. The main infestation completely covered 0.4 ha of pool 1 and was scattered through the channels and in pools 2,3, and 4. The total length of river infested was 1.8 km. The eradication program commenced on 12 January 1977, until 14 December 1982 but regular surveys continued until 1986 to ensure that no re-infestation occurred (Miller and Pickering 1988).

Skeleton weed (Chondrilla juncea)

Skeleton weed was accidentally introduced to Australia in 1910 and now is a widespread weed in south-eastern Australia. It was not detected in Western Australia until 1963 and since 1974 has been the subject of an eradication program. Eradication was being achieved on 50% of individual farms that had been treated and remained in quarantine long enough to confirm elimination of populations (Dodd 1996). The skeleton weed eradication program has reduced the impact and rate of spread of the weed, although new infestations continue to be found at an increasing rate. There is constant debate over the future of the eradication program as the cost of funding it are expected to continue to increase

Data

Information on eradication effort was obtained on a program basis for 12 weeds and these are listed in Table 1. The location of each eradication program is listed as the particular Australian state where it took place. Eradication programs were undertaken by state government authorities, with methods of carrying out campaigns likely to differ between states. While many infested sites may have been treated in the eradication program of a particular weed, none of the information is recorded for an individual site. Rather, all information was recorded for the cumulative area of the weed.

Table 1: List of weeds and eradication program status for particular locations.

Scientific name	Common name	E/O	Location
Terrestrial species			
Bassia scoparia	kochia	E	WA
Chondrilla juncea	skeleton weed	O	WA
Chromolaena odorata	siam weed	O	QLD
Cleome rutidosperma	fringed spider flower	O	NT
Eupatorium serotinum	seroty weed	E	QLD
Galium tricornutum	bedstraw	O	WA
Helenium amarum	bitterweed	E	QLD
Hieracium pilosella	mouse-ear hawkweed	E	TAS
Mikani micrantha	mile-a-minute		QLD
Orobanche ramosa	branched broomrape	O	SA
Aquatic species			
Alternanthera philoxeroides	alligator weed	O	VIC
Salvinia molesta	salvinia	E	NT

E=eradicated, O=Ongoing

For each program the following information was obtained: (1) size of treated area at the start of eradication, (2) the date first found, (3) effort per infestation (number of person hours devoted to the site to date), (4) the total costs of the program to date (including treatment, capital and administration costs) and (5) current status of the infestation. In most cases eradication is considered to have occurred when no plants are found in the initial infested area for three consecutive years (Rejmanek and Pitcairn 2002).

Results

The relationship between the mean eradication effort and five initial infestation area categories is given in Table 2 and Figure 1. The five size categories are the same as those in Rejmanek and Pitcairn (2002) for the purposes of comparison, although they defined initial infestation size differently to the definition used in this paper.

Table 2: Areas of initial infestations of exotic weeds at the beginning of eradication programs, numbers of eradicated infestations, numbers of ongoing projects and mean eradication effort for five infestation area categories.

		Initial gross infestation (ha)				
		<0.1	0.1-1	1.1-100	101-1000	>1000
No. eradicated infestations			2	1		1
No. of ongoing projects		1	1	3	1	2
Mean eradication effort per infestation (work hours)	eradicated		400	2,960		15,536
	ongoing	16	15,334	276,456	20,000	68,508
Mean eradication effort per hectare (work hours)	eradicated		400	59		7
	ongoing	258	17,229	3,245	40	2

In general, it seems that about 1/4 of all infestations between 1 ha and 100ha have been eradicated, a similar result to that found in Rejmanek and Pitcairn (2002). While Rejmanek and Pitcairn (2002) reported some successful eradications in the first four area categories and none in the >1000 hectare category, the present study does have a successful eradication in the > 1000 hectare category. This is the exceptionally successful eradication of kochia (*Bassia scoparia*) from the wheatbelt of Western Australia. While a large amount of hours and other resources where committed to eradicating the weed, Kochia lends itself to eradication despite the initial infestation size. The weed existed in well-defined locations and was contained by fences, which limited its natural method of spread by 'tumbleweeds' (Dodd and Randall 2002).

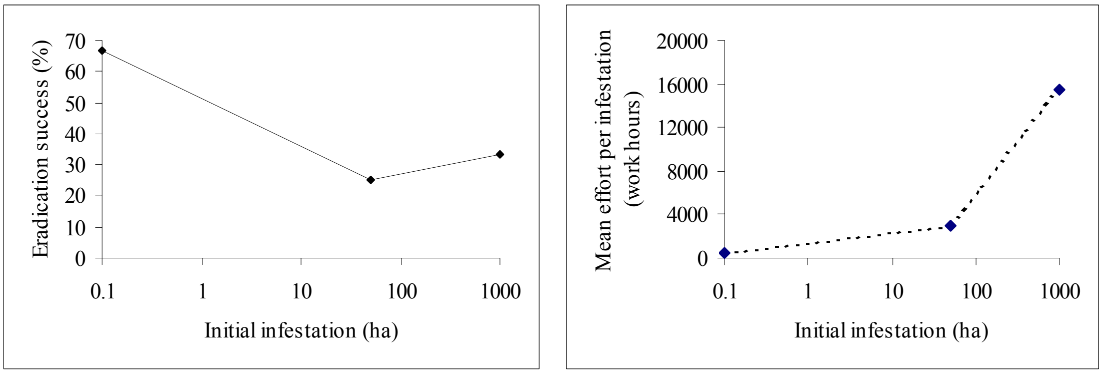

Figure 1: The dependence of the eradication success (%) and the mean eradication effort per infestation (work hours) on the initial size of infestations.

Despite the limited number of eradication projects used to create table 2, (4 eradicated, 8 ongoing), a similar pattern to that reported in Rejmanek and Pitcairn (2002) is obvious. While the total eradication effort increases with the area of infestation, the effort per hectare decreases. Again, a similar conclusion can be emphasised, that even infestations greater than 1000 hectares could technically be eradicated, but the eradication effort per hectare and thus the long-term commitment of resources, would also need to be greater than what it has been in the past. To determine whether small or large eradications programs should go ahead, a necessary step would be to determine the net benefits of eradication programs for each weed, and if positive, there would be merit in proceeding to eradicate.

Another conclusion drawn by Rejmanek and Pitcairn (2002) is also evident in Table 2. In those categories where at least some eradications were successful, mean eradication effort per infestation is consistently greater for ongoing projects than for eradicated infestations. This indicates that, in general, completed eradications were not successful because of the greater effort.

The relationship between mean actual expenditure on eradication program and five initial size categories is reported in Table 3. While comparisons of expenditure on eradication programs for different weeds may be meaningless because of differences in control techniques and damage caused by weeds, it is still interesting to compare mean expenditure per hectare across the five size categories. Despite the limited data set, a pattern emerges. The larger the initial size of the weed infestation, the smaller the resources applied per hectare for eradication. This applies to both eradicated and ongoing projects, although it is worth noting that a smaller investment per hectare was applied to eradicated weeds than is applied to ongoing projects. Both conclusions mirror the work hours involved in eradication programs, although the expenditure figures include other costs incurred by the programs.

Table 3. Areas of initial infestations of exotic weeds at the beginning of eradication programs, numbers of eradicated infestations, numbers of ongoing projects and mean actual expenditure for five infestation area categories.

		Initial gross infestation (ha)				
		<0.1	0.1-1	1.1-100	101-1000	>1000
No. eradicated infestations			2	1		1
No. of ongoing projects		1	1	3	1	2
Mean expenditure per infestation ($)	eradicated		9,000	133,200		494,600
	ongoing	320	800,000	15,466,103	131,500	4,286,571
Mean expenditure per hectare ($)	eradicated		18,000	2,664		225
	ongoing	5,161	898,876	185,937	263	212

Discussion

Despite a limited data set of Australian weed eradication attempts, the authors were able to reinforce conclusions previously drawn by Rejmanek and Pitcairn (2002) for 53 infestations of 18 weeds in the state of California. The first conclusion was that while the eradication effort increased with the area of infestation, the effort per hectare was actually decreasing. Of course, increased effort per hectare over a larger area results in the use of greater resources and, depending on biological characteristics of the weed, a need for a greater commitment of future resources. This is why weeds with a known distribution of 1000 ha or more are often considered as appropriate candidates for containment rather than eradication (Rejmanek and Pitcairn 2002).

A second conclusion drawn by Rejmanek and Pitcairn (2002) is that completed eradications were not successful because of greater effort. Analysis of the Australian data reported in this paper shows that mean eradication effort per infestation is consistently greater for ongoing projects than for eradicated infestations, thus reinforcing this conclusion.

Mean expenditure per hectare across various size categories was also compared in this paper. While comparisons of expenditure on eradication programs for different weeds may be meaningless because of differences in control techniques and damage caused by weeds, analysis showed that the larger the initial size of the weed infestation, the smaller the resources applied per hectare for eradication, although additional analysis of the time series data is required before drawing a more definite conclusion.

This is a preliminary analysis with the main objective of calling attention to the need for better data gathering in eradication programs. Not enough data was available for proper statistical analysis, so the analysis was based on averages.

Further Work

Difficulties in obtaining data on weed eradication programs has meant that, at the time of printing, only 12 Australian eradication programs had been assessed in this paper. Additional data, particularly for eradication programs in the size categories of less than 1 hectare and 101-1000 hectares are required. Data for the eradication of koster's curse (*Clidemia hirta*), rubber vine (*Cryptostegia grandiflora*), mimosa (*Mimosa pigr*a), mesquite (*Prospis spp*.) and limnocharis (*Limnocharis flava*) are known to exist and will be incorporated into the analysis when they are made available to the authors.

In addition, the role of time has not been taken into account in the analysis. Some programs, notable that for skeleton weed, have been in operation for nearly 30 years, where others have been in operation for as little as three years. It may be necessary to take into account length of program when comparing work hours (Table 3) other possible refinements of the analysis include the use of real dollars and discounting.

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