Some general principles for weed eradication programs

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Summary Results of nine weed eradication programs at different stages of their implementation in Australia are reviewed for their effectiveness in reducing weed populations to zero. Based on this review, two general principles for predicting eradication success and for estimating the length of such a program are formulated. Two criteria to do with weed distribution that may have most predictive power are whether the weed species is known to occur at three or fewer locations and whether the total area occupied by the weed is less than 100 hectares. One general principle thus is that populations of invasive species that are confined to only one or several sites of small areal extent are much more likely to be eradicated successfully than those that occur at many locations over a large area. A previously ignored attribute for successful eradication programs seems to be ease of detection of the weed. A second general principle is that the length of an eradication program will be determined by longevity of soil-stored seed and whether it is traded by nurseries. The importance to future eradication programs of assembling results on number of sites and their areas is stressed, if the validity of these generalisations is to be tested more rigorously in the future.

Keywords Weed populations, eradication programs, area of distribution, number of sites, seed longevity, monitoring.

INTRODUCTION

Eradication of a plant population implies deliberate management that leads to its extirpation or extinction from a region or country. As many as 90% of plant species that arrive in a region may not survive to form self-perpetuating populations (Williamson 1996), i.e. they fail to naturalise. Such instances may be thought of as natural extinctions and, though presumably numerically common, little is known about them because they mostly go undetected. This paper refers to those species that have already arrived and become naturalised in Australia but either their population size is still low or their known area of present distribution remains small. Eradication of such species is feasible technically and if the species is known to be invasive elsewhere and, especially, to pose an economic threat to agriculture, a decision may be made to fund an eradication program for that species.

In this contribution we shall review the likely effectiveness of some existing eradication programs in Australia and suggest some other naturalised species that are weeds of either agricultural or natural ecosystems for which eradication would seem especially appropriate. We shall limit the cases to be considered to species that could be eradicated from Australia and not just from individual States of Australia.

SOME CURRENT ERADICATION PROGRAMS IN AUSTRALIA

Helenium amarum* and *Eupatorium serotinum These two weeds of North American origin are both instances of successful eradication from Australia (Tomley and Panetta 2002). The former species, an annual, occupied one site of more than 50 ha in south-eastern Queensland, with satellite infestations occurring about 1 km from where it was first found in 1953. It took 39 years from initiation before eradication was achieved. The eradication program was prolonged because some plants in some sub-optimal situations were difficult to detect, seeds dispersed over a considerable distance and seed longevity is still unknown. For the second example, eradication of *E. serotinum*, a rhizomatous perennial, was quicker to achieve (at 18 years), partly because the species was easier to detect and occupied a smaller area when its eradication program commenced.

These two examples show that time from detection and area of infestation when eradication is initiated are both important criteria in determining the effectiveness of an eradication program and the length of time such a program need continue for. Whether the species is an annual or a rhizomatous perennial seemed to matter less in this comparison, but seed dispersal rates and seed longevity did extend the length of the eradication programs in each case.

***Bassia scoparia* (Kochia)** This case history differs from the previous two in that the eradication program for it began within 1–2 years of the plant's deliberate introduction and planting (Dodd and Randall 2002).

Although this shrubby species, a known weed of western US rangelands, was already widespread in Western Australia, all sites at which it occurred were known both from records of seed sales and because it had been recommended for re-vegetating salt scalds in low-lying areas. The results of a well-funded and co-ordinated eradication program were that no Kochia plants were able to be located seven years after its initiation, and only nine years after the weed's introduction. No plants have been found in the succeeding three years from 1999. Ease of location of all sites at which the weed was known to occur, together with ease of detection of this weed, enabled eradication to be achieved relatively quickly and inexpensively. Monitoring for several more years should ensure complete success of this recent eradication program.

Cleome rutidosperma Fringed spider flower is of tropical African origin and a known serious weed elsewhere, both of cropping and of natural ecosystems. It was first detected in Darwin in 2000 where it is now known from five locations, of which the largest was only 80 m^2 (Mitchell and Schmid 2002). The small areal extent of these five locations and their ready accessibility in suburban Darwin have made eradication of this species inexpensive, rapid and effective to date. No new infestations have been found since 2000.

Hieracium pilosella Another eradication program concerns this hawkweed, a known major weed in the US, Canada and New Zealand. A naturalised population of this weed was found in the Tasmanian midlands in January 2000 and eradication commenced soon afterwards (Rudman and Goninon 2002). It is not known when introduction occurred. Currently, the three patches in one small area (60 m^2) have been treated and few plants remain. Given the relatively short period of seed viability of this species, the subsequent monitoring period should be necessary only for 3–5 years before successful eradication is able to be confirmed. This species continues to have some attractiveness to rock garden enthusiasts and to herbal medicine and records of it keep cropping up in nurseries on mainland Australia. Continued vigilance of nursery lists and stock on offer will be required to prevent its re-introduction to other sites, especially on the Australian mainland. Its yellow daisy flowers and rosette habit resemble those of dandelions and some other daisies.

Chromolaena odorata*, *Mikania micrantha*, *Clidemia hirta* and *Limnocharis flava These four case histories are considered together because they are all potentially serious weeds of tropical American origin which have been detected in northern Queensland since 1994 (Waterhouse 1999) and for which eradication programs are now in place. The first to be detected in Australia was Chromolaena or Siam weed in 1994 when numerous small to extensive infestations were discovered. The program for eradication of this shrub species continues currently. It has taken longer and is proving more expensive than originally conceived because of problems associated with the inaccessibility of some known infestations in rugged country and the persistence of the seed bank that has accumulated since its probable introduction at least 25 years before the weed's detection. Mikania, a rapidly growing vine, is another major weed in other countries that was detected in Australia in 1998 and an eradication program instituted almost immediately. Because it was detected as several populations (total area >5 ha) occurring in the same region of northern Queensland as Siam weed, the eradication program for Mikania could be linked with that for Siam weed and total cost thereby reduced. Eradication of Mikania from the Bingil Bay area currently seems likely but eradication of the plant from northern Queensland now seems less likely because two other naturalised occurrences have been detected more recently which may have arisen from a separate and earlier introduction. That one of these recent finds was associated with a wholesale nursery makes eradication of this species from Australia even less likely in the medium term. A small infestation of the highly invasive shrub *Clidemia hirta* was discovered north of Cairns in 2001. It now covers several hectares as scattered plants along a drainage line. Because the occurrence is on land formerly used as a nursery, other occurrences are likely to be found, even though the original infestation may soon be eradicated. The fourth species in this group of candidates for eradication from northern Queensland concerns the clumping aquatic herb *Limnocharis flava.* Small populations covering less than 1 ha of this serious weed of the humid tropics were discovered in the Cairns region in 2001. Though this population was controlled rapidly, the existence of a persistent seed bank means continued vigilance will be required for 5 or more years at least. An even more recent discovery of the same weed north of Townsville indicates that the species may be more common than initially thought. Eradication of this species remains problematic because of the possibility of further discoveries in northern Queensland waterways.

Orobanche ramosa This parasitic weed of crops and pastures, of Mediterranean origin, was detected at one site in South Australia in 1992. Its date of introduction is unknown. By 1998/99 the known area of Branched broomrape had increased to 16 sites covering 160 ha.

With increased searching, many more sites were detected and the area of infestation gradually extended over the region to the east of Adelaide. Currently, it is known to occur over an area of 70 × 70 km with the area containing the weed being 32,850 ha. No other infestations are known outside this one large area. A containment program commenced in 1999 that aimed at national eradication in the long term. Branched broomrape is parasitic on a number of pasture and crop plants grown in the region as well as posing a threat to quality of exported grain. Branched broomrape is difficult to detect because its seeds are microscopic and long-lived in soil and its flowering stage occurs for only two or three months of the year. Whilst a policy of containment of Branched broomrape to one area of South Australia may be valid scientifically, a policy of eradication may not be, given the large area of infestation and the problems in detecting the plant and its numerous tiny seeds.

POTENTIAL CANDIDATES FOR ERADICATION

Groves *et al.* (2002) proposed nine weeds of agricultural ecosystems for eradication nationally. These species were *Aeschynomene paniculata*, *Blainvillea gayana*, *Brillantaisia lamium*, *Carthamus leucocaulos*, *Crupina vulgaris*, *Cyperus teneristolon*, *Hieracium aurantiacum*, *H. murorum* and *Onopordum tauricum.* All these naturalised species are characterised by having a small area of known distribution, occurring at only a few sites within that distribution and being known as major weeds of agricultural ecosystems elsewhere. Whilst the majority of these species are recent incursions, *Onopordum tauricum* is known to have been present at two of its three sites in Victoria for at least 90 years and at the third, also in Victoria, for at least 25 years; *Carthamus leucocaulos* has been present in southwestern Australia for at least 25 years also. A similar list for naturalised species occurring as weeds of natural ecosystems has also been finalised recently for Australia (Groves *et al.* 2000). Some of the 49 species on this list (e.g. *Carpobrotus edulis* × *C. virescens*, *Gladiolus caryophyllaceus*, *Romulea rosea* var. *communis*, *Coffea arabica* and *Nassella leucotricha*) are especially appropriate candidates for eradication in that they are of limited areal distribution and occur at few locations.

GENERAL PRINCIPLES

On the basis of the above examples, we suggest six main criteria that will determine success in weed eradication programs. The first two criteria concern population distribution and are:

1. if the total area of distribution is less than 100 hectares, and
2. if the weed is known to occur at three or fewer locations.

The first criterion is based on Rejmanek (2000) and is supported by the effectiveness of successful eradication programs for *Eupatorium serotinum* and *Helenium amarum* (<50 ha) in Australia. The same characteristic will probably drive the future success of eradication of *Cleome rutidosperma* (>1 ha), *Hieracium pilosella* (>1 ha) and *Mikania micrantha* (*c.* 16 ha). In terms of the second criterion—number of locations—*Eupatorium serotinum*, *Helenium amarum*, *Hieracium pilosella* and *Mikania micrantha* are each known to occur at three or fewer locations.

The success of eradication will also depend on:

3. if the weed's location is easily accessible.

For instance, the five locations of *Cleome rutidosperma* all lie within suburban Darwin and may be inspected regularly and easily, thereby ensuring detection of new seedlings and allowing for regular monitoring of all sites. The inaccessibility of a number of sites where *Chromolaena odorata* is known to occur has extended the length of the eradication program for that species.

Although *Bassia scoparia* was known from many sites and was distributed over a large area (3277 ha in 1993, Mack and Lonsdale, pers. comm.), its eradication within 15 years from introduction now seems assured. In this example, the accuracy with which each site was known before eradication began was critical to success of the program.

Eradication success will also depend on:

4. if the weed is readily detectable.

In the case of *Hieracium pilosella* in Tasmania, the eradication program for the only naturalised population known nationally has every chance of success. There have been at least five instances in the last six years, however, where *Hieracium pilosella* has been advertised as available for sale from nurseries in southern Queensland, New South Wales and Victoria. All these instances have been investigated and sales stopped with the co-operation of the nursery owners. Continued vigilance will still be needed to prevent the risk of other populations naturalising in the future.

Thus a further criterion for long-term success of eradication is:

5. if the species is still being traded by nurseries as seed or as established plants.

The longevity of seed or other plant parts in soil will not necessarily determine the overall chances for eradication success but it will certainly extend the period of time required for successful eradication, e.g. in the cases of *Helenium amarum* and *Chromolaena odorata.*

A sixth criterion thus becomes:

6. if seed is long-lived, then the longer will be the eradication program.

Some major weeds show genotypic diversity between taxa within a species. For instance, there are so-called 'weedy and non-weedy' forms of *Chromolaena odorata* (B. Waterhouse, pers. comm.). In the case of *Orobanche ramosa* variation has been reported in host specificity and, consequently, it has been important to determine the range of hosts able to be parasitised by the particular strain present in South Australia - a requirement that has lengthened the time and added to the expense of the containment/eradication program for this variable species. *Bassia scoparia* also has two forms present in Australia, the other form being confined to Western and South Australia but apparently not spreading (Dodd and Randall 2002).

Two general principles that encapsulate the above six criteria are:

1. **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 its location sites are easily accessible and if the weed is readily detectable.**

The two criteria as to whether the weed is traded by nurseries and if it is known to have seed viable in the soil for more than five years are summarised in the second general principle as:

2. **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 longer will be the period required for eradication.**

We believe that consideration of these six criteria and the two generalisations arising from them, will distinguish effectively those weeds that may be accepted as appropriate candidates for eradication from those, like *Orobanche ramosa* in South Australia and *Chondrilla juncea* in some local government areas in Western Australia, that may be more appropriately considered as candidates for containment. We also believe these six criteria to form a basis for constructing a decision tree for the more effective formulation of eradication programs in the future.

Nearly all the examples presented and discussed above are known weeds, usually of agricultural ecosystems, elsewhere. Some information on them is available which can be used as a basis for planning an eradication program. For some naturalised species occurring as 'environmental' weeds of natural ecosystems in Australia, such pre-existing knowledge may not always be available and will need to be gathered *de novo* before eradication programs can be formulated and funded. Such a situation applies to some of the naturalised weeds identified by Groves *et al.* (2000) as threats to native plant diversity and recommended by them for early containment and/or eradication.

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