Evaluating progress in weed eradication programs

F. Dane Panetta[1,3] and Simon J. Brooks[2,3]
[1] Alan Fletcher Research Station, Biosecurity Queensland, Department of Primary Industries and Fisheries, PO Box 36, Sherwood, Queensland 4175, Australia
[2] Tropical Weeds Research Centre, Biosecurity Queensland, Department of Primary Industries and Fisheries, PO Box 187, Charters Towers, Queensland 4820, Australia
[3] Cooperative Research Centre for Australian Weed Management
Email: dane.panetta@dpi.qld.gov.au

Summary Because weed eradication programs are very expensive and commonly take 10 or more years to complete, there is a need to evaluate progress towards the eradication objective. The degree of confidence that can be placed in any measure of eradication progress is a function of the effort that has been invested in finding new infestations and in monitoring known infestations. Determining eradication endpoints is particularly difficult, since plants may be extremely difficult to detect when at low densities and it is virtually impossible to demonstrate seed bank exhaustion. Recent work has suggested that an economic approach to this problem should be adopted. We propose some rules of thumb that could be used to determine whether to continue an eradication program or switch to an alternative management strategy.

Keywords Weed eradication, extirpation, delimitation, detection, monitoring, seed bank.

INTRODUCTION

Eradication is a weed management strategy that is appealing because the alternatives of containment or broadscale control require permanent, ongoing investment of time and money, unless effective biological control can be achieved. Weed eradication programs are generally very expensive and commonly take 10 or more years to complete (Mack and Lonsdale 2002), so there is a need to evaluate progress towards the eradication objective.

EVALUATING PROGRESS

The three criteria for assessing progress towards eradication are delimitation (determination of the full extent of a weed incursion), containment (prevention of spread from known infestations) and extirpation (local extinction of the incursion) (Panetta and Lawes 2005). Because incontrovertible evidence of containment failure may be difficult to obtain routinely, it has been argued that assessment of conformity to the delimitation and extirpation criteria is sufficient for the purpose of evaluating an eradication program (Panetta 2007).

The simplest measure of delimitation is the constancy of total infested area over time, i.e. the lack of discovery of new weed infestations. However, the degree of confidence that may be placed in estimates of total infested area is a function of search effort (Panetta and Lawes 2005); total infested area may remain constant simply because little or no effort has been made to detect further infestations. Research to date has largely focused on quantifying the *active* (targeted) component of search effort. This search mode can be highly effective in determining the extent of individual infestations and in detecting linked or satellite infestations. Trace-back and trace-forward methods have been effective in relation to the latter and, increasingly, landscape models (e.g. Pullar *et al.* 2006) are being used to refine search strategies. A delimitation measure that takes into account active search effort has been devised recently (Panetta and Lawes 2007).

The detection of new infestations where there are large disjunctions between these and known infestations remains problematic. Here the importance of *passive* surveillance (e.g. detection capacity arising from public awareness) cannot be underestimated (Brooks and Galway 2008). How to assess the effectiveness of passive surveillance and how to combine both surveillance modes into a single measure of search effort are current research challenges.

With regard to the extirpation criterion, eradication efforts at individual infestations are commonly divided into active and monitoring (or surveillance; see Holloran 2006a) stages (Panetta 2007). As is implied, control is imposed during the first stage, whereas weed detection is the sole activity during the second. Infestations revert to the active stage upon detection of new plants. Decreases in plant numbers during the active stage can be taken as evidence of progress towards eradication (Holloran 2006a), but Panetta (2007) highlights the potential for reproductive escape (i.e. failure to prevent reproduction) to lead to very protracted active stages. For this reason transition to the monitoring stage is seen as the critical indicator of progress.

Conformity to the extirpation criterion can be gauged either through frequency distributions of the time since most recent detection of the weed at all

infestations (Panetta 2007) or through time series stacked bar charts, where the bar for each year can be subdivided into active, monitoring and eradicated components (Holloran 2006a,b) (Figure 1).

Panetta and Lawes (2007) have recently developed a method whereby delimitation and extirpation measures are simultaneously presented in an eradograph (Figure 2). Apart from the benefits of a joint appraisal of conformity to these two criteria, this approach takes into account how long each infestation has been in the monitoring phase and requires no assumptions regarding when eradication could be declared for any particular infestation (see below).

By way of interpretation of an eradograph, a weed incursion is delimited when the trace reaches (and remains at) zero on the y-axis. Eradication occurs when the extirpation measure exceeds maximum seed longevity for the targeted weed (Panetta and Lawes 2007). For the two eradication programs represented in Figure 2, clearly program 'b' is out-performing program 'a' with regard to both criteria.

How can such graphical representations (i.e. stacked bar charts and eradographs) of performance be used to inform decision making with regard to maintenance of an eradication strategy or the adoption of another approach to incursion management?

MAKING DECISIONS

There are two basic types of decisions that must be made in the course of a weed eradication program. The first relates to when eradication can be declared for an infestation (or for multiple infestations). Historically, periods of between 2 to 5 years without detection have been the basis for declaring eradication. In some cases these have simply been arbitrary values, with nil or relatively little biological basis, but in others (e.g. *Bassia scoparia* L.; Dodd and Randall 2002) they have been based upon *a priori* knowledge of seed persistence, coupled with field observations. Recently, Regan *et al*. (2006) have argued that an economic perspective should be employed in determining when to cease a weed eradication program, given the uncertainty related to estimates of seed persistence and the imprecision of survey techniques. In this approach, an optimal stopping time exists as a trade-off between the cost of continued monitoring and the cost of escape and damage if eradication is declared too soon.

The second type of decision, and by far the more difficult of the two, relates to whether an eradication program is 'on track' or is likely to evolve into a *de facto* ongoing control program. Species that are targeted vary considerably (e.g. with regard to seed persistence), so eradication programs should be evaluated in relation to the best performance that could occur. This would be the case when a weed incursion is delimited and all infestations are (at least) in the monitoring phase. Rapid delimitation will be a function of both timely detection of the incursion and a dedicated search effort, both active and passive. Prolonged active phases (i.e. failures to transition to the monitoring phase) most likely result from a failure to detect and treat all plants before they can reproduce (Panetta 2007). In some cases this can be addressed by more frequent site visits and increased search effort during individual visits, but species that are not readily detectable until they flower and then quickly produce seeds (e.g. *Helenium amarum* (Raf.) H.L.; Tomley and

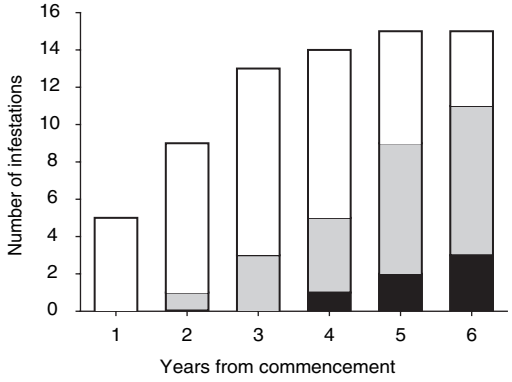

Figure 1. Status of infestations of a weed with a short-lived seed bank during the course of a hypothetical eradication program. Infestations are in the active (white bars) or monitoring (grey bars) phases, or have been eradicated (black bars).

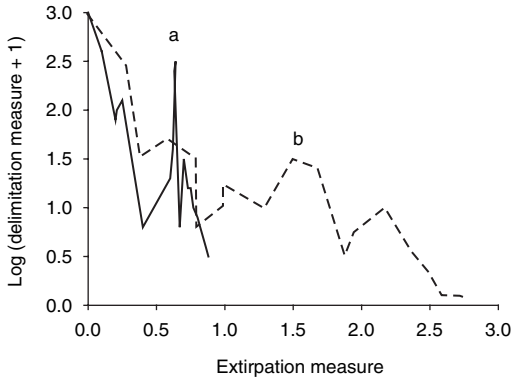

Figure 2. Eradograph demonstrating progress towards eradication in two hypothetical programs targeting the same species. In each case progress is assessed annually over 20 years. See Panetta and Lawes (2007) for definitions of the delimitation and extirpation measures.

Panetta 2002) or cases where seed production is not totally prevented by control at the flowering stage (e.g. *Chromolaena odorata* (L.) R.M.King & H.Rob.; Setter and Campbell 2002) are particularly problematic.

SOME RULES OF THUMB

When very serious weeds are targeted (e.g. by the current Australian national cost-shared weed eradication programs) there will be an understandable reluctance to abandon an eradication approach, but we suggest some broad guidelines relevant to making this decision. Since delimitation is the fundamental criterion for eradication success (Panetta and Lawes 2005), performance with regard to this criterion is most critical. We argue that any program that has not achieved delimitation by 10 years is unlikely to do so and that another incursion management strategy, such as containment, should be considered. Performance with regard to the extirpation criterion may be evaluated either in terms of the proportion of infestations in the active phase (Figure 1), or the value of the extirpation measure (Figure 2). If a majority of infestations are active at the 10 year mark, we suggest that eradication is not likely from this perspective either. Critical values for the extirpation measure will have to be defined relative to potential seed persistence for the targeted species.

The timing of such decision making is to some extent arbitrary. The choice of 10 years is conservative, but takes into account the political and other sensitivities that are commonly associated with any sustained, major investment. It may become obvious sooner that the incursion is considerably more widespread than originally thought and/or that delimitation is not achievable. Ideally, the feasibility of eradication (Panetta and Timmins 2004) should be reassessed whenever there is a major absolute increase in known infested area. In some cases, this could lead to the decision to adopt another incursion management strategy much earlier than 10 years.

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