When is eradication of exotic pest plants a realistic goal?

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Abstract Using a unique data set on eradication attempts by the California Department of Food and Agriculture on 18 species and 53 separate infestations targeted for eradication in the period 1972-2000, we show that professional eradication of exotic weed infestations smaller than one hectare is usually possible. In addition, about 1/3 of infestations between 1 ha and 100 ha and 1/4 of infestations between 101 and 1000 ha have been eradicated. However, costs of eradication projects increase dramatically. With a realistic amount of resources, it is very unlikely that infestations larger than 1000 ha can be eradicated. Early detection of the presence of an invasive taxon can make the difference between being able to employ offensive strategies (eradication), and the necessity of retreating to a defensive strategy that usually means an infinite financial commitment. Nevertheless, depending on the potential impact of individual weedy species, even infestations larger than 1000 hectares should be targeted for eradication effort or, at least, substantial reduction and containment. If an exotic weed is already widespread, then species-specific biological control may be the only long-term effective method able to suppress its abundance over large areas.

Keywords Costs of eradication; early detection; eradication effort; exotic pests; initial infestation; invasive plants; noxious weeds.

INTRODUCTION

Many control methods and their combinations (usually involving mechanical, chemical, and biological means) are available to managers for containing, controlling, or eradicating harmful alien plants. However, sound management strategies demand an objective means for setting priorities. Undoubtedly, exotic taxa with large-scale environmental impacts ("transformers" – see Richardson *et al.* 2000; Rejmánek *et al.* 2002) should always be targets for control and eradication. But when is complete eradication a realistic goal? There are numerous examples where small infestations of invasive plant species have been eradicated. These include *Silybum marianum* on Santa Barbara Island and *Osteospermum fruticosum* on Santa Cruz Island, California (Junak *et al.* 1993; Junak pers. comm.), *Pueraria phaseoloides* in Galápagos (Soria *et al.* 2002), and nine species on Rangitoto Island (Wotherspoon and Wotherspoon 2002) . There are also several encouraging examples where widespread alien animals have been completely eradicated (Dahlsten and Garcia 1989; Chapuis and Barnaud 1995; Priddel *et al*. 2000; more examples are in this volume). Can equally widespread and difficult alien plants also be eradicated? We try to answer this question by using a unique data set on exotic weed eradication attempts by the California Department of Food and Agriculture.

The California Department of Food and Agriculture (CDFA) is actively involved in preventing the establishment and invasion of "noxious weeds." The Food and Agricultural Code of California defines a noxious weed as "any plant species which is, or is liable to be, detrimental or destructive to agriculture, silviculture, or important native species, and difficult to control or eradicate." Each noxious weed is given a pest rating (A, B, C, or Q) which indicates the most appropriate action to be taken against it (O'Connell 1999). An "A" rated weed is subject to action by the CDFA and County Agricultural Commissioner Offices including eradication, quarantine, containment, rejection of shipments, or other holding actions. A "B" rated weed is subject to State action only when found in a nursery; otherwise action is at the discretion of the local County Agricultural Commissioner. A "C" rated weed is not subject to State action other than to provide for general cleanliness in nurseries, otherwise action is at the discretion of the local County Agricultural Commissioner. Those weeds that are widespread and can no longer be eradicated are usually given a "C" rating. A weed is rated "Q" when it is newly detected and seems likely to significantly impact agriculture. These weeds are treated as "A" rated until they are fully evaluated. Currently, there are 128 plant species that are listed as "noxious" by CDFA: 45 are "A" rated, 55 are "B" rated, 24 are "C" rated, and 4 are "Q" rated.

Eradication and other actions directed at "A" rated weeds are performed by personnel in the Integrated Pest Control Branch of CDFA and the County Agricultural Commissioner Offices who work closely together to detect and eradicate exotic weeds state-wide. When a new infestation of an "A" rated weed is detected, the site is visited and size of the infestation is delimited. Two estimates of infestation size, net and gross, are obtained. Gross infestation size is the area over which the weed is distributed. Net infestation size is the area to which treatment is actually applied. Gross infestation size is the area that must be surveyed in return trips following control treatments.

Eradication efforts consist of a series of control treatments to the infestation over several years. Control treatments can include herbicide applications, cultivation, removal of infested soil, and mechanical removal. For large infestations, a crew of workers is required; for small infesta-

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tions, only one individual may complete the work. Following initial treatment, the site is visited several times to examine the area for regrowth or seedling recruitment. This effort is repeated until no plants are found in subsequent visits. Eradication is considered successful when no plants are recovered from the initial infested area for three consecutive years.

To date, 14 exotic weeds have been successfully eradicated from California: whitestem distaff thistle (*Carthamus leucocaulos*), dudaim melon (*Cucumis melo* var. *dudaim*), giant dodder (*Cuscuta reflexa*), serrate spurge (*Euphorbia serrata*), Russian salttree (*Halimodendron halodendron*), blueweed (*Helianthus ciliaris*), tanglehead (*Heteropogon contortus*), creeping mesquite (*Prosopis strombulifera*), heartleaf nightshade (*Solanum cardiophyllum*), Torrey's nightshade (*Solanum dimidiatum*), Austrian peaweed (*Sphaerophysa salsula*), wild marigold (*Tagetes minuta*), Syrian beancaper (*Zygophyllum fabago*), and meadowsage (*Salvia virgata*) (O'Connell 1999). With the exception of *Cucumis* (16 and 32 ha), all gross infestations were smaller than 10 ha and most of them were smaller than one hectare when they were detected.

MATERIAL AND METHODS

Complete information on eradication effort was obtained for 53 infestations of 18 "A" rated species (Table 1). CDFA biologists assigned to the Detection and Eradication Districts for the State of California, CDFA, provided the data. For each weed infestation, the following information was obtained: (1) size of infestation after delimitation (both net and gross area), (2) date first found, (3) total number of visits to the site to date, (4) effort per infestation (number of person hours devoted to the site to date, including travel time to and from the site), and (5) current status of the infestation. The data are summarised in this contribution.

RESULTS

The relation between the mean eradication effort (work hours) and five initial gross infestation area categories is summarised in Table 2 and Fig. 1. The good news is that professional eradication of exotic weed infestations smaller than one hectare is usually possible. Furthermore, about 1/3 of all infestations between 1 ha and 100 ha and 1/4 of infestations between 101 and 1000 ha have been eradicated. Costs, however, increase dramatically. (An approximate estimate of direct costs in USD can be obtained by multiplying work hours in Fig. 1 and Table 2 by USD96; this includes salaries, cost of transportation, and cost of herbicides and equipment). With a realistic amount of resources, it is very unlikely that infestations larger than 1000 ha can be eradicated.

Interestingly, in the first four infestation-size categories, where at least some eradications were successful (Table 2), 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.

Table 1 List of "A" rated weeds in California for which eradication information was obtained.

Scientific name	Common name	No. infestations	Eradicated/ongoing
Terrestrial species			
Alhagi pseudalhagi	camelthorn	5	1/4
Carduus nutans	musk thistle	1	0/1
Centaurea diffusa	diffuse knapweed	6	5/1
Centaurea iberica	Iberian thistle	3	1/2
Centaurea maculosa	spotted knapweed	3	2/1
Cirsium ochrocentrum	yellowspine thistle	3	1/2
Cucumis melo var. *dudaim*	dudaim melon	1	1/0
Cuscuta reflexa	giant dodder	1	1/0
Euphorbia esula	leafy spurge	2	1/1
Halimodendron halodendron	Russian salt tree	1	1/0
Linaria angustifolia ssp. *dalmatica*	Dalmatian toadflax	1	1/0
Onopordum acanthium	Scotch thistle	13	6/7
Onopordum illyricum	Illyrian thistle	1	0/1
Peganum harmala	harmel	2	0/2
Physalis viscosa	ground cherry	1	1/0
Salsola damascena	Damascus saltwort	1	0/1
Aquatic species			
Hydrilla verticilata	hydrilla	5	2/3
Alternanthera philoxeroides	alligatorweed	3	1/2

Another confounding factor could be a bias created by differences in species representing small and large infestations. This would be particularly serious if large infestations consisted of more persistent species than smaller infestations. However, the trend remains the same even within individual species (Fig. 2). Finally, while the eradication effort increases with the area of infestation, the effort per hectare decreases at the same time (Table 2). This suggests that even infestations of >1000 ha could be eradicated, but the eradication effort per hectare would have to be greater. It is important to point out that all three successful eradications of gross infestations >100 ha (Table 2) represented relatively-small net areas (*Linaria angustifolia*: 0.49 ha; *Onopordum acanthium*: 0.20 ha; *Physalis viscosa*: 0.92 ha).

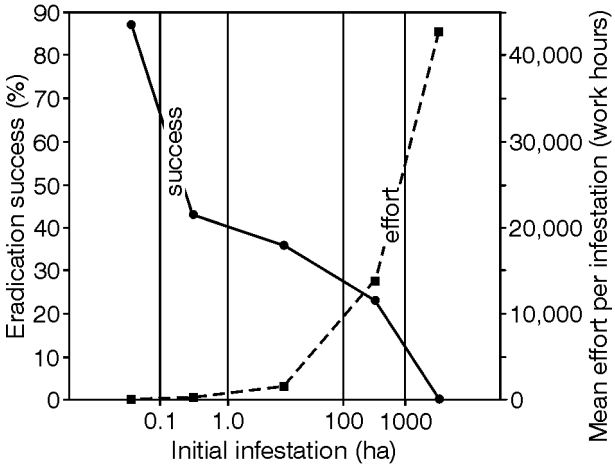

Fig. 1 The dependence of the eradication success (%) and the mean eradication effort per infestation (work hours) on the initial size of infestations. Based on the data for eradication projects of 18 noxious weed species and 53 independent infestations in California (see Table 1).

DISCUSSION

Obviously, a substantial increase in resources for exclusion and early detection of exotic weeds would be the most profitable investment. Without any data, or based on very limited data, others (Auld *et al.* 1987; Chippendale cited in Hobbs and Humphries 1995; Cook and Setterfield 1996; Braithwaite and Timmins 1999; Panetta 1999; Smith *et al.* 1999; Weiss 1999) already made this point. Surprisingly, however, practical implementations are still very rare. We suggest that in all concerned countries, teams of professional botanists should be created for rapid detection and assessment of new infestations of exotic plants. Early detection of the presence of an invasive and harmful taxon can make the difference between being able to employ feasible offensive strategies (eradication) and the necessity of retreating to a defensive strategy that usually means an infinite financial commitment.

Attempts to eradicate widespread invasive species, especially those that do not have any obvious environmental impacts (including suppression of rare native taxa), may be not only hopeless but also a waste of time and resources (Groening and Wolschke-Bulmahn 1992). Volunteers and donors, who would be otherwise willing to participate in eradication of serious pests, may be discouraged by such projects.

Nevertheless, depending on the potential impact of individual weedy species, even infestations larger than 1000 hectares should be targeted for eradication effort, or, at least, substantial reduction and containment. A notable example of a successful containment is the parasitic weed *Striga asiatica* in parts of North and South Carolina (Kaiser 1999). In the 45 years of the eradication programme, the initial gross infestation on 20 000 km^2 was reduced to 2800 ha of very light occurrences. The cost, however, was more than USD 250 million (R. E. Eplee, pers. comm.). Another exceptionally successful project is the practically complete eradication (98% of properties on which it is known to occur) of *Bassia* (*Kochia*) *scoparia* over the past eight years in Australia (3277 ha; 15,536 work hours; R. Randall, pers. comm.).

Table 2 Areas of initial gross infestations (at the beginning of eradication projects) of exotic weeds in California, numbers of eradicated infestations, numbers of ongoing projects, and mean eradication effort for five infestation area categories. The data include 18 species of noxious weedy species (two aquatic and 16 terrestrial) representing 53 separate infestations. NA – not applicable.

		Initial infestation (ha)				
		<0.1	0.1-1	1.1-100	101-1000	>1000
No. of eradicated infestations		13	3	5	3	0
No. of ongoing projects		2	4	9	10	4
Mean eradication effort per infestation (work hours)	Eradicated	63	180	1496	1845	-
	Ongoing	174	277	1577	17 194	42 751
Mean eradication effort per hectare (work hours)	Eradicated	NA	807	103	6	-
	Ongoing	NA	792	648	26	16

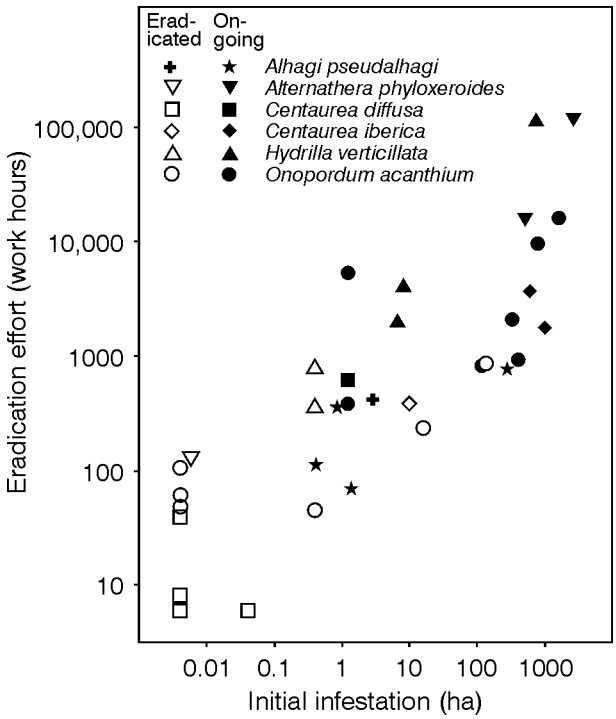

Fig. 2 The dependence of eradication effort on the size of initial infestations of six noxious weedy species in California. This diagram also indicates that eradication of aquatic weeds (*Alternathera* and *Hydrilla*) is more demanding.

In general, however, when an exotic weed is already widespread (>10 000 ha), species-specific biological control (if feasible) may be the only long-term effective way to suppress its abundance over the invaded area. Many successful weed biocontrol projects have been accomplished in Australia, California, South Africa, and other countries (Nechols 1995; Julien and Griffiths 1998; Olckers and Hill 1999; Pemberton 2000). Needless to say that as biological control agents are usually exotic taxa themselves, serious attention must be paid to their possible non-target effects (Louda *et al.* 1997; Wajnberg *et al*. 2001).

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REFERENCES

Auld, B. A.; Menz, K. M. and Tisdell, C. A. 1987. *Weed Control Economics*. London, Academic Press.

Braithwaite, H. and Timmins, S. M. 1999. Weed surveillance –catching 'em early. In Bishop, A. C.; Boersman, M. and Barnes, C. D. (eds.). Australian Weed Conference Papers and Proceedings, pp. 47-50.

Chapuis, J. L. and Barnauld, G. 1995. Rehabilitation of islands of Kerguelen archipelago by eradication of the rabbit (*Oryctolagus cuniculus*): Method applied to ile Verete. *Revue d'Ecologie (Terre et Vie) 50*: 377-390.

Cook, G. D.; Setterfield, S. A. and Maddison, J. P. 1996. Shrub invasion of a tropical wetland: Implications for weed management. *Ecological Applications 6*: 531-537.

Dahlsten, D. L. and Garcia, R. (eds.). 1989: *Eradication of Exotic Pests*. New Haven, Yale University Press.

Groening, G. and Wolschke-Bulmahn, J. 1992. Some notes on the mania for native plants in Germany. *Landscape Journal 11*: 116-126.

Hobbs, R.J. and Humphries, S. E. 1995. An integrated approach to the ecology and management of plant invasions. *Conservation Biology 9*: 761-770.

Julien, M. H. and Griffiths, M. W. (eds.). 1998. *Biological Control of Weeds*. 4th ed., Wallingford, CABI.

Junak, S.; Philbrick, R. and Drost, 1993. A Revised Flora of Santa Barbara Island. Santa Barbara, Santa Barbara Botanic Garden.

Kaiser, J. 1999. Stemming the tide of invading species. *Science 285*: 1836-1841.

Louda, S. M.; Kendall, D.; Connor, J. and Simberloff, D. 1997. Ecological effects of an insect introduced for the biological control of weeds. *Science 277*: 1088-1090.

Nechols, J. R. (ed.). 1995. Biological Control in the Western United States. Oakland, CA. University of California, Division of Agriculture and Natural resources, Publication 3361.

O'Connell, R. A. 1999. The state of California's noxious weed eradication programs. In Kelly, M.; Howe, M.; Neill, B. (eds.). Proceedings of the California Exotic Pest Plant Council Symposium. Vol. 5, pp. 26-30. Sacramento, California Exotic Pest Plant Council.

Olckers, T. and Hill, M. P. (eds.). 1999. Biological control of weeds in South Africa. *African Entomology Memoir 1*: 1-182.

Panetta, F. D. 1999. Can we afford to delay action against weeds in valued natural areas?. In Bishop, A. C.; Boersman, M. and Barnes, C. D. (eds.). Australian Weed Conference Papers and Proceedings, pp. 144-148.

Pemberton, R. W. 2000. Predictable risk to native plants in weed biological control. *Oecologia 125*: 489-494.

Priddel, D.; Carlile, N. and Wheeler, R. 2000. Eradication of European rabbits (*Oryctolagus cuniculus*) from Cabbage Tree Island, NSW, Australia, to protect the breeding habitat of Gould's petrel (*Pterodroma leucoptera leucoptera*) *Biological Conservation 94*: 115-125.

Rejmánek, M,; Richardson, D. M.; Higgins, S. I., Pitcairn, M. J. and Grotkopp, E. 2002. Ecology of invasive plants: State of the art. In Mooney, H. A.; McNeely, J. A., Neville, L.; Schei, P. J. and Waage, J. K. (eds.). Invasive Alien Species: Searching for Solutions. Washington, D.C., Island Press. (In press.)

Richardson, D. M.; Pysek, P.; Rejmánek, M; Barbour, M. G.; Panetta, F. D. and West, C. J. 2000. Naturalization and invasion of alien plants: concepts and definitions. *Diversity and distributions 6*: 93-107.

Smith, H. A.; Johnson, W. S.; Shonkwiler, J. S. and Swanson, S. R. 1999. The implications of variable or constant expansion rates in invasive weed infestations. *Weed Science 47*: 62-66.

Soria, M.; Gardener, M. R. and Tye, A. 2002: Eradication of potentially invasive plants with limited distributions in the Galápagos Islands. In Veitch, C. R. and Clout, M. N. (eds.). *Turning the tide: the eradication of invasive species*, pp. 287-292. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

Wajnberg, E.; Scott, J. K. and Quimby, P. C. (eds.). 2001. Evaluating Indirect Ecological Effects of Biological Control. Wallingford, CAB Publishing.

Weiss, J. 1999. Contingency planning for new and emerging weeds in Victoria. *Plant Protection Quarterly 14*: 112-114.

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 Veitch, C. R. and Clout, M. N. (eds.). *Turning the tide: the eradication of invasive species.* , pp. 381-388. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.