Progress toward Environmental Weed Eradication in New Zealand

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Data on 111 environmental weed eradication programs carried out by the New Zealand Department of Conservation (DOC) have been collected and summarized. A total of 21 programs were discontinued, and 90 are ongoing. Within the ongoing programs, four have been successful in that no plants remain at any known infestations. All four of the successful eradications had a total area across all infestations of less than 1 ha (2.5 ac); however, many similar-sized programs were not successful. Correctly assessing the extent of infestations appears to be a major problem for discontinued programs. Some of the ongoing programs are progressing toward eradication, but this is taking much longer than initially anticipated. The strongest determinant of progress toward eradication was found to be the identity of the DOC administrative area, for reasons that are only speculative. The number and area of initial infestations had no effect on progress toward eradication. However, the rate at which new infestations were located was negatively correlated with progress. Across many programs, progress was restricted by inconsistent infestation visitation. After running for a decade, DOC's weed eradication strategy has yet to provide significant dividends. Environmental weed eradication is clearly more difficult than has previously been acknowledged in New Zealand.

Keywords: Environmental weed, eradication, New Zealand, weed control.

Eradication can be defined as the "elimination of every single individual of a species from an area in which recolonization is unlikely to occur" (Myers et al. 1998). Considerable effort has been put toward predicting when weed eradication programs will succeed, and many predictive factors have been proposed, which vary between programs and target species. According to the above definition, the most important factor, regardless of situation, is the ability to prevent further entry of the species. The next two most commonly cited predictors of successful weed eradication in the literature are the extent of the weed incursion, with smaller infestations being much more likely to be eradicated than larger ones (Panetta and Lawes 2005; Rejmanek and Pitcairn 2002), and seed longevity, with long-lived seeds making eradication more difficult (Cacho et al. 2006; Mack and Foster 2009), partly because of the increased cost of eradication (Cunningham et al. 2004). Additional factors that have been cited include the conspicuousness of the target species (Mack and Foster 2009; Myers et al. 2000), particularly at low densities (Simberloff 2003); the ease of access to all infestations (Cunningham et al. 2004); the availability of sufficient resources (Myers et al. 2000); and whether there are well-established lines of authority for reporting (Simberloff 2003).

If eradications are completed, they can be an economically efficient approach to managing individual weed species (Morfe and Weiss 2006). It is generally agreed that environmental weed eradication is most efficient soon after discovery (Crooks and Soule 1999) or at least before the target weed increases in abundance exponentially (Cunningham et al. 2004; Woldendorp and Bomford 2004). Therefore, it would seem sensible to include eradication in any strategy for managing environmental weeds. However, weed eradication is often prescribed but seldom achieved (Dodd 1990; Hester et al. 2004; Simberloff 2001). Therefore, the success rate of eradication attempts needs to be considered when assessing whether eradication programs should be included within an environmental weed management strategy. Several articles have discussed case studies of successful and failed programs alike (Mack and Foster 2009; Simberlof 2003), but assessments of all the weed eradication programs attempted by a single agency are rare—an exception is the study of Rejmanek and Pitcairn (2002), who assessed 18 species and 53 separate invasions during a 28-yr period and found that one-third of all infestations between 1 ha and 100 ha (between 2.5 ac and 250 ac) had been eradicated. To be confident that attempting multiple eradications is a good strategy, more

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Management Implications

This work summarizes a decade of plant eradication attempts by the New Zealand Department of Conservation. Data on 111 environmental weed eradication programs have been collected and summarized. A total of 21 programs were discontinued and 90 are ongoing. Within the ongoing programs, four have been successful in that no plants remain at any known infestations. All four of the successful eradications had a total area across all infestations of less than 1 ha; however, many similar-sized programs were not successful. Incorrectly assessing the extent of infestations appears to be a major contributing factor in discontinued programs. This highlights the importance of exhaustive delimitation surveys when initiating eradication programs.

Some of the ongoing programs are progressing toward eradication, but that is taking much longer than initially anticipated. The strongest determinant of progress toward eradication was found to be the identity of the administrative Area responsible for running the program. I speculate that some Areas do a better job of starting programs that are more likely to succeed, completing searches and control actions more thoroughly, and recording their data. The number and area of initial infestations had no effect on progress toward eradication, but the number of new infestations found through the course of eradication programs negatively affects progress. Clearing infestations is fundamentally required for eradication; there are likely to be many practical options available to increase the clearance rate of infestations for particular species, e.g., spending longer at each infestation or visiting twice during the growing season. Across many programs, progress was restricted by inconsistent infestation visitation.

After running for a decade, DOC's weed eradication strategy has yet to provide significant dividends. There are few publications that document all eradication efforts, so the success rate of plant eradications is impossible to accurately assess. Environmental weed eradication is clearly more difficult than has previously been acknowledged in New Zealand. It seems likely that too many programs have been undertaken. Better success may have been realized with fewer programs, tighter controls on program starting, and better coordination.

studies concerning the fate of environmental weed-eradication attempts are required.

New Zealand is a very weedy country. There are at least as many naturalized, exotic species as there are indigenous species, and about 20 new, wild, exotic species are discovered nationally each year (Howell 2008). Furthermore, there are an unknown number of new incursions annually at the regional level. Thus, there are many candidates for eradication attempts. The New Zealand Department of Conservation (DOC) includes eradication attempts as part of its environmental weed management strategy (Owen 1998). DOC has a prioritization system that ranks potential eradication programs based on their feasibility and their potential to avoid biodiversity loss.

Between July 1, 1998, and June 30, 2004, DOC initiated 111 environmental weed eradication programs. These programs targeted 43 species and 1,412 infestations. During that period, DOC spent about 20% of its weed control budget on such eradications (C. Howell, unpublished data); the balance was spent on weed control at reserves. This level of activity reflects the belief that conducting eradication programs is an efficient way to minimize future weed control costs. This large data set provides a good opportunity to study weed eradications.

In this study, I analyzed the fate of all 111 eradication attempts that were initiated by DOC between July 1, 1998, and June 30, 2004. The primary aim was to investigate which factors contributed toward progress in eradication in these programs. I tested factors that have been suggested in the literature as well as others suggested by operational staff. I also endeavored to understand how progress was limited in these weed eradication programs. Finally, by including all programs where eradication was attempted, I investigated the success of DOC's weed eradication strategy. It is anticipated that the findings from this study will improve the overall rate of progress toward eradication by improving our understanding of the factors that must be attended to once the program is underway. This study will provide real-world examples of weed eradication attempts at an organization scale over a decade.

Materials and Methods

Defining Eradication Program Extent. A successful eradication program will result in no individuals of the target weed species existing across a large area. In this study, I used the DOC Area boundaries to define the large scale appropriate to eradication (Figure 1). Hereafter, I will use the term *Areas* to refer to these administrative units ($n = 49$ across New Zealand, grouped within 13 Conservancies on June 30, 2008). In rare cases, where weed eradication programs have been reported on at the Conservancy level (i.e., the eradication attempt extended to all Areas within a Conservancy), a separate program was created for each Area so that each program analyzed in this investigation covered only a single Area. By definition, eradication must be attempted across the whole Area, not just a part thereof. Thus, island "eradications" that covered only a small fraction of an Area were not included.

Measuring Progress toward Eradication. I collated operational data for each of the years over which each of the 111 DOC eradication programs was running between 1998 to 1999 and 2007 to 2008. All known infestations of the targeted weed species within the Area were listed. Operational data and interviews with staff were used to classify the status of each infestation for each year the program was operational, using the following categories:

- Active: some plants were detected.
- Cleared: no plants were found.
- Not visited: the infestation was not visited.

Figure 1. New Zealand Department of Conservation Area boundaries as at June 30, 2008.

To assess a program's progress toward eradication, I used an approach similar to that outlined in Holloran (2006). The measure of progress for each program was expressed as the annual proportion of all infestations within the Area that had been cleared. Progress toward eradication is demonstrated by an increasing proportion of infestations cleared. This simple measure of progress was used to assess and compare all 111 DOC eradication programs.

Factors Influencing Progress toward Eradication. I collated a list of 10 factors that were likely to have some influence on the progress of weed eradication programs, using the published literature and anecdotal reports from weed managers:

1. The number of infestations in the first year of the eradication program.
2. The size (hectares) of the sum of all infestations in the first year, as approximated by operational staff.
3. The annual total time (hours) spent at all infestations, averaged for the last 5 years. If hours were not specified in operational reports but costs were, I derived hours using standard rates of NZ\$50 h^{-1} (US\$41.28) for contractors, NZ\$30 h^{-1} for DOC staff, and NZ\$18 h^{-1} for temporary staff on wages. Where neither hours nor costs were available, but it was clear that infestations had been visited, I used an approximate figure of 2 h for each infestation.
4. The number of years between the first record of the weed naturalizing in the Area and the eradication program starting.
5. The growth form of the weed species targeted (trees and shrub, vines, grasses, herbaceous plants, or ferns).
6. The DOC weediness score (Owen 1997) of the target species (sourced from the internal DOC database BioWeb).
7. An assessment of seed longevity in four classes: no seed produced, seed viable for $<$ 1 yr, seed viable for between 1 and 5 yr, or seed viable for $>$ 5 yr. These assessments were sourced from the internal DOC database BioWeb.
8. The number of years the program had been operational.
9. The timeframe required for eradication, as predicted at the outset: within 3 yr, within 5 yr; or $>$5 yr (sourced from program documentation).
10. DOC Area and Conservancy. Both levels of DOC administration were included using the boundaries as at June 30, 2008.

Progress toward eradication, i.e., the proportion of infestations considered "Cleared" in the final year of the study (2007 to 2008), was analyzed in the statistical package R using classification tree models (R Foundation for Statistical Computing, Wien, Austria). All 10 factors listed above were included in nonremoval, dichotomous splitting of the data. Each split in the data is based on the variable with the most significant association (Therneau and Atkinson 1997).

Obstacles to Progress. By definition, eradication cannot be claimed while "active" and "not visited" infestations remain. In any 1 yr, active infestations comprised newly discovered infestations, established infestations not cleared, or previously cleared infestations that have relapsed to become active again. To investigate the effect of the history of each program on the progress estimate in the final year of the study, the proportions of infestations that were new, established, or relapsed were calculated annually, then averaged across years for all programs that were still running in 2007 to 2008. Established and relapsed infestations were distinguished using the status recorded the previous year. Where an infestation was not visited the previous year, the status at the most recent visitation was used. Infestation visitation was also calculated annually and averaged across years.

DOC's Eradication Strategy. The success of DOC's weed eradication strategy up to 2008 was investigated in the following ways:

1. The frequency distribution of progress was calculated for ongoing programs in the final year of the study (2007 to 2008).
2. For the programs where the eradication attempt was discontinued before 2007 to 2008, the average increase in the number of infestations was calculated for the years the programs were running.
3. For the programs with 100% progress in 2007 to 2008, the number of years required to attain that status was measured.
4. The progress of the programs that were expected to be completed by June 30, 2008, was investigated. This expectation was based on the estimated time required for eradication that was made when the program commenced.

Results

Factors Influencing Progress toward Eradication. There were 90 ongoing programs in 2007 to 2008; a summary of the species targeted is presented in Table 1. The classification-tree analysis identified Area as being the most important factor determining progress. The 90 programs were split twice on Area into four clear groups (Figure 2). The first group contained nine programs from five Areas and averaged 66% progress; that group contained three of the four programs with 100% progress. The second group consisted of 34 programs from 10 Areas, which averaged 30% progress. The third group of 22 programs from six Areas averaged 15% progress. The final group of 25 programs from 12 Areas had no or very few ''Cleared'' infestations and averaged only 0.7% progress. Further splits to two groups were supported based on weediness score. For the group averaging 30% progress, programs targeting weeds with the highest weediness scores performed better than those targeting weeds with lower scores. However, the directionality of the split was reversed for the group averaging 15% progress, with programs targeting lower-scoring species outperforming those targeting weeds with higher scores. It should be noted that the splits depicted in this classification tree reflect the best relationships, yet none were highly significant when tested further.

Many of the factors anticipated to have an effect on progress had no detectable effect. None of the measures of the size of the program (number of infestations, size of infestations, or annual time spent) had any detectable effect on progress. Perhaps most surprising is that, across all ongoing programs, there was no relationship between initial area occupied and progress in 2007 to 2008 (Figure 3). There was also no association between weed growth form and the level of progress achieved, nor was there a clear relationship between seed longevity or the length of time for which the program had been running and progress. It was anticipated that programs that had been expected to be completed within 3 yr on initiation would show the greatest progress; however, the initial assessment of the likely term of the eradication effort was not related to progress.

Obstacles to Progress. Of the three possible subcategories of residual ''Active'' infestations, established infestations were the most common, comprising on average 36% of all infestations per program per year (Figure 4). Despite wide variation in the proportion of established infestations, there was no significant correlation with progress. Because all infestations are new in their first year, all programs have at least some new infestations. Across all programs and years, new infestations comprised 20% of all infestations. The average annual proportion of new infestations was negatively correlated with progress ($P < 0.05$). Relapsed infestations were rare, only 25 programs had any relapses at all. Perhaps surprisingly, the average annual proportion of relapsed infestations was positively correlated with progress ($P < 0.05$). Most relapses ($> 97\%$) occurred within 3 yr of the infestation first being classified as ''Cleared.''

Visitation rate was positively correlated with progress ($P < 0.01$). Because eradication is the objective of these programs, it seems reasonable that a high proportion, if not all, infestations would be visited annually. However, for 35 programs (39%) on average, less than 75% of infestations were visited at least annually throughout their history. In some cases, individual infestations went several years without being rechecked. Simply visiting all infestations and carrying out weed control does not guarantee progress—programs with 0% progress had wide-ranging visitation, and there were 16 programs where infestation visitation was in excess of 95%, yet progress was less than 50%.

DOC's Eradication Strategy. Nearly half (48%) of the 90 ongoing programs in 2007 to 2008 had no infestations cleared, indicating 0% progress. A total of 31% of programs had made some progress but had less than half of all known infestations cleared. Only 21% of programs had more than half of their infestations cleared (Figure 5), and of those only four programs had 100% progress. Those four programs shared some common characteristics: in the first year, they all comprised fewer than 10 infestations, and the total area was less than 1 ha.

A total of 21 eradication attempts had been discontinued by 2007 to 2008. These programs targeted 16 different weed species, and the original size of infestations ranged from 0.04 to > 200 ha. In 15 programs, the infestations were not accurately delimited: 12 programs averaged more than a 10% increase in the number of infestations per year—the butterflybush (*Buddleja davidii* Franch.) program in Whangarei, New Zealand, located 131 new infestations in just 4 yr; and three further programs found so many new infestations that they

Table 1. A summary of the species targeted in 90 eradication programs included in this investigation. The average progress is for the final year of the study, the methodology to establish weediness scores can be found in Owen (1997).

Common name	Scientific name	Number of programs	Average progress	Weediness score
Kangaroothorn	*Acacia paradoxa*	2	0	25
Bluemink	*Ageratum houstonianum*	2	1.72414	24
	Akebia quinata	3	0	24
	Ammophila arenaria	2	9.54545	32
	Anredera cordifolia	2	26.7857	27
	Asparagus asparagoides	1	0	30
	Asparagus scandens	2	25	28
	Berberis darwinii	5	0	26
	Bryonia cretica	2	15	26
	Celastrus orbiculatus	13	16.967	30
	Ceratophyllum demersum	1	100	27
	Chrysanthemoides monilifera	2	0	28
	Clematis vitalba	7	24.8742	33
	Cobaea scandens	1	0	30
	Cytisus scoparius	1	28.5714	25
	Dipogon lignosus	2	0	26
	Dryopteris filix-mas	1	0	22
	Ehrharta villosa	1	0	29
	Glyceria maxima	1	0	28
	Gunnera tinctoria	1	0	30
	Hedychium gardnerianum	1	0	31
	Hydrilla verticillata	1	0	26
	Juglans ailantifolia	1	0	21
	Kennedia rubicunda	3	11.1111	31
	Leymus racemosus	1	0	25
	Ligustrum lucidum	1	25	32
	Lycium ferocissimum	1	33.3333	27
	Lythrum salicaria	1	55.6962	31
	Melianthus major	1	0	25
	Miscanthus nepalensis	1	5.12821	27
	Ochna serrulata	3	0	29
	Passiflora tripartita	1	0	27
	Podalyria sericea	1	0	18
	Salix cinerea	1	17.6471	32
	Selaginella kraussiana	1	0	23
	Solanum dulcamara	1	0	20
	Solanum mauritianum	1	25	24
	Spartina alterniflora	3	0	22
	Spartina anglica	11	24.3566	25
	Tropaeolum speciosum	2	0	23
	Tussilago farfara	1	50	26

were discontinued within the first year. Two programs targeting smokebush (*Buddleja madagascariensis* Lam.) were stopped when related programs targeting *B. davidii*, with which it is easily confused when not flowering or at seedling stage, were stopped. Finally, four programs were discontinued when it was established that reinvasion from neighboring Areas or inaccessible private land could not be avoided.

The anticipated timeframes for eradications in this study was within 3 yr, between 3 and 5 yr, and longer than 5 yr (Owen 1998). The time for all infestations to be classified as Cleared was 3 yr for the South Marlborough, New Zealand, common cordgrass (*Spartina anglica* C.E. Hubbard) program, 5 yr for the Motueka, New Zealand, coontail (*Ceratophyllum demersum* L.) and Ruapehu, New Zealand, oriental bittersweet (*Celastrus orbiculatus* Thunb.)

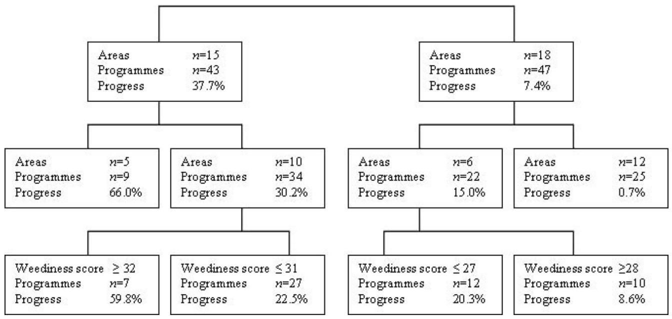

Figure 2. Classification-tree analysis for progress toward eradication in the final year of the study (2007 to 2008). Progress is the proportion (%) of infestations classified as "Cleared."

programs, and 8 yr for the Waikato, New Zealand, old-man's-beard (*Clematis vitalba* L.) program. There are no data available for these programs regarding the expected length of monitoring after all infestations have been cleared. However, there is high certainty that the clearance of infestations was permanent for three programs: the Motueka, New Zealand, *C. demersum*; Ruapehu, New Zealand, *C. orbiculatus*; and South Marlborough, New Zealand, *S. anglica* programs because their infestations had all been cleared for ≥ 3 yr. There is less certainty for the Waikato, New Zealand, *C. vitalba* program because all four infestations were first classified as Cleared in the final year of the study.

Based on the timeframe predicted at their outset, 47 programs were anticipated to be completed by June 30, 2008. It could be expected that these programs should all have 100% progress in 2007 to 2008 or earlier. Of these, 13 programs were discontinued, 18 programs had made 0% progress, 15 programs had between 5 and 67% progress, and only one program had 100% progress. However, a further three programs with open-ended timeframes also had all infestations cleared.

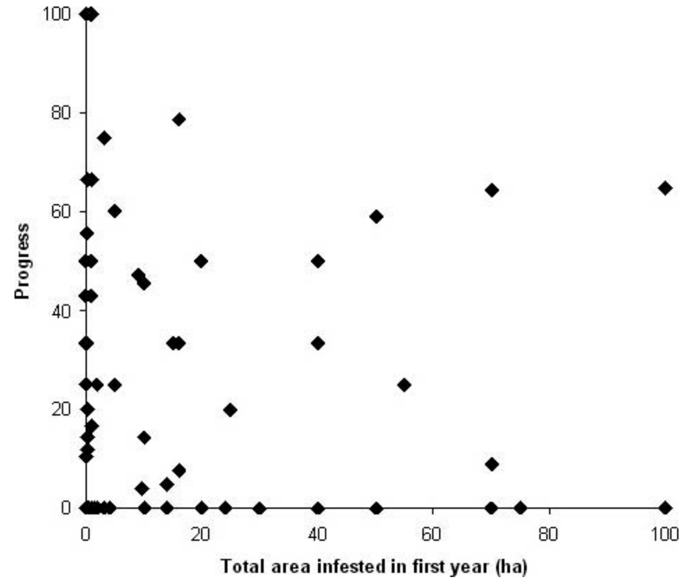

Figure 3. Relationship between total size of the initial infestations and progress toward eradication in the final year of the study (2007 to 2008). Progress is the proportion (%) of infestations classified as "Cleared."

Discussion

Progress toward Eradication. The only clear influence on progress toward eradication for the weed eradication programs running for at least 5 yr and still current in 2007 to 2008 was the DOC Area. Although I do not have the necessary data to tease out the cause of this effect, I speculate that higher performing Areas do a better job of starting programs that are more likely to succeed, completing searches and control actions more thoroughly, and recording their data. These findings support the notion that the rarity of success stories in plant eradication attempts might not be attributable to biological causes (Simberloff 2003). It is interesting that despite Areas being grouped into Conservancies, from which they receive technical advice and support, this higher administrative level did not appear to be a strong factor. Some Areas had portfolios of projects that were progressing well, whereas other Areas in the same Conservancy did not.

Of all the species characters discussed in the literature, seed longevity appeared the most likely to play a role in determining progress toward eradication. In theory, at least, long-lived seed banks should make eradication more difficult (Cacho et al. 2006) and, along with other factors, seed longevity has been shown to influence eradication cost (Cunningham et al. 2004). However, the simple classification of seed longevity used in this study was not related to progress toward eradication.

Because there was variation in progress between some programs targeting the same species, there appears to be little merit in trying to describe particular species characteristics that affect eradication progress across the whole suite of programs.

The unexpected observation that programs targeting high-scoring species achieved greater progress than those programs targeting weeds with lower weediness scores in some Areas (although this trend was reversed in other Areas) warrants further investigation. Intuitively, the attributes that contribute to high weediness scores should also make it harder to eradicate, e.g., large numbers or particularly long-lived seeds. Therefore, it is possible that this contradiction in some Areas relates to a difference in people's behavior rather than plant characteristics—if the target weed is perceived as being more aggressive, there may be greater resolve to complete the eradication from the staff in some Areas.

During the data-gathering phase, staff often commented that they believed that their eradication was technically

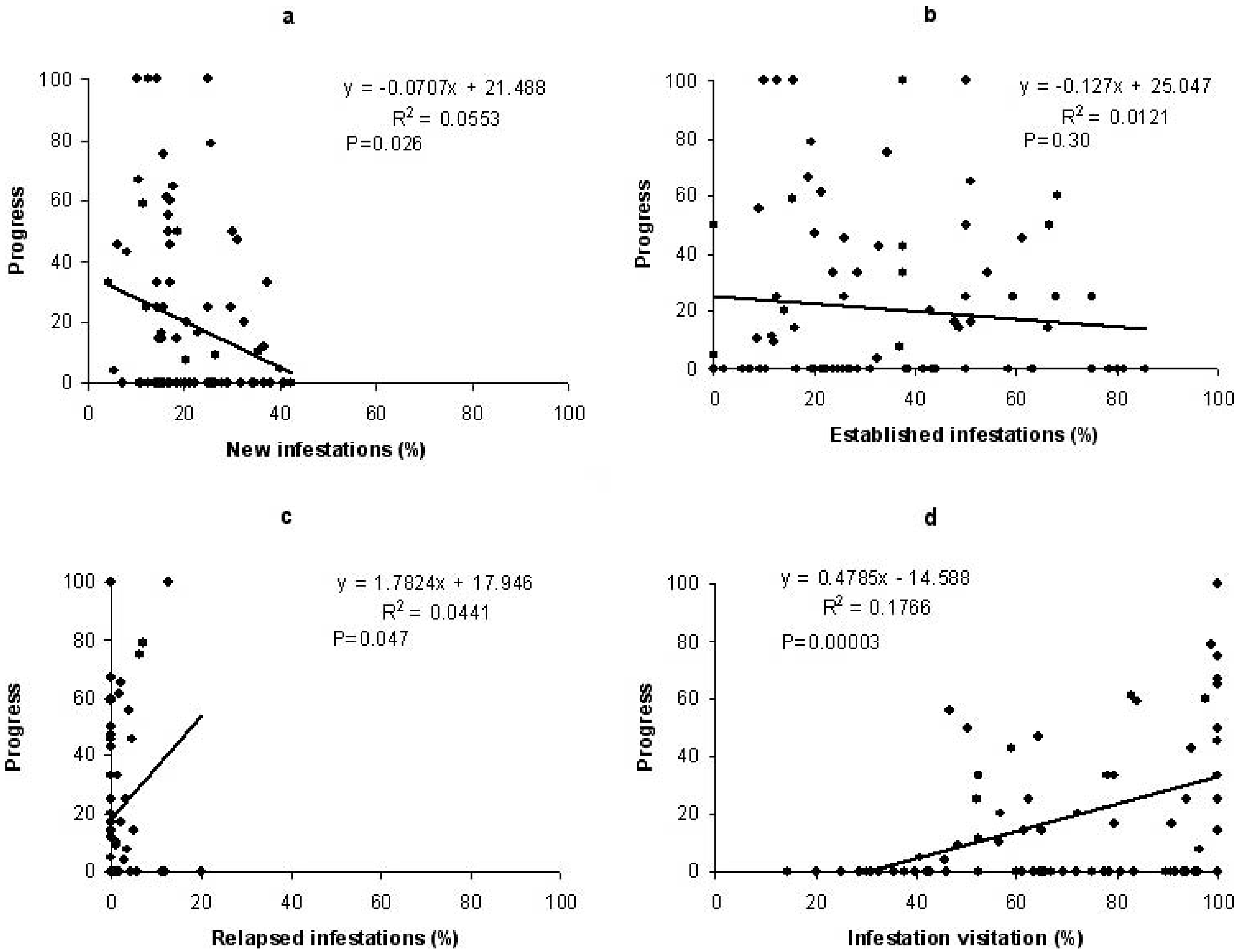

Figure 4. Scatter plots of the relationship between (a) the average proportion (%) of new infestations each year, (b) the average proportion (%) of established infestations each year, (c) the average proportion (%) of relapsed infestations each year, and (d) the average proportion (%) of infestations that were visited each year, and progress toward eradication in the final year of the study (2007 to 2008) for 90 eradication programs. In all cases, progress is the percentage of infestations classified as "Cleared."

feasible, but that the program was inadequately resourced to make this a reality. Data on program costs were difficult to obtain and standardize for comparison across different programs. Unless all the work is contracted out, quantities of commodities, such as herbicide, are typically very small, and the bulk of the program costs are staff time. However, there was no clear relationship between the time spent on a program and progress made. Therefore, it appears unlikely that simply increasing the budget for eradication programs will result in improved progress.

Obstacles to Progress. Although some increase in the number of infestations can be expected and planned for, a rapid increase in the number of infestations in the first few years should be seen as an indication that the goal of the program needs to be reevaluated. This does appear to be occurring within DOC. The discontinued programs typically had high rates of discovery of new infestations. Across the 90 ongoing programs, the frequency with which new infestations were located negatively influenced the progress measure. However, even with new infestations comprising up to 25% of all infestations, good progress remains possible if the rate at which other infestations are cleared stays high and the rate at which infestations relapse is low.

It was not possible to tease out whether new infestations were overlooked in initial surveys, were independent arrivals in the Area, or had arisen from the known infestations during the eradication program. For some programs, the failure may have been in containment, i.e.,

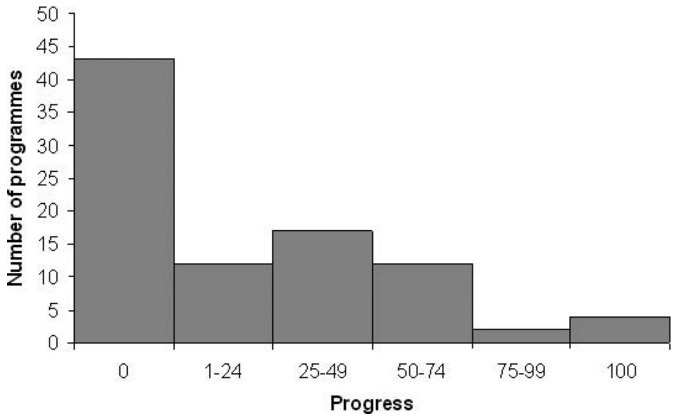

Figure 5. Progress of the ongoing programs in the final year of the study (2007 to 2008). Progress is the proportion (%) of infestations classified as "Cleared."

new infestations arose from known infestations. However, for the tree species Darwin's berberis (*Berberis darwinii* Hook.) and kangaroothorn (*Acacia paradoxa* DC.), at least, it appears that the infestations were initially present but were overlooked, because the new infestations contained adult plants. Failure to delimit the extent of all infestations properly in the first year greatly increases the risk of finding new infestations in subsequent years. As the cost of an eradication program is largely a function of its total area (Woldendorp and Bomford 2004), each new infestation will add considerably to the cost of the program. However, it has been shown that, as long as the amount of newly infested area decreases, eradication remains possible (Panetta and Lawes 2007). The bottom line is that if there are new infestations out there, they need to be found.

The rate at which infestations relapsed from Cleared to Active was low across almost all programs. It has been reported in other eradication programs that the transition to the monitoring phase from an active phase can be highly unidirectional (Panetta 2007). However, the proportion of relapsed infestations in this study could be expected to increase if more infestations were cleared in previous years. The rediscovery of the target weed at a previously cleared infestation could either be caused by seed-bank regeneration or from new arrivals from uncontrolled sources. It was not possible to separate these causes in this high-level study, but the possibility of uncontrolled sources should be investigated within eradication programs when relapses do occur. I speculate that the correlation between relapsed infestations and progress observed in this study is attributable to exhaustive search effort that may not be emulated in less successful programs.

Declaring an eradication program successful as soon as all infestations are considered Cleared is too early. Periods of between 2 and 5 yr have been used to declare eradication success (Panetta and Brooks 2008). In this investigation, more than 97% of relapses occurred within 3 yr of the infestation first being declared Cleared. No time limit will ever guarantee zero relapses, but infestations should be checked annually for at least 3 yr after the last plant has been found, and for significantly longer for species with long-lived seed banks.

Low rates of infestation visitation clearly contributed to the lack of progress. The reasons for high numbers of unvisited infestations varied according to staff interviewed, but typically the infestations were out of the way or difficult to access, making both visiting and clearance difficult. The accessibility of all infestations has previously been cited as a major factor in being able to achieve eradication (Cunningham et al. 2004; Mack and Foster 2009). Other DOC staff commented during data collection that they could not see the value in spending all day searching for a weed they do not find. This suggests that motivation to continue searching is difficult to maintain through weed eradications. No matter what the specifications of the program, achieving good progress always requires that the area be searched widely and all follow-up work be completed. The high rates of unvisited infestations in the least-successful programs suggests that inconsistent visitation of all infestations is a major obstacle to progress toward eradication. This factor may have been underestimated by DOC staff when planning and carrying out eradication programs. It seems likely that progress would be generally advanced by requiring that all infestations be thoroughly surveyed at least annually.

DOC's Eradication Strategy. It is difficult to gauge the progress achieved by DOC in weed eradications to date against a reasonable expectation. Although DOC has not completed many eradications, such is the rarity of completed eradication that many other studies cite programs that are nearly completed (Mack and Foster 2009; Myers and Bazely 2003; Zavaleta et al. 2001). For individual programs, the progress measure cannot be simply translated into the number of years remaining. It seems likely that the last infestations would be the most costly and time consuming to clear. However, progress toward eradication was generally much slower than was predicted at the start of each program. Despite running for at least 5 yr, almost half of the ongoing programs have no infestations classified as Cleared in 2007 to 2008, and only 21% of programs had more cleared infestations than not. It appears that eradication remains a long way off for many programs.

It could be argued that assessing progress using infestation data in this form can obscure progress when infestations are very large (Holloran 2006). During interviews, staff often commented that infestations had been greatly reduced and infestations almost cleared, but because there was no effect of infestation size on progress, that alone, does not explain the generally slow progress.

There are almost certainly some benefits from control even if infestations are not cleared (Mack and Foster 2009). It is likely that many programs in this investigation have resulted in significant reductions in density of the target weed at known infestations. In turn, this suppression is likely to have limited the establishment of new infestations and reduced ecological impacts from those that would have been observed in the complete absence of control. However, the missed opportunities to fund other work (Parkes and Panetta 2009) when eradication is prolonged are considerable. With low rates of completion of eradication programs, the economic calculations that indicate that eradications are a cost-effective tool (Cacho 2004; Harris and Timmins 2009; Morfe and Weiss 2006; Olson and Roy 2002; Zavaleta 2000) no longer hold. Eradication programs should be integrated into weed management strategies (Hobbs and Humphries 1994), but not all newly discovered infestations will be eradicable.

It has been suggested that eradication of exotic weed infestations smaller than 1 ha is usually possible (Rejmanek and Pitcairn 2002). Similarly, it has been noted that successful weed eradication programs consistently involve very small plant populations, comprising one or only a few infestations (Mack and Lonsdale 2002). All four eradication programs with 100% progress identified in this investigation had fewer than 10 infestations that totaled less than 1 ha in the first year. However, there were numerous programs that had similarly sized initial infestations, and yet, much less progress was made. Eradication of even very small populations is by no means assured in the timeframes of this study.

Ideally, no eradication efforts would be discontinued. However, it seems inevitable that at least some programs will be considered impractical to complete with the resources available. That the number of programs discontinued in this investigation exceeded those that were completed by a ratio of 5 : 1 suggests that eradication was much more difficult than was initially anticipated. A common feature of many of the discontinued programs was that the infestations were much more numerous than was initially thought. The decision to discontinue programs was almost always the result of many more infestations being discovered in the first few years of the programs. It seems likely that failure to properly delimit all infestations before commencing eradication programs has resulted in unwarranted optimism about the feasibility of many eradication attempts. It has been shown elsewhere that the cost of a thorough search can be as much as three times greater than search and control of known infestations (Buddenhagen 2006), but this level of investment was not encountered on any DOC programs. It is difficult to speculate on what a reasonable number of discontinued eradications should be. A very low rate of discontinued programs seems desirable, but it is surely better to admit defeat and free up resources for more promising initiatives than to continue on in some instances. The costs of failed eradication attempts, as well as the successful and ongoing programs, must be considered when calculating the dividend generated by successful eradication programs.

Based on the estimated time required for eradication made when programs were initiated, it could be expected that 47 programs would have shown 100% progress by 2007 to 2008. In fact, the completion rate was much less than expected—only four programs. Furthermore, ongoing surveillance is still planned for at least two of these programs. However, the timeframes required for eradication estimated by DOC can be considered optimistic by international standards. Of these 47 programs, 43 programs were anticipated to be completed within 5 yr, and 4 programs within 3 yr. However, completion of environmental weed eradication programs inside 5 yr is almost unheard of. In a study of 12 successful weed eradications (Panetta 2009), only one extremely fortuitous program was successful in < 5 yr. Because eradications more commonly take ≥ 10 yr to complete (Panetta and Brooks 2008), the failure to complete eradications on time in this study may in part be attributable to overly optimistic, predicted timeframes for eradication. It is clear that long-term financial commitment to weed eradication programs will be required for success (Panetta and Timmins 2004). If there is doubt as to the likely term of the eradication effort, it is probably better to try to source funding for longer than the eradication is expected to take (Wittenberg and Cock 2001).

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