CSIRO PUBLISHING
Wildlife Research, 2010, **37**, 360–371 www.publish.csiro.au/journals/wr

Management of animal and plant pests in New Zealand – patterns of control and monitoring by regional agencies

Richard Clayton[A] *and Phil Cowan*[A,B]

[A]Landcare Research, PO Box 40, Lincoln 7640, New Zealand.
[B]Corresponding author. Email: cowanp@landcareresearch.co.nz

Abstract

Context. Significant resources are spent annually in New Zealand controlling pests to mitigate impacts on native biodiversity and agricultural production, but there are few reliable estimates of the benefits. Concerns have been expressed about inconsistent monitoring methodologies, differing frequencies and intensities of control across organisations, and poor definition of desired outcomes.

Aims. To conduct and report on a survey of animal and plant pest control and monitoring by regional agencies, to identify issues with current practice and to provide advice on improvements.

Methods. We surveyed 15 regional agencies in New Zealand about the pest control and associated monitoring undertaken during 2005–08. We recorded the pests targeted, the control work done and its operational details, any result and/or outcome monitoring conducted, and estimated costs.

Key results. About 21% of the NZ$20 million expenditure on pest control was for monitoring. Excluding compliance (62%), monitoring changes in pest populations accounted for 31% of the total monitoring expenditure, whereas only 7% was spent measuring response in the resource that was supposedly being protected. The most common monitoring design (71%) comprised a single treatment area with no non-treatment area, in which only results were monitored. Only three programs (4%) had both treatment and non-treatment areas and both results and outcome monitoring.

Conclusions. Such limited outcome monitoring constrains severely the ability of regional and local authorities to provide robust justification for their pest management activities and expenditures.

Implications. Improved outcome monitoring requires better design of and additional resources for monitoring programs, improved institutional/political support for long-term programs, and better definition of long-term outcomes and objectives for pest management.

Additional keywords: benefits, costs, experimental design, pest management, survey.

Introduction

Many of the exotic species introduced to New Zealand are now established and managed as pests because of the threats they pose to native biodiversity and/or agricultural production (King 2005; Allen and Lee 2006). Agency involvement in pest management involves the Department of Conservation (DOC), local government represented by regional and unitary authorities (RUAs), and the Animal Health Board (AHB). The DOC manages pests on the conservation estate; RUAs are responsible for controlling pests within their geographical boundaries; and the AHB manages wildlife vectors, principally introduced brushtail possums (*Trichosurus vulpecula*), as part of the national strategy for bovine tuberculosis (Tb) management.

Most expenditure on animal pest management is directed at mitigating (i) browsing impacts on native vegetation and agricultural production by brushtail possums (*Trichosurus vulpecula*), lagomorphs, and ungulates; (ii) predation of native animals by possums, four species of rodents, three species of mustelids, and feral cats (*Felis catus*); and (iii) disease transmission, particularly that of bovine Tb to livestock by possums (Parkes and Murphy 2003). About 400 exotic plant species are managed because of the threats they pose to agricultural production, to native biodiversity and to public health and enjoyment of the environment (e.g. Roy *et al.* 2004; P. Williams, pers. comm.).

The desired outcomes of animal and plant pest management are spelled out in various agency documents: the DOC's annual statement of intent (e.g. Department of Conservation 2008), the AHB's national bovine Tb strategy (http://tbfree.ahb.org.nz/Default.aspx?tabid = 88, accessed 10 June 2009), and the regional pest management strategies (RPMSs) of the RUAs. Currently, 61 animal species and 196 plant species are listed as pests under RPMSs (http://www.biosecurityperformance.maf.govt.nz/, accessed 10 June 2009). Only 32 animal pests and 127 plant pests were actually subject to management action during 2005–08 (Appendices 1, 2).

Outcome monitoring is increasingly critical. The costs of government-funded animal and plant pest management in New Zealand currently exceed NZ$100 million per year, ~40% of which is spent by RUAs (Hackwell and Bertram 1999; Nimmo

 10.1071/WR09072 1035-3712/10/050360

Bell 2009). Concerns have been expressed that inconsistent monitoring methodologies and differing frequencies and intensities of control across the range of organisations involved in pest management in New Zealand, varying use of terminology, and differences in processes for defining outcomes impede the ability to gauge the performance of agencies towards achieving outcomes in any common metric or at a national scale (Jones 2008*a*). Adequacy of the design of monitoring is a key issue to ensure reliable knowledge of the effects of pest management. A recent study in Australia (Reddiex *et al*. 2006) highlighted the fact that there were few reliable estimates of the effects of mammal pest management for biodiversity protection, despite the expenditure of considerable resources, and that there is the need to adopt principles of experimental design to improve the reliability of knowledge of the effects of mammal pest control (Reddiex and Forsyth 2006).

Management agencies are thus likely to need increasingly robust data to support future pest control. The DOC and AHB have internal processes already in place for assessing progress towards outcomes, so we have focussed our review on the current situation among RUAs. Regional and unitary authorities have limited resources and thus need to use the most cost-effective and robust management and monitoring methods to ensure that the benefit to the environment and economy are maximised. To help them achieve that goal, this project aimed to summarise (i) current pest management undertaken by RUAs, and (ii) the types of monitoring undertaken in association with pest management, as first steps to improving current practices. When monitoring was carried out, we reviewed the design used and how this influenced the reliability of knowledge generated about the relationship between pest management and outcomes, as done by Reddiex and Forsyth (2006) for Australian pest mammals.

Materials and methods

We surveyed 15 RUAs with regard to the animal and plant pest control and associated monitoring they had undertaken during the period from 1 July 2005 to 30 June 2008. AHB programs (which are often conducted by RUAs as subcontractors to the AHB) were excluded from the survey because they are performance-based contracts designed to achieve a specific residual trap catch index, and they have an associated independent monitoring program that is carried out according to best practice guidelines (NPCA 2008). Information was collected on control conducted as part of RPMSs and also on any other substantial pest control involving RUA resources (either staff time or operating expenditure), for example, RUA-supported community programs.

We compiled a list of questions for use at interviews with RUA staff, based in part on a similar project conducted in Australia (Reddiex *et al*. 2006). The list was refined in discussions with pest control managers and further modified after trialling with one RUA (for details of questions, see Clayton and Cowan 2009). For each control program, we recorded the pests targeted, the control work done and its associated operational details, any result and/or outcome monitoring carried out, and estimates of the effort and/or costs of monitoring. Surveys were conducted in August 2008 with 15 RUAs by face-to-face interviews to ensure accuracy of data and a good level of survey participation, and to facilitate discussion of the local and regional issues associated with each RUA. During subsequent data entry and analysis, occasional contact was made with interviewees to check and clarify information.

We defined a pest control program as any type of pest control that an RUA either funded directly via rates charges or spent time coordinating (even if the control was not carried out by the RUA itself). In classifying the data, the funder of the program was considered to be either the council or the landowner, or both. Tenure of land was classified as private, public, mixed or council-owned. Outcomes of pest control were defined as protection of native biodiversity, production (agriculture and forestry), environmental (e.g. prevention or reduction of soil erosion or maintenance of water quality), amenity, or human health values. Two types of monitoring were examined: result monitoring (often called operational monitoring), which provides an estimate of the proportional changes in the pest population as a consequence of the control action or demonstrates whether or not a pre-set target for pest numbers was achieved by control; and outcome monitoring, which measures the state, or change in state, of the managed system in response to management actions, typically measured by changes in native biodiversity or crop yield.

Control programs were classified as either 'species-led', where control was targeted at individual pest species (e.g. possums), or 'site-led', where a suite of species was controlled in a particular area. In some regions the data from most site-led programs and some species-led programs were grouped because of the large numbers of similar operations. Rather than collecting a multitude of similar data on each of the individual pest management operations, we considered the degree and diversity of monitoring within programs as a whole, given that the overall goals, approach and administration were the same. We took this pragmatic approach because major details of individual operations within the programs did not differ. For example, we grouped information from the Bay of Plenty, where more than 170 sites were managed under one program and budget with the outcome of protecting and restoring biodiversity on private land, and in the Horizons-Manawatu region, where there were 40 possum control operations each with the same operational target.

Labour costs were defined in terms of paid hours for RUA staff. Operational costs included contractor time and the cost of chemicals or control devices. When staff gave costs in hours, we used a common conversion of NZ$50 000 per staff member per year, NZ$350 per day or NZ$50 per hour of staff time. For monitoring costs, we obtained one figure only, incorporating both labour and operating costs. It was not possible to separate costs for site- and species-led programs consistently, so these are not presented separately. Nearly all programs (>80%) on which we collected information were considered as ongoing, having been initiated before the 2005 financial year. Because of this and for simplification of data collection and analyses, we averaged the costs of the three years from 2005 to 2008 to give a single annual estimate for the whole period.

Every attempt was made to ensure accuracy of the data, but in some cases there were inconsistencies between the answers that interviewees gave and the stated goals of the RPMSs. Where this was the case, we have used the verbal version. We also had some difficulty reconciling financial information and ensuring consistency between different regional councils, often because of different internal reporting structures (both financial and operating) between RUAs. The figures reported to us are assumed to reflect the actual dollars spent on control and monitoring. Responsibilities and funding for programs are often shared between RUAs and/or other government or non-government organisations, and so the contributions of individual RUAs may have been underestimated because of the way information was gathered.

We constructed a Microsoft Access database to hold the data and facilitate their analysis. Some data were converted to categories to simplify analysis. Sample sizes vary between analyses because some interviewees did not provide answers to all questions, and programs that undertook only compliance monitoring (i.e. to ensure legal compliance of landholders with pest management regulations) were omitted from Table 2.

Results

Patterns of control

Species-led control programs ($n = 80$) were much more common than site-led programs ($n = 21$). The different number of plant pest ($n = 35$) and animal pest ($n = 49$) programs is partly a reflection of the way in which we treated some of the information, because some species-led programs incorporated both plant and animal control. Plant pest control programs were often focussed on collections of species, rather than the individual species-led programs more typical of animal pest control. Similarly, some site-led programs were a collection of operations in areas managed with the same overall goals and budget.

The primary justification for pest control was stated mostly as biodiversity or production protection (44% each), or amenity and environmental protection (10% combined). Often, more than one justification was provided for control programs. Biodiversity and production protection were by far the most common justifications with highest priority (Table 1). Many programs (57%) had a secondary justification, with biodiversity protection being the most common. Where the outcome was biodiversity and production protection, interviewees indicated a wide range of desired expectations from pest control programs (Table 1). Within biodiversity-focussed programs, there was a wide range of desired outcomes, but the three most frequent (75%) were improved or sustained forest integrity, increased numbers of native birds, and increased dominance of native species. Most production sector-focussed programs had the desired outcome of increased pasture production (45%) or reducing crop losses (23%). Some RUAs also directed resources to pest control for the prevention of bovine Tb (9%), presumably an adjunct to existing AHB programs as a risk management strategy in areas where AHB control has now ceased, or to sustain other perceived benefits of control of wildlife for bovine Tb.

Control programs were undertaken at a range of scales. Similar numbers of programs were applied to a whole region (54) as to part of a region (48), although some detail was lost here as programs often appeared to be described as region-wide for convenience – for example, the stated aim of rook (*Corvus frugilegus*) control was always to eradicate rooks from a region although the actual control took place over only part of the region. Control programs were carried out mostly by RUA staff (28%) or by external contractors (31%), and less frequently by both (19%), or by landowners (22%). Regional and unitary authorities were the sole funders of about half (48%) of the programs and a further 31% had costs shared between the RUA and the landowner. Most

Table 1. Number of control programs for all RUAs with desired outcomes or objectives tabulated against justifications
This table includes all justifications for each program, regardless of their priority order

Desired outcome or objective	Justification					
	Amenity	Biodiversity	Cultural values	Environmental protection	Human health	Production
Ecosystem protection		4		3		1
Forest integrity		37				
Grassland integrity		2				
Increase native species dominance		13				
Increased crop yield						7
Lake integrity				3		
More birds		15				
More fish						2
More pasture						29
Prevent allergies					1	
Prevent Tb						6
Protect bats		1				
Protect crop production						8
Protect native inverts		5				
Protect plantings				4		3
Shrubland integrity		1				
Soil conservation						1
Reduce impacts on lifestyle	5				1	
Wetland integrity		1				
Unspecified	12	7	2		4	7
Total	17	86	2	10	6	64

landowner-funded pest control was compliance-related and was undertaken to meet criteria described in the RPMSs. More than half of the programs (56%) were conducted on land of mixed tenure, i.e. both private and public ownership. Control was undertaken on private land (35%), with only a few examples of programs solely on council land, and these were in regions where RUAs had large networks of regional parks or for objectives such as flood protection. Of the 101 programs, 84 were initiated directly through an RPMS vs another means, e.g. self-help farmer groups.

Although RPMSs specify a large number of pests, namely 61 animal species and 196 plant species, not all of these were apparently targeted for control in 2005–08. Some of this difference was due to the ways in which pests were treated in different RPMSs; for example, some RPMSs named 'rodents' as a pest whereas others named individual species separately. Regional and unitary authority control programs in 2005–08 targeted possums most frequently, followed by mustelids (*Mustela* spp.), rats (*Rattus rattus* and *R. norvegicus*), rabbits (*Oryctolagus cuniculus*), feral goats (*Capra hircus*) and rooks. For plants, Contorta pine (*Pinus contorta*), old man's beard (*Clematis vitalba*), African feather grass (*Pennisetum macrourum*), gorse (*Ulex europaeus*), Nasella tussock (*Stipa trichotoma*), nodding thistle (*Carduus nutans*), woolly nightshade (*Solanum mauritianum*) and broom (*Cytisus scoparius*) were targeted most frequently.

Average total annual expenditure on animal and plant pest control was about NZ$20 million, with roughly the same spent on RUA direct staff costs (NZ$9.7 million) and direct operating expenditure and/or contractor fees (NZ$10.2 million).

Monitoring techniques and expenditure

A wide range of results-monitoring techniques was used to measure the success of pest control in reducing pest numbers (Norbury *et al*. 2001; Partridge *et al*. 2002; Reddiex and Parkes 2003; Hurst and Allen 2007*a*, 2007*b*). For animals, these included (with frequency of use in parentheses) bait take (1), hunter returns (7), modified MacLean rabbit index (4), spotlight counts (9), pitfall traps (1), Wax Tags® (1), residual trap catch (RTC) pre-control (4), RTC post-control (5), RTC pre- and post-control (11), faecal pellet counts (1), tracking tunnels (7) and baited vials (for ants) (5).

For plants, methods used for monitoring changes in weeds after control were aerial photographs (2), annual site inspections only (15), site inspections with follow-up after treatment (15), site inspections with GPS (15), permanent vegetation plots (20 × 20 m) (5), photo-points (7), belt transects (3), plots on transects (1), Reconnaissance (RECCE) plots (Hurst and Allen 2007*b*) (1) and species list with abundance (3).

A smaller set of techniques was used for outcome monitoring, namely photo-points (6), 5-min bird counts (5), foliar-browse index (FBI) (5), permanent vegetation plots (5), aerial photos (2), site inspection with GIS (2), transects (2), and fruit-fall plots, pitfall traps, RECCE plots and species lists (1 each) (Dawson and Bull 1975; Payton *et al*. 1999; Hanford 2000).

About 21% of the total funding spent by RUAs on pest control was used for monitoring. Monitoring for landowner compliance accounted for 62% of all monitoring expenditure, even though it was only done by six of the RUAs. Results monitoring, excluding monitoring for compliance, accounted for 31% and outcome monitoring for ~7% of the total monitoring expenditure (~7% and 1.4%, respectively, of the total spent on council-funded pest control). More than half of the local authorities we surveyed did no outcome monitoring and one program from Environment Canterbury, 'Biodiversity Sites', accounted for almost half of the total expenditure in this category.

Monitoring design

Most (91%) control programs had some form of results target or 'goal'. The specifics of these depended on the pest species concerned or the threatening agents being managed at a site, but the most common targets were a specified percentage reduction in pest numbers (26%), a target threshold (e.g. numbers, area) below which pests were to be reduced (25%), and zero density (24%). Some of these targets were aligned to those of the DOC and the AHB (e.g. possum reduction to ≤5% RTC), and were related to established relationships between pest numbers and impacts (Clayton and Cowan 2009).

Table 2 summarises the design of animal and plant pest control and associated monitoring assessed using the reliability of inference framework developed by Reddiex and Forsyth (2006). Nineteen control programs that were conducted solely for compliance purposes were excluded from the analysis. Overall, 82% of the remaining programs had some form of results monitoring, but only 16% had some form of outcome monitoring. Nine programs (11%) had no monitoring at all. All outcome monitoring, except in one program, had biodiversity protection as its primary goal. There was no monitoring for economic outcomes of pest management for forestry or agricultural production.

The most common monitoring design (71%) was for a single treatment area with no non-treatment area, in which only results were monitored – the second least robust design in Reddiex and Forsyth's (2006) ranking scheme. Only three programs (4%) out of the 83 monitored had both treatment and non-treatment areas and both results and outcome monitoring. Six other programs (three site-led, three species-led, all biodiversity-focussed) had results and outcome monitoring of the treatment area but lacked a non-treatment area.

Discussion

Our review focussed deliberately on pest management efforts of RUAs and provides an important snapshot of current activity.

Table 2. Summary of the design of animal and plant pest control and associated monitoring undertaken by New Zealand regional and local authorities in 2005–08

Treatment areas	Non-treatment areas	Result monitoring	Outcome monitoring	Frequency	%
1	0	No	No	9	10.7
1	0	Yes	No	59	71.4
1	0	No	Yes	5	6.0
1	0	Yes	Yes	6	6.0
1	1	Yes	No	1	1.2
1	1	No	Yes	0	0.0
1	1	Yes	Yes	3	3.6

Collectively, these agencies are the second largest managers of animal and plant pests in New Zealand, and have responsibilities to protect both biodiversity and production. The survey dealt only with RUA pest management, and so underestimates total regional effort because of the large and growing number of community-led biodiversity initiatives for which the highest-priority initial activity is usually pest control (http://www.sanctuariesnz.org, accessed 24 April 2009). Pest management by RUAs is focussed largely on species-led programs, at least in terms of frequency and probably also expenditure, although the latter needs clarification. Many RUA managers commented, however, on the trend towards site-led programs, with better integrated animal and plant pest control aimed to produce a wider range of benefits at key sites (although many of the benefits were implicit expectations rather than explicit goals). The situation in Australia seems similar, with few integrated pest control programs at present, but an emerging trend to multi-species control (Reddiex *et al*. 2006). This change is being driven in part by increasing evidence of undesirable outcomes of single-species pest control (Zavaleta *et al*. 2001; Sinclair and Krebs 2002; Sweetapple and Nugent 2007).

In addition, management agencies are seeking increasingly to justify pest management through multiple benefits, including outcomes such as enhanced carbon sequestration after browsing mammal control (e.g. Funk and Kerr 2007). Although the primary goal for RUA pest control was split equally between biodiversity and productive sector protection, those programs that had productive sector protection as their primary goal used biodiversity protection as a key supporting justification much more often than the reverse situation. We suggest that this may be a reflection of the increasing emphasis on the multiple benefits of pest control on productive lands. The economic emphasis was not, however, reflected in actual measurement – there was no outcome monitoring of the economic benefits of pest management for productive sector protection. This may be because RUAs believe that the particular industries involved should be responsible. It may also be partly because of implicit assumptions of a direct link between pest reduction and reduced losses based on prior knowledge, or it may reflect an unstated application of the precautionary principle – in the absence of prior knowledge, reduce pests to the lowest density possible. Alternatively, it may be because the collection of robust data on production outcomes would require funding to a level and of a duration well beyond the ability of any individual RUA (C. Leckie, pers. comm.). Research to better characterise pest density–impact relationships is likely to have substantial paybacks through optimising the economics of both pest control (how much control and where?) and monitoring (rationalisation of results and outcome monitoring across RUAs).

A wide range of methods and methodologies was used for results monitoring. Apart from RTC and Wax Tag monitoring of possum control, which have been developed specifically for industry and compliance purposes (http://www.npca.org.nz, accessed 13 March 2009), there are no best practice protocols used across RUAs. The DOC has recently begun to develop a comprehensive inventory and monitoring toolbox (McNutt *et al*. 2007) that will establish national standards and specifications for inventory and monitoring methods. In addition, the DOC has a standard operating procedure framework for control that directs operational managers to best practice methodologies (K. Broome, pers. comm.).

Some species are identified as pests in several, sometimes all, of the RPMSs included in this review. There would therefore be value and probably cost efficiencies in coordinating outcome monitoring of these species across councils. The design of appropriate cross-council monitoring will present some challenges. Sites where pest control is undertaken both within and between regions are likely to vary in ways that potentially influence the outcomes of pest control. For example, there are site differences in the susceptibility of native plants to possum browsing, and whatever is responsible for these site differences (e.g. soil fertility) may influence the pattern and rate of recovery of foliage after possum control. Such variation between sites is usually poorly understood, but it may be sufficient, when added to all the other sources of variation, to preclude the development of cross-region outcome monitoring programs because of the costs in establishing robust monitoring systems, or to limit monitoring to identification of trends (Clayton and Cowan 2009). These risks could be evaluated through statistical modelling as a precursor to the design of cross-council monitoring programs. Opportunities for cross-council collaboration in outcome monitoring may be easier to achieve, however, for economic and social/cultural outcomes than for biodiversity ones.

The design and costing of such monitoring programs would need to take into account the extent to which agreement between councils on best practice for methodologies for outcome monitoring for pests of common interest (e.g. possums, predators, gorse) would influence the design and costs of monitoring. Common and consistent methodology could provide the basis for the application of meta-analysis to cross-council data, and so potentially provide greater statistical robustness to outcome monitoring. Alternative monitoring designs would need to be evaluated for both costs and statistical power, based on agreement across councils about the magnitude of change to be considered significant, and the certainty with which such change has occurred (e.g. 95% certainty that the condition of a resource had improved by 20%).

Obtaining consistent financial information proved difficult, and our estimate of about NZ$20 million annual expenditure is only about half of that estimated by Nimmo Bell (2009), although their estimation process encompassed a wider range of biosecurity activities than the present study. We have confidence, however, in our relative estimates of expenditure. About 21% of total funding for pest control was spent on monitoring, of which 62% was spent on monitoring for compliance purposes in response to targets or thresholds set in the RPMSs (e.g. monitoring of rabbits to enforce a requirement in the RPMS for landowner control if the McLean index of rabbit numbers exceeded a specified level). Excluding compliance monitoring, ~7% of total funding for pest control was spent on monitoring results and outcome. This is significantly less than the 15–20% recommended by Choquenot and Warburton (1998) for possum control, based on an analysis of the optimal cost–benefit ratio of monitoring, an approach that could be usefully applied to other pests.

Compared with Australia (Reddiex and Forsyth 2006), many more pest control programs conducted by RUAs in New Zealand had some form of monitoring of either pest or resource (although this may reflect, to some extent, the different definitions of a control 'program'). The design used most frequently for monitoring pest control programs, namely a single treatment area with no non-treatment area in which only results were monitored, was much the same in New Zealand (72%) and Australia (63%). As Reddiex and Forsyth (2006) point out, such a design has very low reliability of inference and generates only anecdotes about the ecological effects of pest control (McArdle 1996). We conclude, as did Reddiex and Forsyth (2006) for Australia, that nearly all regional animal and plant pest control activities in New Zealand incorporate a monitoring design that provides only the weakest inference about the effects of pest control. Harris (1999), in a case study review of regional implementation of the New Zealand Biosecurity Act, made similar observations and recommended *inter alia* development of appropriate monitoring techniques, and greater data gathering within the monitoring programs, including information on the actual costs of pest control and the effectiveness of regional intervention.

Although it was not part of the original survey, but given the low frequency of outcome monitoring, we followed up the survey with a simple question – what were the key issues or barriers to the use of outcome monitoring? There were four general categories of responses. Concerns were expressed about (i) methods for outcome monitoring – the effectiveness of available tools and the design of monitoring programs; (ii) resources, both staff and money, that were often lacking to conduct effective monitoring programs and/or analyse the information; (iii) institutional and/or political issues about support for long-term programs, and a view from councillors that killing pests was the priority; and (iv) other issues such as the short-term cycle of planning (usually three-yearly), lack of forward planning precluding baseline data collection, lack of clarity of links between strategic and operational goals and objectives, and failure to set specific, long-term objectives for pest management. Many of these issues appear to be common constraints to adequate monitoring of pest management, not just in New Zealand and Australia but globally (Raffaelli and Moller 1999; Parkes *et al*. 2006; Reddiex and Forsyth 2006). Additionally, what constitutes adequate experimental design and the importance of replication remain issues under debate both from a statistical point of view and in a management context (see Reddiex and Forsyth 2006). The current national pest management framework led by the Ministry of Agriculture and Forestry Biosecurity New Zealand (MAFBNZ), discussed below, provides an excellent opportunity to increase commitment significantly within RUA governance and management for outcome-monitoring programs to demonstrate the effectiveness of the pest management expenditure.

Resource and experimental design constraints are compounded by methods and approaches for measuring biodiversity benefits of pest management that are not well developed, particularly compared with standard methods for measuring changes in crop losses (e.g. Walker 1983; Hone 2007). Some of those used most commonly in New Zealand, such as FBI and 5-min bird counts, have both practical and theoretical limitations (Dawson and Bull 1975; Payton *et al.* 1999). Two initiatives may change this situation in the next few years. First, the DOC's Natural Heritage Management System will come into use. This system is being developed to create a nationally consistent, scientifically sound system of natural heritage management, enabling prioritisation, planning and monitoring of achievement (Lee *et al*. 2005; Department of Conservation 2008). To support this system, the DOC is working to improve the accuracy and efficiency of its data collection (including field data), and to develop a greater ability to integrate data both internally and with other agencies (such as regional and local authorities). There is ongoing development of nationally consistent inventories, classification systems, prioritisation processes, and monitoring and reporting methods. The longer-term aim is to develop the Natural Heritage Management System into a system that is shared with others to contribute towards national planning and reporting on the state of New Zealand's biodiversity. Second, MAFBNZ is developing a performance management framework (PMF) for New Zealand pest management (Jones 2008*a*, 2008*b*; Lawless *et al*. 2010) that encompasses national reporting. Such a system will require agreement with RUAs on outcomes and measures for regional and national reporting, both of operational results of pest management and a variety of outcomes (e.g. biodiversity, production). The necessary changes to RPMSs and development of outcomes by RUAs that need to take place in collaboration with the development of the PMF are currently underway (Jones 2009).

Regional and unitary authorities are already undertaking proactive steps in advance of the PMF, such as streamlining their reporting systems, sharing GIS-enabled database systems, and proposing the creation of a biodiversity managers group aligned with the existing biosecurity and pest management group. Developing and supporting systems such as these will undoubtedly help with overall better management of pests in the local government sector.

Conclusions

This survey provides key baseline information on RUA animal and plant pest control in New Zealand against which future changes in control activity and monitoring can be evaluated. The survey also highlights the need for better definition of the desired outcomes of pest management, appropriate indicators of progress towards outcomes, and greater consistency across regions in the collection, analysis and reporting of information about pest management activities and the outcomes of pest management. At least NZ$20 million is spent annually by RUAs on animal and plant pest management, but monitoring, particularly of outcomes, is generally not well resourced and lacks adequate support within RUAs, particularly at the governance level. Resource constraints and inadequate methods for measuring the benefits of pest control for biodiversity have resulted in the common use of monitoring designs that generate little reliable knowledge about the ecological effects and benefits of pest control. These issues are not new, from neither a New Zealand nor an international perspective (Romesburg 1981; McNab 1983; Caughley 1998), but the question remains as to why they have not been better addressed. Some of the changes that are needed to the New Zealand pest management system appear to have been recognised (Jones 2008*a*) and are being driven by the development of an overarching performance management framework for pest management that will allow national pooling and sharing of information on pest management and monitoring through a centralised integrated 'toolbox' (Gear 2010), and that will include consistent reporting at a national level (Lawless *et al*. 2010).

Acknowledgements

This project would not have been achievable without the help and patience of many staff in the regional and district councils, particularly Bill Martyn, James Lambie and Campbell Leckie, and the support of all the biosecurity managers. Ben Reddiex and Mike Harre (MAFBNZ) provided much helpful advice and guidance. Mark Fuglestad helped create the database. Guy Forrester and the late Greg Arnold provided statistical advice. Bruce Warburton, Chris Jones, Campbell Leckie and Henrik Moller commented on the manuscript, which was edited by Anne Austin. The project was funded jointly by the Foundation for Research, Science and Technology Envirolink program, a consortium of 15 regional and unitary authorities, and MAFBNZ.

References

Allen, R. B., and Lee, E. G. (Eds) (2006). 'Biological Invasions in New Zealand.' (Springer-Verlag: Berlin.)

Caughley, G. (1998). Control of wild animals. In 'The Future of New Zealand's Wild Animals. Seminar 2000 Proceedings, New Zealand Deerstalker's Association'. pp. 101–103. (New Zealand Deerstalker's Association: Christchurch.)

Choquenot, D., and Warburton, B. (1998). How much pest monitoring is enough? Allocation of monitoring resources in pest management programmes. Landcare Research Contract Report LC9899/05 for Department of Conservation, Wellington.

Clayton, R. I., and Cowan, P. E. (2009). Best practice operational and outcome monitoring for pest management – a review of existing council approaches and activity. Landcare Research Contract Report LC0809/085 for Horizons Regional Council, Palmerston North.

Dawson, D. G., and Bull, P. C. (1975). Counting birds in New Zealand forests. *Notornis* **22**, 101–109.

Department of Conservation (2008). Statement of Intent 2008–2011. Department of Conservation, Wellington.

Funk, J., and Kerr, S. (2007). Restoring forests through carbon farming on Maori land in New Zealand/Aotearoa. *Mountain Research and Development* **27**, 202–205. doi:10.1659/mrd.0921

Gear, I. (2010). Physical control and monitoring tools. Future of pest management working paper 3. Available at http://www.biosecurity.govt.nz/files/pests/surv-mgmt/pmp-working-paper-3.pdf [Verified 25 March 2010].

Hackwell, K., and Bertram, G. (1999). 'Pest and Weeds. The Cost of Restoring an Indigenous Dawn Chorus.' (New Zealand Conservation Authority: Wellington.)

Hanford, P. (2000). 'Native Forest Monitoring. A Guide for Forest Owners and Managers.' (Forme Consulting Group: Wellington.)

Harris, S. (1999). Regional implementation of the Biosecurity Act 1993. MAF Policy Technical Paper 99/4, Wellington.

Hone, J. (2007). 'Wildlife Damage Control: Principles for Managing Vertebrate Pests.' (CSIRO Publishing: Melbourne.)

Hurst, J. M., and Allen, R. B. (2007*a*). 'A Permanent Plot Method for Monitoring Indigenous Forests – Field Protocols.' (Manaaki Whenua Landcare Research: Lincoln, New Zealand.)

Hurst, J. M., and Allen, R. B. (2007*b*). 'The Recce Method for Describing New Zealand Vegetation – Field Protocols.' (Manaaki Whenua Landcare Research: Lincoln, New Zealand.)

Jones, C. (2008*a*). Performance Measurement in New Zealand Pest Management. A review of national and international processes and requirements for a national performance measurement framework. Landcare Research Contract Report LC0809/015 for MAF Biosecurity New Zealand, Wellington.

Jones, C. (2008*b*). Demonstrating the Value of Performance Measurement: a Series of Case Studies. Landcare Research Contract Report LC0809/060 for MAF Biosecurity New Zealand, Wellington.

Jones, C. (2009). Alignment of council pest management programmes with intervention logic models for performance measurement. Landcare Research Contract Report LC0910/016 for MAF Biosecurity New Zealand, Wellington.

King, C. M. (2005). 'Handbook of New Zealand Mammals.' (Oxford University Press: Auckland.)

Lawless, P., Harre, M., Matthews, F., Petersen, L.-K., and Jones, C. (2010). Future of pest management working paper 1. Available at http://www.biosecurity.govt.nz/files/pests/surv-mgmt/pmp-working-paper-1.pdf [Verified 25 March 2010].

Lee, W. G., McGlone, M., and Wright, E. (2005). Biodiversity Inventory and Monitoring: a review of national and international systems and a proposed framework for future biodiversity monitoring by the Department of Conservation. Landcare Research Contract Report LC0405/122.

McArdle, B. H. (1996). Levels of evidence in studies of competition, predation and disease. *New Zealand Journal of Ecology* **20**, 7–15.

McNab, J. (1983). Wildlife management as scientific experimentation. *Wildlife Society Bulletin* **11**, 397–401.

McNutt, K., Wright, E., Greene, T., and O'Donnell, C. (2007). 'DOC's Inventory and Monitoring Toolbox – Why are We Standardising Monitoring Methods?' DOC Science Poster 96. (DOC Science and Technical Publishing, Department of Conservation: Wellington.)

Nimmo Bell (2009). Economic costs of pests to New Zealand. MAF Biosecurity New Zealand Technical Paper No: 2009/31.

Norbury, D., Warburton, B., and Webster, R. (2001). Long-term monitoring of mammalian pest abundance in Canterbury. Landcare Research Contract Report LC0001/144 for Department of Conservation, Wellington.

NPCA (2008). 'Possum Population Monitoring Using the Trap Catch Method.' (National Possum Control Agencies: Wellington.)

Parkes, J., and Murphy, E. (2003). Management of introduced mammals in New Zealand. *New Zealand Journal of Zoology* **30**, 335–359.

Parkes, J., Robley, A., Forsyth, D., and Choquenot, D. (2006). Adaptive management experiments in vertebrate pest control in New Zealand and Australia. *Wildlife Society Bulletin* **34**, 229–236. doi:10.2193/0091-7648(2006)34[229:AMEIVP]2.0.CO;2

Partridge, T. R., Whaley, K. J., and Hunter, G. G. (2002). Pest plant control monitoring techniques for regional and district councils. Part 1 Monitoring Framework. Landcare Research Contract Report LC0001/076 for Regional Council Biosecurity Managers Group, Christchurch.

Payton, I. J., Pekelharing, C. J., and Frampton, C. M. (1999). 'Foliar Browse Index: A Method for Monitoring Possum (*Trichosurus vulpecula*) Damage to Plant Species and Forest Communities.' (Manaaki Whenua Landcare Research: Lincoln, New Zealand.)

Raffaelli, D., and Moller, H. (1999). Manipulative field experiments in animal ecology: do they promise more than they can deliver? *Advances in Ecological Research* **30**, 299–338. doi:10.1016/S0065-2504(08)60020-3

Reddiex, B., and Forsyth, D. M. (2006). Control of pest mammals for biodiversity protection in Australia. II. Reliability of knowledge. *Wildlife Research* **33**, 711–717. doi:10.1071/WR05103

Reddiex, B., and Parkes, J. (2003). 'Conservation benefits of Animal Health Board possum control on public conservation lands. I. Experimental design.' Landcare Research Contract Report LC0203/062 for Department of Conservation, Wellington.

Reddiex, B., Forsyth, D. M., McDonald-Madden, E., Einoder, L. D., Griffioen, P. A., Chick, R. R., and Robley, A. J. (2006). Control of pest mammals for biodiversity protection in Australia. I. Patterns of control and monitoring. *Wildlife Research* **33**, 691–709. doi:10.1071/WR05102

Romesburg, H. C. (1981). Wildlife science: gaining reliable knowledge. *The Journal of Wildlife Management* **45**, 293–313. doi:10.2307/3807913

Roy, B., Popay, I., Champion, P., James, T., and Rahman, A. (2004). 'An Illustrated Guide to Common Weeds of New Zealand.' (New Zealand Plant Protection Society: Canterbury, New Zealand.)

Sinclair, A. R. E., and Krebs, C. J. (2002). Complex numerical responses to top-down and bottom-up processes in vertebrate populations. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* **357**, 1221–1231. doi:10.1098/rstb.2002.1123

Sweetapple, P. J., and Nugent, G. (2007). Ship rat demography and diet following possum control in a mixed podocarp-hardwood forest. *New Zealand Journal of Ecology* **31**, 186–201.

Walker, P. T. (1983). Crop losses: the need to quantify the effects of pests, diseases and weeds on agricultural production. *Agriculture Ecosystems & Environment* **9**, 119–158. doi:10.1016/0167-8809(83)90038-5

Zavaleta, E. S., Hobbs, R. J., and Mooney, H. A. (2001). Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology & Evolution* **16**, 454–459. doi:10.1016/S0169-5347(01)02194-2

Manuscript received 10 June 2009, accepted 8 April 2010

Appendix 1. Pest animals under management by RUAs, with the number of operations in which they were specifically targeted

Species	Total number of operations targeting that species
Possum (*Trichosurus vulpecula*)	29
Mustelids (*Mustela erminea*, *M. fero*)	19
Rats (*Rattus norvegicus*, *R. rattus*)	16
Rabbit (*Oryctolagus cuniculus*)	11
Goat (*Capra hircus*)	11
Rook (*Corvus frugilegus*)	10
Feral cat (*Felis catus*)	9
Argentine ant (*Linepithema humile*)	6
Deer (species not specified)	4
Magpies (*Gymnorhina tibicen*)	4
Dama wallaby (*Macropus eugenii*)	3
Darwin's ant (*Doleromyrma darwiniana*)	3
Catfish (*Ameiurus nebulosus*)	2
Hare (*Lepus europaeus*)	2
Koi carp (*Cyprinus carpio*)	2
Pig (*Sus scrofa*)	2
Bennett's wallaby (*Macropus rufogriseus*)	1
Black house ant (*Ochetellus glaber*)	1
Brushtailed rock wallaby (*Petrogale penicillata*)	1
Fallow deer (*Dama dama*)	1
Gambusia (*Gambusia affinis*)	1
Hedgehog (*Erinaceus europaeus*)	1
House mouse (*Mus musculus*)	1
Parma wallaby (*Macropus parma*)	1
Perch (*Perca fluviatilis*)	1
Red deer (*Cervus elaphus*)	1
Rudd (*Scardinius erythrophthalmus*)	1
Sika deer (*Cervus nippon*)	1
Swamp wallaby (*Wallabia bicolor*)	1
Tench (*Tinca tinca*)	1
Wapiti (*Cervus elaphus nelsoni*)	1
Wasps (*Vespula germanica*, *V. vulgaris*)	1
White-footed ant (*Technomyrmex jocosus*)	1

Appendix 2. Pest plants under management by RUAs, with the number of operations in which they were specifically targeted

Species	Total number of operations targeting that species
Contorta pine (*Pinus contorta*)	11
Old man's beard (*Clematis vitalba*)	11
African feather grass (*Pennisetum macrourum*)	10
Gorse (*Ulex europaeus*)	10
Nasella tussock (*Nasella trichotoma*)	9
Nodding thistle (*Carduus nutans*)	9
Woolly nightshade (*Solanum mauritianum*)	9
Broom (*Cytisus scoparius*)	8
Climbing spindleberry (*Celastrus orbiculatus*)	8
Ragwort (*Senecio jacobaea*)	8
Boneseed (*Chrysanthemoides monilifera*)	7
Moth plant (*Araujia sericifera*)	7
Spartina (*Spartina* spp.)	7
Senegal tea (*Gymnocoronis spilanthoides*)	6
Variegated thistle (*Silybum marianum*)	6
Weeds (not specified)	6
Wild ginger (*Hedychium gardnerianum*)	6
Banana passionfruit (*Passiflora mollissima*)	5
Darwin's barberry (*Berberis darwinii*)	5
Australian Sedge (*Carex longebrachiata*)	4
Bathurst bur (*Xanthium spinosum*)	4
Cathedral bells (*Conaea scandens*)	4
Chilean needle grass (*Stipa neesiana*)	4
Evergreen buckthorn (*Rhamnus aleternus*)	4
Lagarosiphon (*Lagarosiphon major*)	4
Lantana (*Lantana camara*)	4
Manchurian wild rice (*Zizania latifolia*)	4
Mignonette (*Reseda luteola*)	4
Saffron thistle (*Carthamus lanatus*)	4
Smilax (*Asparagus asparagoides*)	4
White-edged nightshade (*Solanum marginatum*)	4
Boxthorn (*Lycium ferocissimum*)	3
Chinese pennisetum (*Pennisetum alopecuroides*)	3
Climbing asparagus (*Asparagus scandens*)	3
Cotoneaster (*Conineaster* spp.)	3
Egeria (*Egeria densa*)	3
Hornwort (*Ceratophyllum demersum*)	3
Madeira vine (*Anredera cordifolia*)	3
Pampas (*Cortaderia* spp.)	3
Privet (*Ligustrum* spp.)	3
Purple loosestrife (*Lythrum salicaria*)	3
Reed sweetgrass (*Glyceria maxima*)	3
Water poppy (*Hydrocleys nymphoides*)	3
Alligator weed (*Alternanthera philoxeroidesi*)	2
Asiatic knotweed (*Reynoutria japonica*)	2
Blackberry (*Rubus fruticosus*)	2
Bur daisy (*Calotis lappulacea*)	2
Chilean flame creeper (*Tropaeolum speciosum*)	2
Eel grass (*Vallisneria australis*)	2
Elderberry (*Sambucus nigra*)	2
Giant needlegrass (*Austrostipa rudis*)	2
Gunnera (*Gunnera tinctoria*)	2
Hawkweed (*Hieracium* spp.)	2
Hawthorn (*Crataegus monogyna*)	2
Himalayan honeysuckle (*Leycesteria formosa*)	2
Holly (*Ilex aquifolium*)	2
Japanese honeysuckle (*Lonicera japonica*)	2
Kudzu vine (*Pueraria montana*)	2

(*continued next page*)

Appendix 2. (*continued*)

Species	Total number of operations targeting that species
Marshwort (*Nymphoides geminata*)	2
Mist flower (*Ageratina riparia*)	2
Phragmites (*Phragmites australis*)	2
Plumeless thistle (*Carduus acanthoides*)	2
Rhamnus (*Rhamnus* spp.)	2
Royal fern (*Osmunda regalis*)	2
Spiny emex (*Emex australis*)	2
Sweet pea shrub (*Polygala myrtifolia*)	2
Sycamore (*Acer pseudoplatanus*)	2
Acmena (*Eugenia smithii*)	1
African club moss (*Selaginella kraussiana*)	1
Agapanthus (*Agapanthus praecox* subsp. *orientalis*)	1
Apple of Sodom (*Solanum linnaeanum*)	1
Balloon vine (*Cardiospermum halicacabum*)	1
Barberry (*Berberis glaucocarpa*)	1
Bomarea (*Bomarea* sp.)	1
Bittersweet (*Solanum dulcamara*)	1
Blue passion flower (*Passiflora caerulea*)	1
Blue-leaved wattle (*Acacia saligna*)	1
Broomsedge (*Andropogon virginicus*)	1
Brush wattle (*Paraserianthes lophantha*)	1
Burdock (*Arctium minus*)	1
Bushy asparagus (*Asparagus aethiopicus*)	1
Californian thistle (*Cirsium arvense*)	1
Chinese privet (*Ligustrum sinense*)	1
Common ivy (*Hedera helix*)	1
Cotton thistle (*Onopordum acanthium*)	1
Crack willow (*Salix fragilis*)	1
Devil's fig (*Solanum torvum*)	1
Devil's tail (*Polygonum perfoliatum*)	1
Elaeagnus (*Elaeagnus* × *reflexa*)	1
Elodea (*Elodea canadensis*)	1
German ivy (*Senecio mikanioides*)	1
Giant buttercup (R*anunculus acris*)	1
Giant gunnera (*Gunnera* sp.)	1
Giant reed (*Arundo donax*)	1
Goats rue (*Galega officinalis*)	1
Great reedmace (*Typha latifolia*)	1
Green cestrum (*Cestrum parqui*)	1
Grey willow (*Salix cinerea*)	1
Heather (*Calluna vulgaris*)	1
Hemlock (*Conium maculatum*)	1
Horse nettle (*Solanum carolinense*)	1
Houttuynia (*Houttuynia cordata*)	1
Japanese spindleberry (*Euonymus europaeus*)	1
Jasmine (*Jasminum polyanthum*)	1
Kangaroo grass (*Themeda triandra*)	1
Knotweed (*Polygonum polystachyum*, *Reynoutria japonica*)	1
Mexican feather grass (*Nassella tenuissima*)	1
Montbretia (*Crocosmia* × *crocosmiiflora*)	1
Mountain pine (*Callitris rhomboidea*)	1
Noogoora bur (*Xanthium strumarium*)	1
Parrots feather (*Myriophyllum aquaticum*)	1
Purple nutsedge (*Cyperus rotundus*)	1
Purple pampas (*Cortaderia jubata*)	1
Red cestrum (*Cestrum fasciculatum*)	1
Reed canary grass (*Phalaris arundinacea*)	1
Sagittaria (*Sagittaria platyphylla*)	1
Scotch thistle (*Cirsium vulgare*)	1

(*continued next page*)

Appendix 2. (*continued*)

Species	Total number of operations targeting that species
Scrambling lily (*Geitonoplesium cymosum*)	1
Siberian lyme grass (*Leymus racemosus*)	1
Spanish heath (*Erica lusitanica*)	1
Stonecrop (*Sedum acre*)	1
Sweet briar (*Rosa rubiginosa*)	1
Tutsan (*Hypericum androsaemum*)	1
Undaria (*Undaria pinnatifida*)	1
White bryony (*Bryonia cretica*)	1
Wild kiwifruit (*Actinidia deliciosa*)	1
Wild turnip (*Brassica rapa* subsp. *sylvestris*)	1
Yellow water lily (*Nuphar lutea*)	1