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Control of pest mammals for biodiversity protection in Australia. I. Patterns of control and monitoring

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Abstract. Foxes, wild dogs, feral cats, rabbits, feral pigs and feral goats are believed to have deleterious impacts on native biodiversity in Australia. However, although considerable resources have been expended controlling these six species, little is known about national patterns and costs of control and monitoring. We therefore conducted a survey of pest-control operations undertaken by conservation-focused organisations in Australia. A total of 1306 control operations were reported, with most conducted during 1998–2003: there was little information prior to 1990. Foxes and rabbits were the most, and feral cats the least, frequently controlled pest species. The total area on which control was undertaken in 2003, the year for which most information was available, ranged from ~0.4×10^4 km^2 for feral cats to ~10.7×10^4 km^2 for foxes. A wide range of techniques and intensities were used to control each of the six species. The estimated cost of labour expended on control in 2003 ranged from $\$0.4 \times 10^6$ for feral cats to $\$5.3 \times 10^6$ for foxes. Monitoring of the pest or biodiversity occurred in 50–56% of control actions in which foxes, wild dogs and feral cats were targeted, but only 22–26% of control actions in which rabbits, feral pigs and feral goats were targeted. Our results are discussed in relation to previous studies of pest animal control and monitoring in Australia.

Introduction

Since Europeans settled in Australia, at least 59 native mammal species have become extinct, rare, or vulnerable (Short and Smith 1994), and many other native species and ecological communities have been adversely affected (Burbidge and McKenzie 1989; Smith and Quin 1996). A suite of mechanisms has been proposed to explain these declines in native biodiversity, including habitat loss, disease, climate change, altered fire regimes, and the impacts of exotic mammals (Burbidge and McKenzie 1989; Morton 1990; Smith *et al*. 1994; Smith and Quin 1996).

Of the many exotic mammals that have established populations in Australia, the federal *Environmental Protection and Biodiversity Act 1999* identifies five species as threatening 'the survival, abundance or evolutionary development of a native species or ecological community' by four main types of impact (Department of the Environment and Heritage 2005): predation by foxes (*Vulpes vulpes*) and feral cats (*Felix catus*); competition and land degradation by rabbits (*Oryctolagus cuniculus*) and feral goats (*Capra hircus*); and predation, habitat degradation, competition and disease transmission by feral pigs. For details on these impacts see Saunders *et al*. (1995) for foxes, Dickman (1996) for feral cats, Williams *et al*. (1995) for rabbits, Choquenot *et al*. (1996) for feral pigs, and Parkes *et al*. (1996) for feral goats. Wild dogs (*Canis lupus familiaris*, *Canis lupus dingo*, and hybrids) have also been implicated in the extinction and decline of native species in Australia (Corbett 1995; Fleming *et al*. 2001).

Many organisations attempt to mitigate the impacts of these six pest species by deliberately killing the pest (termed 'control'). The aim of control is either to eradicate the pest population or maintain it at low densities ('sustained control') (e.g. Braysher 1993; Saunders *et al*. 1995; Choquenot *et al*. 1996; see below). Although some studies have attempted to estimate the costs of control operations (e.g. Bomford and Hart 2002), there has not been any national review of mammalian pest control in Australia.

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In this paper, we summarise the results of a national survey of fox, wild dog, feral cat, rabbit, feral pig, and feral goat control conducted by organisations in Australia for the protection of native biodiversity. In particular, our aims were to summarise (i) the area subject to control, (ii) the types and frequencies of control, (iii) the types of monitoring, and (iv) the labour costs of control operations.

Materials and methods

Survey design

Although we were primarily interested in control operations aimed at protecting native biodiversity, we attempted to identify all federal, state and territory organisations that may have conducted control of six mammalian pest species: fox, wild dog, feral cat, rabbit, feral pig and feral goat. We attempted to contact all universities and non-metropolitan shires, and all agricultural boards in New South Wales and South Australia. Each agency provided a list of people who had knowledge of past and present control operations: these people provided the information used in our survey.

Our survey was mostly conducted by face-to-face interview. This process avoided potential misinterpretation of the survey questions and ensured a high survey response rate, both common problems in mail surveys (Dillman 1978). However, a small proportion of surveys were conducted by telephone and email. Interviews were conducted between August 2003 and May 2004.

The complete list of questions that we asked in our survey is given in Reddiex *et al*. (2004). The survey was structured so that the following information could be extracted from the completed questionnaires. We first defined a 'control operation' as deliberate control of one or more pest species at the same time, using the same control techniques, within a defined area. Control operations could target more than one of the six pest species. Each control operation was assigned a unique name. 'Land tenure' was classified as 'public' (i.e. land administered by local, state or federal government), 'private' (i.e. privately owned land) or 'public and private' (i.e. contained both public and private land). We listed the organisation(s) both funding and conducting the control operation and classified each agency as 'public', 'private' or 'public and private'. Interviewees were asked to list which of the six pest-animal species (one or more) were present, and which species were targeted, in each control operation. The 'aim' of control operations were defined as 'eradication' (i.e. deliberate extinction of the pest) (see Bomford and O'Brien 1995), 'sustained control' (control in perpetuity) (e.g. see Forsyth *et al*. 2003) or 'other'. We defined the 'objective of control' as intending to protect 'threatened species' (e.g. protected flora and fauna species), 'native habitat conservation' (e.g. native habitat that may be browsed by pest herbivores), 'agricultural production values' (e.g. pasture biomass or lamb survival), or 'other'. Interviewees could select multiple objectives of control. Control operations were defined as either 'ongoing' or 'ceased'. If the operation had ceased, we classified the reason for the operation ceasing as 'aim attained', 'funding ceased' or 'other'.

'Control actions' were the pest-control activities conducted within each control operation. Since an operation may include multiple control actions the total number of control actions collected in this survey is greater than the number of control operations. Information on monitoring associated with each control action was also recorded. We defined 'years of control' as the first and subsequent years that a control action was undertaken. Information was used only for control actions that occurred before 2004. We defined 'duration of control per year' as the number of days per year that pest animals were targeted by the control activities: for some control techniques this value was known (e.g. the number of days that traps were open) but for others the duration was estimated by the survey participants (e.g. number of days that aerially applied 1080 (sodium monofluoroacetate) meat baits remained lethal to foxes). Some interviewees were unsure of the duration of control for 1080 meat baits (aerial or ground baited), and in these instances we estimated the duration of control following each application as 30 days, although we acknowledge that bait life will vary depending on the temperature and precipitation at a site (Fleming and Parker 1991; Twigg *et al*. 2000). In many instances the duration of control per year was the sum of several independent control events throughout a calendar year (e.g. trapping for seven nights on each of four occasions per year gives a total of 28 days duration of control per year).

'Control techniques' were classified as: 'ground-based baiting' (using carrot, meat, grain or other bait), 'aerial-based baiting' (using meat or other bait), 'ground-based mustering', 'aerial-based mustering', 'ground-based shooting', 'aerial-based shooting', 'trapping', 'warren ripping/fumigation', and 'other'. 'Area of control' was estimated by the interviewees for each control action (km^2). We then calculated the 'intensity of control' as the number of the control units per square kilometre (e.g. five aerially applied meat baits km^{-2}; 0.05 days of ground shooting km^{-2}). Interviewees were also asked to estimate the labour (number of person-days) expended on each control action. For mapping purposes we obtained Australian map grid coordinates for the centre point of each control action.

We also asked interviewees about monitoring associated with each control action. We asked whether any monitoring of changes in the abundance of the targeted pest species, native species, or agricultural resource was undertaken. We classified the 'type of monitoring' as: 'aerial surveys', 'bait take', 'daylight counts', 'sandpads', 'spotlight counts', 'trapping', 'vegetation surveys', or 'other'.

Data summaries

Data summaries, except where specified, were based on control actions rather than control operations. The total area of control per species was presented for each year (from 1998 to 2003). Because some operations had multiple control actions within the same year, we calculated the total area of control using the maximum specified area of control per year. Although this may have underestimated the total area of control, we believe that the estimates would have been substantially more biased if we used all control action data because in many instances multiple control actions were undertaken in the same area.

For ease of presentation we classified the reported control techniques into nine types: ground-baiting using carrot bait, ground-baiting using meat bait, aerial-baiting using meat baits, aerial mustering, ground mustering, aerial shooting, ground shooting, trapping, and warren ripping. However, because interviewees reported their use of meat baits per unit area as either the number or weight (kg) of baits, we further subdivided aerial-baiting using meat baits into those two classes.

If the same control operation targeted more than one pest species, information from that operation and its control action(s) and monitoring events were used in data summaries of each targeted species. The results presented are thus accurate for an individual species but should not be summed across species. Since most information was collected for control actions during 1998–2003 (see below), data summaries of temporal patterns are based only on data for that period. We used ArcView ver. 3.2 (ESRI, Redlands, CA) to produce maps of the distributions of control actions for each species.

Sample sizes vary between analyses because: (i) not all information was provided for all questions, (ii) in some control operations there were multiple control actions, and (iii) in some control actions there were multiple monitoring events. Sample sizes are either stated in the text or displayed on figures.

We estimated the annual labour cost of pest animal control during 1998–2003 by multiplying the number of person-days by AU$320. The

daily rate of $320 was estimated as the average salary/wage plus organisational overheads. Although we asked for estimates of 'other operational costs', we did not include these data in our analyses because many respondents did not provide those estimates (cf. person-days).

Results

Organisations surveyed

The organisations that we contacted are listed in Appendices 1 and 2. We conducted 112 interviews with representatives from 27 organisations. In all states/territories, except Northern Territory, one organisation provided >70% of the control operations. Of the federal organisations that we surveyed, the Australian Defence Force conducted 68% of control operations. Only one organisation (Department of Agriculture, Western Australia) declined to be involved in our review.

We also contacted 486 shires, 39 universities and 55 agricultural boards (Appendix 2). Across all states and territories, 22% of shires had conducted some pest animal control, but most of this control was in response to ratepayer complaints. None of the control conducted by shires was suitable for our data summaries because key information was unavailable. Although 8 (21%) of the 39 universities had been associated with pest control, only two control operations could be included in this review (Appendix 2). All agricultural 'boards' contacted were involved in pest animal control, but only two operations could be included here (Appendix 2). The agricultural boards that we surveyed seemed to largely focus on coordinating farmers/farmer groups/private organisations to undertake control rather than doing it themselves.

Patterns of control

We obtained data for 1306 control operations. Most control operations were in Victoria (n = 585), New South Wales (n = 360) and Western Australia (n = 167). Of the six pest animal species, the most frequently targeted species throughout Australia were foxes (n = 505 control operations) and rabbits (n = 412), followed by wild dogs (n = 192), feral pigs (n = 139), feral goats (n = 104), and feral cats (n = 55). For all six pest species, most operations were undertaken on public land (range across species: 86–95%); ≤6% were undertaken solely on private land. Most control operations were both funded (range: 86–97%) and undertaken by public agencies (range: 88–96%).

Pest species other than those targeted in the control action were often present in the control area (Table 1). For example, >70% of fox control operations also had either rabbits and/or feral cats present. More than one of the six pest species were controlled in only 7% of control operations and in 99% of those operations two pest species were controlled. If multiple species were targeted in the same operation, fox and dog combinations were the most common (76%): the next most common combination was feral pig and feral goat control.

Most (83%) control operations were classified as ongoing (i.e. planned to continue past 2003: Table 2). Compared with feral cat (58%) and rabbit (68%) control operations, a higher percentage of fox, wild dog, feral pig, and feral goat operations were ongoing (range across species: 85–92%). The lower proportion of ongoing feral cat operations was due to many operations ceasing because the goal of eradication was achieved. In contrast, the lower proportion of ongoing rabbit operations was due to many operations ceasing because of a lack of funding.

The following sections summarise results for each of the six pest species based on data for control actions. There were 2516 control actions for the 1306 operations. The number of control actions per operation ranged from one to nine, but most control operations (63%) consisted of one control action.

Fox control

Most fox control actions were conducted during 2000–03 (Fig. 1). The number of control actions in the most recent complete year (2002; n = 468) was more than eight times larger than in any year during 1990–94. Sustained control was the aim of nearly all fox control actions (96%; n = 841); only 4% of control actions aimed for eradication. Control actions aiming for eradication were largely restricted to areas deliberately fenced to prevent immigration of foxes. The priority of the objectives for fox control actions were similar to those reported for the other two carnivorous pest species (i.e. feral cats and wild dogs; see below): preservation of

Table 1. Overlap in the distributions of six pest species within control operations

For each pest species targeted, the percentage of control operations with other pest species present and the percentage of control operations where other pest species were targeted are shown. *N* is the number of control operations

Species targeted	*N*	Other pest species present/targeted											
		Fox		Wild dog		Feral cat		Rabbit		Feral pig		Feral goat	
		Present	Targeted	Present	Targeted	Present	Targeted	Present	Targeted	Present	Targeted	Present	Targeted
Fox	389	–	–	39.3	20.1	75.6	1.0	70.2	0.3	23.7	0.0	25.2	0.0
Wild dog	175	90.3	44.6	–	–	77.1	0.6	41.7	0.0	41.7	4.6	25.7	0.0
Feral cat	40	70.0	10.0	27.5	2.5	–	–	67.5	0.0	22.5	2.5	20.0	0.0
Rabbit	112	92.9	0.9	20.5	0.0	68.8	0.0	–	–	18.8	0.0	27.7	0.0
Feral pig	126	75.4	0.0	46.8	6.3	69.0	0.8	52.4	0.0	–	–	42.9	7.1
Feral goat	90	78.9	0.0	25.6	0.0	60.0	0.0	50.0	0.0	46.7	10.0	–	–

threatened species (82%), habitat conservation (19%) and agricultural production values (19%) (Table 3). Over all pet species, agricultural production values were the sole objective of 5% of control actions. When agricultural production values were the sole objective of fox control actions, the value of concern was protection of domestic livestock. The objective of control did not change in 93% of fox control operations. In the 7% of fox control actions in which the objective of control did change, a shift in management priorities from protecting agricultural production values to biodiversity values was the main reason for the change.

In 2002 and 2003, fox control was undertaken on $>10.5 \times 10^4$ km^2 annually (Table 4). The area of control operations varied widely during 1998–2003, with a median of 60 km^2 and a range of 0.01–13 000 km^2 (Fig. 2). Most fox control operations were undertaken in the south-west and south-east of Australia (Fig. 3).

The median annual length of fox control actions (i.e. duration of control) during 1998–2003 was 70–90 days (Fig. 4). The duration of fox control was influenced by technique and frequency of control. The main techniques used to control foxes were meat baiting (84%) and trapping (7%) (Table 5). Meat baits were mainly Foxoff® or dried meat baits, and exclusively contained the toxin 1080. The intensity of fox control varied between control techniques (Fig. 5). The median intensities of the main fox control techniques were as follows: aerial meat baiting, 5.0 baits km^{-2}; ground meat baiting, 1.4 baits km^{-2}; trapping, 0.2 traps km^{-2}. The wide range in intensities for some control techniques (e.g. ground meat baiting ranged from 0.003 to 80 baits km^{-2}) likely resulted from both small areas being intensively treated (e.g. 8 baits in a 10-ha reserve) and larger areas being overestimated by interviewees. One control technique was used in 99% of fox control actions.

The average number of labour days expended annually in a fox control action during 1998–2003 ranged from 26 to 38 (Table 6). The estimated annual cost of labour expended on fox control during 1998–2003 was $\$1.8–5.3 \times 10^6$ (Table 6).

Information on monitoring was provided for 87% of fox control actions. If bait take was included as a monitoring technique (see Discussion) then monitoring of either foxes or native species was undertaken in 56% of those control actions; if bait take was excluded, only 32% of control actions included monitoring. The monitoring techniques varied according to whether the pest species, native species and/or agricultural production values were being monitored. Bait take was the primary monitoring technique utilised when foxes were monitored (75% of control actions: Table 7); sandpads were used in 23% of control actions. Trapping small mammals was the most common technique used for monitoring native species (59%), followed by daylight (26%) and spotlight (17%) counts (Table 7).

Wild dog control

Most wild dog control actions occurred during 1999–2003 (Fig. 1). The number of control actions in the most recent complete year (2002; $n = 166$) was more than six times larger than in any year during 1990–94. Sustained control was the main aim of nearly all wild dog control actions (96%; $n = 312$); only 3% of control actions aimed for eradication. As for foxes and feral cats, the main objectives for wild dog control actions were preservation of threatened species (57%), habitat conservation (31%) and agricultural production values (46%) (Table 3). In most control actions the agricultural production value of concern was domestic livestock. The objective of control did not change in 99% of wild dog control operations.

In 2002 and 2003, wild dog control was undertaken on $>3.3 \times 10^4$ km^2 annually (Table 4). The area of control operations varied widely during 1998–2003, with a median of 74 km^2 and a range of 0.02–4000 km^2 (Fig. 2). Most wild dog control operations were conducted in south-eastern Australia (Fig. 3).

The median annual length of wild dog control actions (i.e. duration of control) during 1998–2003 ranged from 53 to 60 days (Fig. 4). Duration of control was influenced by both the technique and frequency of control. The main techniques used to control wild dogs were meat baiting (78%) and trapping (19%) (Table 5). Meat baits were mainly either Foxoff® or dried meat, and exclusively contained the toxin 1080. The

Table 2. Percentage of control operations, for each of six pest species, classified as either 'ongoing' or 'ceased'

There were three possible reasons for control operations ceasing: the goal was attained, there was no funding, or 'other'. *N* is the number of control operations

Species	*N*	Status of control operations			
		Ongoing (%)	Ceased; goal attained (%)	Ceased; no funding (%)	Ceased; other (%)
Fox	388	85.1	0.5	11.3	3.1
Wild dog	175	92.0	0.0	2.3	5.7
Feral cat	40	57.5	27.5	7.5	7.5
Rabbit	111	67.6	4.5	25.2	2.7
Pig	126	88.1	4.8	1.6	5.6
Goat	90	84.4	8.9	3.3	3.3

intensity of control varied between control techniques (Fig. 5). The median intensities of the main control techniques were as follows: aerial meat baiting, 6.0 baits km^{-2}; ground meat baiting, 0.4 baits km^{-2}; trapping, 0.2 traps km^{-2}. One control technique was used in 99% of wild dog control actions.

The average number of labour days expended during 1998–2003 (range: 43–67) in a wild dog control action was high and constant in comparison to all pest species other than feral cats (Table 6). The estimated annual cost of labour expended on wild dog control during 1998–2003 was $\$1.1–3.2 \times 10^6$ (Table 6).

Information on monitoring was provided for 88% of wild dog control actions. Monitoring of either the pest species or native species was undertaken in 48% of those control actions. Sandpads (56%) and bait take (54%) were the main techniques for monitoring wild dogs (Table 7). Trapping for small mammals was the most common technique for monitoring native species (49%), followed by daylight counts (26%) and sandpads (23%) (Table 7).

Feral cat control

Most feral cat control actions were undertaken during 1998–2003 (Fig. 1). The number of control actions for the most recent complete year (2002; n = 35) was five times larger than in any year during 1990–94. Sustained control was the main aim for most feral cat control actions (66%; n = 103); 34% aimed for eradication. Most control actions with the aim of eradication were conducted on islands or within areas deliberately fenced to prevent immigration of feral cats. As for foxes and wild dogs, the objectives for feral cat control actions were preservation of threatened species (88%) and habitat conservation (22%). However, in contrast to foxes and wild dogs, only 3% of feral cat control actions had the objective of protecting agricultural production values

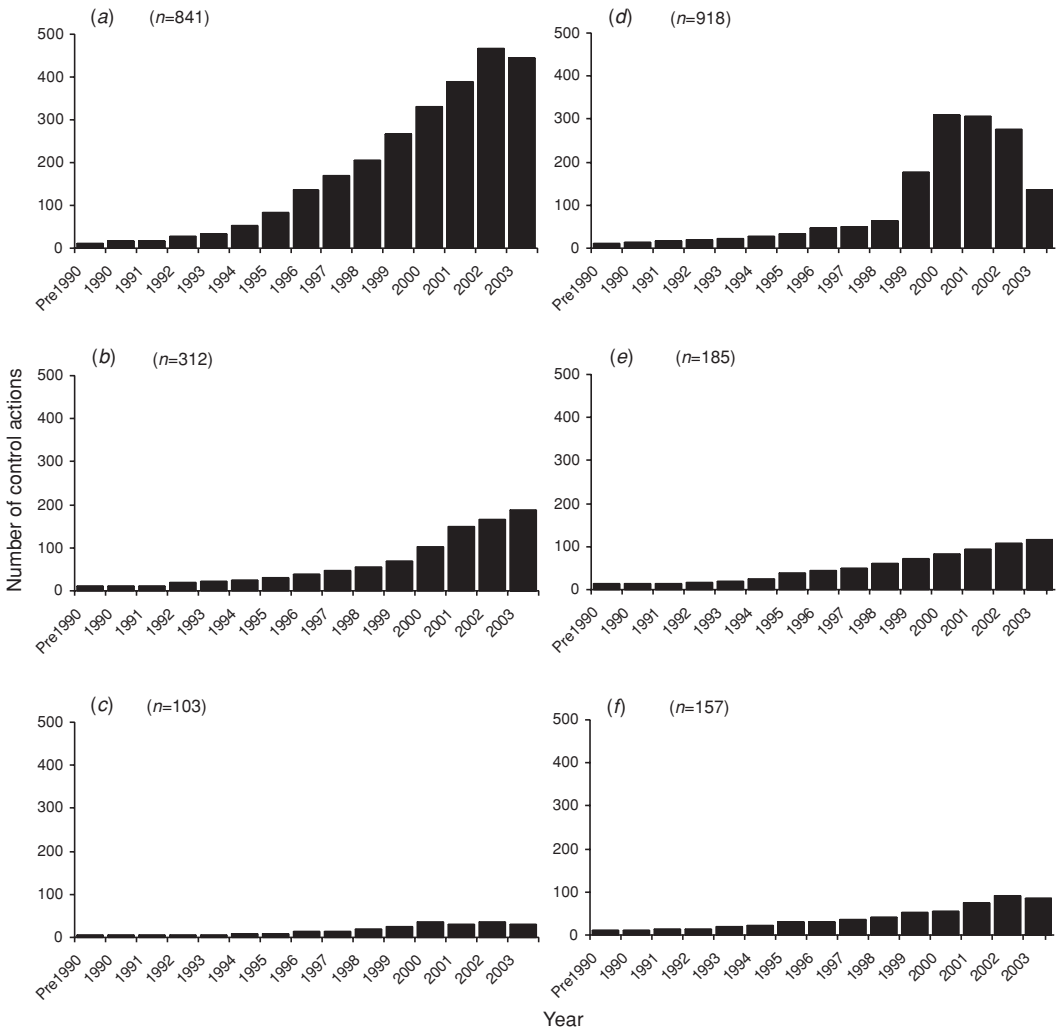

Fig. 1. Annual number of control actions for each of six pest species during 1990–2003. Data for pre-1990 have been pooled into one class. The total number of control actions per species is shown in parentheses (pest species: *a*, fox; *b*, wild dog; *c*, feral cat; d, rabbit; *e*, feral pig; *f*, feral goat).

Table 3. Percentage of control actions for each of six pest species with the objective of protecting 'threatened species', 'habitat conservation', 'agricultural production values', or 'other'
Multiple objectives may have been selected per action. *N* is the number of control actions

Species	*N*	Control objective (% of control actions)			
		Threatened species	Habitat conservation	Production values	Other
Fox	841	82.0	19.3	19.0	4.5
Wild dog	312	57.1	30.8	46.2	4.2
Feral cat	103	88.3	22.3	2.9	1.9
Rabbit	918	88.5	97.2	5.9	0.8
Pig	185	31.4	83.8	30.8	6.5
Goat	157	47.8	93.6	12.1	0.0

(Table 3). The objectives of control did not change in 95% of feral cat control operations.

In 2002 and 2003, feral cat control was undertaken on $>0.4 \times 10^4$ km^2 annually (Table 4). The area of control operations varied widely during 1998–2003, with a median of 6 km^2 and a range of 0.01–1050 km^2 (Fig. 2). Most feral cat control operations were undertaken in the south-west and south-east of Australia (Fig. 3).

The median annual length of feral cat control actions (i.e. duration of control) during 1998–2003 ranged from 21 to 42 days (Fig. 4). Duration of control was influenced by both the technique and frequency of control. The main techniques used to control feral cats were trapping (59%), meat baiting (21%) and shooting (18%) Table 5). The intensity of control varied between control techniques (Fig. 5). The median intensities of the main feral cat control techniques were as follows: aerial meat baiting, 17.5 baits km^{-2}; ground meat baiting, 3.5 baits km^{-2}. The median intensity of trapping (3.5 traps km^{-2}) was higher for feral cats than for foxes and wild dogs. Only 8% of feral cat control actions used more than one control technique.

The average number of labour days expended annually in a feral cat control action was higher than for any of the other five pest species during 1998–2003, ranging from 37 to 149 (Table 6). The high average number of labour days resulted from a (successful) control operation aiming to eradicate feral cats on Macquarie Island: annual labour days for that operation ranged from 1001 to 1870. The estimated annual cost of labour expended on feral cat control during 1998–2003 was \$0.3–1.0 $\times 10^6$ (Table 6).

Information on monitoring was provided for 94% of feral cat control actions. Monitoring of either feral cats or native species was undertaken in 50% of those control actions. A wide range of techniques was used to monitor feral cats, including sandpads (40%), bait take (37%), trapping (10%), and spotlight counts (10%) (Table 7). Trapping small mammals was the most common technique for monitoring native species (75%). Almost 63% of control actions monitoring native species reported using 'other' monitoring techniques, mostly radio-telemetry (Table 7).

Rabbit control

Most rabbit control actions were undertaken during 2000–02 (Fig. 1). The number of control actions for the most recent complete year (2002; $n = 277$) was more than 10 times larger than in any year during 1990–94. Sustained control was the aim of nearly all (96%) rabbit control actions ($n = 918$); only 4% aimed for eradication. As for feral pigs and feral goats (see below), the main objectives for rabbit control actions were habitat conservation (89%) and threatened species (97%); only 6% of control operations aimed to protect agricultural production values (Table 3). The objectives of control did not change in 98% of rabbit control actions. For the 2% of control actions in which the objectives of control did change, a shift in management priorities from agricultural production values to biodiversity values was the most common reason for the change.

In 2002 and 2003, rabbit control was undertaken on $>1.2 \times 10^4$ km^2 annually (Table 4). The area of control operations varied widely during 1998–2003, with a median of 2 km^2 and a range of 0.005–8000 km^2 (Fig. 2). The post-RHD (*c*. 1998) control techniques focused on warren ripping and fumigation. Most rabbit control operations were conducted in south-eastern Australia (Fig. 3).

The median annual length of rabbit control actions (i.e. duration of control) during 1998–2003 ranged from 10 to 20 days (Fig. 4). Duration of control was influenced by technique and frequency of control. The most common techniques used to control rabbits were warren fumigation and ripping (73%), followed by ground baiting with carrots and/or grain (18%) (Table 5). Other non-listed control tech-

Table 4. Total annual area of control (km^2) for each of the six pest species during 1998–2003
Area is based on the number of control operations per species per year, which is shown in parentheses

Year	Fox	Wild dog	Feral cat	Rabbit	Feral pig	Feral goat
1998	78063 (189)	12641 (43)	2879 (15)	17390 (53)	43909 (53)	24111 (40)
1999	80851 (237)	16056 (58)	2849 (17)	16976 (132)	46577 (64)	36957 (46)
2000	95740 (278)	15671 (79)	2952 (24)	19007 (200)	46348 (73)	37202 (50)
2001	95300 (326)	22956 (116)	3355 (24)	11350 (215)	69397 (86)	54123 (64)
2002	105157 (382)	33669 (132)	4356 (26)	12097 (216)	62498 (98)	59722 (76)
2003	106747 (384)	34209 (157)	3740 (24)	20091 (115)	60152 (106)	53569 (73)

niques for rabbits included the release of rabbit fleas and the myxoma virus, and the injection of rabbits with RHD virus. The intensity of control varied between control techniques (Fig. 5). More than one control technique was used in only 4% of rabbit control actions.

The average number of labour days expended annually in a rabbit control action ranged from 13 to 38 during 1998–2003 (Table 6). The estimated annual cost of labour expended on rabbit control during 1998–2003 was \$0.7–1.4 $\times 10^6$ (Table 6).

Information on monitoring was provided for 93% of rabbit control actions. Monitoring of either rabbits or native species was undertaken in 22% of those control actions. Spotlight (73%) and daylight (19%) counts were the main techniques for monitoring rabbits (Table 7). Vegetation survey was the most common technique for monitoring native species (80%), followed by trapping (20%) (Table 7).

Feral pig control

Most feral pig control actions were undertaken during 1998–2003 (Fig. 1). The number of control actions for the most recent complete year (2002; n = 107) was more than three times larger than in any year during 1990–94. Sustained control was the aim of most feral pig control

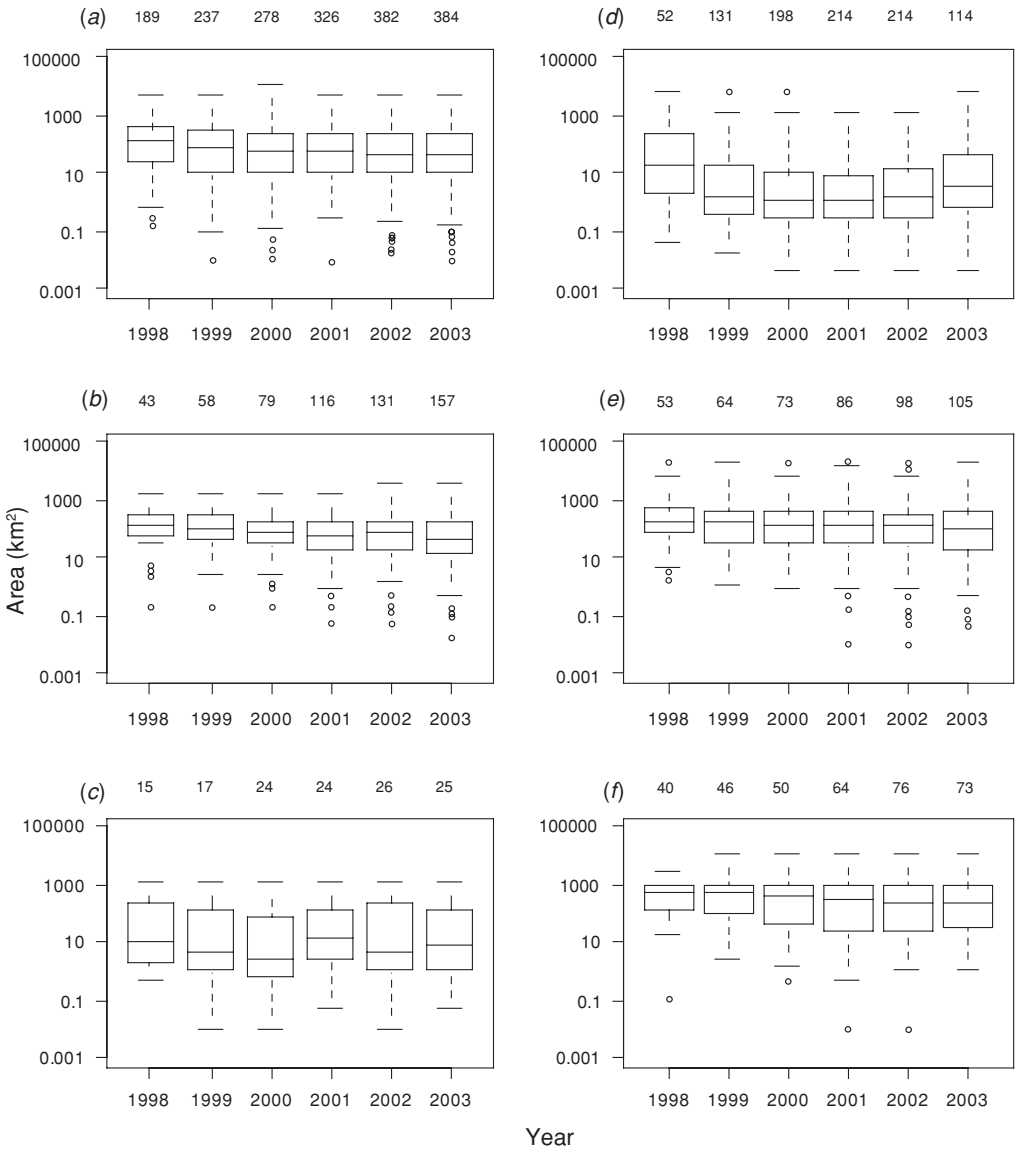

Fig. 2. Box-and-whisker plots of the annual area of control operations for each of six pest species during 1998–2003 (pest species: a, fox; *b*, wild dog; *c*, feral cat; *d*, rabbit; *e*, feral pig; *f*, feral goat). The number of operations per species per year is shown on the figure. Note that the *y*-axis is a log-scale. The lower and upper boundaries of each box indicate the 25th and 75th percentiles, the line within the box is the median, whiskers indicate 1.5 × the interquartile range, and open circles represent areas outside the whiskers.

actions (89%; $n = 185$); only 7% of control actions aimed for eradication. As for rabbits and feral goats, the main objective for feral pig control actions was habitat conservation (84%), followed by threatened species (31%) and agricultural production values (31%) (Table 3). The objectives of control did not change in 98% of feral pig control actions. For the 2% of control actions in which the objectives of control did change, a shift in management priorities from agricultural production values to biodiversity values was the most common reason given for the change.

In 2002 and 2003, feral pig control was undertaken on $>6.0 \times 10^4$ km^2 annually (Table 4). The area of control operations varied widely during 1998–2003, with a median of 140 km^2 and a range of 0.01–20 000 km^2 (Fig. 2). Most feral pig control operations were conducted in south-eastern Australia (Fig. 3).

The median annual length of feral pig control operations (i.e. duration of control) during 1998–2003 ranged from 13 to 21 days (Fig. 4). Duration of control was influenced by the technique and frequency of control. The most common techniques used to control feral pigs were trapping (49%), aerial shooting (25%) and ground baiting (17%) (Table 5). Although the intensity of control varied between control techniques, the median intensity of aerial and ground shooting (h km^{-2}) were similar (Fig. 5). More than one control technique was used in only 6% of feral pig control actions.

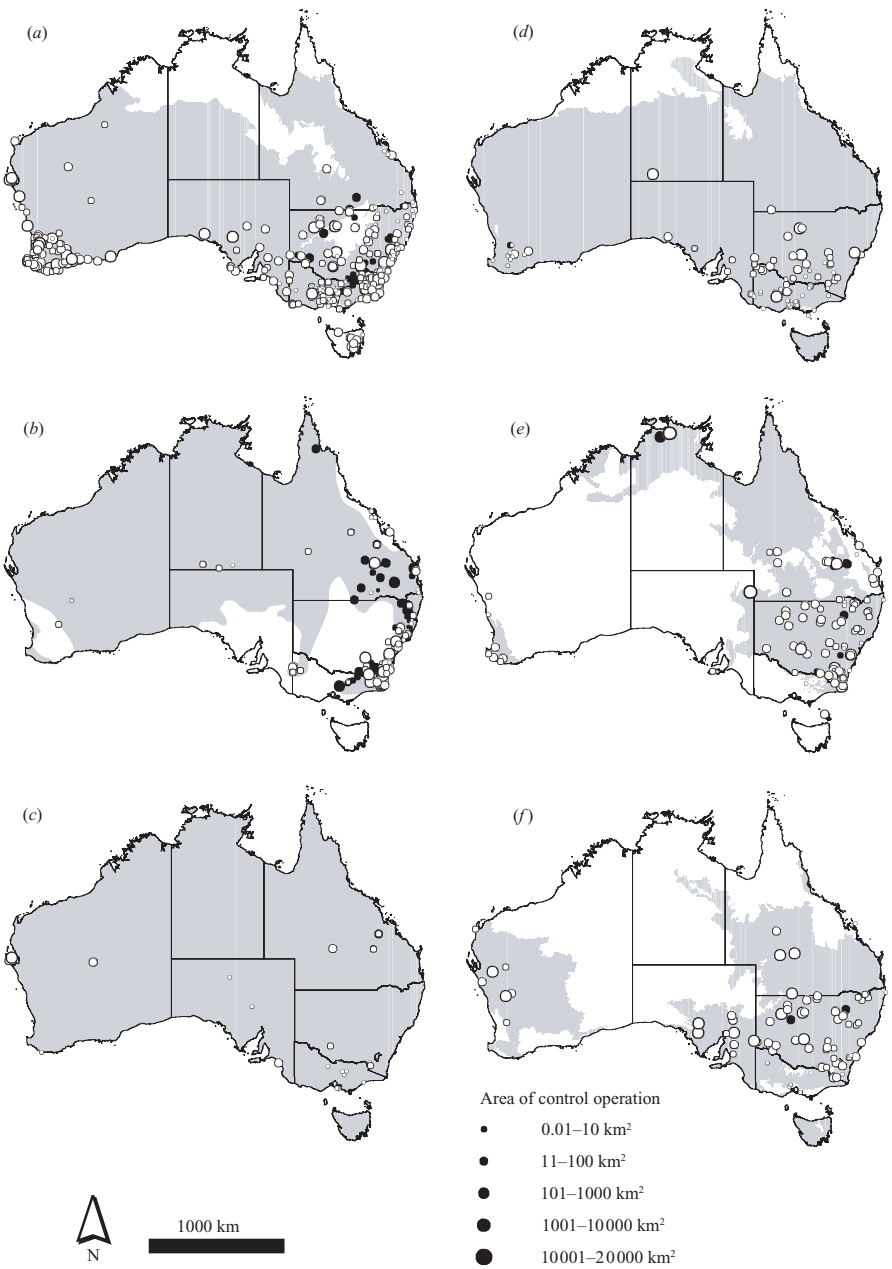

Fig. 3. Distributions of pest species and control operations in 2003 (pest species: *a*, fox; *b*, wild dog; *c*, feral cat; *d*, rabbit; *e*, feral pig; *f*, feral goat). Open circles represent control actions with the objective of protecting 'threatened species' or 'habitat conservation'; closed circles are control actions with the objective of protecting agricultural production values.

The average number of labour days expended annually in a feral pig control action was relatively constant during 1998–2003, ranging from 22 to 29 (Table 6). The estimated annual cost of labour expended on feral pig control during 1998–2003 was \$0.5–0.9 × 10^6 (Table 6).

Information on monitoring was provided for 97% of feral pig control actions. However, only 23% of those control actions monitored either feral pigs and/or native species. Six techniques were used for monitoring feral pigs: aerial surveys, bait take, daylight counts, sandpads, spotlight counts, and trapping (Table 7). Vegetation survey was the most common technique (50%) for monitoring native species, followed by daylight counts (33%) and 'other' (33%) (Table 7).

Feral goat control

Most feral goat control actions were undertaken during 1998–2003 (Fig. 1). The number of control actions for the most recent complete year (2002; $n = 90$) was >4 times larger than in any year during 1990–94. Sustained control was the aim of most feral goat control actions (84%; $n = 157$); only 16% of control actions aimed for eradication. As for rabbits and feral pigs, the main objective of feral goat control actions was habitat conservation (94%), followed by threatened species (48%) and agricultural production values (12%) (Table 3). The objectives of control did not change in any feral goat control actions.

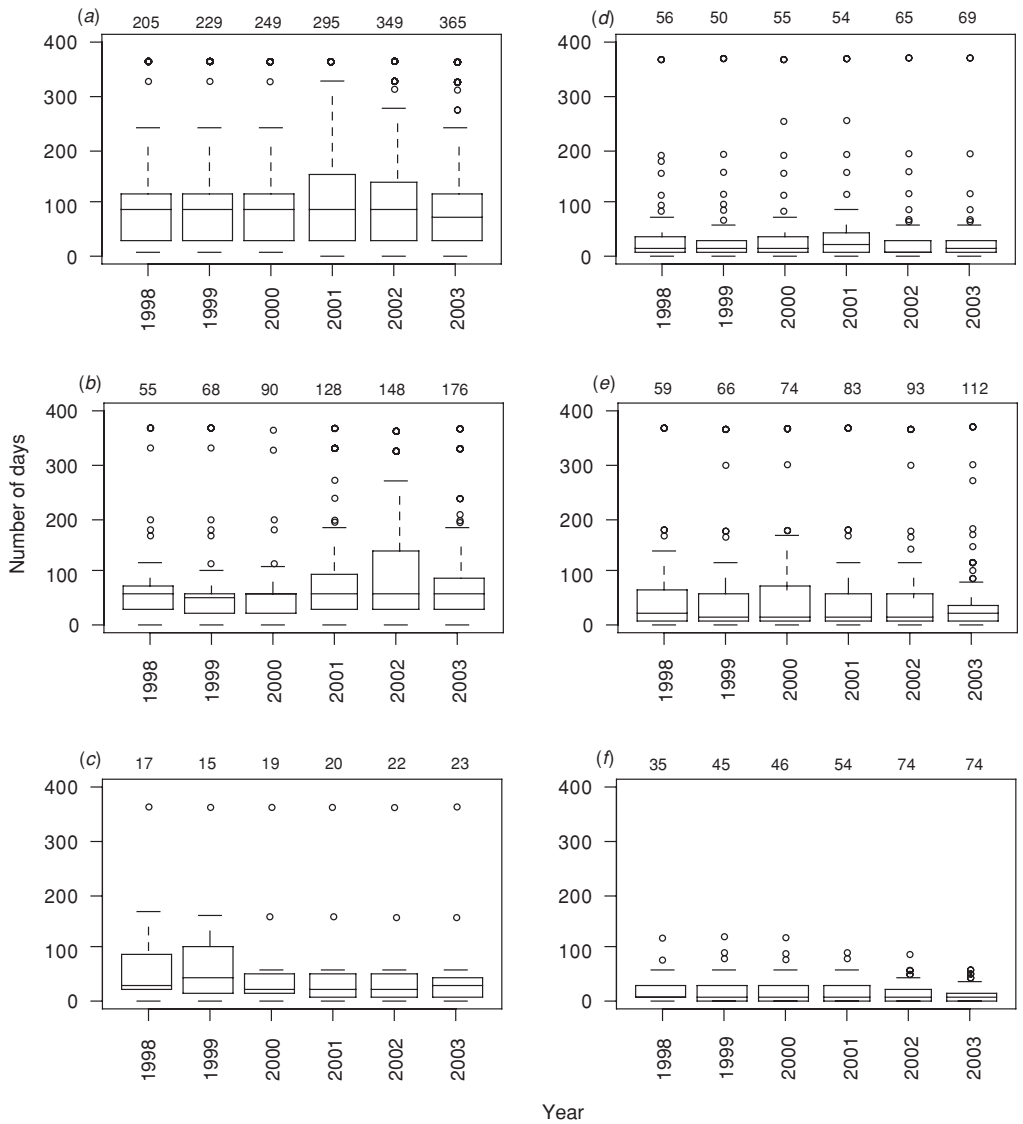

Fig. 4. Box-and-whisker plots of the number of days per year in which control actions were undertaken for each of six pest species (pest species: *a*, fox; *b*, wild dog; *c*, feral cat; *d*, rabbit; *e*, feral pig; *f*, feral goat). The number of control actions per species per year is shown on the figure. The lower and upper boundaries of each box indicate the 25th and 75th percentiles, the line within the box is the median, whiskers indicate 1.5 × the interquartile range, and open circles represent numbers outside the whiskers.

In 2002 and 2003, feral goat control was undertaken on $>5.3 \times 10^4$ km^2 annually (Table 4). The area of control operations varied widely during 1998–2003, with a median of 360 km^2 and a range of 0.01–11 357 km^2 (Fig. 2). Most feral goat control operations were undertaken in the south-west and south-east of Australia (Fig. 3).

The median length of feral goat control operations (i.e. duration of control) during 1998–2003 ranged from 5 to 8 days (Fig. 4). Duration of control was influenced by the technique and frequency of control. The techniques used to control feral goats were ground shooting (43%), aerial shooting (29%), trapping (11%), and mustering (11%) (Table 5). The intensity of control varied between control techniques (Fig. 5). More than one control technique was used in only 2% of feral goat control actions.

The average number of labour days expended annually in a feral goat control action ranged from 32 to 52 during 1998–2003 (Table 6). The estimated annual cost of labour expended on feral goat control during 1998–2003 was $\$0.7–0.9 \times 10^6$ (Table 6).

Information on monitoring was provided for 99% of feral goat control actions; 26% of those control actions monitored either feral goats or native species. Daylight counts (48%) and aerial surveys (30%) were the main techniques used for monitoring feral goats (Table 7). Vegetation survey was the most common technique (84%) for monitoring native species (Table 7).

Discussion

Our review deliberately focused on organisations that conducted control to protect native biodiversity rather than agricultural production values. Nearly all of the control actions undertaken by these organisations had the objective of protecting or enhancing native biodiversity; only 5% of control actions had the sole objective of protecting agricultural production values. Although there has not been a similar review of control conducted to protect agricultural production values, control of foxes, wild dogs, rabbits, feral pigs, and feral goats (but not feral cats) for that purpose was probably undertaken over at least a similar-sized area to that reported here to protect native biodiversity (Saunders *et al*. 1995; Williams *et al*. 1995; Choquenot *et al*. 1996; Parkes *et al*. 1996; Fleming *et al*. 2001; Bomford and Hart 2002).

Most of our data were from either federal- or state-funded agencies (Appendices 1 and 2). Since conducting the survey we have become aware of some non-governmental organisations and individuals that have conducted control for the protection of native biodiversity but were not contacted, and inevitably there would be others, particularly individual landholders, of which we were unaware. Hence, there was likely some bias towards government-funded control, but it is impossible to estimate the extent of this bias. However, we believe that our methods were sufficiently objective and transparent that this survey could be repeated. Hence, we caution that our results should not be interpreted as a census (i.e. 'complete enumeration') of control operations aimed at these six species in Australia. Rather, we believe that our results are a valuable 'snapshot' of control aimed at foxes, wild dogs, feral cats, rabbits, feral pigs, and feral goats with the objective of protecting native biodiversity in Australia.

Our results are primarily derived from control actions undertaken during 1998–2003. There are at least four possible explanations for the increasing number of control actions reported since 1990 (Fig. 1). First, the real number of control actions may have increased over time. Several survey participants believed that this was true for their area of interest, and the area of land managed by some of the organisations that we surveyed (Appendix 1) has increased over this period. Saunders and McLeod (in press) suggest that during the last decade there has been a large increase in the proportion of people perceiving foxes to be a major threat to environmental and agricultural values. However, it is unlikely that pest animal control has increased 8–25-fold during 1990–2003 for all six pest species. Second, there may have been a trend

Table 5. Percentage of control techniques utilised for the control of each of six pest species
The total number of control techniques for each species is shown in parentheses. Note: due to rounding error some columns do not sum to 100.0%

Control technique	Fox (850)	Wild dog (315)	Feral cat (111)	Rabbit (948)	Feral pig (196)	Feral goat (160)
Ground baiting; carrot[A]	0.0	0.0	0.0	17.7	10.2	0.0
Ground baiting; meat[B]	76.5	72.4	11.7	0.2	7.1	0.0
Aerial baiting; carrot	0.0	0.0	0.0	0.2	0.0	0.0
Aerial baiting; meat	7.9	5.4	9.9	0.1	0.5	0.0
Aerial mustering	0.1	0.0	0.0	0.0	0.0	5.0
Ground mustering	0.0	0.0	0.0	0.0	0.5	11.3
Aerial shooting	0.0	0.0	0.0	0.1	25.0	29.4
Ground shooting	4.7	2.9	18.0	6.0	6.1	42.5
Trapping	7.2	19.0	58.6	0.4	49.5	11.3
Warren[C]	2.9	0.0	0.0	72.8	0.0	0.0
Other	0.7	0.3	1.8	2.4	0.5	0.6
Total	100.0	100.0	100.0	99.9	99.4	100.1

[A]Includes grain baiting. [B]Includes Foxoff® and meat baits. [C]Ripping and fumigation.

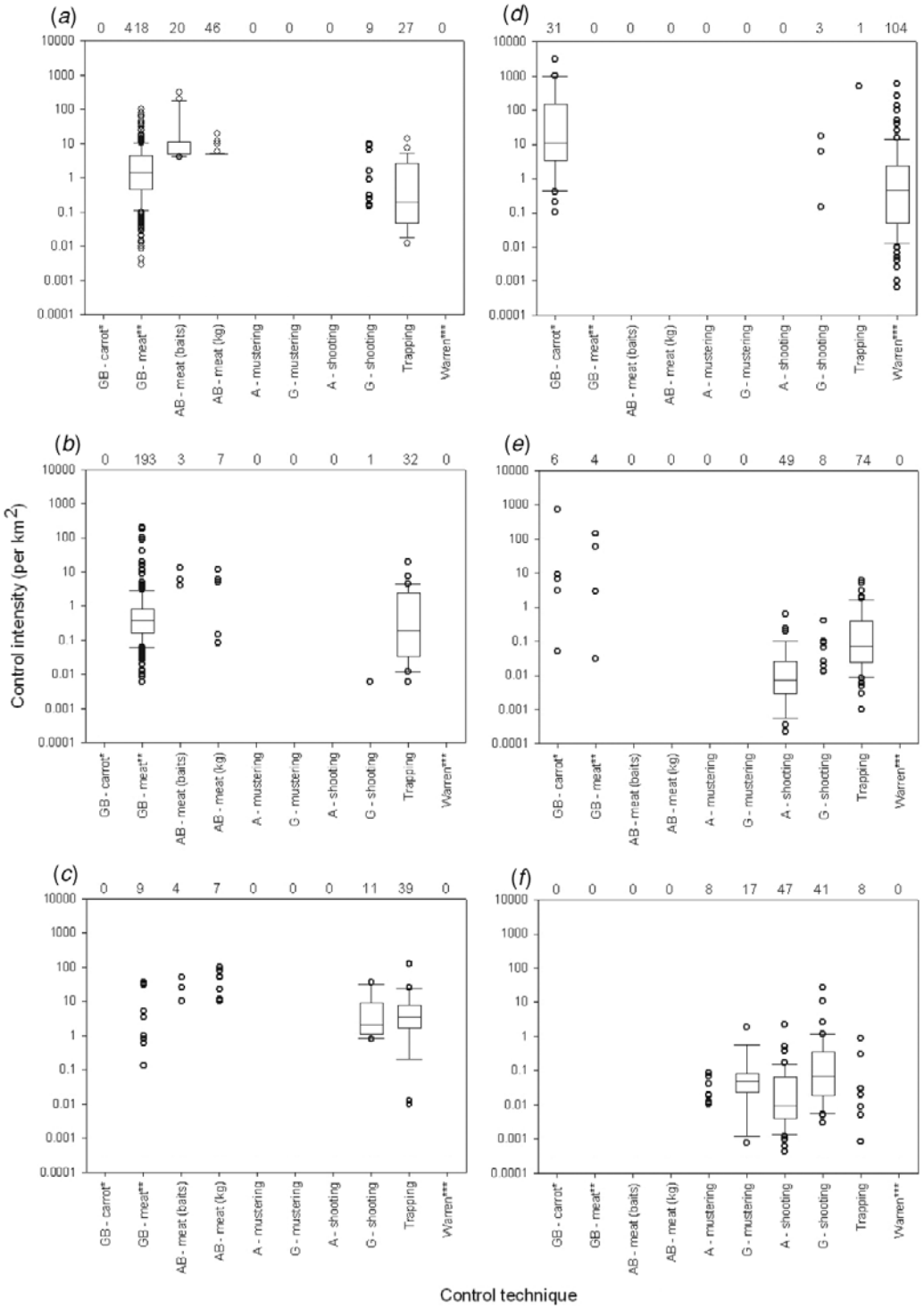

Fig. 5. Box-and-whisker plots of the intensity of 10 techniques used to control each of six pest species (pest species: *a*, fox; *b*, wild dog; *c*, feral cat; *d*, rabbit; *e*, feral pig; *f*, feral goat). GB, ground baiting; AB, aerial baiting; A, aerial; G, ground. Units are as follows: GB carrot, kg km^{-2}; GB and AB meat, baits km^{-2} year^{-1}; A and G mustering, A and G shooting and warren, days km^{-2}; trapping, traps km^{-2}. *, includes grain baiting; **, includes Foxoff® and meat baits; ***, ripping and fumigation. The number of control actions per control technique (n) is shown above the x-axis. Note that the y-axis is a log-scale and box-and-whisker plots are produced only when $n \geq 10$; open circles are shown when $n < 10$. The lower and upper boundaries of each box indicate the 25th and 75th percentiles, the line within the box is the median, whiskers indicate 1.5 × the interquartile range, and open circles represent control intensities outside the whiskers.

Table 6. Average annual number of person-days taken to undertake control actions and estimated annual cost of labour expended on control of each of six pest species during 1998–2003
The total number of control actions for each species is shown in parentheses. A daily labour cost of $320 was assumed and costs were rounded to the nearest $1000

	Fox	Wild dog	Feral cat	Rabbit	Feral pig	Feral goat
Average number of days						
1998	28 (199)	67 (55)	149 (18)	38 (52)	29 (58)	52 (37)
1999	29 (252)	58 (69)	118 (23)	15 (162)	28 (66)	45 (48)
2000	26 (317)	43 (94)	94 (34)	13 (294)	27 (78)	44 (51)
2001	31 (377)	55 (141)	103 (28)	14 (280)	29 (87)	35 (69)
2002	34 (451)	57 (162)	46 (27)	15 (256)	27 (100)	32 (85)
2003	38 (426)	53 (181)	37 (27)	19 (129)	22 (113)	32 (80)
Cost (AU$ $\times 10^3$)						
1998	1871 (206)	1176 (55)	858 (18)	783 (64)	549 (60)	700 (42)
1999	2485 (266)	1305 (70)	910 (24)	876 (177)	642 (71)	766 (53)
2000	2737 (330)	1420 (103)	1116 (37)	1322 (310)	734 (84)	784 (56)
2001	3828 (390)	2648 (150)	1018 (31)	1396 (308)	877 (93)	833 (74)
2002	5032 (468)	3015 (166)	517 (35)	1286 (277)	932 (107)	918 (90)
2003	5332 (444)	3197 (188)	371 (31)	827 (136)	820 (117)	857 (85)

towards many more control operations conducted over a smaller average area now than previously. However, our data showed no evidence of such a trend over the period 1990–2003 (see Fig. 2 for 1998–2003 data). Third, much of the control now aimed at protecting native biodiversity may formerly have been conducted under the guise of protecting agricultural values. Although we have no means of assessing this possibility with our data, we note that most states and territories have funded agencies (or parts of agencies) dedicated to protecting native biodiversity since at least 1990. Fourth, the organisations surveyed may lack methods for retaining 'institutional memory' about pest control actions that they conducted. Our interviews indicated that, within most organisations, detailed knowledge about pest animal control programs resided with the staff that managed the programs on a day-to-day basis. Hence, knowledge of that control was lost when those staff left the organisation. Until recently, none of the organisations surveyed had electronic storage systems for recording pest animal control actions (i.e. where, when and how). Although Parks Victoria has recently developed a database for recording this information, the database does not store monitoring and some other important variables. Thus, despite the large amounts of money that must have been spent on pest animal control in Australia (see below), the records of how and where most of that money was spent are not easily accessible, if indeed they exist.

Integrated control

Our data indicate that few integrated pest control programs are undertaken by conservation-focused organisations in Australia. Despite the majority (59%) of control operations

Table 7. Percentage of control actions utilising different techniques for monitoring (a) each of the six pest species, and (b) native species when each of the six pest species was targeted for control
N is the number of control actions. Rows do not sum to 100.0% because some control actions used multiple monitoring techniques

	N	Aerial survey	Bait take	Daylight counts	Sandpads	Spotlight counts	Trapping	Vegetation surveys	Other
(a) Pest species									
Foxes	305	0.0	75.1	0.0	22.6	10.8	1.0	0.0	3.0
Wild dogs	113	0.0	54.0	0.0	55.8	5.3	0.0	0.0	2.7
Feral cats	30	0.0	36.7	0.0	40.0	10.0	10.0	0.0	16.7
Rabbits	166	0.0	10.2	18.7	6.0	73.5	0.6	0.0	4.8
Pig	34	17.6	11.8	23.5	8.8	11.8	11.8	5.9	11.8
Goat	27	29.6	0.0	48.1	7.4	0.0	3.7	0.0	22.2
(b) Native species									
Foxes	144	4.2	0.0	25.7	1.4	16.7	59.0	0.7	17.4
Wild dogs	47	0.0	0.0	25.5	23.4	0.0	48.9	0.0	0.0
Feral cats	8	0.0	0.0	12.5	0.0	12.5	75.0	0.0	62.5
Rabbits	30	0.0	0.0	16.7	0.0	6.7	20.0	80.0	3.3
Pig	6	0.0	0.0	33.3	0.0	0.0	0.0	50.0	33.3
Goat	19	36.8	0.0	0.0	5.3	0.0	10.5	84.2	0.0

having other pest species present in the area controlled, most (93%) operations targeted only one pest animal species. Furthermore, many of Australia's native species are threatened by more than one pest species. For example, of 40 mammal species listed as threatened by either foxes or feral cats in the *Environmental Protection and Biodiversity Act 1999*, 29 are listed as being threatened by both pest species. Only 7% of control operations targeted multiple pest species, most (76%) of which were foxes and wild dogs: these species can both be killed using poison meat baits (Saunders *et al*. 1995; Fleming *et al*. 2001).

Controlling one pest species may either reduce, increase or have no effect on the abundance of sympatric pest species. For example, controlling rabbits with 1080 can also kill foxes through secondary poisoning (Eveleigh 1986) or by reducing the abundance of the primary prey of foxes (e.g. Holden and Mutze 2002). In contrast, control of foxes and/or feral cats may result in an increase in the abundance of rabbits (Pech *et al*. 1992; Banks *et al*. 1998). Several studies also suggest that the abundance of feral cats may increase if foxes are controlled to low densities (e.g. Algar and Smith 1998; Molsher *et al*. 1999; Short *et al*. 1999; Catling and Reid 2003). It is important to understand the effects of pest control in multi-pest systems to avoid undesirable outcomes. Zavaleta *et al*. (2001) described several examples of invasive plants increasing in abundance following the eradication of invasive herbivores. Hence, controlling one pest species alone may have minimal benefits for biodiversity unless other pests and/or weeds are simultaneously controlled.

National costs of pest animal control for biodiversity protection in Australia

Our estimates of the annual national expenditure on pest animal control in Australia (Table 6) should be considered conservative for two main reasons. First, our review focused primarily on organisations with a conservation focus, and significant pest animal control is undertaken on private land in Australia. Second, our estimates of costs were based on an assumed labour rate ($320 day^{-1}) and did not include operational costs such as bait, vehicles, helicopter charter, firearms, and traps. Although the full costs of implementing control actions were requested, many interviewees could not provide that information.

Notwithstanding the above caveats, our costs indicate several interesting patterns (Table 8). The greatest annual expenditure of labour was on fox control ($\$5.3 \times 10^6$) followed by wild dogs ($\$3.2 \times 10^6$), but a similarly low investment was made controlling the four other pest species (range: $\$0.9–1.4 \times 10^6$). Our estimates contrast with those reported by Bomford and Hart (2002) for 'agricultural and environmental damage' control costs by Australian government agencies (Table 8). According to Bomford and Hart (2002), the greatest expenditure by government organisations was on rabbits ($\$10 \times 10^6$), followed by wild dogs ($\$4 \times 10^6$), feral pigs ($\$2.5 \times 10^6$), foxes ($\$2 \times 10^6$), feral goats ($\$2 \times 10^6$), and feral cats ($\$10^6$). Bomford and Hart (2002) collated their estimates from state/territory representatives of the Vertebrate Pest Committee. For each state/territory, the costs of control were gleaned from government agency budgets; hence, the extent to which institutional overheads were included in those estimates would have been highly variable (Q. Hart, Bureau of Rural Sciences, personal communication), and their estimates are likely to be very conservative as they do not fully account for salaried positions and associated infrastructure (Bomford and Hart 2002). The almost 10-fold difference in the costs of rabbit control estimated in our study compared with that of Bomford and Hart (2002) may be due to the different methods used to estimate costs, or a consequence of most rabbit control being conducted for the protection of agricultural values rather than for native biodiversity. There may also have been a real decline in rabbit control following the substantial RHD-induced declines in rabbit abundance throughout Australia (e.g. Edwards *et al*. 2002*a*).

Bomford and Hart (2002) also estimated annual landholder expenditure on control to be $250 per landholder. Bomford and Hart (2002) suggested that expenditure by landholders was greatest for rabbits ($\$10 \times 10^6$), followed by foxes ($\$5 \times 10^6$), wild dogs ($\$2.5 \times 10^6$) and feral pigs ($\$2.5 \times 10^6$). Our survey did not sample individual landholders. However, some landholders would conduct control of at least some of the six pest species in our study with the aim of protecting native biodiversity. Understanding patterns of pest control and monitoring by landholders is an area for future work.

There are few other estimates of the cost of pest control in Australia. Saunders and McLeod (in press) estimated that the total annual cost of ground baiting operations for foxes in New South Wales would be in the order of $\$7.3 \times 10^6$. Estimates of cost are largely driven by labour, which is accounted variably among organisations. Nonetheless, on the basis of this study and Saunders and McLeod (in press), it appears that Bomford and Hart (2002) underestimated the costs of control.

Table 8. Costs (AU$ × 10^6) of feral animal control in Australia by government agencies estimated by this study and by Bomford and Hart (2002)

Note that labour costs are not mutually exclusive between pest species in this study

Species	This study[A]	Bomford and Hart (2002)
Fox	5.3	2.0
Wild dog	3.2	4.0
Feral cat	1.1	1.0
Rabbit	1.4	10.0
Feral pig	0.9	2.5
Feral goat	0.9	2.0

[A]Largest estimate for the years 1998–2003.

Area subject to control

In 2003, the area subject to control ranged from 0.3×10^6 ha for feral cats to $>10.5 \times 10^6$ ha for foxes. These are the first estimates of the area of Australia subject to pest control by conservation-focused government agencies. However, these values should be considered estimates for two main reasons. First, the area of control is likely to have been underestimated in control operations in which multiple control actions were undertaken in the same year. In those cases we used the maximum area of control per operation because in some control operations control actions were undertaken in the same area. Second, survey participants had to estimate the area in which a given control technique impacted on a pest population. For example, what is the area for control for an action that used 1080 fox baits placed along a 10-km fire trail? In many cases the area of control was simply the area of a given land tenure (e.g. park or reserve).

Some control actions may have been conducted over areas too small to substantially reduce pest abundance for a sustained period. Many control operations were undertaken over areas that equated to a few home ranges of the pest species (Fig. 2) and for short periods (e.g. two weeks per annum: Fig. 4): such areas would be quickly recolonised by pests. Interviewees in our survey indicated that some control operations in small areas and of short duration were often undertaken to appease adjoining landholders.

Control techniques

Although the techniques available for controlling pests have been described in detail elsewhere (e.g. Saunders *et al*. 1995; Williams *et al*. 1995; Choquenot *et al*. 1996; Parkes *et al*. 1996; Fleming *et al*. 2001), this is the first study to describe the frequency of use for these techniques. Ground-based meat baiting using Foxoff® or dried meat containing the toxin 1080 was the dominant technique used to control foxes and wild dogs. Similarly, West and Saunders (2003) reported that 74% of fox control in New South Wales was undertaken with 1080 baits. Apart from aerial baiting, which was undertaken only over large areas in Western Australia ($>3.5 \times 10^6$ ha annually), ground baiting is the least labour-intensive control technique available. Following the widespread reduction in rabbit numbers throughout Australia caused by RHD (e.g. Edwards *et al*. 2002*a*), warren ripping with fumigation has become the main technique for controlling rabbits (e.g. Edwards *et al*. 2002*b*).

The reduction in pest abundance achieved by control is likely to be influenced by a range of factors including control method, control intensity, timing of control, pest density and home-range size, habitat complexity and type, season, frequency, cost, and coverage (Saunders and McLeod, in press). Our data suggest that bait densities during some fox control operations may be much lower than the optimal rate, although we note that those optimal rates are likely to vary depending on habitat type and fox density. Fleming (1997) suggested that a density of 4.4 ground baits km^{-2} was too low to effectively reduce fox abundance, but the median ground bait density was only 1.4 baits km^{-2}. However, the median aerial bait density of 5 baits km^{-2} was within the range suggested by Algar and Kinnear (1992) and Thomson and Algar (2000) as most effective for fox control (5–6 baits km^{-2}). Some of the extreme intensities recorded for control techniques (Fig. 5) may have resulted from control being conducted over very small areas (e.g. fox control with 8 baits per 10 ha) and/or incorrect estimation by interviewees of the area of control.

Monitoring

Most control operations that we surveyed were being undertaken with the general objective of protecting native biodiversity (either 'threatened species' or 'native habitat conservation'). Evaluation of whether benefits to biodiversity accrue from such control, and thus whether a given management strategy is working or requires alteration, can be ascertained only through monitoring (Possingham 2001). There are two types of monitoring (Choquenot *et al*. 1996). 'Operational monitoring' is an estimate of the proportional changes in the pest population as a consequence of the control action. 'Performance monitoring' (or 'outcome monitoring') is an estimate of the effectiveness of the operation at protecting native biodiversity. Many control actions (range: 44–78% for the six pest species) had not undertaken either operational or performance monitoring. In the absence of monitoring the only information gained from those control actions are 'anecdotes' (Reddiex and Forsyth 2006).

The higher incidence of monitoring for carnivores largely reflects the inclusion of bait take (e.g. buried 1080 baits whose fate is checked) as a monitoring technique. For example, 75% of the 305 fox control actions that monitored foxes used bait take as their operational monitoring technique. Bait take requires little additional resources compared with other monitoring techniques such as spotlight counts or sandpads. However, because vertebrates can have either innate or learnt behavioural aversions to control methods (Prakash 1988; Saunders *et al*. 1995), the same method should not be used to monitor changes in pest abundance as was used to control the pest. Bait take is not independent of the control method and changes in bait take do not necessarily relate to the number of pests killed. For example, some baits are cached by foxes (Saunders *et al*. 1993, Saunders *et al*. 1999; Thompson and Fleming 1994), or not eaten due to bait shyness or neophobia to baits (van Polanen Petel *et al*. 2001). Non-target species may also consume high proportions of baits relative to foxes (e.g. goannas, *Varanus rosenbergi*: Twigg *et al*. 2001). Therefore, bait take may provide little information on the actual success or otherwise of the control operation in terms of changes in pest animal abundance, and on assessing whether control actions benefit native species or ecological communities.

In most control actions the aim of monitoring was to index the abundance of pest animals and/or native species, which is often cheaper and technically simpler than estimating population size (Caughley 1980; Thompson *et al*. 1998; Engeman 2005). The suitability of techniques for a given control activity will vary depending on several factors, including topography, habitat complexity, whether the species is nocturnal or diurnal, and behavioural traits such as trap shyness. The high proportion of bait take monitoring for the carnivores reflects the proportion of baiting undertaken for these species in which presence/absence of a bait can be recorded, as opposed to poisoning of rabbits and feral pigs, which often involves the widespread distribution of small baits. The main technique used to assess changes in the relative abundance of the carnivores was sandpads. A wide range of sandpad methods is used in Australia, with each method generating data of varying usefulness depending upon a variety of factors (e.g. Allen *et al*. 1996; Thomson *et al*. 2000; Engeman 2005). For example, the relationship between the index and the number of animals per sampling unit can have a strong influence on interpretation of the index (Thompson *et al*. 1998). In some instances the sandpad technique becomes less sensitive as density increases (e.g. Edwards *et al*. 2000; Thomson *et al*. 2000; Engeman 2005). Relative abundance of the herbivorous species was mostly estimated from direct observations (primarily aerial surveys, daylight counts and spotlight counts): these techniques can be used quickly over large areas, and can be used either as an index or to estimate density (e.g. Buckland *et al*. 2001).

Differences in techniques used to monitor native species during control actions (Table 7) appear largely due to the objectives of control actions and the types of species threatened by the pests. The main objective of control of foxes, wild dogs and feral cats was conservation of threatened species (primarily small mammals and birds threatened by predation and competition), whereas habitat conservation was the main objective for the control of herbivorous pests (e.g. floral communities threatened via foraging and habitat degradation). Birds and mammals comprised 81–90% of the native species listed as threatened by foxes, wild dogs and feral cats under the *Environmental Protection and Biodiversity Act 1999*; plants comprised no more than 2% of the listed species (Department of the Environment and Heritage 2004). In contrast, birds and mammals comprised 18–44% of the native species listed as threatened by rabbits, feral pigs and feral goats, but flora comprised 30–64% (Department of the Environment and Heritage 2004).

Conclusions

This is the first national survey of pest animal control in Australia. The data provide an estimate of the type, frequency and extent of control and monitoring activities for foxes, wild dogs, feral cats, rabbits, feral pigs, and feral goats during 1998–2003. Our results provide a baseline against which to evaluate future large-scale changes in control activities and monitoring, and highlight the need for institutions to have systems for storing information about their pest control activities. We found that institutional memory about pest control activities declined sharply after 5 years and was almost non-existent after *c*. 10 years.

The total area on which control was undertaken in 2003, the year for which most information was available, ranged from 0.3×10^6 ha for feral cats to 10.5×10^6 ha for foxes.

A wide range of techniques and intensities was used to control each pest species, but the relative cost-effectiveness of these for achieving the objectives and aims of pest control are unclear; this is an important area for further work.

The estimated cost of labour expended on pest animal control in 2003 ranged from $\$0.4 \times 10^6$ for feral cats to $\$5.3 \times 10^6$ for foxes. Monitoring of changes in the abundance of the pest or conservation resource being protected occurred in 50–56% of control actions in which foxes, wild dogs and feral cats were targeted, but only 22–26% of control actions in which rabbits, feral pigs and feral goats were targeted. Changes in the abundance of the herbivorous pests (rabbits, feral pigs and feral goats) were estimated more by direct counts than were the carnivorous pests (foxes, wild dogs and feral cats), which were monitored using bait take or sandpads. There are concerns about the usefulness of bait take to estimate changes in abundance of carnivores.

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Appendix 1. Organisations that were surveyed, the number of interviews conducted with people in each organisation, and the number of control operations surveyed

Jurisdiction	Organisation	No. of interviews	No. of control operations surveyed
Federal	Australian Defence Force	7	11
	Cook Shire Council (Cook Islands)	1	2
	Department of Environment and Heritage	3	3
	Subtotal	11	16
Australian Capital Territories	Environment ACT	2	11
	Subtotal	2	11
New South Wales	New South Wales Parks and Wildlife	18	308
	New South Wales State Forests	9	50
	Rural Lands Protection Board	1	2
	Subtotal	28	360
Northern Territories	Centralian Land Management Association	1	5
	Lowe Ecological Services	1	1
	Parks and Wildlife Centre Northern Territory	1	3
	Subtotal	3	9
Queensland	Department of Natural Resources and Mines	2	6
	Queensland Parks and Wildlife Service	10	74
	Subtotal	12	80
South Australia	Arid Recovery Program	1	2
	Department of Environment and Heritage	12	44
	Rangeland Action Project	1	14
	University of Adelaide	1	1
	University of South Australia	1	1
	Subtotal	16	62
Tasmania	Department of Primary Industries, Water and Environment	4	16
	Subtotal	4	16
Victoria	Department of Primary Industries	5	17
	Department of Sustainability and Environment	9	79
	Melbourne Water	3	6
	Parks Victoria	1	476[A]
	Phillip Island Nature Park	2	5
	Royal Botanical Gardens Melbourne	1	2
	Subtotal	21	585
Western Australia	Conservation and Land Management	13	161
	CSIRO Western Australia	1	3
	Western Australian Field and Game Association	1	3
	Subtotal	15	167
	TOTAL	112	1306

[A]Database on pest animal control supplied by Parks Victoria.

Appendix 2. Number of shires, universities and agricultural boards that were contacted, the percentage that had undertaken pest animal control and the number of operations surveyed

Organisation	Total no.	No. of contacted[A]	Percentage that conducted control	No. of operations surveyed
Shires				
New South Wales	172	128	12	0
Northern Territory	63	13	8	0
Queensland	125	111	66	0
South Australia	72	59	3	0
Tasmania	29	26	4	0
Victoria	48	47	21	0
Western Australia	144	102	4	0
Total	653	486	22	0
Universities				
Australian Capital Territory	3	3	0	0
New South Wales	12	10	10	0
Northern Territory	1	1	0	0
Queensland	10	8	25	0
South Australia	3	3	33	2
Tasmania	1	1	0	0
Victoria	9	9	33	0
Western Australia	4	4	25	0
Total	43	39	21	2
Agricultural boards				
New South Wales[B]	48	26	100	2
South Australia[C]	29	29	100	0
Total	77	55	100	2

[A]Only non-metropolitan shires were contacted.
[B]Rural Land Protection Boards: contact details were supplied for only 26 Boards; staff at the other 22 Boards were either new to the position or the position was vacant (C. Lane, State Council of Rural Land Protection Boards, personal communication).
[C]Animal and Plant Control Boards.