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Management of introduced mammals in New Zealand

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Abstract Of the 31 species of exotic mammals that have current wild or feral populations confirmed in New Zealand, at least 25 are actively managed as pests in at least part of their range to reduce their impacts on biodiversity and production values. This paper summarises the current legal status of introduced mammals, the strategic and tactical options to manage them as pests, and their actual management by different agencies, both as pests and as resources. We then discuss some ways in which management agencies might better integrate their actions, record how much is invested in different types of research on the different species, and summarise the main types of problems the research aims to address.

Keywords mammals; New Zealand; management; pests; control; research

INTRODUCTION

New Zealand was isolated from Gondwana about 85 million years ago, and although mammals (monotremes) were present in Gondwana by this stage (Archer et al. 1994) no terrestrial mammal fossils are known from New Zealand from this period, and only three species of bats were definitely present when humans settled about 900 years ago (Worthy & Holdaway 2002). However, since human arrival, at least 31 species of introduced mammals have established wild or feral populations (King 1990, 2001).

The kiore (see Appendix 1 for a species list of introduced mammals in New Zealand) came, debatably, as early as 2000 years ago with explorers from the Pacific (Holdaway 1996), and certainly (along with the domestic dog) with Maori settlement about 900 years ago, and three other rodent species arrived as stowaways on European ships in the late 18th and early 19th centuries (King 1990). However, most mammals were deliberately released for a variety of reasons (King 1990). The wild ungulates (7 species of deer, Himalayan thar and chamois), the 2 lagomorphs (rabbits and hares), and the 5 wallabies (dama, Bennett's, parma, brushtail rock, and swamp) were generally introduced and released into the wild for hunting purposes. The feral animals (goats, pigs, sheep, cattle, horses, cats) were imported as domestic stock or pets and subsequently formed feral populations when they escaped. Possums were imported to start a fur industry. Some predators (stoats, weasels, ferrets, and hedgehogs) were imported as biocontrol agents to control rabbits, in the case of the mustelids, or invertebrate pests in the case of the hedgehog.

LEGAL STATUS OF MAMMALS AND THEIR MANAGEMENT

Since 1861, wild mammals have been defined and their management prescribed under a variety of general and specific laws, especially since 1930 when central Government began to organise concerted control of those species deemed to be pests. Generally, earlier laws tended to be prescriptive, and sometimes actually inhibited sustainable solutions to pest problems, e.g., when control costs were not equitably shared, as with past rabbit control (Gibb & Williams 1994).

Currently, wild and feral mammals present in New Zealand are defined and their management determined under two main Acts, the Conservation Act 1987 and the Biosecurity Act 1993. These

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modern acts tend to be less prescriptive than the older acts, setting the goals of management, but leaving the “how to manage” questions up to the responsible agencies and affected landowners, albeit constrained by other rules and regulations on animal welfare, pesticide use, or on how to fund the control.

The Conservation Act, administered by the Department of Conservation (DOC), stresses the protection of indigenous biota (including the native bats and marine mammals) and ecosystems, and, by implication in the main act, essentially determines that introduced mammals are pests where they adversely affect these values. This view of introduced mammals is reinforced in two subsidiary acts administered by DOC (the Wildlife Act 1953 and the Wild Animal Control Act 1977). The Wildlife Act lists most introduced mammals in two schedules, declaring them to be either “unprotected” or “noxious and subject to the Noxious Animals Act”. The unprotected mammals include the rodents, mustelids and the hedgehog, whose status as pests is determined by implication in the Conservation Act. It also includes feral horses as unprotected wildlife, although the main herd of horses in New Zealand, the Kaimanawa herd, is given some de facto protection under a management plan (Veltman 2001). The Noxious Animals Act has been repealed, and the animals listed in the schedule (most of the ungulates plus the marsupials) are now the focus of the Wild Animal Control Act. Under this act, DOC has responsibilities for wild animals on land of all tenures, but in practice spends most effort on land it administers. The Crown retains ownership of all wild animals until the animal is legally taken or killed, which requires the permission of the landowner. This gives landowners de facto private property rights to the animals when they are resources, and is balanced by the “beneficiary pays” principles on private land under the Biosecurity Act when the animals are pests.

The Biosecurity Act, administered by the Ministry of Agriculture and Forestry, where it concerns management of pests, sets out the rules for establishing concerted action against species nominated in national or regional pest management strategies. Anyone can propose a pest management strategy. A national strategy exists to manage bovine tuberculosis (Tb), including strategies to manage the mammalian vectors of the disease, and many mammal species are listed in regional governments’ pest management strategies. Essentially, these strategies have to determine whether the benefits of concerted action against the pest outweigh the costs (otherwise control is the responsibility of the landowner), and determine equitable allocation of the costs of concerted control between beneficiaries and “exacerbators”, i.e., those who contribute to the problem. Traditionally, the management agencies (mostly regional councils) have focused on mammals affecting production values on rateable land (e.g., rabbits and vectors of bovine Tb). However, recently they have begun to manage or consider wider environmental and conservation benefits under the influence of a national Biodiversity Strategy.

Some mammals known to be a problem elsewhere in the world (squirrels, muskrats, coypu, beavers, gerbils, prairie dogs, gophers, and some species of foxes, mongooses, and mustelids) are specifically banned from New Zealand. However, apart from these, there is no legal impediment to people applying to import, and even release into the wild, new species of mammals under the Hazardous Substances and New Organisms Act 1999. However, we suspect applicants would have some difficulty in convincing the decision makers (the Environmental Risk Management Authority, ERMA) that any benefits would outweigh the costs. No applications to legally introduce new species of mammal into the domestic animal, zoo, or pet trade have been made to ERMA since its inception in 1999, and the cost to do so may actually encourage illegal importation. However, in recent times but before ERMA was set up, several new species of mammals were imported (1) as domestic stock (Père David’s deer (*Elaphurus davidianus*) and various South American camelids (*Lama* spp.)); (2) into the pet trade (chinchilla (*Chinchilla laniger*), and a generic hybrid between domestic cats (*Felis catus*) and a CITES-listed Asian wild cat (*Prionailurus bengalensis*)); or (3) into zoos (e.g., meerkats (*Suricata suricatta*)). None (to date) have established wild populations, and probably only the chinchilla has much chance of doing so.

No new mammal species has been illegally introduced and established in New Zealand since about 1910, although recent illegal introduction of other vertebrates, e.g., banjo frogs (*Limnodynastes dumerillii*) (Whitaker & Bejakovich 2000) suggests this is merely a reflection of the lack of interest in mammals by collectors. The proactive management of border security under the Biosecurity Act 1993 attempts to stop illegal introductions, and so far as we know has succeeded for mammals. Similarly, no new mammal species has been accidentally introduced and established a wild population since the arrival of European rodents 200 years ago, so the risk posed by mammals appears to be small. However, the regular arrival of other vertebrates, particularly reptiles and amphibians, mostly by shipping (Gill et al. 2001), and the occasional wreck of foreign ships in New Zealand, suggests that the risk is not zero. The main species likely to arrive accidentally (rodents) are already present, but there are significant risks from some of the cold-climate karyotypes of ship rats, which are supposedly more aggressive than those already present (Yosida 1985).

Natural dispersal of new mammal species without the aid of humans is logically restricted to marine animals or to those that can fly. Two species of Australian bats are known to have arrived in New Zealand in the last century. A single little red flying fox (*Pteropus scapulatus*) was found dead in the 1920s (Daniel 1975), and a single little forest bat (*Vespadalus vulternus*) was found dead in a crate imported in 1998 (O'Donnell 1998).

PUBLIC PERCEPTIONS OF MAMMALS AND THEIR MANAGEMENT

Ultimately, the ability or desire of government-funded agencies to sustain management of particular species as pests, and to retain use of the most effective control tools, will depend on society's view of the status of the species. New Zealanders already have mixed, or contradictory, and often passionate views on the value of introduced mammals, e.g., see Lark (2000) and Johnston (2000), and even where they agree on the status of a species as a pest they often disagree on how to manage them, e.g., debates over the future use of genetically modified biocontrol agents or the current use of toxins (Parliamentary Commissioner for the Environment 2000; Green 2003). At the least, these debates place constraints on how pest managers control mammal species.

Of course, perceptions have changed about which species are pests. For example, despite some opposition from biologists and managers of game birds, mustelids were enthusiastically imported and released in the 1880s in an attempt to control rabbits. Government began to have second thoughts about the wisdom of this by 1903 but did not remove all legal protection from the species until 1936 (King 1990), culminating in 2002 with a proposed ban on the sale and breeding of domestic ferrets. Similarly, the legal status of possums has shifted from one of complete protection, through licensed trapping as a resource for fur, to a pest—but one that can provide some resource value (Cowan 1990).

King (1996) categorised public perceptions (within the wider context of views on conservation issues) into four groups: idealists, traditionalists, pragmatists, and commercial users. The idealist would exterminate them all, the traditionalist would accept those that are useful, the pragmatist would accept those that are established, and the commercial user sees them as something to exploit. We can see all these views, for example, in debates over the status of wild deer. The idealist, largely represented by environmental groups in New Zealand, dreams of a day when a technique will become available to eradicate entire pest species. The traditionalist is largely represented by the hunting fraternity who often have a "monarch of the glen" view of deer, and while they say they are happy to limit their numbers, generally battle to keep the idealists and especially the commercial harvesters at bay. The pragmatists are largely represented by scientists and managers who think deer are here to stay, but that they should be managed to limit their spread and damage. The commercial exploiter of deer is represented by the harvest industry who, in the absence of property rights to the animals, cannot arrange any maximum sustained harvest and so take what they can afford to get (Parkes et al. 1996; Nugent et al. 2001a).

In 1996, DOC began a consultation process in an attempt to develop a national deer control plan. A series of reports was produced to show the evidence (both biological and management) on all sides of the argument on how to manage deer (DOC 1997), but views remained polarised as the process of consultation developed. The Department abandoned this attempt to develop a national plan, but promulgated a policy statement reiterating the official view of wild deer as pests, noting the main management aims of limiting their spread and controlling densities in high priority areas. However, it has recently revived plans to constructively engage the competing interest groups (C. Veltman pers. comm.).

Recreational and commercial hunting is encouraged, but as a control tool rather than an end in its own right. Legally, there is nothing to stop recreational hunters attempting to manage deer and other game animals themselves, especially in areas with low conservation values. They already do this to some extent for fallow deer herds in the Blue Mountains (Otago) and at Woodhill (Auckland) and for sambar deer in the Manawatu (Nugent et al. 2001a), i.e., for species not commercially harvested. However, for commercially harvested species such as red deer, hunting organisations cannot restrict their commercial competitors, let alone other recreational hunters. The government sees such a role for itself as being inconsistent with its policy that views the animals as pests (DOC 2001a) and so will not regulate hunters for that purpose.

The official view of introduced mammals as pests is not entirely shared by the public. Fraser (2001) randomly surveyed a large sample of New Zealanders on their perceptions of introduced animals. Most (71–94%) considered the smaller mammals as pests, but their views of the larger ungulate species were more circumspect. Only 4% considered deer as pests, with the remainder being evenly split and seeing deer either as both pests and resources depending on circumstances, or as resources.

The view of the smaller mammal species as pests confirms earlier surveys of particular mammal species. Fitzgerald et al. (1996a) surveyed peoples' views on possums and their control. Most (80%) agreed that possums were a threat to conservation and/or to livestock as a disease risk, and a majority (70%) recognised possums posed a risk to our overseas trade. However, despite the consensus that possums were a pest, views on how to manage possums rarely reached such levels of agreement. A majority agreed that shooting, using possum-specific poisons, and trapping were acceptable, while only a minority found the use of 1080 and various biological control methods to be acceptable. Of the biological control methods, a genetically engineered organism that killed only possums was favoured over imported biocontrol viruses, bacteria, or parasites, and biocontrols targeting fertility were favoured over those increasing mortality.

The Parliamentary Commissioner for the Environment (PCE) also reviewed New Zealanders' perceptions of possums and their control and also noted the conflict about how to manage the pest (PCE 2000). The Commissioner concluded "something was seriously wrong at the interface between science, regulatory agencies and communities", particularly with respect to the development of new control technologies such as genetically engineered products, and recommended research aimed at understanding how society judges the risks, costs, and benefits of pest control options. The PCE clearly believed that merely providing information to society is insufficient to change the paradigms of protagonist groups—in fact such information often further polarises views as the protagonists seize on the facts that suit their case and ignore the rest (see Wilson 1992 for a description of this process in biological controversies).

Surveys of public attitudes towards rabbits and their potential biocontrol agent rabbit haemorrhagic disease (RHD) were carried out using focus groups and telephone questionnaires in 1994 and 1996 (Fitzgerald et al. 1996b; Wilkinson & Fitzgerald 1998), i.e., before and during the proposal to release RHD. Results from 275 respondents participating in both surveys showed that, despite the efforts of the proponents of importing RHD, the level of support fell from 54 to 47% over the 3 years. A third survey taken after the illegal introduction of RHD in 1997 would be interesting now that the actual benefits and costs of the disease are more clear (Norbury et al. 2002; Parkes et al. 2002a).

In 2001, seven facilitated focus group discussions, four groups of the general public and three interest groups, were conducted to examine perceptions of stoats and other mustelids in New Zealand. Stoats were generally viewed negatively, although the four public groups knew very little about the species compared with the interest groups. Views on how to control stoats favoured trapping over use of toxins such as 1080, although some people acknowledged poisons might be a necessary tool in the absence of alternative methods. There was clear discomfort with new potential biocontrol methods, especially those based on genetically engineered organisms (Fitzgerald et al. 2002).

MANAGING MAMMALS AS PESTS

Internal border management

The risk of a species already present on one island reaching other islands of New Zealand is very high, especially between the North and South Islands (see the section below on island management for those mammals found only on one island). Other species are patchily distributed but could, given the chance, occupy much larger areas. It is illegal to liberate wild mammals, and it is illegal to hold some species outside their present range, e.g., Himalayan thar (DOC 1993). This has not stopped people liberating animals or attempting to keep species outside their range both within one island and between islands, resulting in an ongoing need for agencies to manage the risks of human-assisted as well as natural dispersal.

There are two ways to consider this management. Proactive management would seem to give the best results for species and cases where the consequences of establishment would be bad, and where there would be little ability to eradicate the new populations. Being proactive would largely involve setting out rules about keeping or liberating mammals, not allowing farming of the species in some places, or by improving containment standards to stop them escaping. Nevertheless, such laws have not stopped people moving species into new areas, generally to establish new hunting opportunities, e.g., feral pigs (McIlroy 2001) and Himalayan thar (Forsyth & Tustin in press). The regional restrictions on farming animals such as deer in Northland and around Mt Egmont National Park have reduced the risk of these species spreading into the deer-free areas—but not the risk of illegal liberation (Fraser et al. 2003).

An attempt to be proactive in reducing the future impacts of ferrets has been initiated with a ban on breeding ferrets in captivity and their commercial sale as pets (DOC 2002). The assumption that escaping domestic pets would make any difference to the abundance of feral ferrets was untested, but ferrets abandoned after past failed fur farming ventures may have posed a significant threat to vulnerable species (Pierce 1996). However, the risk of domestic ferrets escaping into areas free of feral ferrets (now largely only islands, given their current distribution on the North and South Islands; Clapperton 2001) will be reduced by the ban.

In 2003, the Government substantially increased the penalties for illegal liberation of pests. This followed the threats to release stoats on Stewart Island made by people opposed to DOC's potential control of whitetail deer on the island. Similar threats to release possums on Kapiti Island (from which they had been eradicated) were made by people opposed to deer control plans in Fiordland. The threats in these cases were apparently not carried out as no stoats or possums have been found. It remains to be seen whether such proactive action, i.e., legislating for penalties, will deter either the threats of eco-terrorism (and avoid the costly responses government must undertake to check them) or the actual commission of the offence.

In contrast, reactive management is likely to be better justified where the risk of liberation, escape or spread is high, and where the probability of successful eradication of the new population is also high. Surveillance systems, early detection, and prompt action are the keys to success. Reactive management is suited to cases where the proactive approach has failed (e.g., to prevent the establishment of new deer herds in Northland; Fraser et al. 2003), or where natural spread is inevitable unless the source population can be eradicated (e.g., dama wallabies around Rotorua, Sadleir & Warburton 2001; Anon. 2002).

Management of established species in their current range

Strategic options

Currently, pest mammals are managed for three broad purposes: to protect indigenous species and communities, to reduce vectors of Tb, and to protect production values, and, depending on the species and where it lives, these purposes may overlap. Whatever the purpose, there are two positive strategic options to manage pest mammals: (1) where a one-off management action provides a permanent benefit (eradication or some forms of biological control); or (2) where the management action has to be sustained in perpetuity to achieve a benefit (sustained control or fencing). A third option is to “do-nothing”.

Eradication

Eradication is a favoured strategy for pests (e.g., Myers et al. 2000), but it makes sense as a policy only if it is achievable. If it is attempted when it was never achievable, the subsequent default management by sustained control is often abandoned when the eradication attempt fails, yet a sustained control option might still have protected the resources. The obligate rules that must be met before eradication is possible are simply that all animals must be at risk (or at least all of one sex, or all those in source populations; J. Hone pers. comm.), killed at rates faster than they can replace their losses at all densities, and the risk of immigration must be zero (Parkes 1990). The desirable rules are that animals must be detectable at low densities, a discounted cost-benefit analysis should favour eradication over sustained control (particularly for pests on production values), and the policy environment (see Simberloff 2001) should be conducive to the attempt (Bomford & O'Brien 1995). For most species and populations in New Zealand, one or more of the obligate rules cannot be met, and so eradication is not possible over the entire range of the species. However, eradication has been successful at a local population scale for many patchily distributed species where the rules can be met (e.g., for some feral goat populations; Parkes 1993a), and for many mammals on islands (Towns & Broome 2003 and below).

It is likely that brushtailed rock, swamp, and parma wallabies will be eradicated from their entire

New Zealand range (on Kawau Island), and the small populations of feral horses, sheep, and cattle (Parkes 2001; Veltman 2001) could probably be removed if the will to do so was present (although escapes and liberations from the domestic populations might require repeat actions). It has been argued that some other species with limited distributions on the mainland such as Himalayan thar (e.g., McSweeney 1984) and dama wallabies (Anon. 2002) might also be vulnerable to eradication using current techniques, or that other species might be removed with new techniques (Hackwell & Bertram 1999). It is unlikely that any new technique or strategy will ever meet all the obligate rules to allow the more widespread species on the mainland to be eradicated, and uncertainty about success and the monetary and political costs of attempting to eradicate restricted species such as thar has discouraged any serious planning to eradicate them (DOC 1993; Hughey & Parkes 1997).

Biological control

Biological control using diseases or predators is inherently more risky than conventional control because, unlike a trap or toxic bait, the agent of control cannot be easily "turned off" if the consequences are adverse. Mustelids were introduced as a biological control for rabbits in New Zealand, and in some places (Gibb & Williams 1994), but not all (Reddiex et al. 2002), they successfully limit rabbit numbers. However, the solution was probably worse than the problem as the predators are major pests in their own right (e.g., King 1990). The rabbit haemorrhagic disease virus is the only recent biocontrol agent of mammals introduced to New Zealand. The disease has persisted naturally since its illegal introduction in 1997, and has successfully suppressed many problem rabbit populations without leaving too many immunised survivors (Parkes et al. 2002a). Reduction in rabbit numbers has obvious benefits in terms of the lower costs of conventional control, less use of toxins, and less herbivory, but also less welcome consequences from more weeds, more hares and possums, and more predation on native animals from predators (Norbury et al. 2002; Murphy et al. unpubl. data).

Biological control aimed at reducing fertility is being researched in New Zealand, particularly for possums (Cowan 2000). The concept (Tyndale-Biscoe 1994) of using immunological blocks to fertility using genetically-modified living organisms as vectors for the agent has been shown to work in the laboratory, although significant constraints (animals that do not respond, public opposition to genetically modified organisms, and the views of Australians who value their possums) have yet to be solved before the technology could contribute to control of possums in New Zealand. Nematodes, bacteria, and viruses have been mooted as potential vectors for possums (e.g., Cowan 2000), but none have been genetically modified and tested for their efficacy as vectors in the field.

Sustained control

If one-off strategies are not possible, then sustained control provides the only positive option to manage mammal pests. This requires a much more complex understanding of the pest-resource interaction so managers know when, where, and how often to intervene with control actions (Hone 1994). In any sustained control operation managers should use the optimal strategy (frequency, intensity, and spatial pattern) and tactics (the most efficient, effective, and environmentally safe) methods that halt or ameliorate the damage caused by the mammal pest—if only because sub-optimal control in one operation either fails to protect the values at risk (not enough control), or precludes other choices for the limited budgets available (too much control).

Sustained control is by far the most common strategy employed against mammal pests in New Zealand. We discuss the strategy in the sections on management agencies, and in light of the research needed to underpin the strategy later in this paper.

Tactical options

There have been many reviews and collations describing control methods of pests in New Zealand, e.g., in a series of workshops on the conventional control of possums (Anon. 1996a), the biological control of possums (Anon. 1998), and on ferrets (Anon. 1996b), on the use and consequences of toxins (see papers in *New Zealand Journal of Ecology 23*), and on research on stoat control methods (Parkes & Murphy in press).

Generally, the scale of the pest problem, the target densities required, and the rates of recovery and behaviour of the pest species towards the control methods available all determine which control technique is used. Toxic baits remain a favoured method in New Zealand (Table 1). Aerial baiting is the favoured method to initially reduce widespread pests with low rates of increase such as possums (using compound 1080), and for the eradication of insular rodents (using brodifacoum). However, because the technique induces bait or toxin shyness (Hickling et al. 1996) if used too frequently, the ongoing maintenance control for possums is usually done either using a variety of ground-control methods such as cyanide baits or by trapping, or the time between control events is lengthened.

Sustained control of species with high rates of increase is either via biocontrol (for rabbits now that RHD has arrived), or by ground-based methods such as trapping (for stoats) or bait stations (for rodents). A tactical option for fertility control is to use a genetically modified plant bait with the fertility antigen but with no living component to reduce fertility in post-conventional control possum populations. If it worked, the method would avoid any risks posed by a self-replicating vector, and could be "turned on and off" to slow the rate of recovery of the possum population and so decrease the frequency of conventional control required (Cowan 2000).

MANAGEMENT BY THE DEPARTMENT OF CONSERVATION

Most management of mammals to ameliorate their impact on conservation values is conducted by DOC. The Department administers about 78 000 km^2 (29%) of New Zealand, and all of this land on the main islands has at least one species, and up to 15 species (in the Two Thumb Range in Canterbury) of introduced mammals present; usually at least one ungulate, one rodent, one mustelid, and one marsupial species. The Department manages mammals at an estimated annual cost of c. $40 million, or 23% of its budget in 2001/02 (DOC 2002).

The costs of the unremitted damage to conservation assets without a market value caused by mammals depend on how much we value the assets, and the problem of defining that sum and the ways it could be accounted for are the subject of controversy (e.g., Hackwell & Bertram 1999; Stephens 1999; Cullen & Bicknell 2000).

Table 1 Amount (kg) of active ingredients of toxins used against mammal pests in New Zealand.

Toxin	Amount (kg)	Main target species
1080	2700	Possum
1080	20	Rabbit
Potassium cyanide	1800	Possum
Sodium cyanide	130	Possum
Pindone	2.75	Rabbit
Brodifacoum[1]	8.0	Rodents
Coumatetralyl	0.4	
Warfarin	0.15	
Diphacinone	0.2	
Bromodiolone	0.2	
Yellow phosphorus		
Zinc phosphide		

[1]Excludes the amount used in commercial products sold to control commensal rodents.

Island eradications

There are about 735 islands over 1 ha in size in the New Zealand archipelago, from Raoul Island in the Kermadec group at 29°S to Campbell Island in the subantarctic at 52°S, of which the Department manages c. 250. Most islands are known to have or have had introduced mammals present, and only 158, totalling only 2162 ha, are known never to have had any introduced mammals. To date, at least 167 populations of wild or feral mammals representing 17 species have been eradicated (Table 2).

The three main islands (North, 11 372 900 ha; South 15 043 700 ha; and Stewart 168 000 ha) have only eight mammal species in common (possums, hedgehogs, Norway rats, ship rats, feral cats, feral sheep, and red deer). Dama wallabies, feral horses, sambar, sika and rusa deer are found in the wild only in the North Island, and Bennett's wallabies, chamois, Himalayan thar, wapiti, and perhaps moose only in the South Island. No species occurs only on Stewart Island.

There are six islands, ranging between 10 000 and 100 000 ha in size, that total 214 108 ha and all have or have had introduced mammals (up to 11 species on Chatham Island), and on only the smallest (Campbell Island, 11 331 ha) have they all been eradicated. On the others, several species with limited distributions on the islands have been eradicated—feral pigs on Stewart Island, goats on Auckland Island, and a few dama wallabies illegally liberated on Great Barrier Island. Currently, only feral goats on Great Barrier Island (28 510 ha) are the subject of an eradication attempt.

There are 23 islands between 1000 and 10 000 ha in size, with a total area of 78 180 ha, and again all have or have had populations of introduced mammals (with 10 species currently present on Arapawa Island, 7785 ha). Five islands, totalling 17 459 ha, in this size range have been made mammal-free: Raoul Island (2950 ha) with four species eradicated, Tuhua Island (1277 ha) with four species eradicated, Kapiti Island (1970 ha) with five species eradicated, Codfish Island (1396 ha) with two species eradicated, and Adams Island (9896 ha) on which sheep and pigs died out naturally. Note: eradication of rodents and cats on Raoul and Tuhua Islands was attempted in 2002 and success remains to be confirmed.

There are 57 islands between 100 and 1000 ha in size, totalling 15 775 ha, of which four (Tawhiti Rahi, Solander, main Snares, and Disappointment, totalling 918 ha) have never had populations of introduced mammals, and 17 (4161 ha) have been cleared of all mammals.

About 646 islands are less than 100 ha, totalling 6821 ha, of which 158 (1244 ha) have never had mammals, 62 (1369 ha) have been cleared of all mammals, and the rest have mammals (n = 167) or their status is unknown but most are likely to have mammals (n = 259) as they are within swimming distance of the mainland for species such as ship rats, stoats, or deer.

Thus, only 2162 ha (0.7% of the total area of New Zealand's islands or 0.008% of the total area of New Zealand) have never had any introduced mammals and are in that sense pristine. Sixty-eight islands have been cleared, adding a further 30 189 ha to the total that are now free of introduced mammals.

The tiny contribution that islands (other than the main three) make to the land mass of New Zealand belie their importance to biodiversity both as evolutionary nodes for the remote islands, and as arks for species that cannot survive easily on the mainland (Atkinson 1989). The Department of Conservation plans to continue its eradication programme on priority islands where reinvasion is unlikely. These plans include the removal of kiore from Little Barrier Island, rats from the Ohena group, which would make them mammal-free, and removal of feral goats from Great Barrier Island and pigs from Auckland Island, which would still leave other species present (DOC 2000a).

The Department also has proactive procedures to limit the risk that mammals will colonise new islands, and contingency plans to deal with any new incursions. A significant management problem is the ability to detect new populations at very low densities (or remnant ones at the end of eradication campaigns) in time to react effectively. The Department did not detect stoats on Stewart Island after a recent (but unconfirmed) report that they were present, but a very large effort is required to detect the presence of such a low density population with any statistical power using current techniques (Choquenot et al. 2001).

Table 2 Known status of mammals on islands around New Zealand (J. Parkes unpubl. data).

Species	No. islands with confirmed populations	No. islands where the species has been eradicated	Largest island where the species has been eradicated and size (ha)	No. islands where the species has died out naturally
Kiore	25	34	Raoul (2950)	0
Mice	28	12	Enderby (710)	1
Norway rats	26	30	Campbell (11 331)	
Ship rats	46+	9	Moturoa (146)	
Feral cats	24	10	Raoul (2950)	5
Feral dogs	0	0		2
Stoats	28+	5	Anchor (1130)	0
Possums	14	10	Rangitoto (2321)	2
Wallaby spp.	1	3	Rangitoto (2321)	
Hedgehogs	7	0		0
Rabbits	24	14	Enderby (710)	10
Feral pigs	8	16	Great Mercury (1718)	9
Feral goats	10	22	Raoul (2950)	9
Deer spp.	37+	1	Nukuwaiata (242)	3
Feral cattle	3	2	Campbell (11 331)	2
Feral sheep	4	2	Campbell (11 331)	4

Tactically, projects to eradicate mammals fall into two types, depending on the species. For rodents, eradication is now routinely achieved, on islands up to 11 331 ha to date, with applications of the primary control tool, aerial poisoning (Towns & Broome 2003). For most other species such as rabbits (Parkes 2002; Torr 2002), feral goats (Parkes et al. 2002b), and possums (Cowan 1992) some individuals always survive the primary control technique and then must be detected and removed by a secondary control operation, usually via a different technique. It will be interesting to see whether rodents fall into this category as managers attempt to clear islands in the next size order of magnitude.

Mammals will remain on many islands where any of the three obligatory conditions for successful eradication (Parkes 1990) cannot be met. In these cases managers may still manage the mammals, but must use sustained control strategies, which at best can kill all the residents and sustain control of any immigrants. For example, some islands within stoat swimming range of the mainland, about 1.2–1.6 km, have had resident stoats removed (e.g., Maud (309 ha and 900 m from South island) and Anchor (1130 ha and 800 m from South Island). The biological benefits equal those achieved by eradication, but the logistical benefits are less because a sustained effort has to be maintained to detect and deal with the inevitable immigrants. Three such events for stoats and a single weasel have been recorded on Maud Island since 1980 (Crouchley 1994; E. Murphy unpubl. data).

National wild animal control plans

The Department manages three mammal species (brushtail possums, feral goats, and Himalayan thar) under national control plans under the Wild Animal Control Act 1977.

Nationally coordinated control campaigns against feral goats have been conducted by government agencies since 1930 (Parkes 1993a). However, the goat problem worsened in the 1980s after an enthusiasm for goat farming waned, resulting in many new feral herds (Parkes 1993a; Fraser et al. 2000). In 1990, this led Government to allocate extra funding for goat control, and to develop a national feral goat control plan. The plan ranked 483 sites for potential control operations covering 21 000 km^2 (Parkes 1993a; DOC 1998). Currently, the Department controls goats over about 14 000 km^2 in 182 operations, at an annual cost of $6.3 million (DOC 2002). Most areas are controlled annually, and none at frequencies longer than once every 4 years (DOC unpubl. data). The feral goat control operation in the 33 000-ha Egmont National Park is the longest sustained control of a wild mammal (other than a commensal pest) in the world, with an annual effort beginning in 1924 at a total cost in today's dollars of perhaps $25 million for about 100 000 goats (Forsyth et al. in press).

The New Zealand Forest Service began large-scale possum control in the 1960s, largely in areas where forest canopies were collapsing. The Department inherited this piecemeal control in 1987, and by 1992 had conducted control over 68 000 ha in 16 operations—only one of which was in an area that had been controlled in the past (Parkes et al. 1997). Government recognised that national coordination of possum control was required (e.g., Guthrie 1993; PCE 1994), and allocated DOC extra funding for possum control in early 1993. As with the feral goats, a national possum control plan was developed by ranking 243 places for potential control operations covering 15 000 km^2 of the 250 000 km^2 range of the species (DOC 1994). The Department currently sustains control of possums over c. 10 650 km^2 in over 200 operations at an annual cost of c. $12 million. The frequency, and so the cost/ha/year, with which maintenance control is applied varies considerably between and within Conservancies. Some managers apply almost continuous control (e.g., most control operations in the Bay of Plenty and Canterbury Conservancies). Others apply control once every 7 years (e.g., most control operations in Wanganui and Wellington Conservancies). Yet others have a mix of control strategies but with the majority having maintenance control applied every 3 or 4 years (e.g., in Northland, Auckland, and West Coast Conservancies) (J. Parkes et al. unpubl. data). Generally, up to 2500 km^2 is treated each year (DOC 2000a; DOC 2002).

The national thar control plan developed under a different process (DOC 1993; Hughey & Parkes 1997). Commercial hunting after 1972 had reduced the thar population by about 90%, and the plan (the planning process began in 1991) was an attempt to retain the conservation benefits of these low densities by organising the recreational, commercial, and official control hunters to kill the required annual harvest of thar to leave a living population of no more than 10 000 animals (about 20% of carrying capacity). The thar plan divided the current range of thar into seven management units, and set threshold densities of between near-zero and 2.5 animals/km^2 above which official control would be triggered. Most of the Department's annual costs are devoted to monitoring thar densities and impacts, with some official control at the southern and northern edges of the range to halt dispersal, plus occasional efforts in areas when numbers exceed the target densities (Choquenot et al. 2000; Forsyth & Tustin 2001).

Regional pest plans under Conservancy Management Strategies

Local control or management plans have been developed by DOC Conservancies for some mammal species, such as the dama wallaby population near Rotorua (Anon. 2002), the feral horses of Kaimanawa (DOC 1996), deer in the Murchison Mountains (Crouchley 2000), and for new populations of deer in Taranaki and Northland (Fraser et al. 2003). In 2001/02, \$8.2 million was spent on the control of "other animal pests", which included cost allocated for the thar management noted above, for deer and feral horses, and for a range of pest fish species and wasps.

The campaign to eradicate recently established deer populations is interesting because it is a multi-agency project with an annual budget of \$185,000, involving DOC, Northland Regional Council, Agriquality New Zealand, the Animal Health Board, and farmer groups. It aims to identify and eradicate all new populations of deer in Northland. It has removed most of the estimated 140 deer from the wild in Northland, leaving perhaps fewer than 10 animals (a few red deer at Mangakahia, and a few sika deer at Russell) in the wild (Fraser et al. 2003). Equally important, the project has reduced the number of farmed deer escaping into the wild, discouraged illegal liberations by demonstrating their low chance of success, and accounted for all reported escapees in 1999/2000 (McKenzie & Gardiner 2000).

Threatened species management

In 2002, DOC listed 563, 234, and 1518 indigenous species of plants and animals that it considered acutely threatened, chronically threatened, or at risk, respectively (Hitchmough 2002). The first category includes those species that face a very high risk of total extinction, the second are those in decline, and the third (although not declining) have small or scattered populations.

To date DOC has published 47 threatened species recovery plans covering 22 plant, 24 invertebrate, 4 amphibian, 25 reptile, 40 bird, and 4 native mammal species. Diagnoses of the causes of decline and/or current threats are non-specific in many plans—the usual suspects, including introduced mammals, are blamed mostly as predators rather than competitors. For example, 37 of the 40 bird plans note mammal predators as a threat, but only 3 of the 40 note mammal herbivores as a threat. For the plant plans, mammal herbivory is noted as a threat for 18 of the 22 species, although again the culprit(s) are rarely identified with certainty, and indeed the causes may be many and complex. Recent research suggests that the interaction between the changes in habitat induced by herbivory and predation (and perhaps parasites) may be the critical cause of decline in some endangered lizards in New Zealand (e.g., Norbury 2001).

One plan that does diagnose the current critical cause of decline is that for the mainland populations of kiwi (*Apteryx* spp.). For kiwi, the stoat is the key pest responsible for the mortality of most juvenile birds (McLennan et al. 1996). The Department has created five kiwi sanctuaries covering c. 40 000 ha where it conducts intensive predator control at an annual cost of c. \$2 million funded out of the New Zealand Biodiversity Strategy and with sponsorship from the Bank of New Zealand. Controlling predators such as stoats is difficult, first because of the lack of a cost-efficient control technique suitable for use over wide areas that can put all stoats at risk, and second because of their high intrinsic rate of increase (Parkes & Murphy in press). It is doubly difficult in some places with other prey species on which the impact of the stoats is periodic but acute (unlike the chronic impacts on kiwi chicks). Here it is difficult to know when best to intervene when stoats, their primary rodent prey (also sometimes a threat in their own right), and both rodents and sometimes their secondary native prey all fluctuate in response to masting events in the forest (Barlow & Choquenot 2000). One strategy to protect some particularly vulnerable species (e.g., kakapo (*Strigops habroptilus*) and hihi (*Notiomystis cincta*)) is to translocate populations to predator-free islands. However, this strategy is not possible for some threatened birds (e.g., blue duck (*Hymenolaimus malacorhynchos*)) because only the main islands have suitable habitat.

In contrast with the long-sustained control of some ungulates (Forsyth et al. in press), predator management has, to date, been sustained for only a few years and over a small part of the area where predators are a problem (Clout & Saunders 1995). Time will tell whether predator control is sustainable, as past governments have abandoned many long-term pest control operations (Parkes 1996). The site-based asset management approach being proposed by the Department (see below) will at least make the consequences of stopping more transparent.

Mainland islands

New Zealand's success in eradicating pests and re-introducing native biota on islands, and an experiment to save mainland kokako populations by intensive management of their potential threats conducted at Mapara (Innes et al. 1999), led some to advocate transferring some of these management practices to intensively managed areas on the mainland—called mainland islands. Six such areas were initiated in 1995 and 1996 covering 10 700 ha (Saunders & Norton 2001). Generally, about 10 species of mammals are present at each mainland island, but a variable number are targeted for control, with possums being the only species controlled at all sites (Saunders & Norton 2001).

The average cost of the management in these areas in 2000 was $271/ha, with an unknown but substantial part being spent on the control and associated monitoring of mammals (Saunders 2000; Gillies et al. 2003). A different suite of mammals is present at each mainland island, although possums, ship rats, mice, and stoats are common to all. The mammals controlled at each site and the intensity of that management also varies, but generally managers have been including more species in their control regimes over time.

The Department has been considering the national purpose of the mainland island approach (Saunders 2000; DOC 2002). The options for future mainland islands, not necessarily always exclusive, are to treat them as (a) public sites to display native biota and conservation in action, in which case adjacency to large cities might be a selection criterion, (b) tactical learning sites where managers learn how to manage a suite of threats intensively, in which case they might be temporary and conveniently located, (c) strategic learning sites where managers learn how to manage ecosystem processes (as advocated by Saunders & Norton 2001), in which case the niceties of replication and experimental controls might be selection criteria, or (d) as part of threatened species recovery plans, in which case they might be sited where priority threatened species occur, or (e) part of a national biodiversity strategy, in which case they might be located in areas of highest value or as core areas in a wider biodiversity plan. No new mainland islands have been instituted while these purposes are clarified and the sites considered in terms of DOC's evolving systems to prioritise its management actions (DOC 2002; Stephens et al. 2002).

MANAGEMENT BY LOCAL GOVERNMENT

Regional councils and some district councils manage mammals under several mandates. First, some councils manage parks and reserves and may control pests there like any other landowner (e.g., Auckland Regional Council in the Hunua Ranges). Second, they have responsibilities to inspect, enforce control, and manage pests proscribed in any regional pest management strategy (RPMS) developed under the Biosecurity Act. Third, because most councils inherited the infrastructure and skills of the old pest destruction boards, they may act as contractors to the Animal Health Board or landowners. Funding for control comes either from ratepayers, usually weighted so landowners that most benefit pay more, entirely from the affected landowner, or for Tb vector management in part from the Animal Health Board. Many councils have avoided potential conflicts of interest arising from their regulatory and delivery roles by forming independent council-owned companies that compete with private contractors to conduct the pest control.

Species included in any RPMS must, in the view of the proposer of a RPMS, cause a sufficiently serious adverse affect on production, conservation, environmental, or social values such that the net benefits of having a concerted regional strategy outweigh the net benefits of leaving the management up to individual landowners. These are not easy rules to assess (Harris Consulting 1995), and regional councils have come to different conclusions about which species should be included in their RPMS (Table 3).

Traditionally, regional governments were concerned largely with mammals affecting production values (e.g., rabbits and possums as Tb vectors), and operated under the rules set out in the Biosecurity Act. However, councils now also have responsibilities to promote sustainable management of natural resources under the Resource Management Act 1991, and have taken notice of the national Biodiversity Strategy and the draft national Biosecurity Strategy. Most councils are increasingly broadening their traditional role of managing pests on agricultural land to include environmental and conservation goals at priority places in their pest management strategies.

MANAGEMENT BY THE ANIMAL HEALTH BOARD

In June 2002, 364 domestic cattle herds and 79 farmed deer herds (0.5% and 1.4% of the total herds, respectively) had some animals (1767 cattle and 1330 deer) that tested positive to bovine tuberculosis (AHB 2002). New Zealand operates a test and slaughter and movement restriction policy for these infected farmed herds in an attempt to reduce the infected herd rate below the internationally accepted level of 0.2%. However, this strategy is compromised by the presence of the disease in wild and feral mammals over c. 24% of New Zealand (Coleman & Livingstone 2000).

The possum is the only confirmed wild animal capable of maintaining the disease in the absence of other infected species, and it can transmit Tb to domestic animals (Pfeiffer 1994). Many other species of mammals (particularly ferrets, feral pigs, and deer) also become infected in the wild but, apart perhaps from ferrets (Caley 1998), they do not apparently sustain the disease in the absence of infected possums and livestock (Morris & Pfeiffer 1995).

The Animal Health Board funded $54 million of vector control in 2001/02, with funding from the Crown (38%), levies on producers (55%), and regional council ratepayers (6%). Most of the work targets possums and ferrets, but includes some populations of feral pigs and deer. In 2001/02, the AHB funded wild animal control over 3 897 500 ha where it had previously controlled wild animals, and over 682 100 ha of new areas (AHB 2002), almost double the area treated in 1997/98 (Coleman & Livingstone 2000). The strategy used by the AHB is to reduce possum populations below a target density based on an epidemiological threshold at which the disease should not be sustained (Barlow 2000), and hold the population below this density until the disease dies out. This strategy has halved the incidence of Tb in the sympatric domestic herds since 1998, but to date has not always slowed the extension of areas with infected wild animals.

Table 3 Summary of mammal species that meet the Regional Pest Management Strategy (RPMS) requirements, those actually controlled, and those noted but that do not meet the RPMS requirements by regional and district councils and an estimated annual cost of mammal control. Most costs are taken from the 2001/02 year and do not include funding to councils from the Animal Health Board for Tb vector control.

Regional Council	Species under the RPMS	Species listed but not in the RPMS	Annual RPMS budget $
Northland	Possum, rabbit, deer	Mustelids, cat, rats, goat, wallabies	1,861,800
Auckland	Possum, goat, deer	Mustelids, wallabies, rabbits	1,261,330
Waikato	Possum, goat, mustelids	Dama wallaby, rabbits	897,400
Bay of Plenty	Possum, dama wallaby, cats, rabbit, goat, rats, mustelids		1,219,000
Gisborne DC	Possum, rabbit/hare, goat, feral cattle	Mustelids, cats, wallabies, chinchilla	467,000
Taranaki	Possum, rabbit	Goat, hare, wallabies, cats, mustelids, deer, pigs	1,139,500
Hawke's Bay	Possum, rabbit/hare, goat		1,473,000
Manawatu/Wanganui	Possum, rabbit	Mustelids, dama wallaby, goats, pigs, deer, hares	1,165,700
Wellington	Possum, rabbit	Goats, mustelids	1,496,600
Marlborough DC	Rabbit, possum		174,000
West Coast			Nil
Canterbury	Rabbit, Bennett's wallaby	Deer, goats, mustelids	1,500,000
Otago	Rabbit, hare, chinchilla		2,633,000
Southland	Rabbit, cat, possum, deer, goats, pigs, mustelids, chinchilla, Bengal cats		1,102,000
Total budget			c. 16.2 million

MANAGEMENT BY MAORI, PRIVATE, AND OTHER LAND MANAGERS

Private landowners with mammals affecting their production values conduct widespread control operations, mostly against rabbits (Parkes 1995) and vectors of bovine Tb (AHB 2002). Their expenditure is unknown but substantial (Hackwell & Bertram 1999), as was shown by the savings made possible in just one area when conventional control of one pest was no longer needed. The effect of rabbit haemorrhagic disease on rabbits in the Mackenzie Basin has saved farmers about $3.5 million on conventional control costs since 1997 (J. Parkes unpubl. data). Costs to manage commensal rodents on private property are unknown.

Maori tribes and trusts are major landowners of both farmland and exotic forests, where they have the same concerns with introduced mammals as other landowners. In indigenous forests, Maori are increasingly interested in pest control to restore components of the original environment that are of particular cultural significance. For example, Ngati Hine are controlling predators at Motatau in Northland primarily to protect keruru (*Hemiphaga novaeseelandiae*) (Prime et al. 1999), and the Lake Waikaremoana Hapu Restoration Trust is controlling stoats to protect kiwi populations in a 1500 ha area in the southern Urewera (J. Waiwai pers. comm.). The owners of Tinui Island (95 ha) are currently planning the restoration of their island in the Marlborough Sounds, which will entail eradicating Norway rats, kiore, and feral pigs (Anon. 1995).

Private individuals and groups are also taking an increasing role in biodiversity protection, which, as for the state agencies, largely entails mammal pest control. There are two paradigms under which these groups operate: ongoing control of all or the worst pests, or local eradication maintained by exclusion fences.

As an example of the first, the Maurice White Trust manages the 1000-ha private Hinewai/Otanerito Reserve on Banks Peninsula, where the primary focus is regional biodiversity protection. Here the domestic animals have been removed, feral goats eradicated, and possums and stoats regularly trapped (Wilson 2002). As an example of the second, the Karori Reserve Trust manages a fenced area of 250 ha near Wellington from which all mammals (apart from mice) have been eradicated, and where the primary objective is educational. This approach is being emulated or planned by private groups in several places around New Zealand, e.g., Maungatautari (3200 ha) and on several peninsulas in the Marlborough Sounds.

One of the largest multi-species sustained control operations is conducted by the New Zealand Army on its 63 000-ha training area at Waiouru. Here, rabbits, possums, hares, and feral horses are subjected to annual control, and red and sika deer and feral pigs are subjected to recreational hunting with the multiple goals of maintaining the open grassland landscapes suitable for the army to train in and to protect indigenous biodiversity (Parkes & Warburton 2002).

MANAGING MAMMALS AS ASSETS

Almost all the mammal species deliberately released into the wild in New Zealand were brought in as assets for sport, food, or fur, and many New Zealanders still regard wild or feral mammals in this light.

Recreational hunting

Recreational hunting of mammals in New Zealand is largely unmanaged, compared with that in Europe or North America. There are few bag limits, one-sex only rules, or hunting seasons, and hunters require only the permission of the landowner (usually DOC) to gain access to their prey. Special areas (recreational hunting areas) were established in the 1980s where commercial hunting was restricted, but most special management of these areas for recreational hunting purposes is no longer maintained. The exceptions are the areas set aside for the fallow deer herds in the Blue Mountains and Caples Valley in the South Island and in Woodhill Forest near Auckland, and for sambar deer in the Manawatu where hunting organisations manage the herds. These herds do have some management, generally restricted access or restricted harvests, to improve hunting opportunities (Nugent et al. 2001a).

The only national survey of recreational hunters was conducted in 1988 (Nugent 1992). He estimated that c. 150 000 people were involved in hunting, at an annual expenditure of $100 million, and shot c. 5.8 million mammals that year, mostly possums and rabbits.

Pest managers see the harvests of recreational hunters as a potentially useful control method. This is generally true in that total recreational harvests are large compared with commercial or official control harvests (Nugent 1992), and so keep mammal populations below carrying capacity to a greater or lesser extent. However, the extent depends on the species and place (e.g., hunters do hold thar numbers at the low densities achieved by past commercial exploitation, but only in places where they have easy access; Forsyth 1999), and on the density of animals required to benefit conservation values. Recreational hunters rarely maintain densities of their prey low enough to protect particularly vulnerable species (Choquenot & Parkes 2001; Nugent et al. 2001b).

Commercial exploitation

Commercial harvesting of red deer for game meat began in the late 1950s. Annual harvests of over 100 000 animals were taken during the early 1970s (Challies 1990), but these have fallen to between 10 000 and 30 000 per year since about 1980, with the annual variation being explained almost entirely ($r^2 = 0.89$) by the price of venison (Parkes in press; Nugent et al. 2001a). Perhaps 70 000 live animals were caught in the 1980s for stocking deer farms, but this harvest has now ceased as farm-bred stock fill the need for new animals and because of risks that wild deer might introduce bovine Tb into the farmed deer herds. Government used to limit the number of helicopter operators permitted to hunt deer, largely to sustain the industry, while maximising the harvest (Challies 1991), even though Government could not influence the price of venison that had determined the size of the harvest.

Substantial numbers of feral pigs were killed and sold each year, mostly on the black market (McIlroy 2001), and there are small harvests of chamois and thar for game meat (Nugent et al. 2001a; Parkes in press). Commercial harvests of these species stopped in 2002 because of the increased costs to inspect carcasses of wild game destined for export. These costs were imposed on exporters after animals were (possibly) taken illegally from areas where toxic baits had been distributed for possums. The harvest of wild deer has resumed, but with restrictions on who the game factories will buy from, plus the extra costs of testing for residues. It remains to be seen how this will affect the economics of the industry.

Parkes (in press) has reviewed the commercial exploitation of red deer, Himalayan thar, and possums, and discussed under what circumstances the harvesters might be satisfied and still provide some benefits for those who see the animal as a pest—are there win-win solutions? Commercial harvesting of deer is biologically sustainable because the forests provide a refuge for deer that survive and remain difficult to access by the helicopter-based hunters. The conservation benefits of the venison harvest are very large in the open grassland habitats of the alpine zones once favoured by deer, but are limited in the forests (Nugent et al. 2001b). Commercial harvesting of thar decimated the population, and provided significant conservation benefits (Parkes & Thomson 2001), but was not politically sustainable (Hughey & Parkes 1997). Capturing these conservation benefits at minimal cost to DOC has been the focus of the current thar control plan (DOC 1993). Commercial harvests of possums for fur are, like those for deer, driven by price, and are sustainable. However, they provide no extensive reduction in possum numbers and so little conservation benefit—a win-neutral solution.

INTEGRATING NATIONAL STRATEGIES TO MANAGE MAMMALS

Integrating management between agencies

Responsibility for the management of pests and weeds (from pre-border and border management to management of spread of current pests to *in situ* control of pests) is spread across many agencies and individuals with differing mandates and purposes. A national Biosecurity Strategy and a set of Cabinet Minutes (Anon. 2003) “instructs” the government agencies involved with pest and weed management to treat the whole issue of pests and weeds in a more coordinated way, and “directs” attention to management, monitoring, and research gaps.

Two primary considerations face all agencies wanting to manage mammalian pests: no one has enough money to do everything, and goals or mandates differ. Constraints on funding means actions have to be prioritised, and the differing goals of the various agencies managing mammals means different priorities. It makes no sense to force agencies to change their goals, which determine what mammals they manage at what places. However, where the target pests and places coincide (as they sometimes do for possum control for conservation and Tb vector control), agencies have some opportunity to integrate their actions—but only to some extent. Complete operational integration is not optimal, because each agency has different strategic needs. The Animal Health Board aims NOT to sustain its control, but rather to reduce possums, mostly along bush-pasture margins, to a target density index, which they will maintain by frequent control until they have eradicated Tb from the area. Then they will stop. In contrast, DOC might aim for higher or lower target possum densities, and apply frequent or infrequent control depending on the resource it is trying to protect, and it is committed to sustained management in perpetuity.

Regional council management of mammals for biodiversity or environmental protection goals is more suitable for integration with the Department's priorities. Parkes (2000) has suggested some options for councils to add value to Central Government's mammal control. Regional councils could: (a) Set regional priorities for biodiversity or public education values and manage mammals in areas not already managed by other agencies. They could do this either intensively as regional mainland islands or by single-species pest control, e.g., as in Regional Parks managed by the Auckland Regional Council. (b) Select core areas for intensive management within the broader-scale management conducted by other agencies. (c) Take over pest control in the areas that the AHB will abandon if they succeed in eradicating Tb, e.g., as proposed for possum and ferret control on Banks Peninsula managed by Environment Canterbury.

Integrating management for biodiversity goals

Government's biodiversity policies, the Biodiversity Strategy (Anon. 2000) and Bio-What? (Kneebone 2000) feature introduced mammals as a major cause of the decline of indigenous biodiversity, and they stress the need for an integrated approach to their management. The Biosecurity Strategy is intended to encourage integration between agencies, but there is also the intention that each agency also look at how it might provide better results by managing whole systems. This is especially so for managers with biodiversity goals as they consider how to move from species protection aims, to biodiversity and ecosystem management aims (Saunders & Norton 2001).

The different frameworks DOC uses to manage mammals have been developed or inherited somewhat in isolation from one another. They have, or have had, discrete funding trails whose start dates did not coincide; some were managed by different sections of the Department; they have different goals and so often focus on different pests; and they have had different systems to prioritise where the management is best taken. Integration between the management of mammal species has been by coincidence—high priority sites for one pest species are often not high priority for another—and the results, both at places and nationally, have been sub-optimal. For example, it would have made sense to prioritise the national feral goat and possum control plans to take simultaneous account of goats' long-term effect on forest regeneration and possums' medium-term effect on forest canopies, and deal with both species where they are sympatric at high priority places. However, decisions on where to control goats were made in 1990 and those on possums in 1994, so at least goat control prioritisation did not consider possum control possibilities. Similarly, the plan to manage the impacts of Himalayan thar in the Southern Alps is sub-optimal without simultaneous management of some of the introduced herbivores that are sympatric with them (Forsyth et al. 2000).

The Department is currently developing a system, the Natural Heritage Management System (NHMS), which will integrate these frameworks. The aim of the system is to ensure a full range of natural habitats and ecosystems with their indigenous species are protected, and it will do this by providing a set of tools. With respect to the management of introduced mammals, these tools include systems to map and classify land (e.g., Leathwick et al. 2000), "natural hertitage assets" (= places with conservation values), and threats such as mammal species distributions and densities (e.g., Fraser et al. 2000). The Department will also map and record what management was done, at what cost, and measure what was achieved, in terms of the changes both to the threat managed and to condition of the conservation values present.

Part of the system most relevant to management of mammals, called "Measuring Conservation Achievement" (MCA) will allocate funding to and measure the results of management of natural heritage assets (DOC 2001b; Stephens et al. 2002). In summary, the allocation system scores the "natural character" of a place by assessing the degree of modification from pests and weeds, human disturbance, and fragmentation, and then attempts to predict the status of the place with and without management weighted by the urgency of the problem and the feasibility that the proposed management will succeed to give a "project merit" score. Competing projects of equal value are then sorted by their cost.

Management of mammals illustrates some of the issues to be resolved if the MCA part of NHMS is to achieve its potential. First, it will not be easy to predict the consequences to the natural character of a place of reducing the densities of single or several mammal pest species. Currently, the approach has been to use simple numerical responses to compare changes in the density of one pest species with changes in the biomass, numbers, or quality of some indicators of the conservation values (Stephens et al. 2002), and to extrapolate estimates of pest densities across unmonitored sites using a regression of measured densities against a range of spatial environmental parameters (e.g., for possums; Fraser et al. 2002). Apart from the absence of these numerical (and functional) relationships for many pest-resource impacts, damage functions (Hone 1994) alone are often poor predictors of responses to management at different places or times (Choquenot & Parkes 2001).

Second, the system will potentially allow rankings of projects to control mammals, either singly or in combination, in this place or that place. The assumption is that picking the best of the candidate projects will give optimal national outcomes. However, this may not be so unless the candidate projects are nominated in some way to take account of their spatial relationships. For example, DOC's national annual expenditure on management of mammals, and the associated monitoring, is c. $40 million. If DOC allocated all $40 million to managing mammal pests under the mainland island strategy, and maintained the current level of monitoring at these places, it could afford to sustain effective control on c. 1500 km^2 (c. 2% of the conservation estate). Could any 2% of these lands be selected that would maximise biodiversity and protect everything we wanted to protect, and what would we lose by not managing the other 98%? In contrast, DOC could allocate all of the $40 million to controlling one or two major and manageable pests, such as possums, and so treat c. 75% of the estate. It would be easier to select the areas to be treated, but what would we lose by not managing all the other threats on the estate?

Although no one is suggesting one or the other of the above strategies be followed, clearly some combination of broadscale management to maximise the national benefits of dealing with critical AND manageable species, and intensive management of multiple pests to maximise the local benefits, should give the best national results—but how should we balance the benefits or avoid the opportunity costs implicit in both strategies?

For example, the approach taken in the northern Urewera mainland island, i.e., core areas (originally picked for kokako protection goals) within much larger areas of extensively managed habitat, suggest one strategy to better integrate the management of mammals. In this strategy, management is most intensive (most pest species controlled to the maximum extent possible) in the core, and then less intensive control (fewer species and/or less frequently) in zones around the core to produce different levels of *in situ* benefits.

RESEARCH ON MAMMALS IN NEW ZEALAND

In 2000/01, the latest year for which we have information, $14 million was spent on research on introduced wild and feral mammals in New Zealand. Most was spent on research on possums (71% of the total budget) and control technologies (61% of the total budget), especially those involving the new technologies aiming to control reproduction or to vaccinate mammals that are disease vectors (Table 4). There are national review processes on particular mammal species or problems, such as the National Science Strategy for Possums and Bovine Tuberculosis (Anon. 2001) and DOC's stoat research fund (DOC 2000b), that influence or direct funding priorities, but no overall national system at this level to consider how research might be partitioned between mammal species or between the types of research, e.g., the categories we have used in Table 4.

Research on control techniques

In the past, managers in New Zealand have tended to focus on getting their tactics right, either to improve efficiency or reduce risks to other species (e.g., see the substantial improvements in efficiency and safety in possum control that have been achieved over the last 20 years; Morgan & Hickling 2000; Spurr 2000).

For species such as stoats and rodents, the techniques available for sustained control (largely trapping or ground-based poisoning) are expensive, difficult to apply frequently over large areas, and have had animal welfare problems. Therefore, a large part of current research has been invested in trying to find new control tools that are more efficient and humane (Parkes & Murphy in press). For other species such as possums, managers already have a large variety of effective and efficient control methods (aerial and ground poison baiting, and trapping) but the best methods (poisoning) are potentially at risk due to public opposition. In this case, most of the tactical research is directed at finding alternative techniques (e.g., reproductive control technologies—although they too have social risks especially when they involve genetic modification), or making the current techniques more environmentally safe or humane.

Research on control strategies

For many pest problems the main gains in efficiency from using conventional control are now to be made in finding optimal strategies rather than new control methods. At their simplest, the "press" versus "pulse" strategies (Hickling 1995) are usually applied to pests with chronic versus acute impacts, respectively (Parkes 1993b). However, optimal decisions on which species to control, where, and when to intervene are key management questions that require answers, given that New Zealanders cannot afford to manage all mammals everywhere all the time.

Diagnosing which mammals are critical threats to the resources to be protected is not always simple (e.g., Caughley 1994), especially in New Zealand ecosystems where impacts may fluctuate as extrinsic factors, such as mast fruiting, alter the pest-resource interactions (Dilks et al. 2003). Understanding the negative consequences that may arise when only part of the suite of mammals present is controlled is beginning to receive more research attention in New Zealand (e.g., DOC undated). The biological problem is that we are only just beginning to understand the trophic cascades that are sometimes unleashed when one or more pest species are managed (e.g., Dilks et al. 2003). For example, reduction in rabbit numbers, the dominant wild herbivore in semi-arid grassland habitats, had led to an increase in hare and possum numbers (with changing risks to native plants and from bovine Tb) (Norbury et al. 2002), but a decrease in ferret numbers (with uncertain changes to the risks to native prey as per capita impacts increase (Murphy et al. unpubl. data), and changing risks from bovine Tb due to the way possums and ferrets interact as vectors (Caley 1998).

Deciding where to manage mammals is also an active research topic, both at the national scale for individual mammal species (DOC 1993, 1994, 1998) and within the developing asset management process (DOC 2001b), and at a local scale. In the latter case, for example, the use of mainland islands as core areas that export benefits to areas receiving less or no management requires bioeconomic and ecological research on core sizes sufficient to preserve species *in situ* and sustain populations outside the core, even if only by dispersal.

Deciding when and how intensively to intervene remains a major area of management uncertainty in

Table 4 Research investment in 2000/01 (in \$NZ × 1000) on introduced mammals by species and by research category. Data for later years have not been collated but would not alter the general trends.

Research category	Possum	Stoat	Rodents	Ferret	Rabbit	Deer	Birds	Pig	Goat	Cat	Others	Total	% of total
Impacts	120	50	30	114	45	25	0	75	0	0	14	473	3
Ecology	258	440	429	0	0	150	0	0	0	10	0	1287	9
Epidemiology	700	0	0	300	250	60	0	0	0	0	0	1310	10
Conventional tactics	488	377	50	416	0	75	90	0	60	30	0	1586	12
Biotechnology tactics	6143	288	300	0	0	0	0	0	0	0	2	6733	49
Strategies	1252	47	0	25	0	0	0	0	0	0	0	1324	10
Consequences	237	100	130	0	50	0	0	0	0	0	0	517	3
Monitoring techniques	451	50	29	0	0	0	0	0	0	0	0	530	4
Total research	9649	1352	968	855	345	310	90	75	60	40	16	13 760	
% of total research	71	8.5	7	6	3	2	0.6	0.5	0.4	0.3	0.1		
Control budget 2002/03	60 000	2000	?	10 000	1000	100	?	?	6300	?	?		

many control operations in New Zealand. There is a substantial body of theory to underpin such decisions (e.g., Caughley & Sinclair 1994; Hone 1994), and a substantial amount of empirical practice in pest management in New Zealand. However, few New Zealand pest control operations have been conducted and monitored in such a way as to inform (or be informed by) this theory (Choquenot & Parkes 2001). This lack is changing as managers recognise the scale of the problems they face and the need to be efficient (Innes et al. 1999), and as they start to consider how to manage multiple threats at different trophic levels (e.g., Oksanen & Oksanen 2000), or by using food web approaches (e.g., Pimm 1982), or to measure benefits at the ecosystem level (e.g., Wardle et al. 2001).

Unless the pest can be eradicated, managers are obliged to achieve target pest densities at which the impact is acceptable (at its simplest, viable populations of the affected species), or to measure the condition of the resource directly—some do only the first, others only the second, and others measure both pest and resource. We argue that both need to be considered. Keeping pest densities well below the threshold incurs opportunity costs, which are not recognised if only the resource is monitored. Failing to keep them below these densities compromises the resource protection goals, which are not recognised if only the pest is monitored. Measuring both, at least in some subset of management operations, will improve understanding of the pest-resource relationships and allow unexpected results to be identified and perhaps even interpreted in a way to improve management practices.

There are several ways of arriving at these relationships. Managers can "take their best shot", monitor the effects on pest and resource, and then either reduce or increase the effort according to the outcomes (e.g., Innes et al. 1999). This is an inefficient way of learning by doing compared with more formal adaptive management approaches, but is often the only choice in the absence of any other information. It generally provides little explanation of how the pest-resource-management interactions work, and so its predictions are often site- and state-specific. Managers with some knowledge about how the system works can predict outcomes of management, and the best way to do this is to use some form of model, either conceptual, e.g., as used to describe the relative effects of red deer and possums in a forest (Nugent et al. 2001b), or more formally in a deterministic model that predicts outcome without explaining mechanisms (e.g., Barlow 2000 for Tb epidemiology in possums), or a mechanistic model that purports to explain how the interactions work (e.g., Choquenot & Ruscoe (2000) for beech mast-mouse systems, or Bayliss & Choquenot (2002) for how food regulates possum densities).

Choquenot & Parkes (2001) have reviewed three types of pest-resource models, damage functions, density-dependent predator-prey models, and interactive models, to see how useful they are to help managers set threshold densities for vertebrate pest control in New Zealand. Models using the damage function, i.e., how the change in resource abundance changes with pest abundance, are useful in setting pest targets in a short-term, tactical way, but cannot be used to predict outcomes when the pest-resource interaction operates in both directions, or when extrinsic factors influence the resource, or to compare alternative control strategies. Models based on density-dependent predator-prey systems (e.g., Bayliss & Choquenot 2002) are useful in setting targets for pest control, and because they capture the dynamics of the control on pest abundance and of pests on the stability of resources, they allow longer-term, strategic issues to be predicted—which cannot be achieved by simple damage functions. However, such models do not capture the usually pervasive effects of density-independent environmental factors affecting the pest-resource system. Interactive models (Caughley 1977) have the same advantages as the predator-prey models but also allow the effect of density independent perturbations in the system to be explicitly included. Where the reduction in pest numbers is itself independent of pest density, the effect of management options such as the frequency of control can be predicted.

Research by management

A solution to these complexities faced by managers is to use the approach of a formal adaptive management experiment (Walters 1986). This approach is often recommended in national policies on mammalian management in New Zealand (e.g., Anon. 2000), but is rarely carried out—other than at a trial-and-error level. The first attempt to use adaptive management was in an effort to identify the critical threats to kokako (*Callaeas cinerea wilsoni*) (Innes et al. 1999). The rarity of the bird meant that the niceties of experimental design were restricted and most information came from the monitoring of unreplicated changes in management (not always driven by the needs of the experiment). Nevertheless, the process has provided considerable tactical insights into how to protect kokako, and suggested ways (generally by decreasing the frequency of possum control and by identifying which mammals are worst) to improve efficiency. This has allowed managers to begin to develop predictive models that will allow better predictions and tests of different management options (Basse et al. 2003).

Possum management to protect forest conservation values is a widespread activity, and in contrast to the kokako case, allows a range of management options to be explored by an adaptive management experiment. The outcomes of this possum management are uncertain (Norton 2000; Veltman 2000). This uncertainty is reflected in the variable frequency with which DOC managers apply control (annual to once every 7 years), and in the monitoring cues they use to trigger the control (a set timetable, possum densities, or resource conditions) even when the goals of the control are similar. A large adaptive management experiment is underway to test the costs and eventually the benefits of applying control at different frequencies using set frequencies, possum densities, or resource conditions as the cue to trigger control (Choquenot & Parkes 2000; Parkes et al. unpubl. data).

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Appendix 1 Introduced mammal species in New Zealand with a summary of their population size, range, and management. Information is taken from King (1990, 2001) unless noted in the table. + = minor control effort in part of the species' range, ++ = control effort of a large part of a limited species range, +++ = national control effort, ++++ = substantial national control effort, 0 = eradication on some islands planned or underway. No symbol means the species is not targeted as a pest, but may be harvested by hunters. DOC, Department of Conservation; AHB, Animal Health Board; RCs, Regional Conservancies.

Species		Range (km^2)	Estimated population size	General trends in numbers	Relative amount of pest control by main agencies		
					DOC	AHB	RCs
1 Dama wallaby	*Macropus eugenii*	1695	>100 000	Stable	++		++
2 Bennett's wallaby	*Macropus rufogriseus*	1700	<50 000	Increasing			++
3 Parma wallaby	*Macropus parma*	23	<10 000	Stable	0		
4 Rock wallaby	*Petrogale penicillata*	23	for all 3 on	Stable	0		
5 Swamp wallaby	*Wallabia bicolor*	23	Kawau I.	Stable	0		
6 Possum	*Trichosurus vulpecula*	250 000	>50 million	Decreasing	++++	++++	+++
7 Hedgehog	*Erinaceus europaeus*	100 000	>10 million	Stable	+		
8 Rabbit	*Oryctolagus cuniculus*	150 000	<10 million	Stable	+		++
9 Hare	*Lepus europaeus*	150 000	<5 million	Increasing	+		+
10 Kiore	*Rattus exulans*	2000	?	Stable	0		
11 Norway rat	*Rattus norvegicus*	200 000	?	?	+0		
12 Ship rat	*Rattus rattus*	200 000	<100 million	Variable	++0		
13 Mouse	*Mus musculus*	200 000	>100 million	Variable	+0		
14 Stoat	*Mustela erminea*	200 000	<200 000	Variable	+++		+
15 Weasel	*Mustela nivalis*	100 000	?	Variable	+		
16 Ferret	*Mustela furo*	100 000	<100 000	Decreasing	++	+++	++
17 Feral cat	*Felis catus*	200 000	<50 000	Variable	+		+
18 Feral horse	*Equus caballus*	500	<1000	Stable	+		
19 Feral pig	*Sus scrofa*	93 000	>100 000	Variable	+	+	
20 Feral cattle	*Bos taurus*	2000	<1000	Decreasing			
21 Feral goat	*Capra hircus*	39 500	<400 000	Decreasing	+++		+
22 Feral sheep	*Ovis aries*	2000	<1000	Stable			
23 Chamois	*Rupicapra rupicapra*	49 800	<50 000	Increasing			
24 Himalayan thar	*Hemitragus jemlahicus*	7000	<10 000	Stable	++		
25 Red deer	*Cervus elaphus*	120 600	<250 000	Increasing	+	+	
26 Wapiti	*Cervus e. nelsoni*	1800	<5000 (all hybrids?)	Decreasing			
27 Sika deer	*Cervus nippon*	6000	<50 000	Stable	+		
28 Sambar deer	*Cervus unicolor*	5346	<5000 ?	Stable			
29 Rusa deer	*Cervus timorensis*	469	<1000	Stable			
30 Fallow deer	*Dama dama*	4995	<10 000	Stable	+		
31 Whitetail deer	*Odocoileus virginianus*	2000	<20 000	Stable			
32 Moose[1]	*Alces alces*	? 0	<10 ?	?			

[1]The presence of a relict moose population is yet to be confirmed (Tustin 1998).