13th Australasian Vertebrate Pest Conference

Keven Drev

Proceedings

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Hosted by Manaaki Whenua – Landcare Research
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INTRODUCTION

13th Australasian Vertebrate Pest Conference
The Museum of New Zealand (Te Papa), Wellington, New Zealand
2-6 May, 2005

This volume is a pre-conference compilation of working papers. Papers were selected on submission of short abstracts, and then authors were offered the opportunity to submit papers or extended abstracts for inclusion in this proceeding. The contents have not been peer-reviewed by the conference organisers but have been lightly edited for layout, style and format. Otherwise they are printed as received from the authors.

Copies of the Proceedings are available from the Landcare Research web site:

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The Australasian Vertebrate Pest Conference is primarily sponsored by the Vertebrate Pest Committee (VPC) and approved by its parent body, the Australia/New Zealand Natural Resources Management Ministerial Council. The 13th conference was organised and hosted by Landcare Research.

The 2005 Conference is the 13th in the series and the first in New Zealand. Previous conferences have been held in Perth (1957), Hobart (1960), Canberra (1964), Melbourne (1968), Canberra (1973), Canberra (1978), Dubbo (1983), Coolangatta (1987), Adelaide (1991), Hobart (1995), Bunbury (1998) and Melbourne (2001).

Programme Committee:

John Parkes (Chair)
Landcare Research, Lincoln, New Zealand

Mick Statham
Tasmanian Institute of Agricultural Research, Tasmania

Glenn Edwards
Parks and Wildlife Commission, Alice Springs, NT

Conference Organisers:

John Parkes, Wendy Weller and Ben Reddiex

Conference Programme

Monday 2 May

0900 – 0940	**Registration and morning tea**
0940 – 1000	**Welcome by Tangata Whenua o Te Papa and the Hon. Damien O'Connor (Minister of Agriculture)**

Theme 1: Policy, planning, strategies and community programmes
(Chair: Phil Cowan)

1000 – 1020	**CRUMP, Don:** The legislative framework for pest management in New Zealand
1020 – 1040	**HARRISON, Andrew:** Consolidating leadership and coordination for pest management in New Zealand – changes and directions
1040 – 1100	**MAHON, Paul:** Strategic control of exotic vertebrate pests for the conservation of biodiversity: Threat Abatement Planning in New South Wales, Australia
1100 – 1120	**EDWARDS, Glenn:** Managing feral camels in Australia
1120 – 1140	**MURRAY, Andrew; Rob Poore; Gordon Friend and Nick Dexter:** The Southern Ark project
1140 – 1200	**SAUNDERS, Glen; Michelle Walter; Lynette McLeod; Peter West and Steve McLeod:** Fox management and production outcomes in NSW –benefits and future directions
1200 – 1300	**Lunch**

(Chair: Graham Nugent)

1300 – 1320	**KEITT, Brad; Aguirre, A.; Howald, G.; Croll, D.; Tershy, B.:** Protecting biodiversity by conserving islands: an integrated regional approach
1320 – 1340	**CROWELL, Michelle and Keith Broome:** Taming HSNO for pest managers
1340 – 1400	**BULLER, Chris; Helen Cathles; David Dall and Rob Hunt:** 'Nil tenure' approach to invasive animal management in Australia – extending the paradigm
1400 – 1420	**McGEARY, Julie:** Enhanced fox management program – Phase 2 Baseline survey
1420 – 1440	**RIETHMULLER, Jason; Steve McPhee; Scott McLean; Dave Ritchie; John Matthews; Dave Blackie; Ian Brown; and Gary Box:** Facilitating the management of foxes on private land: Are landholders interested?

1440 – 1500	**SCANLAN, Joe and Julianne Farrell:** A preliminary mouse abundance prediction model for the central Queensland grain producing region
1500 –1520	**Afternoon tea**
1520 – 1540	**WALSH, Andrew M. and Tim J. Wardlaw:** An integrated pest management strategy to manage mammal browsing on State Forest in Tasmania

Theme 2: Pest fish
(Chair: Geoff Hicks)

1540 – 1600	**OSBORNE, Matt; Nicholas Ling and Brendan Hicks:** Abundance and movement of koi carp (*Cyprinus carpio haematopterus*) in the lower Waikato River system
1600 – 1620	**GILLIGAN, Dean and Leanne Faulks:** Assessing carp biology in NSW: The first step in a successful implementation strategy for daughterless carp
1620 –1640	**GREWE, Peter; Natasha Botwright; Janina Beyer; Jawahar Patil and Ron Thresher:** Sex specific apoptosis for achieving daughterless fish
1640 – 1700	**BROWN, Paul:** Simulation of carp (*Cyprinus carpio*) population and control dynamics in the Murray-Darling basin, Australia
1700 – 1720	**HAYNES, Gwilym; Peter Crewe, Dean Gilligan and Frank Nicholas:** Investigation into population genetics of common carp (*Cyprinus carpio*) in the Murray-Darling Basin of Australia

1730
Drinks and finger food

Tuesday 3 May

Theme 3: Monitoring and detecting pests
(Chair: Elaine Murphy)

0900 – 0920	**FISHER, Penny and Louis Tremblay:** A practical bait marker for brushtail possums – whisker marking by rhodamine B
0920 – 0940	**ENGEMAN, Richard M.; Bernice Constantin; Stephanie A. Shwiff; Henry T. Smith and John Woolard:** Research to support and enhance feral swine removal efforts
0940 – 1000	**EFFORD, Murray and Grant Norbury:** Ferret population assessment: progress and challenges
1000 –1020	**Morning tea**
1020 –1040	**Fraser, Wayne and Jim COLEMAN:** Bovine Tb persistence in low-density possum populations – the patchiness problem
1040 – 1100	**VINE, Samantha; Mathew Crowther; Chris Dickman; Steve Lapidge; Nick Mooney and Anthony English:** Detection of the red fox (*Vulpes vulpes*) at low population density
1100 – 1120	**GLEESON, Dianne M.; Robyn Howitt and David Morgan:** Improving the accuracy of DNA-based methods for estimating population parameters of vertebrate pests
1120 – 1140	**NUGENT, Graham; Jackie Whitford; Mary McEwan:** DNA-based mark-recapture of wild deer: using fawns to capture their mothers
1140 – 1200	**FELDMAN, Mark:** The red-eared slider turtles (*Trachemys scripta elegans*) in New Zealand
1200 –1300	**Lunch**

(Chair: Grant Norbury)

1300 – 1320	**O'CONNOR, Cheryl; Grant Morriss and Elaine Murphy:** Toxic bait avoidance by mice
1320 – 1340	**KING, Kim; R.D. Martin; R.M. McDonald; G. Tempero; A. Dekrout; S. Holmes and M. Stirnemann:** Automated monitoring for detection of small mammal pests
1340 – 1400	**ROLLINS, Lee Ann; Andrew P. Woolnough; William B. Sherwin and Ron Sinclair:** The origin of the species: using genetics in pest management

Theme 4: Pest control tools

1400 –1420	**SINCLAIR, Ron; Greg Mutze:** Bait delivery of rabbit haemorrhagic disease virus (RHDV) to improve the effectiveness of RHD outbreaks on rabbit populations

1420 – 1440	**JAMES, John; Jarrod Coote; Brad Westhead; Megan Waayers; Kelly Backhouse and Steve McPhee:** The effectiveness of broadscale warren ripping after the occurrence of rabbit haemorrhagic disease in central Victoria
1440 – 1500	**SUTHERLAND, Don:** Burrowing rodent control using bio-degradable foam injected into burrows
1500 –1520	**Afternoon tea**

(Chair: Ben Reddiex)

1520 – 1540	**DUCKWORTH, Janine; Xianlan Cui; Frank Molinia; Werner Lubitz; Petra Walcher and Phil Cowan:** Fertility control vaccines for brushtail possum management in New Zealand – targets and delivery systems
1540 – 1600	**COWAN, Phil; Mark Ralston; and Warwick Grant:** Parasites – possibilities for control of common brushtail possums in New Zealand
1600 – 1620	**Bax, Nicholas and Ronald THRESHER:** Genetic control options
1620 – 1640	**O'LEARY, Sean; Megan L. Lloyd; Geoffrey R. Shellam and Simon Maddocks:** Mechanisms leading to permanent infertility in mice following immunisation with recombinant murine cytomegalovirus expressing murine zona pellucida 3
1640 – 1700	**SMITH, Michelle; Steven Lapidge; Brendan Cowled; and Linton Staples:** The design and development of PIGOUT® – a target-specific feral pig bait

Wednesday 4 May

Theme 4 continued: Control tools and their consequences
(Chair: Cheryl O'Connor)

0900 – 0920	**DALL, David; Steven Lapidge and Rob Hunt:** Increasing the efficiency of control of canid pests in Australia
0920 – 1940	**MURPHY, Elaine; Andy Lavrent; Duncan MacMorran; Lloyd Robbins and Philip Ross:** Development of a humane toxin for the control of introduced mammalian predators in New Zealand
1940 – 1000	**GENTLE, Matt; Peter Elsworth and Bob Parker:** Sodium fluoroacetate residue in feral pig (*Sus scrofa*) carcasses – is it a significant secondary poisoning hazard?
1000 – 1020	**Morning tea**
1020 –1040	**MOONEY, Nick; C. Emms and T.E. Bloomfield:** Minimising the effects of 1080 fox baiting on non-target species and vice versa while maximising the risks to foxes in Tasmania

Theme 5: Eradication and border control
(Chair: John Parkes)

1040 – 1100	**Mooney, Nick; C. Emms and T.E. BLOOMFIELD:** Developing a strategic fox eradication program in a sceptical social environment
1100 – 1120	**BROOME, Keith; Pam Cromarty; and Andy Cox:** Rat eradication – how to get it right without a recipe?
1120 – 1140	**Galvan, Juan Pablo; Gregg Howald; Araceli Samaniego; Brad Keitt; James RUSSELL; Michel Pascal; Michael Browne; Keith Broome; John Parkes and Bernie Tershy:** A review of commensal rodent eradication on islands
1140– 1200	**MORGAN, Dave; Graham Nugent; and Bruce Warburton:** Local elimination of possum populations – feasibility and benefits
1200 – 1300	**Lunch**
1300 – 1320	**DONLAN, C. Josh; Karl Campbell; Victor Carrion; Christian Lavoie and Felipe Cruz:** Conservation action in the Galapagos: large-scale introduced herbivore eradications
1320 – 1340	**O'KEEFFE, Scott:** Investing in conjecture: eradicating the red-eared slider in Queensland
1340 – 1400	**KIRKWOOD, Roger; Peter Dann and Richard Dakin:** Protecting penguins from foxes on Phillip Island
1400 – 1420	**AGUIRRE, Alfonso; Francisco Casillas; Cesar Garcia; Bradford Keitt; Luciana Luna; Marlenne Rodriguez; Bernie Tershy and Bill Wood:** Protecting endemic plant species by removing feral goats (*Capra hircus*) from Guadalupe Island, Mexico

1440 – 1500	**WOOLNOUGH, Andrew P.; Marion C. Massam; Ron L. Payne and Greg S. Pickles:** Out on the border: keeping starlings out of Western Australia
1500 – 1520	**Afternoon tea**
1520 – 1540	**BOMFORD, Mary:** Risk assessment for the import and keeping of exotic vertebrates

Theme 6: Animal welfare
(Chair: Bruce Warburton)

1540 – 1600	**Ngaio J. Beausoliel; David J. MELLOR; and Kevin J. Stafford:** Animal welfare issues associated with marking wild animals for identification
1600 – 1620	**BEAUSOLIEL, Ngaio J.; David J. Mellor and Kevin J. Stafford:** Ethical responsibilities of scientists marking wild animals for identification
1620 – 1640	**LITTIN, Kate E. and David Mellor:** Can we fix it? Yes we can! Making vertebrate pest control ethical
1640 – 1700	**O'CONNOR, Cheryl; Bruce Warburton and Mark Fisher:** Ethics and the killing of wild sentient animals

Thursday 5 May

Theme 7: Bird pests
(Chair: Jim Coleman)

0910 – 0920	**Introduction to bird pest symposium**
0920 – 0940	**THOMPSON, Jim and Craig Walton:** Bird pest policy and management in Queensland: risk management or risk taking?
0940 – 1000	**TRACEY, John; Mary Bomford; Quentin Hart; Glen Saunders; and Ron Sinclair:** National guidelines and research priorities for managing pest birds
1000 – 1020	**Morning tea**
1020 – 1040	**KENTISH, Barry; Anne Wallis; David Brennan; Dean Hartwell; Craig Whiteford, and Ian Temby:** Corella problems in western Victoria: chronology of the management of a native pest species
1040 – 1100	**MORGAN, Dai; John Innes; Joseph Waas and Eric Spurr:** Interspecific aggression in magpies: impacts on other birds in New Zealand
1100 – 1120	**MacLEOD, Catriona J.; and Keven W. Drew:** Factors influencing the spatial distribution of introduced birds on arable farms in New Zealand
1120 – 1140	**SPURR, Eric and Jim Coleman:** Cost-effectiveness of bird repellents for crop protection
1140 – 1200	**Martin, John and Joan DAWES:** Egg oil: a tool for the management of pest bird populations
1200 – 1300	**Lunch**
1300 – 1320	**LAPIDGE, Steven; David Dall; Joan Dawes; John Tracey; Ron Sinclair and Andrew Woolnough:** STARLICIDE® – The benefits, risks and industry need for DCR-1339 in Australia
1320 – 1340	**SINCLAIR, Ron and Jason Turner:** Managing urban noise impacts from bird scaring devices: a new and balanced approach

Theme 8: Diseases in vertebrate pests
(Chair: Glen Saunders)

1340 – 1400	**Fleming, Peter; Steve McLeod and John TRACEY:** Wildlife, livestock and foot-and-mouth disease: models for feral goats and sheep
1400 – 1420	**HENZELL, Robert:** Weather and the long-distance movement of rabbit haemorrhagic disease virus
1420 – 1500	**Mutze, Gregory; Steve McPHEE; Kym Butler; John Kovaliski and Lorenzo Capucci:** Variation in activity of rabbit haemorrhagic disease due to rabbit population density and a benign calicivirus
1500 – 1520	**Afternoon tea**

1520 – 1540	**RAMSEY, Dave and Murray Efford:** Evaluating vaccination strategies for control of bovine tuberculosis (*Mycobacterium bovis*) in brushtail possums using a spatially explicit model
1540 – 1600	**NUGENT, Graham; Jackie Whitford and Ivor Yockney; Andrea Byrom and Jim Coleman:** Do feral pigs play an important role in New Zealand's Tb problem?
1600 – 1620	**BYROM, Andrea; Graham Nugent; and Ivor Yockney:** The role of ferrets in landscape-scale spread of bovine Tb in the high country of New Zealand's South Island
1620 – 1640	**Animal Control Technologies Award 2005:** **SAALFELD, W. Keith:** A successful unsuccessful feral animal management program
1900	**Dinner at Te Papa** **Presentation of Animal Control Technologies Award**

Friday 6 May

Theme 9: Ecology of vertebrate pests
(Chair: David Choquenot)

0900 – 0920	**GLEN, Al:** Do introduced predators compete with native carnivores?
0920 – 0940	**NORBURY, Grant and Richard Heyward:** Predictors of clutch predation of banded dotterels in braided rivers of the Mackenzie Basin, New Zealand
0940 – 1000	**RUSCOE, Wendy; Joe Elkinton; Dave Choquenot and Rob Allen:** Predation of mountain beech seed by an introduced rodent
1000 – 1020	**Morning tea**
1020 – 1040	**REDDIEX, Ben; John Parkes; Richard Heyward and Michael Scroggie:** Impact of rabbit grazing post-RHD in Central Otago, New Zealand
1040 – 1100	**CHOQUENOT, David and John Parkes:** Ground disturbance by feral pigs: ecosystem engineering or just rooting around?
1100 – 1120	**KABOODVANDPOUR, Shahram and Luke K.-P. Leung:** Relationship between yield loss pf sorghum caused by the house mouse, *Mus domesticus*, and number of mice
1120 – 1140	**TOMPKINS, Daniel M. and Clare J. Veltman:** Unexpected consequences of vertebrate pest control
1140	**Farewell**

POSTERS

JOHNSTON, Michael; Roger Wilson; Bob Rogers; David Titley and Ian Miller: Development of a trap monitoring system for wild dog traps

RIDLEY, Geoff: The bare bones of the HSNO Act

FARRELL, Julianne: Developing 'Best Practice' strategies for managing mice in Queensland's grain producing regions

MEENKEN, E.D.; Butler, K.L.; McPhee, S.R.; Backhouse, K.; and Kovaliski, J.: Population dynamics of wild rabbits after the occurrence of rabbit haemorrhagic disease in Victoria.

JENNINGS, Scott and Lisa Farroway: Adaptive management of kangaroos on reserves in South Australian

WATKINS, Peter and Peter Baker: Is effective long-term management of rabbits in semi-arid region reserves possible? — Ten years on

O'HALLORAN, Kathryn; Denise Jones and Penny Fisher: Ecotoxicity of sodium fluoroacetate (1080) to plants

PONTIN, Karen; Michelle Smith and Linton Staples: Interrupting erupting mice – turning reaction into proaction

AGNEW, David: Southland Conservancy island biosecurity plan

BLOOMFIELD, T.E.; Mooney, N.; and Emms, E.:: The red fox in Tasmania; An incursion waiting to happen

THORN, Kate and Robert Coventry: The West Coast integrated pest management program: a coordinated community approach to pest management on the Eyre Peninsula, South Australia

CHRISTIE, Jenny; Josh Kemp; Chris Rickard and Elaine Murphy: Can trap data from predator control operations be used to relate stoat and ship rat capture success to micro-habitat features?

TAO ZHENG and Henry Chiang: Possum enteroviruses – potential vectors for biocontrol of possums: antibody responses and viral excretion in possums exposed to possum enteroviruses by the oral route

HORTON, Paul; Andrea Byrom; Caroline Thomson; Dianne Gleeson; Robyn Howitt; Brian Karl and Kerry Borkin: Hair tubes: an effective means of detecting stoats

Winifred Kirkpatrick and Marion MASSAM: Risk assessment: helping to prevent pets from becoming pests

PARKES, John; Schmechel, Frances; Fraser, Wayne: Eradicating feral goats from Banks Peninsula

RUSSELL, J.C. and M.N. Clout: Rodent incursions on New Zealand islands

NITSCHKE, Tim and B. Dowley: An efficient and accurate way to dose 1080 predator baits

THE LEGISLATIVE FRAMEWORK FOR PEST MANAGEMENT

Don Crump

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ABSTRACT: The legislative framework for statutory pest management in New Zealand is provided by the Biosecurity Act 1993 (the Act). The Act provides for regional and national pest management strategies. A strategy is a high level plan that is established in legislation that describes the organisms to be managed, how they are to be managed, who will manage them and who will pay. Theoretically any person can make a proposal for the preparation of a strategy, either national or regional. The proviso is that persons proposing a strategy may be required to pay the costs of the proposal and also suggest who will pay the on going costs of the strategy. In practice there have been few strategies developed by private organisations.

Endemic pests in New Zealand are unlikely to be eradicated because once an organism is established it is either very difficult or impossible to eradicate. Consequently for most endemic organisms the question is whether it is desirable to control it and to what degree or level of control. The level of control is an economic question and depends on the benefit likely to result from different levels of control. For agricultural pests of pastoral farming the value of meat, wool and dairy products will influence the level of management or control that it is optimal to apply to an endemic organism that causes economic harm. The level of control applied to an organism that causes harm to the environment would depend on the value of the environment where the damage occurs. Whether or not endemic organisms in any part of New Zealand are managed, will depend on the characteristics of the region where they are located. Whether an organism is regarded as a pest in any area or region depends on the competing economic activities in a particular area or region. Consequently an organism may be a pest in one region and not in another. For this reason criteria in the Act generally require endemic pests to be managed by regional pest management strategies. Criteria in the Act also limit the use of national strategies and dictate that most pests will be managed by means of regional strategies. Currently there are three national pest management strategies in existence. Some people hold the view that there should be many more national strategies and that the reason why there are not more is that the process of making a national strategy is considered to be onerous. The paper will examine and evaluate the process for making a national strategy.

The Bovine Tuberculosis National Pest Management Strategy (the strategy) provides an example of the use of the Act for pest management. The characteristics of the bovine tuberculosis problem in New Zealand and the current scale of the strategy to deal with the problem are discussed. The paper describes the pest management strategy, outlines the suite of legislation used to implement the strategy and the steps required to complete the five year review of the strategy. The time and resources needed to complete a statutory review of the strategy are considered by some to be excessive. The review process and its cyclical nature and the steps in the process where consultation with stakeholders is required, are discussed and evaluated. Finally, the strengths and weaknesses of the pest management legislation are analysed.

CONSOLIDATING LEADERSHIP AND COORDINATION FOR PEST MANAGEMENT IN NEW ZEALAND – CHANGES AND DIRECTIONS

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ABSTRACT: One of the main problems in New Zealand's biosecurity arrangements, as identified in *The Biosecurity Strategy for New Zealand*, is fragmentation. It contributes to a lack of coordination and integration, no overall view of priorities, uneven capability across the system resulting in inconsistencies, and an insufficiently broad view of the values that biosecurity protects.

To address these problems, the New Zealand Government agreed that the accountability arrangements for biosecurity were to be reorganised by giving the chief executive of the Ministry for Agriculture and Forestry (MAF) accountability for end-to-end management of the biosecurity system, including pest management.

This accountability changes included assigning MAF two new accountabilities for pest management:

- national leadership and coordination of pest management; and
- accountability for national pest management programmes.

The latter are defined as:

- Control of established pests - programmes that involve either eradicating a harmful organism from all of NZ, containing it to within a small area within NZ, or excluding it from the North or South Islands
- Management of pathways & vectors (generic and domestic) – programmes that involve controlling the movement of pests along a modest number of high-risk, nationally significant domestic pathways or vectors

MAF has recently established a fledgling pest management capability to take on these new accountabilities, and is beginning to build direction.

An early step has been to initiate a process to collectively agree a single set of pest management priorities, then establish a mechanism to align the efforts of pest managers with these and improve coordination. This has involved a series of workshops and other consultation steps, and seeking agreement through key governance bodies. The overall process and outcomes of this to date will be presented.

MAF's initial steps as it begins to build direction will be also be outlined.

STRATEGIC CONTROL OF EXOTIC VERTEBRATE PESTS FOR THE CONSERVATION OF BIODIVERSITY: THREAT ABATEMENT PLANNING IN NEW SOUTH WALES, AUSTRALIA

Paul Mahon

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ABSTRACT: Exotic vertebrate pests are among the most significant threats to biodiversity throughout the world. In Australia, the introduction of three species of carnivore, the wild dog (*Canis lupus dingo* and *C. l. familiaris*), the feral cat (*Felis catus*) and the red fox (*Vulpes vulpes*), has contributed to severE declines and extinctions of a broad range of ground-dwelling and semi-arboreal mammals, ground-nesting birds and freshwater turtles. Similarly, the introduction of herbivores such as the rabbit (*Oryctolagus cuniculus*) and the goat (*Capra hircus*) has had significant impacts on native plants, native herbivores, soil stability and water quality. Exotic fish such as the plague minnow (*Gambusia holbrooki*) and carp (*Cyprinus carpio*) threaten native aquatic species.

Preventing the incursion of exotic species or eradicating them soon after their arrival is clearly preferable if biodiversity is to be conserved. However, the establishment of exotic species over broad areas including whole continents provides a more challenging problem for wildlife managers. Given limited resources, control of widely distributed pests must be prioritised to focus on sites where the impacts are likely to be greatest. In New South Wales, targeted vertebrate pest control is being developed and delivered through Threat Abatement Plans. Prepared under the NSW Threatened Species Conservation Act, these plans have three specific objectives: (1) to establish collaborative (across tenure) control programmes at priority sites indentified for the conservation of native fauna. These priority sites are selected by indentifying those threatened species that are most likely to be impacted by a given pest and the sites at which these impacts are predicted to be most critical. (2) to develop best-practice guidelines for control which balance effective control with minimising any negative effects of control methods on non-target species. (3) to measure the response of targeted threatened species to pest control. At present, plans for red foxes and plague minnow are being implemented while plans for feral cats, rabbits, feral pigs (*Sus scrofa*), goats and deer (Cervidae spp.) are being developed. This paper reviews the development and implementation of these plans.

MANAGING FERAL CAMELS IN AUSTRALIA

Glenn Edwards

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ABSTRACT: Feral camels (*Camelus dromedarius*) became established in Australia in the late 1920s and are now widely distributed across the arid and semi-arid parts of Queensland, South Australia, Western Australia and the Northern Territory. In 2001 there was a minimum of 300,000 feral camels in Australia and that the population was increasing at a rate of about 10% per annum (Edwards *et al*. 2004).

Feral camels already have demonstrable environmental, economic and cultural impacts. While there is a clear need to better quantify the relationship between camel impacts and camel density, the fact that feral camels already occur at densities at which impacts are evident (Dörges and Heucke 2003; Edwards *et al*. 2004), coupled with the continued unchecked increase in feral camel population size demands the immediate development and implementation of effective management programs for the species.

Providing effective management of feral camels and their impacts across Australia in the longer-term presents a challenging and complex problem. To date, management effort has been largely *ad hoc* and has had little impact on populations overall. The scale of the management effort required to stabilise camel numbers and abate their impacts is directly related to the size of the feral camel population- in the face of an increasing population, the longer the delay, the greater the effort required. Wild-harvest is an attractive management option because it removes camels from the wild and it can provide income for land managers, in particular Aboriginal people living in isolated communities. However, wild harvest is unlikely to ever effectively control camels across most of their range because most feral camels currently inhabit areas that are remote, sparsely populated by people, have exceedingly poor road networks and which contain no infrastructure suitable for either holding or handling camels. Aboriginal people are key stakeholders in camel management and their attitudes to feral animals often differ markedly to those of non-Aboriginal people (Rose 1995). Aboriginal people are often happy to support live-removal programs for feral animal species and to receive the benefits that such programs provide (e.g. employment, training and income) but generally do not support the shooting of animals to waste. In addition, some Aboriginal people who have been exposed to Christianity view feral animals like camels as benign because they feature in biblical stories (Rose 1995). Feral camels are very mobile and move over very large areas (up to 5,000 km^2: Grigg *et al*. 1995; Edwards *et al*. 2001). Consequently, extensive buffer zones will be needed in arid regions to protect environmentally sensitive areas and infrastructure from camel impacts. Also, because feral camels are widely distributed and wide ranging, it is imperative that the governments of all states and territories harbouring camels act together to manage the species across it's entire range.

As a first step towards managing feral camels across their entire range, a national workshop addressing the issue will be held in Alice Springs, Northern Territory, in April 2005. The outcomes of this workshop will be discussed.

REFERENCES

Dörges, B.; Heucke, J. 2003. Demonstration of ecologically sustainable management of camels on aboriginal and pastoral land. Final report on project number 200046 of the National Heritage Trust, Canberra, Australia.

Edwards, G. P.; Eldridge, S. R.; Wurst, D.; Berman, D. M.; Garbin, V. 2001. Movement patterns of female feral camels in central and northern Australia. *Wildlife Research 28*: 283–289.

Edwards G. P.; Saalfeld K.; Clifford B. 2004. Population trend of feral camels in the Northern Territory, Australia. *Wildlife Research 31*: 509–517.

Grigg, G. C.; Pople, A. R.; Beard, L. A. 1995. Movements of feral camels in central Australia determined by satellite telemetry. *Journal of Arid Environments 31*: 459-469.

Rose, B. 1995. Land management issues: attitudes and perceptions amongst Aboriginal people of central Australia. A report to the Central Land Council, Alice Springs, NT, Australia, and the National Landcare Program, Canberra, ACT, Australia.

THE SOUTHERN ARK PROJECT

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ABSTRACT: The Red Fox, *Vulpes vulpes*, is increasingly regarded as one of the major threats to mammalian biodiversity on the Australian mainland. All State and Federal conservation agencies consider that reduction in fox numbers will have a beneficial effect on native fauna, and there have been some very positive results in a number of States where large-scale fox control programs have been implemented.

The Southern Ark project aims to facilitate the recovery of native animals and improve the stewardship of public land in East Gippsland, Victoria, through an integrated, large scale fox control program that is maintained year-round. It represents the first large-scale attempt to control foxes in natural ecosystems in eastern Australia. This program will rely on the establishment and maintenance of approximately 5,000 permanent bait stations across one million hectares of public land (State Forest and National Parks and Reserves). This area of land represents 5% of the State of Victoria.

East Gippsland is well placed for the establishment of a large-scale fox control program. Ecologically, the region has a wide range of fauna that are currently threatened by fox predation, as well as a range of species that, while not considered endangered, will never-the-less benefit from a reduction in fox predation. From a logistic standpoint, although the region includes some of the most pristine ecosystems found in Victoria, it also possesses a well-maintained network of all-weather vehicle tracks. This feature will greatly aid the establishment and maintenance of a successful baiting program. The relatively small percentage of freehold land, which tends to be concentrated into discrete areas, will allow fox baiting to be carried out across large areas of the region with little inconvenience to members of the public.

The implementation of the Southern Ark project strongly relies on the results achieved during the research project known as Project Deliverance, which demonstrated a positive response by a number of medium-sized mammals to ongoing fox control. The Long-nosed Potoroo, *Potorous tridactylus*, and the Southern Brown Bandicoot, *Isoodon obesulus*, demonstrated a significant positive response to ongoing fox control. These species are considered as “vulnerable” and “endangered” respectively under the Federal *Environment Protection and Biodiversity Conservation Act* 1999. Long-nosed Bandicoot, *Perameles nasuta*, numbers continued to decline during the course of the study, irrespective of fox control. As the most insectivorous of the terrestrial medium-sized mammals monitored, the decline of this species coincided with an extended period of below-average rainfall.

The effectiveness of the fox control program on foxes will be intensively monitored in a number of areas using the changes in the level of bait-take, faecal density counts along selected transects and the monitoring of footprints on sand pads.

The population response of the medium-sized terrestrial mammal species (potoroos and bandicoots) will be monitored across a number of sites across the coastal and foothill forests of Far East Gippsland. Cage trapping and the establishment of grids of hair tubes will form the basis of the mammal-monitoring program.

East Gippsland retains an intact suite of native predators. This includes three species of large forest owl, the Lace Monitor, the Spotted-tailed Quoll, and wild dogs. Great care is being taken to minimise the impact on non-target species.

FOX MANAGEMENT AND PRODUCTION OUTCOMES IN NSW – BENEFITS AND FUTURE DIRECTIONS

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ABSTRACT: The European red fox is a major pest in Australia threatening a range of native fauna and preying on livestock, in particular lambs. The profile of the fox as a pest animal has undergone a dramatic change over the last decade with its promotion as a major threat to the environment and agriculture by government agencies, conservation groups and pest control companies. This change has also occurred partly in response to the withdrawal of commercial harvesting operations with the collapse of the fur trade. Accompanying this elevation of public perceptions has been an exponential increase in fox control activities, particularly lethal baiting. Despite intensive efforts, particularly for agricultural protection, the fox remains ubiquitous throughout mainland Australia.

In our most recent (2004) pest animal survey conducted in NSW and the ACT it was estimated that the fox inhabited 792,974 km^2 or 98.6% of the state. Of all control strategies used against the fox, 77% of actions consisted of lethal (1080) baiting. Unfortunately, the body of evidence based on unequivocal evaluation of fox control on agricultural lands is poorly reported and we have to rely heavily on anecdotal or unpublished information to sustain the notion that ongoing control campaigns against the fox produce positive cost-benefits. Evidence of impact on production values is often based on historical observations that may need to be re-affirmed in the light of current agricultural practices. There is also a bias in that those scientific evaluations that are available on control efficacy and impact are conducted mostly by government agencies with access to relatively high levels of resources and in some cases using non-representative techniques. It is questionable how much these evaluations reflect the outcomes of the majority of fox control programs conducted by private land managers either in isolation or as part of group campaigns.

In NSW, we are currently undertaking a large-scale replicated study which looks at the relationship between the extent of fox baiting and lamb production; and the frequency of fox baiting and lamb production. This project is based on the "Outfox" program that is an extension activity aimed at promoting the benefits of group baiting by rural producers. The study area covers approximately 5 million hectares and four Rural Lands Protection Boards. Extent and frequency of fox baiting is being mapped from the NSW register of 1080 use, and data on lamb production is being collected from postal surveys of sheep producers within the study area.

PROTECTING BIODIVERSITY BY CONSERVING ISLANDS: AN INTEGRATED REGIONAL APPROACH

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ABSTRACT: Most recent animal and plant extinctions have occurred on islands and were caused, at least in part, by introduced species. This is because most island ecosystems historically lacked mammalian predators and herbivores and therefore island flora and fauna often lack evolved defenses against these introduced mammals. Removing introduced mammals from islands can protect island ecosystems, and we believe this can be done effectively by regional island conservation organizations that integrate: (1) applied research and priority setting; (2) public education and policy work; (3) capacity building; (4) conservation action; and (5) monitoring and evaluation. In Northwest Mexico and California we developed such an organisation to protect the region's 296 islands. These islands have 39 breeding seabirds and 388 endemic species and subspecies, in a region with greater endemism per unit area than the Galapagos Islands. Non-native mammals have been introduced to at least 66 islands and are responsible for the probable extinction of 20 endemic vertebrate species and subspecies. Starting in 1994 Island Conservation and Grupo de Ecologia y Conservacion de Islas have collaborated with national management agencies, local island users, universities and NGO's to remove one or more introduced mammals from 27 of the 66 islands in the egion withnon-native mammals. A total of 38 populations of *R. rattus*, goats, sheep, donkeys, pigs, cats, dogs and rabbits have been eradicated. Only one project failed, the attempted eradication of rabbits from 2,926 ha Clarion Island. These conservation actions have protected 13,500 ha, 201 seabird colonies and 78 endemic taxa. In Mexico, this work cost $188 USD per hectare for each invasive mammal removed, $17,000 USD per seabird colony protected and $35,000USD per endemic species or subspecies protected. We are now turning our attention to larger more complex islands within the region such as the eradication of goats and cats from 26,500 ha Guadalupe Island.

TAMING HSNO FOR PEST MANAGERS

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ABSTRACT: The legislation for vertebrate pesticides in New Zealand has recently been overhauled. New controls on these substances now run to hundreds of pages of legalese. To enable Department of Conservation staff to cope with this change we have analysed and interpreted controls into meaningful actions to ensure compliance. Existing Standard Operating Procedures were modified and new ones established to integrate all legal and policy compliance. Managers now have quick access to a list of pesticide tools available for each target pest. This list links to performance standard sheets that summarise controls and form part of the permission DOC grants for vertebrate pesticide use on land managed by the department. Internal monitoring of the system is planned to start soon.

INTRODUCTION

The legislation for vertebrate pesticides in New Zealand has been overhauled to standardise the regulation of hazardous substances and to meet international protocols. For the last twenty years, vertebrate pesticides have been regulated largely by one Act (the Pesticides Act 1979) and one Regulation (the Pesticides (Vertebrate Pest Control) Regulations 1983). These have been replaced by two more complex Acts and 28 associated regulations, and vertebrate pesticides have been renamed Vertebrate Toxic Agents (VTAs).

The purpose of the Hazardous Substances and New Organisms Act 1996 is to "protect the environment and the health and safety of people and communities by preventing or managing the adverse effects of hazardous substances and new organisms."

The Agricultural Compounds and Veterinary Medicines (ACVM) Act 1997 aims to manage risks associated with the use of chemicals in agriculture. These are:

- risks to trade in primary produce-mainly concerned with the presence of residues in export goods
- risks to animal welfare
- risks to agricultural security
- to ensure domestic food residue standards are not breached, and
- to ensure users of agricultural compounds have sufficient consumer information about the products

Pest control field workers are now required to comply with a greater number of more complicated rules. To enable Department of Conservation staff to cope with this change we have analysed and interpreted the legislation into meaningful actions to ensure compliance.

HOW THE HSNO ACT IDENTIFIES CONTROLS

The Environmental Risk Management Authority (ERMA NZ) administers the HSNO Act. The HSNO Act defines a process for ERMA NZ to create regulatory controls for hazardous substances (see Figure 1).

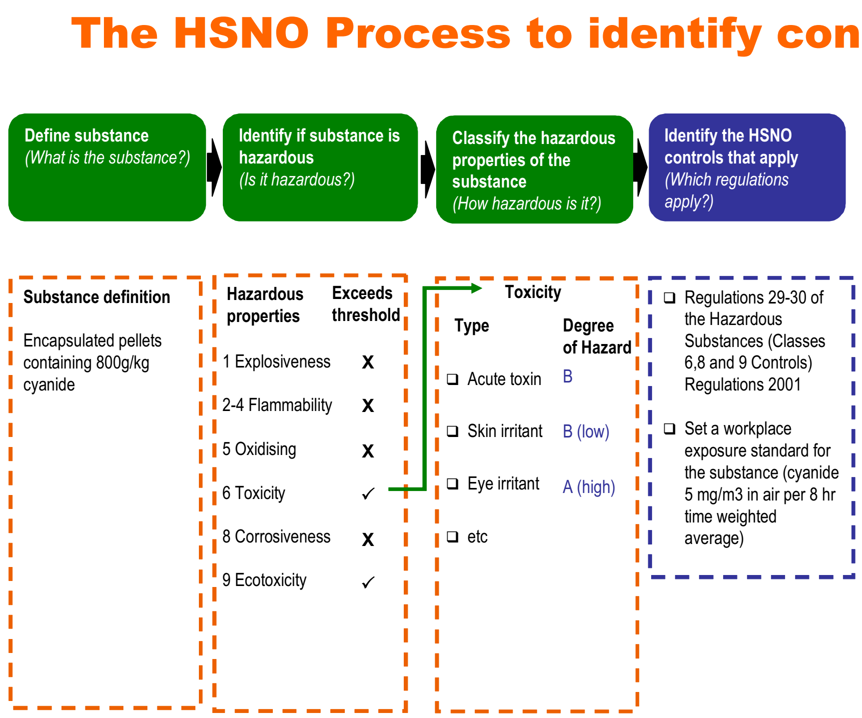

Fig. 1. The HSNO process to identify controls

Substances are initially defined, to put clear boundaries around the hazardous substance and avoid duplication. Substance definitions can be broad (e.g.; bait containing 0.25 to 0.5g/kg pindone) or narrow (e.g. encapsulated pellets containing 800g/kg cyanide). ERMA NZ has defined Vertebrate Toxic Agents for transfer from previous legislation. For new hazardous substances, the applicant proposes a substance definition.

The next step is to identify whether substance meets the criteria to be called hazardous. Each substance is assessed against a series of hazardous properties or "Classes." If the substance exceeds the minimum threshold for any Class, it is a hazardous substance. All Vertebrate Toxic Agents exceed the threshold for Class 6 Toxicity and Class 9 Ecotoxicity.

To classify the hazardous substance, the types of hazards are specified for each Class. For example in Class 6, the types of hazards to humans include acute toxicity, carcinogenicity, and effects on reproduction and lactation. For each type of hazard the degree of hazard is also assessed to further describe the severity or nature of the effect.

The final step is to identify the HSNO controls that apply. HSNO controls are rules the hazardous substance user must comply with to 'control' the risk of adverse effects. The hazard classification automatically identifies the 'default' HSNO controls that apply. The Authority that governs ERMA NZ has the power to then vary or add to the default HSNO controls.

DOC QUALITY MANAGEMENT

The Department has a quality management approach to pest control (Broome & Crowell 2001). This means that we have systems in place to manage risk and continuously improve our effectiveness.

On public conservation land the public expects DOC to take care and do things right every time. Quality management of pest operations:

- Gives the public confidence that VTAs are used responsibly and for the right reasons.
- Equips DOC pest managers to apply VTAs efficiently and effectively.

We need to apply the highest standard of decision making and professionalism to retain the current availability of pest control tools. This means lifting our game as pest managers. Our systems aim to help pest managers know what they need to do to achieve legal compliance, meet public expectations, and contribute to the long-term sustainability of pest control in New Zealand.

The DOC Performance Standards sheet is the most critical part of the systems for ensuring legal compliance. There is one sheet tailored to every way of using VTAs where all the relevant rules are captured and interpreted (see Appendix 1 for an example). Each sheet lists all the standard operating procedures (SOPs) that apply. SOPs establish standards and process steps to carry out specific tasks in a quality way. For example, there is a SOP for handling VTAs safely and another that covers how to notify the public about pest operations.

The DOC Performance Standards sheet also lists the performance standards, or conditions, that DOC applies over and above the SOPs listed to further manage risks. The sheet forms part of the permission DOC grants for the use of VTAs on public conservation land.

HOW DOC BUILT HSNO INTO ITS SYSTEMS

DOC responded to the introduction of HSNO controls for VTAs by modifying the content of the SOPs and performance standards listed on the DOC Performance Standards sheets. To achieve this we used the following process:

1. Collation of Information

The HSNO controls that apply to Vertebrate Toxic Agents cannot be found from a single source. There are a number of documents that cross-reference and complement one another, so these must be read together:

- Nine of the 28 Regulations made under the HSNO Act
- The New Zealand Gazette Issue No. 141 (October 2004)
- The Transfer Reports prepared by ERMA NZ staff that formed the basis for the Gazette Notice
- The Worker Exposure Standard published by the Occupational Safety and Health Service.

2. Interpretation

Because the HSNO Regulations apply to the full range of hazardous substances, we needed to put them into a pest management context and interpret them into plain English. For example, one of the HSNO controls refers to Regulation 7 of the Hazardous Substances (Classes 6,8, and 9 Controls) Regulations 2001:

"*Equipment used to handle substances—*

1) A person in charge of a class 6, 8.2, 8.3, or 9 substance must ensure that equipment used to handle the substance—

(a) retains the substance, without leakage, at all of the temperatures and pressures that it is used in; and

(b) dispenses or applies the substance, without leakage, at a rate and in a manner that the equipment is designed for."

We interpreted this to mean that all equipment used to handle, dispense or carry VTAs (such as bait stations or back packs) must be fit for purpose and be free of defects – in other words no rips, holes or cracks.

The hazard classification of a substance determines which default HSNO controls apply, causing variation in the scope of application between controls. In our interpretation, we sometimes expanded the scope to apply a given control to all VTAs in order to simplify compliance for our staff. For example, one HSNO control requires that users carry a Material Safety Data Sheet when carrying more than specified minimum quantities of a named Vertebrate Toxic Agents. For the VTAs we use, the minimum quantities ranged between "any quantity" and "more than 3kg" so we decided to simplify this to "any quantity of any VTA" as a matter of DOC policy.

Lastly we identified what change we needed to make, for DOC systems to comply. The options were:

- No change required because DOC is complying already
- Modify an existing SOP
- Create a new SOP
- Include a new performance standard on the DOC Performance Standard sheet

In the **Equipment used to handle substances** example, this meant modifying existing Safe Handling of Pesticides SOP to include our interpretation that equipment must be fit for purpose. We set up a spreadsheet to match each interpretation of controls to the option chosen.

3. Projects

Eight project briefs were drawn from the spreadsheet, one for each new or modified SOP and three others. Each project involved drafting the change and testing with DOC staff to verify that our interpretation complies with the law; is pragmatic to achieve; and minimises operational implications. Feedback from testing sometimes led to revisions before briefing the accountable DOC General Manager on significant operational implications. His approval meant that the change became policy. The deliverables for these projects required changes to the relevant DOC Performance Standard sheets. New SOPs or performance standards were added, and the Approved Handlers logo was used to signal those pesticides where a HSNO licence must be held to handle the Vertebrate Toxic Agent unsupervised.

4. Implementation

DOC needs HSNO compliance in practice so it was critical to implement the changes well (Broome and Crowell 2001). Training was designed, piloted and delivered throughout DOC in eighteen two-day workshops, involving about 160 pest staff. A communication plan managed the identification of target audiences, key messages, and resources required. For example, we prepared information packs to support staff in briefing contractors. Copies of the SOP's and Performance Standard sheets were posted on the web for their access.

STILL TO COME

Compliance with most HSNO controls became compulsory for the use of Vertebrate Toxic Agents on 1 May 2005. Some controls have a longer transitional period for compliance, including the Hazardous Substances (Identification) Regulations 2001 that govern the content of warning signs. We have delayed updating the DOC standard for warning signs to allow us to reconcile the legal requirements with what the public will understand.

After we completed staff training, the NZ Food Safety Authority finalised the conditions of registration they will apply to VTAs under the ACVM Act. Now manufacturers are updating product labels to include these conditions. We are planning to use a similar process to integrate these requirements into our systems.

The next step will be compliance monitoring to verify whether the changes have been put into practice and to identify reasons for non-compliance.

ACKNOWLEDGEMENTS

We gratefully acknowledge the comments and improvements suggested by Alastair Fairweather and Greg Sherley. Gina Weldon designed the Power Point presentation given at the conference. Alastair, Gina and Patrick Whaley were also part of the team for this work.

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APPENDIX 1: Example Performance Standard Sheet

Pesticide use details

Is it a DOC or external operation?

Approved handler required

♦ INCLUDE ONE SHEET PER PESTICIDE USE ♦ COMPLETE SHADED AREAS ♦

Pesticide Use #19	Cyanide 800g/kg Encapsulated pellet with prefeed paste Bait bags (Feratox)	Target Pests: Possums

DOC/AHB* Operation	Caution Period
[Insert name of treatment block(s)/area here]	*[Insert caution period for this operation – consult Public Notification SOP]*

* Delete the one that is not applicable

Which DOC SOPs and policies apply

DOC	AHB	DOC SOPs & Policies Shall Be Followed
✓	✓	Public Notification for Pesticide Operations SOP, including Warning Signs (hamro-93976)
✓	✓	Safe Handling of Pesticides SOP (AHB operations apply clean up & disposal chapter only) (hamro-95527)
✓		Storage and Disposal of Hazardous Substances SOP (wgnho-83176)
✓		Standard for the Transportation of Hazardous Substances (wgnho-81352)
✓		Operational Reporting SOP (hamro-70771)
✓		Consultation Policy and Guidelines (wgnho-10803)
✓	✓	National Requirements for Trapping and Cyanide Use (wgnho-49191)
✓	✓	Identifying Boundaries for Pesticide Operations SOP (hamro-95867)

Compulsory restrictions

Compulsory Restrictions

✓ This pesticide use is prohibited where weka are present.

Compulsory performance standards

Performance Standards

*Compulsory for **all** operations*

✓ This pesticide must not be used, stored or prepared, with any prefeed, bait or attractant which is likely to lead any person to believe that the substance is intended for human consumption.

✓ Unless in approved container supplied by the manufacturer, this pesticide must not be used in any culinary utensil or other container which is likely to lead any person to believe the contents are intended for human consumption, regardless of any modification or other warning labels attached.

✓ Consent providers must be given at least 24 hours notice before the pesticide is applied and a close liaison will be maintained throughout the operation.

✓ The baits must be dyed green or blue.

✓ *= Compulsory for this operation*

☐ Remove bait bags and residual bait at end of the operation.

☑ *[Add further standards as required, using extra pages if needed. Attach conditions from other consents as separate pages.]*

Additional performance standards to consider

Information Needs

*Compulsory for **all** operations*

✓ Caution Period Monitoring: Monitoring physical breakdown of bait is required. See Public Notification SOP Appendix 4.

Compulsory field trials or monitoring that apply

✓ *= Compulsory for this operation*

☐ Monitoring: Follow best practice for pre and post control result monitoring to estimate percentage kill for possums and where possible rodent indices and report results in operational report.

☐ Monitoring: Pay special attention to sign and observations of feral and domestic animals feeding/ accessing bait bags (difficult to establish through residue testing). Document in operational report.

Additional information needs to consider

My approval dated *[date]* is subject to these performance standards being met. Compliance monitoring may occur.

____

[Name] Area Manager

Minimum level of approval

'NIL TENURE' APPROACH TO INVASIVE ANIMAL MANAGEMENT IN AUSTRALIA – EXTENDING THE PARADIGM

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Abstract: Research into control measures for wild dogs and foxes in Australia is yielding improved tools and techniques. Despite these advances and no matter how effective the innovation, the mobility and prevalence of these invasive animals in the Australian environment renders effective management an elusive goal. Often, failure of adoption, at the appropriate scale, is a major impediment to effectiveness. In NSW, wild dogs are estimated to be present in almost 30% of Rural Land Protection Board jurisdictions, and there is some evidence that their density has increased over the last 20 years.

Wild dog attacks in the Brindabella and Wee Jasper valleys of southern NSW have had significant financial, social and environmental impacts over a long period. In 2000, local landholders, RLPBs and State agencies committed to a 'nil tenure' approach, involving affected stakeholders in planning and implementing an agreed solution. The result has been a 75% reduction in stock losses (Hunt 2002).

This paper:

- outlines the 'nil tenure' approach and its success in the Brindabella and Wee Jasper valleys;
- discusses the opportunities for and limitations to the approach; and
- outlines plans to employ the paradigm in the recently-announced Australian Invasive Animals Cooperative Research Centre's projected 'demonstration sites'.

RESULTS

Nil tenure and the Brindabella / Wee Jasper wild dog/fox control program

The *nil tenure* approach can be defined as the collective identification of an invasive animal problem, irrespective of tenure boundaries and legal obligations, and a stakeholder- community commitment to implementing a solution.

The Brindabella / Wee Jasper wild dog/fox control program adopted a nil tenure approach and is amongst the most successful, documented, examples of district canid control. In this case study the stakeholders were:

- Local landholders
- National Parks and Wildlife Service
- Yass Rural Lands Protection Board
- NSW State Forests

The action sequence and investments in the Brindabella /Wee Jasper case ran:

- 'Grass-roots' concern over wild dog attacks raised at a meeting of the New South Wales National Parks and Wildlife Service South West Slopes Regional Advisory Committee and local landholders in Wee Jasper on the 9th November 2000. A high level of social impact was recorded, on top of economic and environmental damage. The meeting agreed to work on a local solution to the wild dog issue.
- Planning – a ten-person working group was established in December 2000, drawn from the agencies and local landholders. Triple-bottom-line impacts were documented. Impact mapping (with tenure boundaries absent) identified historic stock loss areas and wild dog residential areas (commonly remote bush areas) and transit routes to grazing areas. Based on this mapping, the available control options were considered and the most effective combination of specific-site bait stations and trapping were selected.
- Only when solutions had been resolved was a tenure overlay produced for the impact/control site map and subsequent cost-sharing agreements.
- A cooperative plan for a nine-month trial was endorsed and implemented.
- A "Cooperative Wild dog/Fox Control Plan' for July 2002 to June 2005 was developed and published.
- A 5-year plan (2005-2010) will be signed off in May 2005.

Investments

The Brindabella / Wee Jasper wild dog/fox monitoring program in 2001-2 cost participating agencies approximately $18,000 in cash. The control program was budgeted at $268,120 in total.

The costs were split between agencies as follows:

Agency	**% of the effected area under their control**	**% of program costs**	**3 year investment**
State Forests	35%	33%	$89,400
NPWS	41%	39%	$102,798
Yass RLPB – representing private lands	24%	28%	$75,972

These figures do include community group inputs or the Working Group's labour.

Characteristics of the nil tenure approach

The Brindabella/Wee Jasper experience suggests that the following list of factors necessary to successfully initiate a *nil tenure* exercise are:

1. a history of significant economic, social and environmental damage;
2. experience that a problem is not manageable on a single property – resolution possible only by integrated local management;
3. local area includes a number of different tenures;
4. there is a local 'champion' to militate for action;
5. there is willingness to invest in planning, identification of objectives and obtaining pre-activity data;
6. there is a 'community' commitment to a multi-year action-plan and reaching agreed objectives;

7. commitment to wide and on-going consultation, information dispersal and media exposure;
8. availability of effective tools, techniques and local skilled personnel;
9. continued monitoring and evaluation ('before and after' measurements to confirm scale of problem, benefits, return on investment etc).

Results of the Brindabella/Wee Jasper Plan's implementation

The initiative produced striking results, with a clear correlation between investment in coordinated control and reduction in stock losses (Fig. 1).

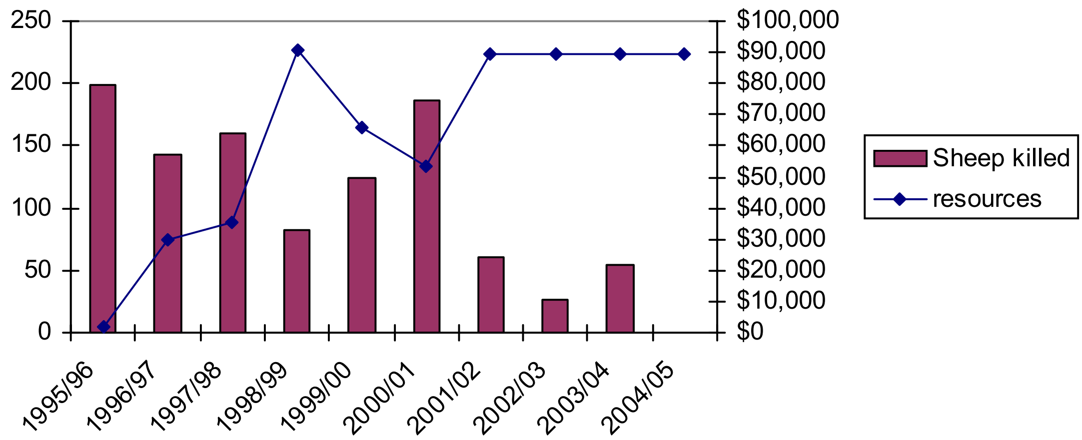

Fig. 1 Stock losses and resource commitments (Hunt 2002).

Wider adoption of nil tenure?

Following the demonstrated benefits of the approach, it was proposed in 2004 that the NSW RLPB State Council accept *nil tenure* for management of other terrestrial vertebrate pests across NSW. Despite in-principal acceptance, there are only a few recently initiated examples of the approach being subsequently applied. All states do however have requirements for 'best management practice' for invasive animal control. For example:

Agency	**Statement**
Commonwealth Rabbit Threat Abatement Plan[1]	"The success of this threat abatement plan will depend on cooperation between all key stakeholders, including land owners and land managers, community groups, local government, State and Territory conservation and pest management agencies… Success will only be achieved if all participants are prepared to allocate adequate resources to achieving effective on-ground control …"
Qld Pest Animal Strategy 2002-2006	"Consultation and partnership arrangements between local communities, industry groups, State government agencies and local governments must be established to achieve a collaborative approach to pest management."[2]
NSW 'Outfox the fox' program (Walter *et al.* 2004)	NHT funded 3 year trial to match 1080 baiting effort against lambing rates to determine the effectiveness of group baiting regimes. Preliminary findings confirm fox' resilience to control; intersection of public/private interests is at the core of any successful strategy.

[1] http://www.deh.gov.au/biodiversity/threatened/publications/tap/rabbits/3.html

[2] http://www.nrm.qld.gov.au/pests/strategies/pdfs/animalstrategy.pdf

Three perspectives on the demand for a *nil tenure* approach

1. From the perspective of **agencies and policy development**, the commentary of Prof Tony English in a report to NPWS (English and Chappel 2002) on management of invasive animals is instructive:

   "A conventional scientific approach has almost invariably been taken in defining feral animal problems, focusing on agricultural and biodiversity impacts. Increasingly, this approach seems inadequate for dealing with the complexity and conflict surrounding invasive animal control. An interdisciplinary approach to the problem is therefore recommended. While scientific and technical information is essential … the dominance of this information can reinforce community perceptions that feral animals are a national park problem and not related to the broader causes and conditions. Proposing a solution which addresses wider community values, rather than one which focuses on the ecological problem (which may be seen by some as a narrow scientific or environmental goal), will provide a more convincing argument. This approach will hopefully see a reduction in the all too common 'blame game' in relation to feral animals, which is of benefit to nobody."

2. From the perspective of **landholders**, polled by PAC CRC at Wimmera Field days, March 2005:
   Approximately 150 landholders polled about the importance of all stakeholders in adoption of best management practices (BMP) for fox control – 60% acknowledged they could not control pest impacts simply by adopting BMPs themselves, they:
   - wished to see an integrated approach,
   - needed help in developing such an approach and
   - had little faith in government agencies being able to control invasive animal problems.

3. From the perspective of **peak industry bodies**, the message is similar. Australian Wool Innovation Ltd has recently (2005) held discussions with WA woolgrowers about the possibility of a *nil tenure* approach to fox/dog problems in the rangelands.

The 'pluses and minuses' of *nil tenure*

Where *nil tenure* may be appropriate	**Where likely to be inappropriate**
Problem species exhibits clear and repeated cross-tenure behaviour.	Problem species exhibit no clear predictable pattern of activity or problem highly localised
Impacts acknowledged by all tenure-holders (or sufficient majority)	• Problem most effectively handled on each effected property. • Not all affected tenure-holders accept there is a major problem, (e.g. wild dog attacks in mixed grazing regions likely to effect lambing rates more than calving, so cattle farmers may be less effected than wool-growers.)
Recruitment process not so fast that control impractical	Recruitment /reinvasion pace too fast or unpredictable (e.g. insect swarms)
Practical solutions available	No large-scale practical solution available (e.g. for cane toads)

Where *nil tenure* may be appropriate	Where likely to be inappropriate
Commitment to multi-seasonal, integrated, program	Medium-term resource commitment not available
Coincidence of public and private interests	• Diversity of ownership and different statutory obligations applying to publics vs private land; • Diversity of property management plans within a region and consequent lack of common purpose;
Scale is appropriate	Scale too wide to secure community consensus
NRM and on-farm economic objectives coincide	Divergence of NRM and on-farm economic objectives
Investment available – govt cash, landholder time	Not all effected landholders willing /able to invest (e.g. hobby farmers, absentee landholders).

Planned activity of AIA CRC and opportunities to trial *nil tenure*

The Australasian Invasive Animals CRC will begin on 1st July 2005 and its research and applications acknowledge that management of invasive pests is complex because it exists in a social context.

Any bio-physical solutions to invasive pests must be grounded in a solid science-based understanding of the problem. Solutions must, however, also address the problem in its practical, social, ethical, and legislative context. AIA CRC will use between ten and fifteen *Demonstration Sites* to research the practical management of invasive animals in different social (e.g. land tenure, ethical challenges) and technical (e.g. pest species, ecosystems) environments across Australia. Demonstration projects will be the focus for participatory action research programs to discover how to manage complex invasive pest control. Where there is the opportunity to apply the principle identified in this paper, they will be.

Demonstration sites, which are now being developed with the CRC's partners, will be the first 'port-of-call' for new AIA CRC research products and strategies. Biocontrol methods (carp), baits (fox, wild dog, invasive pig, rabbit, cat), viruses (house mouse, carp, rabbit), and lures (fox, wild dog, carp, invasive pig) and innovative strategies that move beyond simplistic single-species / single-solution concepts will be ground proofed through exhaustive and publicly critiqued ecological experimentation.

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ENHANCED FOX MANAGEMENT PROGRAM – PHASE 2 BASELINE SURVEY

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ABSTRACT: The Enhanced Fox Management Program was introduced in 2002 as part of a Victorian Government initiative to minimise the impact of foxes on environmental, economic and community values. Phase 1 involved a one-year fox bounty trial. Phase 2 replaced the bounty and aimed to increase coordinated baiting participation rates amongst land managers in sheep producing areas of Victoria. This paper reports on a baseline survey conducted as an evaluation component of the second phase, that collected information on motivation for fox control and methods used, perception of control success, and current baiting practice. The survey found 27% of land managers in sheep producing areas currently use baiting to control foxes, and 58% of those baiting coordinate their baiting with neighbours. Barriers to achieving program success will be the reluctance of land managers to view fox control as a community responsibility rather than an individual business activity, resistance to the use of 1080 baits because of the perceived risk to dogs, and the perceived administrative 'red tape' burden associated with baiting. The survey will be readministered after autumn baiting in 2005 to assess the impact of the Enhanced Fox Management Program phase 2.

INTRODUCTION

A three-year Enhanced Fox Management Program (EFMP) was introduced in 2002 as part of a Victorian Government initiative to minimise the impact of foxes on environmental, economic and community values. As part of the EFMP, a fox bounty trial was introduced across Victoria in July 2002 to reduce the number of lambs killed by foxes. A bounty of $10 was paid on each complete fox tail or fox tail skin deposited by a resident of Victoria at approved government works depots around the State. Bounty applicants were required to provide their personal details and information on where and when the foxes were taken.

An evaluation of the bounty trial found that it failed to reduce fox numbers to critical levels below which a long-term negative rate of population growth could be expected. The evaluation report recommended that the bounty trial be discontinued and replaced with targeted and coordinated programs predominantly based on baiting, to assist landholders to achieve a sustained reduction in fox abundance for a defined benefit (VIAS 2003).

The second stage of the EFMP was therefore developed to:

- Motivate the community to manage foxes on private land in a more coordinated, long-term and strategic manner;
- Increase broad-scale group-coordinated fox control programs on private land;

Monitoring programs were implemented to determine the efficacy of these community-based fox control programs and to provide information to landholders to improve the management of foxes.

The baseline survey is an evaluation component of the second stage of the EFMP and forms the 'before' of a 'before & after' comparison. The purpose of the survey is to provide baseline information on:

- landholder perception of fox problems and their response to the problems,
- general control, motivation and perception of success,
- baiting practice,
- attributes of baiters and non-baiters.

METHODS

Telephone interviews were conducted in January 2004 with 503 managers of private agricultural properties with an area greater than 10 hectares, in four sheep producing regions of Victoria (Edenhope, Euroa, Hamilton and Underbool). A stratified sampling design was used, with the sample size in each region being proportional to the total number of properties greater than 10 hectares in those regions, estimated from the Vicmap Property digital map layer. Lists of all telephone numbers for each region were generated, from which a random sample was taken.

Because improved baiting practice is a specific objective of the EFMP, it was necessary to ensure that large enough sub-samples of current ‘baiters’ were obtained to capture reliable baseline data. For this reason, quotas were imposed on the random samples. Numbers of baiters and non-baiters sampled randomly were recorded, but once the quotas for non-baiters in each region were reached, subsequent non-baiters were excluded from the final sample. Case weights for each observation in the final sample were then calculated to reflect the sample fraction relative to the population fraction. These weights were used within all statistical calculations to remove the bias associated with differential quotas. All percentages, means and significance levels reported in this paper are population estimates based on a case-weighted analysis of the survey results. Full details of the sampling design and case weighting are available in McGeary (2004).

A response rate of 30.3% was achieved. This took into account those excluded because quotas of non-baiters were exhausted. Totals for both the random sample and the final survey sample are shown in Table 1.

Table 1. Sample sizes

	Region			
Baiting **Practice**	**Edenhope**	**Euroa**	**Hamilton**	**Underbool**
	Random sample			
Baiters	30	57	78	32
Non-baiters	64	95	201	35
Total 592	**94**	**152**	**279**	**67**
	Survey sample			
Baiters	31	64	78	32
Non-baiters	58	87	133	20
Total 503	**89**	**151**	**211**	**52**

RESULTS

1. Landholder perception of fox problem and response to problem

Overall, the perception of foxes as a problem is high, with 80.2% of land managers believing foxes are a problem in their neighbourhood and 66.9% of land managers having done something since July 2002 to control foxes on the property they manage. Of those not controlling foxes, 60.2% claim they "do not have a real problem with foxes, or do not see many foxes". Other reasons given for not controlling foxes include "neighbour controls them" (8.4%), and "don't have a chemical licence/course certificate" (4.2%).

Of those respondents who recognise foxes as a neighbourhood problem, 13.3% have not attempted some form of control on their own property. The most common reason given is that foxes are not a real problem. This implies that respondents are distinguishing between foxes being a neighbourhood problem and being a problem on their own property.

2. General control, motivation and perception of success

Of those doing some fox control, 60.7% claim they were prompted to action by "foxes killing or attacking lambs". This rises to 75.1% when losses of all types of livestock are counted. The next most common reasons given were "there are a lot or increased numbers of foxes" (5.1%), and that "fox control is a regular part of a farming program" (4.2%). Only 2.1% claimed they were prompted to undertake fox control to "protect livestock on neighbouring properties". This has implications for involvement in coordinated group baiting campaigns.

Shooting was the most common fox control method used (88.9%), followed by baiting (40.6%) and then den destruction (37.9%). Respondents were asked to rate the level of effectiveness on a scale from 1 (not at all effective) to 5 (very effective) of all the control methods they nominated. Taken individually, shooting was rated as more effective than all other methods (3.75), with baiting the next most effective (3.47). Of all those land managers who use baiting as a control method, 87.8% use it in combination with at least one other method, most often with shooting. Mean effectiveness ratings for baiting ranged from a high of 3.81 when baiting is used alone, to a low of 3.24 when baiting is combined with a method other than shooting. It is likely that those with higher confidence in the effectiveness of baiting see less need to complement it with other methods.

Respondents who indicated they had done some fox control since July 2002, but had not used baiting were asked if they had ever used baiting in the past. A total of 29.9% indicated they had. The reason given most often for no longer using baiting was the risk baiting posed to dogs or actually having lost a dog through baiting (32.6%). The next most common reason given was a lack of confidence in the effectiveness of baits (27.6%). Concerns about there being too much red tape to obtain a permit or not being able to purchase bait without a licence also rated highly (23.1%).

3. Current baiting practice

Baiting frequency and timing

Since July 2004, 27.1% of the land managers surveyed in sheep producing areas of Victoria have used baiting to control foxes. Of those, most (67.4%) usually bait once a year, with only 17.8% usually baiting more often. Figure 1 shows that lambing or kidding generally occurs between March and September, with peaks in April-May and August-September. Baiting activity is highest in autumn, with peaks apparent approximately a month before autumn lambing peaks. No corresponding baiting peak appears before spring lambing.

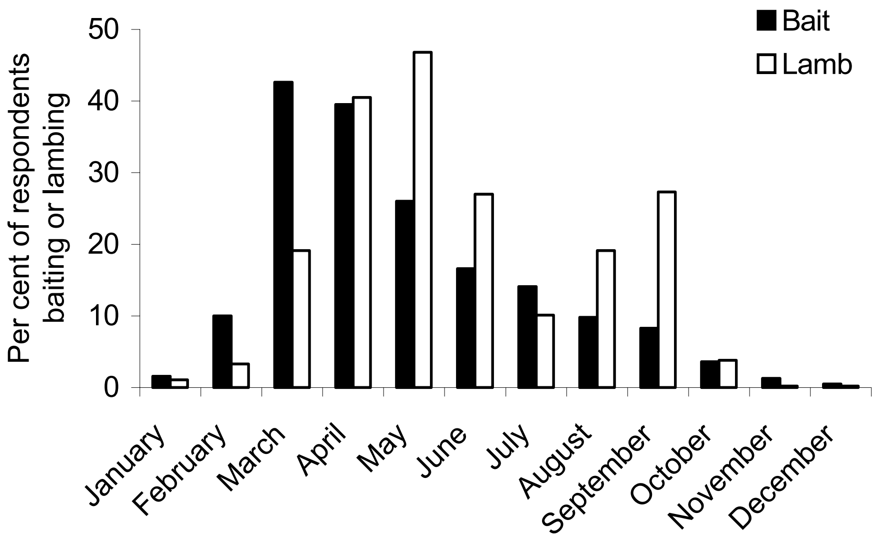

Fig. 1. Baiting and lambing months reported by land managers surveyed in sheep producing regions of Victoria.

Respondents who bait were asked how they decide when to start their baiting program. A total of 59.5% start to coincide with their own lambing, another 30.7% start when foxes are noticed, and only 7.8% are motivated to start baiting to coincide with neighbour or group baiting programs. However, 58.1% of those baiting do so in a group with their neighbours at least some of the time. Most respondents start baiting before lambing starts (84.7%), although 13.7% start baiting at the same time as lambing starts, and 1.6% start after lambing begins. Of those respondents who nominated the time before lambing or kidding at which they start baiting (n=154), 32.6% start four weeks before, while 27.3% start baiting less than three weeks before lambing. The mean number of weeks before lambing is 4.9.

Of those baiting, 37.8% decide to stop their baiting program when baits stop being taken. A further 28.0% stop when they have no more baits to put out. Another 19.3% stop when lambing has finished. A further 6.2% stop when fox activity stops and 2.9% cease baiting once lambing starts.

Maintenance of bait sites

Of those baiting, 41.8% claim to check the bait sites every day, and a high 85.7% claim to check them every four days or more often. While 99.2% of baiters claim to check bait sites, only 66.5% claim to replace baits if they have been taken. This implies 32.7% of baiters are checking the bait sites but not replacing taken baits.

Baiting density
On average, land managers lay bait on 59.9% of their properties, with 19.3% baiting over the entire property. A baiting density of at least one bait per 10 hectares is achieved by 45.3% of those baiting, with a median baiting density, including replacement baits, of 1.042 baits per 10 hectares.

4. Attributes of baiters and non-baiters
As property size increases, so too does the likelihood that baiting has been used as a fox control method ($\chi2 = 63.956$, $p < 0.0005$). Land managers operating a farm business on their property are significantly more likely to have used baiting to control foxes than those not operating a farm business ($\chi2 = 18.076$, $p < 0.0005$), and those breeding livestock on their property are significantly more likely to have used baiting to control foxes than those not breeding livestock ($\chi2 = 21.456$, $p < 0.0005$). Those actively involved in a landholder group are significantly more likely than non-members to have used baiting to control foxes ($\chi2 = 34.630$, $p < 0.0005$), and to have coordinated their baiting with neighbours ($\chi2 = 7.477$, $p = 0.024$). Males are significantly more likely than females to have used baiting to control foxes ($\chi2 = 18.471$, $p < 0.0005$).

5. Additional comments
Respondents were given an opportunity at the end of the questionnaire to add comments. Of all respondents, 43.7% had something to add. The desire to keep the bounty was by far the most often mentioned comment. Non-baiters were not significantly more likely to make this comment than baiters.

CONCLUSIONS

The EFMP program aims to improve coordinated baiting participation rates amongst land managers in sheep producing areas of Victoria. Based on the survey results, an estimated 27% of those land managers use baiting to control foxes, and 58% of those baiting coordinate their baiting with neighbours. Most are prompted to bait to coincide with their own lambing, with only 2% baiting to protect livestock on neighbouring properties. A further 8% believe that because their neighbours are controlling foxes, there is no need for them to undertake any fox control on their own properties.

It is anticipated that the biggest barrier to the program achieving success will be the reluctance of land managers to view fox control as a community responsibility rather than an individual business activity. The aim of increasing spring baiting participation rates will be more difficult to achieve in regions such as Underbool and Edenhope where lambing, and therefore traditional baiting, occurs only in autumn months. Resistance to the use of 1080 baits because of the perceived risk to dogs (33% of those no longer baiting) as well as the perceived 'red tape' burden (23% of those no longer baiting) will also be difficult to overcome.

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FACILITATING THE MANAGEMENT OF FOXES ON PRIVATE LAND: ARE LANDHOLDERS INTERESTED?

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ABSTRACT: Coordinated ground baiting programs to reduce fox predation of lambs were implemented in sheep producing areas of Victoria. Baiting occurred in autumn and spring 2004 with a third program scheduled for autumn 2005. The number of landholders participating, area baited and bait density were monitored over seven, 307-703km^2 areas. Estimates of fox density were determined over 79-105km spotlight transects before and after baiting. For the autumn baiting period the number of landholders participating was low (5-26%), the proportions of areas baited were low (3-36%) and the density of baits too low (0.7-4.1 baits/km^2) to cause major populations declines in monitored areas. However, baits/area baited may have been sufficient (3-53 baits/km^2) to causes short-term population declines at a property level. During spring very few landholders participated in the baiting program. Commencing with an estimated mean density of 0.82 (range 0.48-1.18) foxes/km^2, fox numbers declined after autumn baiting (52%). They remained static prior to spring baiting (51%), declined slightly after spring baiting (38%) and returned to original level (104%) prior to autumn 2005 baiting. The decline in fox numbers resulting from facilitated baiting would not be expected to have a major impact on the fox populations with in the monitored areas.

INTRODUCTION

Nationally the annual cost of fox predation on lambs is estimated at around $40 million, assuming foxes take 5% of all viable lambs Australia wide. Governments are estimated to spend around $2 million on fox control annually and landholders probably spend around $5 million (Bomford and Hart 2002). Coordinated, community-based fox baiting programs integrated with other control measures are considered to be an efficient means to manage foxes.

A three-year Victorian government Enhanced Fox Management Program (EFMP) was introduced in 2002 aimed at minimising the impacts of foxes on agricultural and biodiversity assets. The first phase of this initiative consisted of a trial, where a $10 bounty was paid on each fox tail presented to a collection point. An evaluation of this trial in mid-2003 found that it had failed to reduce fox numbers to a point where a long-term reduction in fox impact could be expected (VIAS 2003). In response to this, it was decided that the remaining two years of the EFMP would be on an integrated approach to fox control, underpinned by community-based, coordinated baiting programs, with a particular emphasis on the protection of the prime lamb and wool industries. The aim was to motivate the farming community to manage foxes on private land in a more coordinated, long-term and strategic manner through targeted extension activities. Monitoring programs were implemented to determine the efficacy of these community-based fox control programs and to provide information to landholders to improve the management of foxes.

METHODS

Monitor sites
Seven priority areas (307-703km^2) were selected from Australian Bureau Statistics data that defined areas of high value prime lamb and wool production. Two coordinated baiting programs occurred over 4-10 week intervals in autumn and spring 2004. A third baiting program is scheduled for autumn 2005. Landholder participation, area baited and bait density were monitored.

Facilitation effort
Traditional extension methods such as media releases, newsletters, field days and phone or personal contacts were used to promote the program. Department staff facilitated the effort and issued fox baits from field sites to aid in landholder access to baits.

Monitoring change in fox abundance
Spotlight fox counts commenced soon after sunset on three occasions before and after coordinated baiting programs were implemented. Counts occurred, where possible, on consecutive nights, along secondary roads (79-105km) from the tray of slow moving utility using a 100w spotlight. Transects where mapped and surveyed to determine area viewed by spotlight and data are presented in foxes/km^2 of area seen.

RESULTS

Landholder participation
For the autumn 2004 baiting period the numbers of landholders participating in the baiting programs were low, the proportions of areas baited were low and the density of baits most likely too low to cause major populations declines in monitored areas (Table 1). However, at most sites, baits/area baited may have been sufficient (3-53 baits/km^2) to causes short-term population declines at a property level. During spring baiting period, no landholders baited at Edenhope, Yarram and Euroa. At the remaining sites the participation of landholders was poor (Table 1).

Table 1. Landholder participation, proportion of area baited for the autumn and spring baiting 2004 and baits/km^2 for the autumn 2004 baiting period.

	Skipton	Hamilton	Edenhope	Yarram	Euroa	Underbool	Woosang
No. of landholders	*114*	*280*	*60*	*170*	*132*	*35*	*66*
Autumn 2004	23%	13%	25%	8%	5%	23%	26%
Spring 2004	4%	2%	-	-	-	7%	9%
Total area (km^2)	*523*	*703*	*489*	*489*	*307*	*639*	*419*
Autumn 2004	36%	30%	16%	11%	3%	12%	27%
Spring 2004	4%	14%	-	-	-	5%	17%
	Autumn 2004, baits/km^2 for the target areas and areas baited						
Target area	2.8	4.1	0.8	1.6	1.5	0.7	3.5
Baited area	7.7	13.7	5.0	14.8	52.7	3.1	13.2

Change in fox abundance

Commencing with an estimated mean density of 0.82 (range 0.48-1.18) foxes/km^2, mean numbers of foxes/km^2 declined after autumn 2004 baiting (0.47, range 0.17-0.72). Fox numbers remained static prior to spring 2004 baiting (0.44, range 0.15-0.88), declined slightly after spring baiting (0.34, range 0.10-0.62) and returned to original level (0.89, range 0.20-1.66) prior to autumn 2005 baiting (Fig. 1).

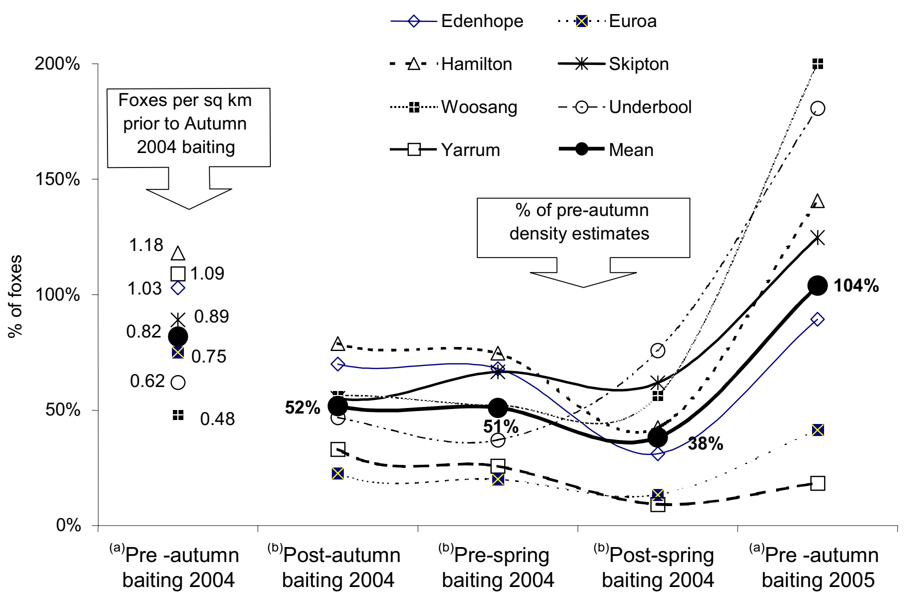

Fig. 1 Foxes/km^2 at the commencement of the program and foxes remaining expressed as a proportion of the pre-autumn 2004 fox densities for estimates taken before and after seasonal baiting programs (a ≠ b, $P<0.05$, t-Test with equal variances)

DISCUSSION

Studies from Australia and overseas demonstrate that for both low and high fox densities, lethal baiting provides the most effective and efficient means of fox control when integrated with other control methods (Saunders and McLeod, in press). In August 2003 the bounty trial was replaced with targeted and coordinated fox control programs, primarily based on coordinated baiting programs but integrating all existing control options. Departmental staff proactively facilitated fox control efforts in local areas using a range of traditional extension methods, to provide landholders with the necessary advice and assistance to enable well planned fox control programs to be organised.

Monitoring of landholder participation and fox abundance resulting from the autumn and spring baiting programs showed landholder participation in baiting programs was too low to achieve effective management of foxes within the monitored areas (Table 1 and Fig. 1). For all sites combined, the participation by landholders for the respective autumn and spring baiting were low (18% and 3%) and the portions of the target areas baited were also low (19% and 6%). This is in accord with a survey carried out before the coordinated baiting programs commenced to provide baseline information on landholder motivation, current fox control practices and perception of success for managing foxes (McGeary 2005). This survey was conducted around the four of the targeted areas and although 80% of landholders perceived foxes to be a problem, the survey found only 27% of landholders used baiting to control foxes. Of those baiting, 67% baited once a year with only 18% baiting more often. Similar baiting frequencies were observed from New South Wales surveys (Balogh 2001) where for those baiting, 90% of respondents baited no more than once per year.

The baseline survey (McGeary 2005) also identified potential explanations for low participation. Landholders preferred shooting as a primary control method due a perception that shooting is a more effective control option. The most common reasons landholders no longer baited was the risk posed to working dogs and concerns related to too much red tape to obtain a license to purchase bait and a permit to obtain baits. Confidence in the effectiveness of baits was also identified as a concern.

This body of work, along with the current surveys of attitude and motivation of fox management, clearly show that even when lamb prices are relatively buoyant, there are barriers for landholder involvement in coordinated broadscale baiting programs. Effective broadscale management of foxes by landholders is inadequate, for there is a apparent knowledge barrier related to a lack of understanding of fox behaviour, population dynamics, dispersal characteristics, 1080 toxicology etc. Spotlight counts of fox abundance shows fox populations within the areas they manage rebounding to original numbers within 12 months (Fig. 1). For those that do bait, the reduction of foxes at a local level may reduce lamb predation but this is difficult to quantify and there may be a perception across the broader farming community that controlling foxes to improve flock productivity may be of limited benefit.

Information to address all of the potential explanations for low participation were addressed through the extension programs. Many of these barriers were recognised early and strategies were developed that aimed to address them. Despite the large amount of targeted information available from experienced Departmental staff backed by detailed research and experience from Victoria and interstate, participation rates in coordinated bating programs remain low. This problem is not unique to this program and has often beset pest animal control programs elsewhere.

Extension information could be developed to better target these gaps in knowledge. But in the eastern states of Australia the efficacy of ground baiting foxes over large areas has not been extensively evaluated so it is difficult to advise landholders how to manage foxes effectively. Toxic ground baiting is dependent on factors such as: timing of baiting programs (fox/prey biology and behaviour), frequency of baiting, duration of baiting, baiting density relative to fox density, bait placement across the landscape. More applied research is require to determine optimum ground baiting practice and to evaluate the benefits of baiting at a local level compared to broadscale baiting.

Further research is also required into the social drivers and barriers to landholder participation in pest animal control programs. Large bodies of evidence exist to demonstrate the effectiveness of well delivered programs, a range of tools exist for managing the impacts of many of our major pest animal species and yet challenges often still remain in getting these techniques effectively applied on the ground by land managers.

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A PRELIMINARY MOUSE ABUNDANCE PREDICTION MODEL FOR THE CENTRAL QUEENSLAND GRAIN PRODUCING REGION

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ABSTRACT: A preliminary, mouse abundance model was constructed using artificial neural networks and data on trap success rates spanning a ten-year period in neighbouring catchments in Central Queensland. To predict trap success (percentage of traps that catch mice) in June, the model uses trap success rates in December and February, as well as rainfall in January/February and March/April. With a relatively small number of years in which all these data are available, there is a danger than the network may be 'overtrained', whereby the network 'memorises the data' rather than minimising the underlying dynamics. The preliminary model will be evaluated in coming seasons. In addition, the data used to construct the Cantrill model will be used to construct an artificial neural network to see if these provide any increased predictive power for southern Queensland.

INTRODUCTION

Mouse populations fluctuate widely in grain-producing areas within Queensland. Cantrill (1992) developed a plague prediction model for the central Darling Downs of southern Queensland. This is used to give advance warning of likely high mouse populations in that area. In Central Queensland, there are fewer data on mouse population indices as in southern Queensland, but there is the need for predictions of mouse abundance to enable grain-growers to plan their pest management programs effectively and efficiently.

The model of Cantrill (1992) is a rule-based model, built upon 12 years of regular trapping across the central Darling Downs. The original model has been slightly modified to take account of more recent data (up to 2002) and has a reasonably high success rate. There are not sufficient data for Central Queensland (Dawson and Callide valleys) to develop a similar, rule-based model.

Artificial neural networks have been used to estimate animal population changes using parental populations, rainfall and other climatic information (e.g. Obach *et al*. 2001). These models have advantages when the complexity and dynamic nature of the features being studied limit the development of simulation models (e.g. Schleiter *et al*. 1999). They are used for forecasting populations (e.g. incidence of cyanobacteria in the River Murray – Maier *et al*. (1998)). Ideally, these networks are developed using large data sets – for example, Maier *et al*. (1998) had 7 years of weekly data of eight variables.

We used trapping data for mice in Central Queensland to develop an artificial neural network that could predict mouse abundance in June, based on previous trap success rates and rainfall in preceding months.

METHODS

Monthly trapping data are available for two locations in Central Queensland (Dawson Valley and Callide Valley) for most years between 1990 and 2004, although trapping was conducted in only about half of the months with none at all in 5 years (giving a total of 60 trapping events in each catchment). The gaps in the data for years when data for most months were available were interpolated using spline estimation in TableCurve 2D. This enabled a data set of 6 years at each location where trap success for December, January and the following June was available for analysis. Rainfall data for January-February, and for March-April were obtained from records available on the Datadrill web site of Department of Natural Resources and Mines (http:\\nrm.dnr.qld.gov.au\silo\)

An artificial neural network (using Neuralyst) was developed using trap success in December and February, and rainfall for the two 2-month periods to predict the trap success in June (which was generally the month of the highest mouse abundance). Other rainfall and trap success dates were tested, but did not improve the fit to observed data. There were insufficient data to divide the data set into a training set and a test set. Because of the relatively small number of data samples, there is an acknowledged potential for overtraining of the network, resulting in the network learning the individual data points rather than detecting the underlying patterns.

The network was then used to predict trap success for a range of conditions. There are insufficient data to test these predictions against field data.

RESULTS

Observed mouse abundance varied between locations and between months (Fig. 1). Care must be taken when examining these differences as sampling was conducted in less than half of the months and these were not always the same months at different locations.

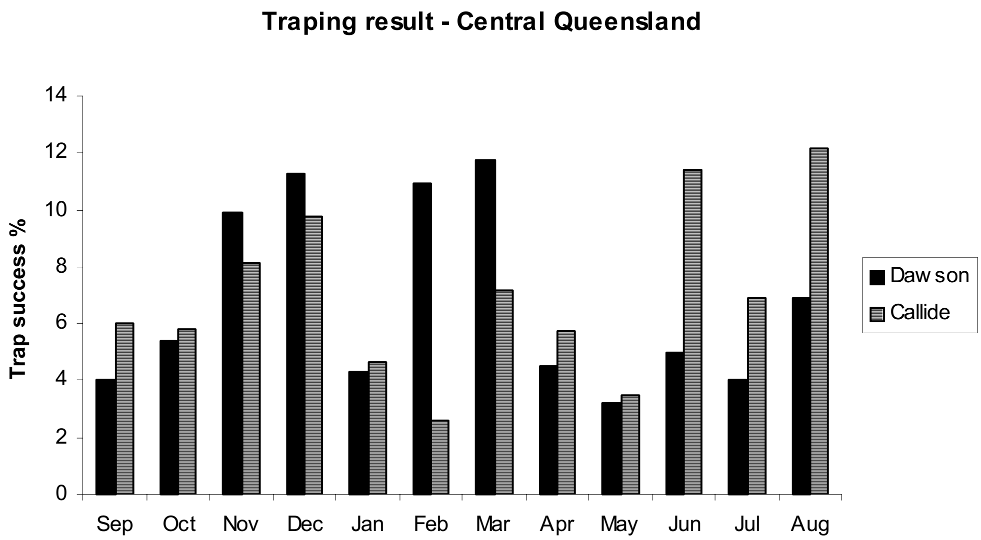

Fig. 1. Mean trapping success (for 1990 to 2004) for the two locations in Central Queensland. (Note trapping not conducted in all months).

The network developed fitted all the observations used in its development, which should be the case given the small sample size. The factors used in the network were trap success in December and February as well as rainfall totals for Jan-Feb and Mar-Apr. This was the minimum set of variables required to give a relatively stable network when one data point was omitted. The data points with high trap success in June had a strong influence on the network weights, and therefore on its predictions.

Predictions were made using the network, for a range of trap success in December and February as well as a range of rainfall totals for Jan-Feb and Mar-Apr. The highest trap success in June was generally achieved when rainfall in Jan-Feb was 150mm and 5mm in Mar-Apr (data not shown). Under these conditions, the predicted trap success in June was predicted for a range of trap successes in Dec and Feb (range from 2% to 35%) that covered the range of conditions observed in the data used in development of the network. These results are shown in Fig 2.

The highest predicted June trap success was observed when the December trap success was between 10 and 13%, irrespective of the February trap success. When December trap success was between 5 and 10% and February trap success was between 2 and 10, the predicted trap success in June was also high.

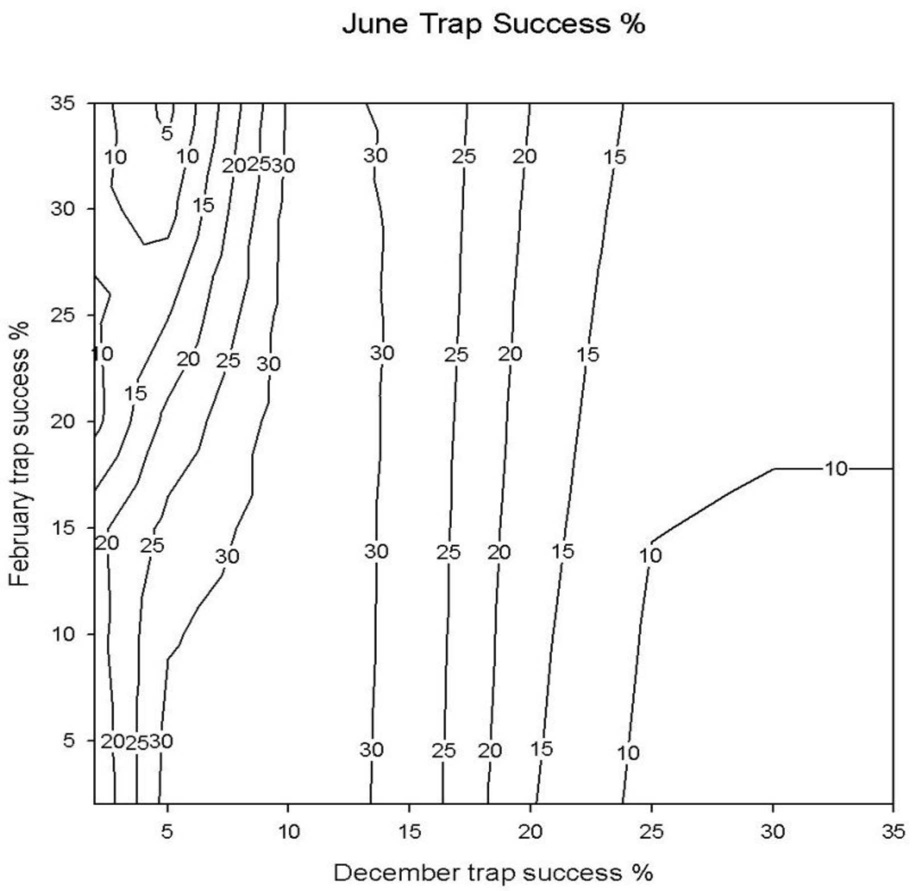

Fig. 2. Contour graph of predicted June trap success given December and February trap success, and given 150mm rainfall in Jan-Feb and 5 mm in Mar-Apr.

DISCUSSION

Moderate mouse abundance in December, followed by high rainfall in January-February and then low rainfall in March-April produced the highest mouse abundance in June. The trap success in February was less important than trap success in December, when using the effect on June trap success as the criterion for importance.

The preliminary results shown here suggest that artificial neural networks have potential to be used to predict the likelihood of high mouse abundance in winter in Central Queensland. Neural networks have the advantage that they can be used when the relationships between environmental characteristics and trap success are not well developed. Also, there is scope for linking artificial neural networks and formal simulation models. This integration produces hybrid models that may improve model accuracy by incorporating alternative and complementary sources of knowledge (Oliveira 2004).

The reliability of predictions will be tested during future trapping events. This may enable predictions to be made on the basis of less information than was required to develop the model of Cantrill (1992) for the Darling Downs region of southern Queensland.

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AN INTEGRATED PEST MANAGEMENT STRATEGY TO MANAGE MAMMAL BROWSING ON STATE FOREST IN TASMANIA

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ABSTRACT: Browsing of sown and planted tree seedlings by mammalian herbivores (wallabies, pademelons, possums and rabbits) is currently a significant biotic risk faced by production forestry in Tasmania. Use of the poison 1080 has historically been the principal method of managing mammal browsing. However it's use, particularly against native herbivores, is controversial and in 2004 the Premier of Tasmania announced that the use of 1080 on State Forest would cease from December 2005. New knowledge of the development of browsing-damage over space and time in young eucalypt plantations has now provided the framework to guide implementation of a suite of tactics to manage browsing, each to a particular level of browsing risk. In this paper we outline the strategy being adopted for the replacement of 1080-based management of mammal browsing in State Forest in Tasmania with integrated pest management.

INTRODUCTION

Forestry Tasmania is a Government Business Enterprise, responsible for managing 1.5 million hectares of State forest. In financial year 2003/04, 11300ha of native forests were regenerated, while 6100ha of eucalypt plantations and 2900 ha of pine plantations were established (Forestry Tasmania Annual Report 2003-04). Eucalypt plantations established under Forestry Tasmania's Intensive Forest Management Program, are managed for the production of sawlog and veneer through effective site selection and cost effective pruning, fertilising, thinning, and pest management techniques (Farmer and Smith 1997).

Native, and introduced, herbivorous mammals are significant pests in forest establishment in Tasmania (Statham 1983; Wardlaw and de Little 2000). The animals involved are the Bennett's wallaby (*Macropus rufogriseus*), brush-tail possum (*Trichosurus vulpecula*), Tasmanian pademelon (*Thylogale billardierii*), and occasionally the introduced European rabbit (*Oryctolagus cuniculus*).

If seedlings are less than one metre tall, and the browsing damage is repeated and severe, then browsing impacts on seedling survival and growth (Neilsen 1981, Wilkinson and Neilsen 1995). Left unmanaged, browsing can result in significant areas of seedlings failing to establish or be suitable for managing to produce sawlogs, thus devaluing the crop. For example, Neilsen and Wilkinson (1995) studied 586ha of unprotected *Eucalyptus nitens* and *E. regnans* plantations and found 63% of area failed due to browsing.

For many years the primary means to mitigate damage has been the use of the poison 1080 (sodium monofluoroacetate) to reduce local browser populations. The use of 1080 has been highly controversial in Tasmania (Fabian 2001). In 2001 a government sponsored community consultation process set a benchmark to phase out the use of 1080 by 2015 (Tasmania Together Government Activity Report 2002). Forestry Tasmania has a corporate objective to enjoy the broad support of the Tasmanian community for State forest management, and has made a commitment to reduce absolute use of 1080 by a minimum 25% between financial years 1999/2000-2004/2005. By financial year 2002/2003 Forestry Tasmania had exceeded this benchmark with a 38% reduction in the amount of 1080 used (Forestry Tasmania Sustainable Forest Management Report 2002/2003). In September 2004 the Tasmanian Premier Paul Lennon gave the commitment to parliament that the use of 1080 on State Forest would cease from December 2005. During the 2004 Federal Election campaign, the Howard Government made a commitment to fund research to help eliminate the use of 1080 on private lands in Tasmania, as well (Loghnane 2005).

The reduction in 1080 use by Forestry Tasmania has been largely due to an increase in the use of shooting. The leader of the Tasmanian Greens, a party that tabled a bill in State Parliament to ban 1080 (for all users except those involved with fox eradication) (Booth 2004), has advocated shooting as an alternative to 1080; “And of course, we mustn't forget good old-fashioned shooting. There are some times when that is the most appropriate method to be used as long as you have skilled people who are doing it.” (Putt 2003). Further, the leader of the Australian Greens, Bob Brown, has also suggested shooting as an alternative to 1080; “There is electric fencing, and ultimately it is better to shoot the animals. It's much better for the environment than the indiscriminate 1080. They're using 1080 because it's cheaper than bullets" (Harvey and Sexton 2004).

Despite tacit approval of the use of shooting from such high profile political leaders, is likely that replacing 1080 with a single lethal option will quickly lose broad community support. For example, an opinion survey of Melbourne and Sydney residents, commissioned by the government department Tourism Tasmania, found that approximately 10% of respondents agreed that it is acceptable to use 1080 protect seedlings, while only around 30% agreed that it is acceptable to use professional shooters to protect seedlings (Roy Morgan 2004). Further, it is likely that shooting will be uneconomical and ineffective in a number of situations. An approach that maximises the use of non-lethal options for managing browsing, in order to reduce the need for lethal control, would be a better option both in terms of economics and social acceptability.

In this paper we outline our approach for developing a way of managing browsing mammals using the principles of integrated pest management (IPM). In particular we describe how we have used a risk-based framework to design the elements of an IPM strategy against marsupial browsers.

Understanding browsing risk

Over the past four years, we have undertaken regular and intensive assessments of browsing damage in unprotected eucalypt plantations, during the first few months after planting. These surveys, which included mapping the damage using Global Positioning Satellites, have provided us with an objective basis for classifying plantations into categories of browsing risk based on the rate at which browsing increases over time. We are currently undertaking a similar survey approach in sown native forest coupes

As a result of the surveys, we could classify the plantations into browsing risk classes, i.e. low-risk (the initial rate of browsing was less than 0.5% of seedlings damaged per day); moderate-risk (between 0.5% and 2% of seedlings damaged per day); and high-risk (over 2% of seedlings damaged per day) (A. Walsh, unpublished data). The rate of damage is important because if it is slowed down sufficiently, the growth of seedlings can continue to a stage beyond which browsing has little impact. Bulinski (1999) found a strong correlation between the percentage of seedlings browsed and the mean severity of damage to individual seedlings. Thus, in plantations where the percentage of seedlings browsed is high, the severity of damage and the impact on survival and growth is high as well.

We also found spatial patterns in browsing damage within plantations. We have not yet completed analysis of the relationship between spatial patterns of damage and site factors. However severe damage is sometimes confined to small areas in a plantation, which we call hot-spots. These hot-spots can occur in low-risk as well as higher-risk plantations. For example, the plantation illustrated in Figure 1 was a low-risk plantation, except for the presence of hot-spots. In high-risk plantations the hot-spots have spread to cover most of the plantation.

Fig. 1. Aerial photo and map of a *Eucalyptus globulus* plantation, showing browsing damage 19 weeks after planting. Dots represent position of surveyed seedlings, with open circles representing unbrowsed seedlings and filled circles representing seedlings that suffered browsing at any time during the study. Damage is clustered in a "hot-spot" in the top right hand corner, which is probably related to pademelons sheltering in forest in daytime then moving through the plantation to graze on pasture in the adjacent farm land at night as indicated by the arrow (A. Walsh, unpublished data).

The risk-based IPM for browsing mammals

The aim of the spatio-temporal studies is to enable us to predict the coupe browsing-risk, and the location of hot spots before planting/sowing. This will allow for integrated pest management by planning appropriate threat-abatement measures before damage occurs. Table 1 presents a prototype IPM strategy in which various tactics for managing browsing in a new plantations are deployed on the basis of risk and timing (pre-, at or post-planting).

Table 1. Outline of the browsing IPM strategy and the tactics used for eucalypt plantations of various browsing risk profiles (note hot-spots can be found in each browsing risk profile).

<table>
<tr><th rowspan="2">Stage of deployment</th><th colspan="4">Coupe browsing risk</th></tr>
<tr><th>Low</th><th>Moderate</th><th>High</th><th>Hot spots</th></tr>
<tr><td rowspan="2">Before planting</td><td colspan="4">Nursery manipulation of seedlings</td></tr>
<tr><td></td><td colspan="2">Shooting +/- trapping</td><td></td></tr>
<tr><td>At planting</td><td></td><td colspan="2">Repellents with diversionary feed</td><td>Tree guards or big seedlings</td></tr>
<tr><td>After planting</td><td></td><td colspan="2">Monitoring +/- shooting or trapping</td><td>Tree guards</td></tr>
</table>

Nursery manipulation of seedlings

Research is planned to develop techniques to manipulate seedlings during nursery cultivation in order reduce the likelihood and impact of browsing damage to individual seedlings by;

- decreasing seedling palatability by exploiting the heritability of high levels of particular plant-secondary compounds in eucalypt leaves (O'Reilly 2000),
- decreasing palatability by toughening seedlings through a regime of regular flexing, which has been shown (in captive animal trials) to increase lignin production and confer a small but significant decrease in palatability (Burton 2003), and
- increasing growth rates after transplanting by applying high-nitrogen fertiliser during nursery development (Close *et al.* 2002). A particular focus of this approach will be to develop ways to manipulate the fertiliser regime so as to also reduce the palatability of nitrogen-rich seedlings.

Pre-plant shooting and/or trapping

In high-risk plantations, and some moderate-risk plantations, lethal methods to reduce browser populations will be required before planting. Diversionary feed, such as chopped carrot, will be used as bait in order to monitor the need for, and effectiveness, of shooting operations. Diversionary feed will also be used to attract the cryptic browsers into highly visible areas where they can be shot efficiently and humanely.

Trapping, where animals are caught and held alive in a cage overnight, before being shot the following morning, does not rely on establishing a line of sight to the targeted animal. We expect this method to be more effective than shooting in areas of reduced visibility due to vegetation, topography or harvest debris. While commonly used to manage possums, it is not an established method for managing pademelons. Two trap designs that may be suitable to capture pademelons already exist (Kinnear *et al.* 1988; Pollock and Montague 1991). However two other traps designs have recently been developed in Tasmania. Research and development is underway to test these latter designs to ensure they are humane, as well as to determine their effectiveness in reducing the rate of browsing.

Experience of US wildlife damage managers has shown that in order to maintain public trust when using lethal methods, an important consideration is to document that the animals taken are indeed the ones causing the damage (Dolbeer 2003). It may be possible to more confidently predict which species of browsing mammal is likely to be the most damaging in a particular situation by conducting animal tracking studies to try and detect associations between damage and site.

Repellents with diversionary feed

The repellents, WR-1® and PlantPlus® (known as PinePlus® in New Zealand) have been shown to reduce browsing damage (Marks *et al.* 1995, Delbridge and Lutze 1998, Johnston *et al.* 1998, Broekman and Wood 1999, Montague 2001, Witt 2002, A. Walsh unpublished data). Depending on the level of browsing risk, repellents slow the rate of browsing, which allows more time for seedlings to toughen and grow, as well as time to conduct lethal control operations if needed. These repellents are most cost-efficiently used by applying to seedlings whilst in the nursery just before dispatch. In the case of PlantPlus, this restricts the period of repellency to a narrow window of 2-3 weeks after planting (A. Walsh, unpublished data). The cost-effectiveness and practicality of re-applying repellent to planted seedlings in the field, and the species-specificity of the repellents (in order to deploy to correct areas) requires further investigation. Both WR-1 and PlantPlus require registration by the Australian Pesticides and Veterinary Medicines Authority.

Diversionary feed is required in order for repellents to be effective, as it provides animals an alternative to the seedlings treated with repellents (L. Clark pers comm, A. Walsh, unpublished data). The deployment of such crops in plantations could involve the use of existing vegetation growing on the site, sowing a decoy crop on site, or feeding out forage grown elsewhere. Further research is needed to select the most suitable crops/food for diversionary feed, develop cost-effective means for deployment, and evaluate the effect of diversionary feed on the behaviour of target animals (with respect to crop damage), as well as any non-target effects.

Tree guards or big seedlings

Traditionally, hot-spots of severe browsing damage in plantations could be found even where 1080 was used, and even after multiple poisoning operations. Where these hot-spots occupy only a small section of the plantation, it is likely to be more effective to use tactics tailored specifically for these areas. Tree guards or extra-tall seedlings have been identified as the most practical option to protect seedlings in hot-spots. Ideally, hot-spots will be identified prior to planting so that appropriate tactics can be deployed before damage occurs. Because of their greater cost, these options would be used on a reduced number of seedlings.

Tree guards that are currently available are unsuitable for industrial eucalypt plantations, and further research and development is required to provide an improved design. Extra-tall seedlings are grown in the nursery to the "browse-proof" height of 70-100 cm, and are coated with the repellent WR-1®. A field trial to evaluate the performance of tall seedlings is in progress. Fencing also remains an option that can be used in certain situations, particularly in suitable terrain where neighbouring vegetation communities harbour browsing mammals. However, the deployment of a physical barrier needs to be carefully considered due to the substantial costs ($AUD7000/km) and the potential for severe crop losses if the barrier fails.

Post-plant monitoring ± shooting or trapping

The non-lethal tactics just outlined may be sufficient to manage browsing in low risk plantations and hot-spots. In moderate and high-risk plantations, non-lethal tactics are not likely to provide sufficient protection. We have developed cost-effective monitoring method (A. Walsh, unpublished data) to detect when further controls are needed for protection. We plan that such monitoring, done regularly, would guide the use of post-plant shooting or trapping operations.

Sustainable management of browsing mammal populations

We have developed a strategy that aims to manage browsing during the relatively short time period that plantations are vulnerable, and spatially only at the coupe level. However the current forestry – agriculture interface favours high densities of the browsing mammals (Coleman *et al.* 1997, Efford 2000). In the longer term, this crop protection approach to managing browsing is not likely to be sustainable if used in isolation.

Another approach is to undertake landscape-scale management. Property based game management plans are being used increasingly in Tasmania to provide landscape-scale management (Game Management Services Unit 2004). The tools of property-based wildlife management plans are currently limited to culling. Further research is needed to expand the range of tactics available to manage populations at the landscape level. This should include research to better understand the response of browsers to the forestry – agriculture interface, as well as investigating the inter and intra-species interactions and their effect on browsing damage.

ACKNOWLEDGEMENTS

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ABUNDANCE AND MOVEMENT OF KOI CARP (*CYPRINUS CARPIO HAEMATOPTERUS*) IN THE LOWER WAIKATO RIVER SYSTEM

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ABSTRACT: Koi carp (*Cyprinus carpio haematopterus*) are classified as noxious pests under the 3rd schedule of the Freshwater Fisheries Regulations 1983, and an unwanted organism under the Biosecurity Act 1993. Details of their introduction in the late 1960s are unknown but they have since spread widely throughout the Auckland/Waikato Regions, with isolated illegal liberations in other parts of the country. They have become the dominant fish biomass at all Waikato River sites that we have studied. Information on population parameters and movement of these fish in the Waikato system is necessary to underpin efforts to manage this pest. Biomass estimates for carp range from 500 – 2200 kg/ha at some sites in the lower Waikato River and its associated tributary lakes, and they now dominate the lower river system comprising approximately 80% of all fish biomass within areas studied. Past studies have established that serious ecosystem deterioration may be caused by carp at densities exceeding 450 kg/ha. Exotic fish species comprised much of the remaining fish biomass (goldfish, rudd, catfish).

To study movement and growth, we have dart-tagged and released 1300 koi carp (2.73 tonnes) throughout the lower Waikato River system to determine whether koi were locally resident or migratory. Fish were captured by boat electrofishing and released at the site of capture. To date, we have recaptured 24 fish (a recapture rate of 2%). Recaptures included boat electrofishing and returns from recreational bow hunters. Time at liberty of these fish ranged from 5 to 462 days, with no significant relationship between time at liberty and distance moved. 23 of the recaptured fish moved less than 1 kilometre from the original point of capture while the remaining fish (a large spawning female) moved a distance of approximately 7 kilometres from the main stem of the river into an adjacent lake/wetland complex. This suggests that most koi do not travel great distances in the Waikato River system, but raises the possibility that some fish may move to find suitable spawning habitat. This is in contrast to Australian studies of common carp (*Cyprinus carpio carpio*) within the Barmah–Millewa Forest area; females remained close to floodplains in readiness for spawning but males migrated large distances. Koi carp aged by scale annulus counts ranged from young of the year to 10 years of age, with most fish in the 5-6 year age class. Growth rate analysis indicates that New Zealand koi grow faster than Australian carp, however, anecdotal reports from bowhunters suggest that the average size of koi shot in the lower Waikato River has declined over the last 5-10 years, which may indicate increasing intraspecific competition or resource limitation. There was no obvious size or seasonal bias on the capture of koi carp by boat electrofishing or on recapture of tagged individuals.

ASSESSING CARP BIOLOGY IN NSW: THE FIRST STEP IN A SUCCESSFUL IMPLEMENTATION STRATEGY FOR DAUGHTERLESS CARP

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ABSTRACT: Introduced carp (*Cyprinus carpio*) populations spread throughout the Murray-Darling Basin in south-eastern Australia following extensive floods in the 1970's (Shearer and Mulley 1978). Carp are now the dominant species within the Murray-Darling Basin and are considered noxious in most states of Australia (Koehn *et al.*2000). An effective control program is a necessary part of rehabilitating the Murray-Darling Basin (MDBC 2004). An IPM strategy including the development of 'daughterless' biotechnology (CSIRO 2002) is being developed by the CRC PAC in order to address that need. A fundamental stage in developing an IPM program is an assessment of the status and population biology of carp populations throughout the Murray-Darling Basin. As a result, a state-wide data collection program was initiated in New South Wales (and will be rolled-out to cover the entire Murray-Darling Basin).

Data collection involved four components of sampling: larval sampling to identify 'hot-spots' of carp breeding; benchmarking the sex ratio throughout NSW (prior to release of 'daughterless' carriers) and collecting DNA samples for genetic population structure assessment; assessing spatial and temporal variation in reproductive condition throughout NSW and assessing spatial variability in population dynamics.

The results of sampling undertaken to date suggest that there is little spatial variability in the carp breeding season throughout the basin, with widespread spawning activity in both Spring and Autumn. In contrast, there is substantial spatial variability in carp breeding sites, with carp breeding generally restricted to large wetland systems in the lower parts of catchments and large impoundments at higher altitudes. Spawning areas identified so far (in order of importance) are the Gwydir wetlands (up to 300,000 larvae per ML), Namoi wetlands (up to 7,700 larvae per ML) and the Barmah-Millewa Forest (up to 1,700 larvae per ML). The benchmark of sex-ratio throughout NSW identified that sex ratio is not a uniform 1:1, with a general pattern of female-dominated populations in the north and male-dominated populations in the south.

These results provide useful information for the effective implementation of an IPM strategy. When the additional information on age structure is available from the analysis of otoliths, and with the aid of detailed models of carp dynamics, there will be a sound basis for the design of an IPM strategy.

The current project is restricted to NSW, but it will be implemented across the entire Murray-Darling Basin under a new CRC (the Australasian Invasive Animal CRC), which comes into effect in July 2005.

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SEX-SPECIFIC APOPTOSIS FOR ACHIEVING DAUGHTERLESS FISH

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ABSTRACT: The central theme to the Daughterless Carp Approach (DCA) is the conversion of female embryos to males via RNAi knockdown of aromatase gene expression. Modelling of the DCA has indicated that rate of reduction in population size is directly related to copy number of the gene construct in transgenic fish. However, high copy number has been suggested to be responsible for silencing of transgenes after several generations in integrated transgenic lines. One method to circumvent using multiple copies of the same transgene would be to target RNAi knockdown of alternative sex determining genes in the female pathway thereby effectively achieving increased copy number of male determining loci while minimising the risk of long term silencing. Selective destruction of cells responsible for promoting female sexual development has also been implicated in promoting development of male gonads and may also provide alternative mechanism for achieving a daughterless fish. Population modelling has indicated that the approach of using a sex specific sterilizing or sex specific lethal gene construct can be as effective as a sex-altering construct. Development of mechanisms for either sterilizing (Sex Sterile) or killing embryos (Sex Lethal) using a sex specific gene construct has therefore become a parallel line of daughterless research to compliment constructs achieving sex reversal using RNAi. This paper will discuss the recent advances in developing both sex specific sterile/lethal constructs and their application to the Daughterless Carp project.

SIMULATION OF CARP (*CYPRINUS CARPIO*) POPULATION AND CONTROL DYNAMICS IN THE MURRAY-DARLING BASIN, AUSTRALIA

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ABSTRACT: The recent development of carp population models CarpSim (PIRVic) and carpmod (CSIRO) has allowed the simulation of a range of management options on closed single-populations of carp. At recent meetings of the National Carp Modelling and Assessment Group it was agreed that the CSIRO group would concentrate on simulating the dynamics of a range of genetic management tools, and the PIRVic group would develop CarpSim as a broadly applicable carp management simulator and expand the spatial context of it s simulations. Previous CarpSim simulations were parameterised using field data from two stocks in the Victorian Murray-Darling Basin (MDB). Fieldwork in NSW, SA and Qld is currently targeting a range of additional MDB stocks to enable realistic parameterisation of a MDB model with sub-populations and movement patterns between them. Once this new data is available is will be used to populate the next generation of CarpSim simulations. The latest development of the model (CarpSim2) will investigate the effects of spatial partitioning in the carp population on the efficacy of a range of carp control methods.

Management scenarios that can be simulated will include fishing, trapping, poisoning, spawning-sabotage, and genetic technologies such as daughterless. CarpSim2 is being developed in visualbasic.net as a stand-alone, Windows based application with user friendly front-end and numerical and graphical outputs. Until the new field data is available, hypothetically parameterised discreet sub-populations, connected by a range of movement-rate scenarios will be used to demonstrate CarpSim2 and explore the effects of spatial segregation.

INVESTIGATION INTO POPULATION GENETICS OF COMMON CARP (*CYPRINUS CARPIO)* IN THE MURRAY-DARLING BASIN OF AUSTRALIA

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ABSTRACT: Common carp (*Cyprinus carpio*) were introduced to Australian waterways early last century. The early introductions, however, either did not give rise to established populations in the wild, or formed populations that did not migrate far outside the area in which they were introduced. In the 1960s carp bred by Boolara Fish Farms were used to stock farm dams in Victoria. Although attempts were made to eradicate these fish, some managed to escape into the Murray-Darling Basin. After this introduction, carp populations in the Murray-Darling began to grow rapidly, and carp began to establish in new areas. Flooding in the 1970s facilitated this spread, by allowing carp to pass over drowned-out weirs and providing abundant habitat for spawning.

Carp have since become a major freshwater pest in Australia. Thriving in disturbed habitats, they degrade waterways and compete with native fish for resources. They are now established in every state and territory, except the Northern Territory. Their broad tolerance to salinity and temperature gives them the potential to occupy possibly all permanent freshwater habitats in Australia. They can be found in nearly all parts of the Murray-Darling Basin, except in some northern reaches where their progress has been hindered by dams, and at some higher altitudes where habitats are not permissive. Effective control of carp will require understanding their population biology. Many aspects of carp population biology can be elucidated through population genetic studies.

Historical evidence indicates that four genetic strains of carp have been introduced into Australia: Prospect, Boolara, Yanco and Koi. The Prospect strain was among the first carp to be introduced into Australia. These carp were imported from Europe and introduced into Prospect Reservoir in the Sydney Basin, where they have persisted to the present day and from where they were used to found other populations of carp around Sydney. The Boolara strain refers to the carp bred by Boolara Fish Farms. This strain is thought to be a result of an illegal import from Europe, although the company claims that all their carp were taken from Prospect Reservoir. Koi carp are an ornamental variety of carp originally bred in Japan, which are now present in many Australian waterways. The Yanco strain is thought to be descended from 'Singapore' Koi, released into the Murrumbidgee Irrigation Area in the 1930s or 1940s.

Previous population genetic studies on carp in Australia have used morphology, allozymes and RFLP of whole mitochondrial DNA. These methods have been used successfully to diagnose the four strains of carp, although the Boolara and Prospect strains were could not be distinguished from each other in all studies. Weak genetic structuring has detected between some locations. The carp populations in the Murrumbidgee Irrigation Area have been shown to be more genetically diverse than in the rest of the Basin, consistent with both Yanco and Boolara carp being present in this region. There is evidence that Koi carp have contributed DNA to numerous populations. There is also evidence that the four strains can interbreed freely.

This study aims to gain further insights into the population genetics of carp in Australia. Carp are currently being sampled from every major river in the Murray-Darling Basin, above and below every major dam. Carp have also been collected from sites around the Sydney Basin, and negotiations are underway to get DNA samples from carp populations in Europe and Asia. Genetic variability is being assessed by means of microsatellite genotyping, and by using sequence data from mtDNA loci and from the ovarian aromatase gene.

To date, fin-clips have been collected from approximately 1100 carp, 65 wild goldfish and 23 carp-goldfish hybrids, and DNA has been extracted from a total of 638 of these samples. Sample collection and DNA extraction are ongoing. Multilocus PCR has been optimised for 11 microsatellite loci, with ongoing optimisation for at least another three such loci. Sequences have been obtained for the mitochondrial D-loop and the ovarian aromatase gene in both carp and goldfish.

There are many questions that can be explored in the present study. Computer programs will be used to test for departure from admixture, to estimate the number of genetically distinct populations (if any exist) and to ascertain how different populations are related to each other. Introgression between carp and goldfish will be investigated, as will the European and Asian origins of carp in Australia. Effective population size and levels of geneflow and per generation will also be estimated. A thorough and ongoing survey of the literature is being undertaken, to ensure that the most appropriate of the many recent developments in analysis methodology are utilised to extract maximum information from the samples.

A PRACTICAL BAIT MARKER FOR BRUSHTAIL POSSUMS – WHISKER MARKING BY RHODAMINE B

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ABSTRACT: Practical field measurement of bait uptake by brushtail possums in New Zealand will become more important as new bait types, deployment methods, and active control agents reach field-testing stage. Potential markers of bait uptake were identified, fed to captive possums and efforts made to detect subsequent physiological marking. Clenbuterol (in hair) and amiodarone (in blood) were not suitable, but rhodamine B (RB) marked possum whiskers reliably. Further investigation with captive possums dosed with 10 mg/kg RB found no significant differences in the mean proportions of marked whiskers at 2, 6, 10, 20 and 40 weeks after dosing, indicating that marking persistence could be at least 40 weeks in field conditions. There were also no effects of the position of marked whiskers in the mystacial array on persistence of marking, and no significant differences in the mean proportions of marked whiskers in male and female possums. The probability that a randomly selected whisker was marked was 0.6, indicating that six whiskers should be used as the minimum sample size in field applications of RB. Fluorescence microscopy thus provides a reliable method for detecting marking in possum whiskers in field applications of RB as a bait marker.

INTRODUCTION

Bait delivery of active agents (e.g. toxicants, biocontrol agents, vaccines) to populations of brushtail possums (*Trichosurus vulpecula*) in New Zealand is currently expected to retain a significant role in broad-scale management of their impacts. The efficacy of such control strategies relies on a high proportion of a field population encountering and consuming bait. Accurate quantification of field bait uptake will become more important as new bait types, deployment methods, and active agents reach field-testing stage. Techniques for measurement of bait uptake by possum populations require reliable identification of individuals that have consumed baits in the field, and are currently limited by practical constraints. Ideal characteristics of a compound that acts as a biological marker of bait uptake include ease of application to bait material, no effect on bait acceptance, and easily detected, relatively persistent marking. Markers with increased persistence are important for field study logistics in order to allow sufficient time for the recovery of animals to be examined for marking. Three compounds (clenbuterol, amiodarone and rhodamine B) were assessed against these criteria as bait markers in captive possums. Clenbuterol is a cardiovascular drug that can be detected in hair following oral administration and has been used successfully as a bait marker in dogs (Gleixner *et al.* 1998). Amiodarone is another cardiovascular drug, with a long half-life in humans and rats (e.g. Gill *et al.* 1992).

Rhodamine B (RB) is a non-toxic dye that fluoresces orange under ultraviolet light, and following ingestion can produce systemic marking in hair, detectable through fluorescence microscopy (Fisher 1999). This property of RB has been utilised in bait marker techniques for European badgers (*Meles meles*) (Southey *et al.* 2002), stoats (*Mustela erminea*) (Spurr 2002), house mice (*Mus domesticus*) (Jacobs *et al.* 2002) and Australian native mammals, including brushtail possums (Fairbridge *et al.* 2003). In possums, contact marking by RB of the mouth and gastrointestinal tract was found to persist for approximately 1 week (Morgan 1981). Greater persistence was expected if RB could be shown to reliably mark possum hair (whiskers), and in following trials we sought to more accurately define the persistence and incidence of systemic rhodamine B marking in possums using fluorescence microscopy.

METHODS

1. Marking of captive possums by rhodamine B, clenbuterol and amiodarone

Thirty wild-caught brushtail possums were acclimatised to indoor individual housing at the Landcare Research animal facility, Lincoln. They were dosed with three potential bait markers in a ration of palatable food (non-toxic cereal pellet bait), and subsequently sampled as shown in Table 1. Treatments were prepared by soaking individual rations (25-g pellets) in 1.5 mL of a solution of the appropriate marker in water (37.14 mg/mL RB, 0.33 mg/mL clenbuterol, or 2.0 mg/mL amiodarone), then drying at 40°C for 2 h. Possums were offered treated pellets (Table 1) for a maximum of three consecutive days, until the required dose (either 50 mg RB, 0.5 mg clenbuterol, or 3 mg amiodarone) was consumed.

For RB sampling, possums were lightly anesthetised with CO_2:O_2 (2:1) and three mystacial vibrissae (whiskers) were sampled from each by plucking, ensuring that the bulb of the whisker was removed intact. Whiskers were sampled at specified intervals after the first and a second dose of RB (Table 1) and washed and mounted for fluorescence microscopy as described by Fisher *et al.* (1999). Microscopy was carried out using a Zeiss Photomicroscope III, with a high-performance filter set for rhodamine B 200, comprising band pass interference exciter filter BP546/12, barrier filter LP590 and chromatic beam splitter FT570, a halogen UV light source and ×2.5 objective. Individual whiskers were recorded as 'marked' or 'not marked' and the position and appearance of any marking described.

For clenbuterol marking, sufficient fur to yield approximately 50 mg of hair powder was plucked, soaked in water for 1 h, rinsed twice with 30 mL water, twice with 30 mL 0.1% bovine serum albumin (BSA) solution, and three times with 30 mL 0.2% Tween 80, then dried at 60°C. Samples were pulverised to powder with a Mikro-Dismembrator II then stored at −25°C. Clenbuterol was extracted (1 mL of 50 mM aqueous 1,4-dithiothreitol, 50 µl of 5 M sodium hydroxide and 2.5 mL of tertiary butylmethyl ether (TBE)) and shaken overnight at room temperature. The ether was separated by centrifugation and the extraction repeated for 1 h using only TBE. The ether phases of each sample were combined and evaporated at 60°C. The residues were dissolved in 300 µL assay buffer (7.12 g/L Na_2HPO_4, $2H_2O$, 8.5 g/L NaCl, 1 g/L BSA, pH 7.2) and appropriate dilutions assayed using an enzyme immunoassay kit (RIDASCREEN® Clenbuterol Fast, R-Biopharm GmbH, Germany). Recovery efficiency was evaluated using powdered hair samples spiked with clenbuterol at 10, 30 and 50 ng/g. For amiodarone marking, possums were anaesthetised with fluothane and blood samples (1 mL) taken from the tail vein into heparinised tubes and centrifuged to obtain serum, which was frozen at −25°C until analysed. Amiodarone serum levels were measured by HPLC as described by Manfredi *et al.* (1995), with a least detectable level (LDL) of 0.4 µg/mL.

Table 1 Treatment of thirty captive possums with three different chemical markers and collection of samples for analysis of marking

Day	**Procedure**
0	First treatment RB (50 mg per possum) offered (*n* = 30)
14	Ten whiskers from each possum sampled for RB detection
18	Clenbuterol (0.5 mg per possum) offered (*n* = 30)
28	Whiskers (28 days after first RB) and fur (13 days after clenbuterol) sampled Second treatment RB (50 mg per possum) offered (*n* = 30)
56	Whiskers (56 and 28 days following first and second RB treatments, respectively) and fur (41 days following clenbuterol treatment) sampled
84	Fur (69 days following clenbuterol treatment) sampled Amiodarone (3 mg per possum) offered (*n* = 12, 6 male and 6 female)
98–140	Blood sampled for amiodarone (14, 29, 42 and 56 days after treatment)

2. Persistence and reliability of detection of rhodamine B marking in possums

Twenty-four wild-caught possums (12 M, 12 F) were acclimatised to captivity as before, briefly anaesthetised with fluothane, weighed and gavage dosed with 10 mg/kg RB. This dose was selected to simulate a field situation where a 3-kg possum fed on 5 g of bait containing 0.5% RB (w/w). Groups with equal sex ratios were killed for sampling of all whiskers after 2 weeks (*n* = 6), 6 weeks (*n* = 6), 10 weeks (*n* = 4), 20 weeks (*n* = 4), and 40 weeks (*n* = 4). Whiskers were plucked and washed as previously described, identified according to their location on the possum (Fig. 1), and stored in individual bags (rather than mounted on slides). Strong bilateral symmetry exists in possum vibrissae (Lyne *et al.* 1974), and it was assumed that marking on the left-hand side would be representative of that on the right-hand side. All left-side whiskers were examined for markings using fluorescence microscopy as described. Individual whiskers were recorded as ‘marked’ or ‘not marked’ and the position and appearance of any marking described. To investigate the effects of sex, time since dosing, and location of whiskers (row) on the proportion of marked whiskers, a generalised linear mixed model was fitted to the data, using GenStat® version 6.1 (GenStat Committee 2002).

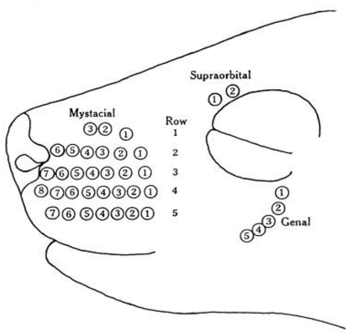

Fig. 1 Location of mystacial, genal and supraorbital vibrissae follicles of the brushtail possum (adapted from Lyne *et al.* 1974).

RESULTS

1. Marking of captive possums by rhodamine B, clenbuterol and amiodarone

Possums consumed an average of 47.4 mg RB each on the first treatment, and 31.3 mg each on the second treatment, and may have recognised RB baits as less palatable on a second exposure. Marking of possum whiskers by RB appeared as a fluorescent-orange band that could be distinguished from the natural background fluorescence often present at the hair root. Single RB bands were found on most whiskers. After the second RB treatment, fewer whiskers showed double bands (Table 2). Possums consumed an average of 0.44 mg clenbuterol over 3 d, but clenbuterol was not detected in hair extracts. It appeared something in the hair extract, possibly increased pH, was interfering with the assay so that high background levels were present and a standard curve could not be produced. The 12 possums offered amiodarone consumed an average of 2.5 mg each, but amiodarone was not detected in their serum.

Table 2 Number of possum whiskers marked with rhodamine B.

No. whiskers marked per sample	**Day 14**	**Day 28**	**Day 56 (after first RB dose) & Day 28 (after second RB dose)**	
			1 band	**2 bands**
0/3	1	2	3	19
1/3	7	3	4	9
2/3	12	9	13	1
3/3	9	16	9	0
% of whiskers marked	66.7	76.7	65.5	12.6
No. marked possums*	28/29	28/30	26/29	10/29

*30 possums were used but two slides were lost

2. Persistence and reliability of detection of rhodamine B marking in possums

There were no significant differences in the mean proportions of marked whiskers at 2, 6 10, 20 and 40 weeks after dosing (Fig. 2). There was no significant effect of position on the marking of whiskers (Fig. 3), and no significant differences in the mean proportions of marked whiskers in male (0.65 ± 95% CI 0.53 – 0.76) and female (0.53 ± 95% CI 0.40 – 0.65) possums.

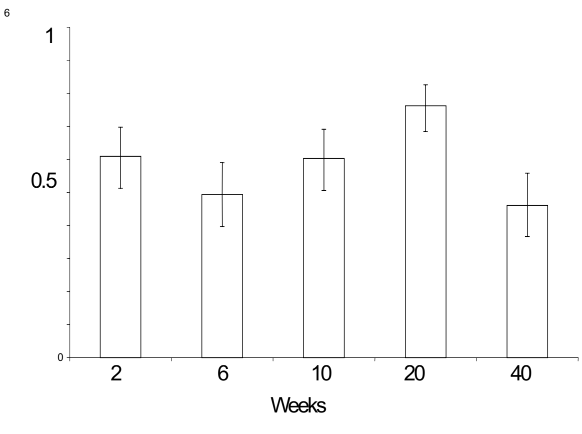

Fig. 2 Proportion of left-hand-side possum whiskers (y-axis) ± SE marked at different sample times after dosing with 10 mg/kg rhodamine B.

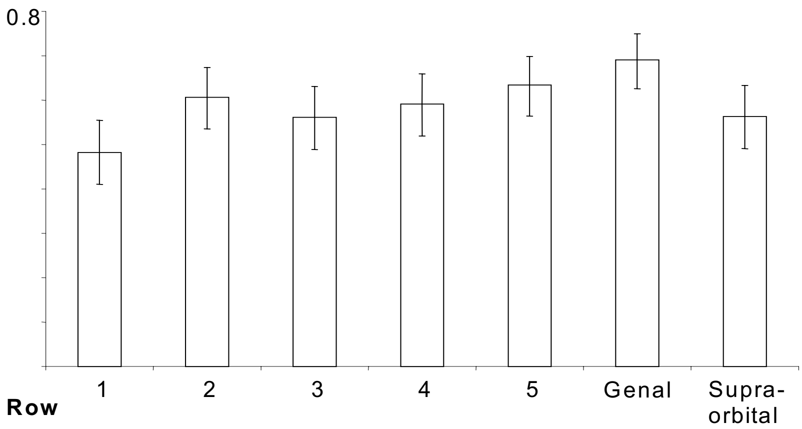

Fig. 3 Proportion of left-hand-side possum whiskers (*y*-axis) ± SE, marked after dosing with 10 mg/kg RB.

The overall mean proportion of left-hand-side whiskers with RB marking was 0.597 (upper 95% CI = 0.6801, lower 95% CI = 0.5071), suggesting that approximately 60% of vibrissae were actively growing at the time of dosing with RB. The probability that a random whisker is marked was approximated as 0.6, with the complementary probability that a random whisker is not marked being 0.4, so that the probability that at least one whisker will be marked in a random sample of four was 0.9744 (above 95% chance).

DISCUSSION

Neither amiodarone nor clenbuterol appeared to be suitable bait markers for possums. It was not possible to fully evaluate clenbuterol as a bait marker because of the limited flexibility of the relatively expensive commercial kit; regardless, the preparation of hair samples for clenbuterol extraction is labour intensive and requires specialised equipment, which reduces its practicality as a bait marker. However, RB marking can be reliably determined in whisker samples taken from possums up to 40 weeks after the last intake of RB. The practical implications of these results are that male and female possums are equally likely to be marked by an RB intake of 10 mg/kg or more. Whiskers sampled to examine for marking can be taken from any position in the mystacial, supraorbital or genal array with an equal probability of detecting marking if it is present. Allowing for sampling of club hairs (i.e. inactive whiskers not likely to be marked) and breakage of whiskers during sampling in field conditions, it is recommended that six whiskers should be used as the minimum sample size in field applications of RB as a bait marker in possums. For practical application in field conditions, when possums need to be released after sampling, it is suggested that the genal and supraorbital whiskers of one side are sampled. Successive intakes of RB can produce a series of fluorescent bands in whiskers (e.g. Fisher 1999; Purdey *et al.* 2003), as demonstrated in this trial with possums. The apparently lower incidence of 'double marking' in comparison to 'single marking' may be due to the differences in individual whisker growth at the times of ingestion of RB, e.g. the probability that a whisker is actively growing and therefore marked by RB at multiple times of RB ingestion may be lower than for a single instance.

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RESEARCH TO SUPPORT AND ENHANCE FERAL SWINE REMOVAL EFFORTS

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ABSTRACT: Swine adversely affect the environment in most places around the world where they have been introduced into the wild. In many of those places swine removal is key to protection of a variety of special habitats, wetlands in particular. We have pursued several avenues of research and technique development to enhance swine removal efforts, primarily in Florida. An easily-applied passive tracking index (PTI) with good statistical properties has been effective for monitoring swine distribution and relative abundance, thus aiding the location of control method applications and the evaluation of control results. A quadrat sampling methodology used in conjunction with the PTI population surveys was developed to estimate the amount of habitat damaged by swine in an area. Another method employs a series of transects specially developed to efficiently estimate damage to the exposed portions of the last remnant of a formerly extensive basin marsh system in Florida. Besides estimating damage levels, we developed credible means for monetarily estimating the value of the damage based on the dollar amounts that wetland regulators have allowed permit applicants to spend in mitigation attempts to replace lost wetland resources. Estimation of damage levels and their associated economic values before and after swine control permitted economic analyses of the removal efforts. Universally, the economic analyses demonstrated enormous benefit-cost ratios for swine removal, as well as large values per swine removed.

INTRODUCTION

Feral swine (*Sus scrofa*) are a particularly destructive exotic species in many places around the world (e.g., Seward *et al.* in press). They negatively impact the environment through habitat degradation, predation on native species, and competition with native species (Choquenot *et al* .1996; Taft 1999). Swine were first introduced into the wild in North America by DeSoto in the 1500's in Florida (Towne and Wentworth 1950), where today they flourish and cause widespread damage. The species possesses the highest reproductive potential of any large mammal in North America (Wood and Barrett 1979, Hellgren 1999), and the species currently inhabits many areas in such large numbers that it adversely impacts the environment and surrounding agriculture. Over 500,000 have been estimated to inhabit Florida (Layne 1997). Feral swine also can harbor a number of diseases transmittable to livestock or humans (e.g., Conger *et al.* 1999, Romero and Meade 1999, Taft 1999, Becker *et al.* 1978). In particular, the swine industry in the USA has nearly eradicated swine brucellosis and pseudorabies, but feral swine serve as a potential reservoir from which these diseases can be transmitted to domestic stock (Taft 1999, Taylor 1999). In Florida, large proportions of unique natural environments have been lost to urban development and agriculture. The U.S. Department of Agriculture/Wildlife Services (USDA/WS), the USA federal agency mandated to resolve human-wildlife conflicts, has been actively engaged to protect these increasingly rare and fragile natural habitats by removing the feral swine inhabiting them. Here we describe research thrusts aimed at supporting and enhancing the swine removal efforts.

RESULTS

Population indexing

Due to the logistical and theoretical difficulties associated with density estimation methods (e.g., see Leidloff [2000] for an excellent overview of potential problems with capture-recapture methods), indices of abundance, rather than absolute abundance estimates, were the only practical means for monitoring swine (Choquenot *et al.* 1996). For our purposes, a passive tracking index (PTI) has been an efficient means to monitor feral swine (Engeman *et al.* 2001). The method originated for monitoring wild canids in Australia (Allen *et al.* 1996) and in the U.S. (Engeman *et al.* 2000), and also proved simultaneously effective for swine (Engeman *et al.* 2002a). This low-tech method places a series of tracking plots throughout the area of interest. At each plot, the number of swine track sets (number of intrusions into the plot) is recorded for two consecutive days at each assessment time. After 24 hours, the plots are examined for spoor and resurfaced (tracks erased and surface smoothed) for the next day s observations. The PTIs and associated variances are calculated according to Engeman (in press) and Engeman *et al.* (1998) where a mixed linear model (e.g., McLean *et al.* 1991; Wolfinger *et al.* 1991) describes the number of intrusions on each plot each day. The mean number of track intrusions on each plot is calculated for each day, and the index value is the mean of the daily means. Adding to the robustness of the index, the variance formula derivation was based on a nonzero covariance structure among plots and among days, that is, without assumptions of independence among plots or days (Engeman *et al.* 1998). Maintaining permanent passive tracking plot locations maximizes index comparability across time (Ryan and Heywood 2003), providing a useful means to assess the changes in feral swine abundance while simultaneously providing information to describe the spatial distribution of their activity. Applications of the tracking plot information and the PTI included 1) optimizing the timing and strategy for swine removal, 2) minimizing labor by identifying areas where swine removal would have maximal effect, 3) assessing efficacy of removal efforts, and 4) serving as a detection method for re-invasion and identifying directions from which re-invasion occurs.

Damage assessment

Due to variability among habitats and associated difficulty in traversing the terrain, different sampling methods are more efficient for estimating damage in different circumstances. We applied quadrat and line-intercept, or transect-based, methods for sampling swine damage to natural environments. Swine damage was identified as ground overturned during foraging (rooting) activity. Tracks verified the species responsible. Armadillos (*Dasypus novemcinctus*) are the only other species in Florida that could produce superficially similar (small) patches of damage, which are easily distinguished from swine damage by examining tracks and whether the ground was overturned, or dug by forefeet.

Quadrat based

A quadrat sampling method was developed to use in conjunction with the PTI plot locations for estimating habitat damage by swine (Engeman *et al.* 2003). Each tracking plot location defines the location for 2 damage assessment plots. On one side of the road, a damage plot is established 1 m perpendicularly outward from the road edge. Each damage plot is a 5 × 1 m rectangle, with the long dimension paralleling the road, 1 m outward from the road. Each 5 × 1 m plot is established using a 1 × 1 m square constructed of PVC pipe. This square is folded over 4 more times beyond its initial placement to establish the plot. Cryptically placed, sand-coloured, wooden stakes in diagonal corners define the plot for future reference. The second damage plot defined at the same road location is constructed in the same manner on the opposite side of the road beginning 3 m in the opposite direction from the first plot, and leading away from the opposite damage plot.

The 1 × 1 squares are used to provide accurate and readable measurements of the area damaged within the 5 × 1 m plots to the nearest 5%. String is placed in a "+" sign across the 1 × 1 square to divide the area into 4 equal quadrants. Thus, damage is measured over 20 of these 0.25 m^2 quadrants for each of the 5 × 1 m plots. Damage is estimated as the mean percent of area of damage across the plots.

Transect based
In habitats where it is possible to follow a straight-line transect, damage is sampled on transects spaced through the area. This was particularly effective for assessing damage to the exposed portion of the last remnant of a once-extensive basin marsh system in Florida (Engeman *et al.* 2004b, in press), where tape measure transects were placed along the perpendicular distance from the water's edge to the interface between the marsh and the surrounding community of upland vegetation (Engeman *et al.* 2004b, in press). The total distance of each transect is measured, as well as the distance directly on the transect that was damaged by swine. This amount could represent a single patch of damage or the combined distances of multiple patches. Damage not lying directly under on the transect is not recorded. Damage is estimated as the mean percent of length of damage length across the transects.

Economic evaluations
Besides estimating the quantity of habitat damaged by swine we also wished to apply a credible monetary valuation for that damage. Determination of monetary values for protected habitats is not a straight-forward nor precise process. A means of applying a monetary value on a unit-area basis to damaged native habitats is needed to estimate the unit (per-ha) and total cost of swine damage. Engeman *et al.* (2002b) discuss a variety of ways to apply monetary values to threatened and endangered animal species. Analogies to these methodologies were considered for application to habitat values, as well as other avenues specific to habitat issues (Engeman *et al.* 2004a). One simplistic consideration for valuation of habitat is to appraise the land on the basis of market value. However, special habitats such as wetlands have limited "market value", and if such habitat is selectively protected, the market value diminishes even further (King 1998). The use of contingent valuation surveys for special habitats, analogous to those applied to endangered animals, tend to be even more abstract appraisals of value (King 1998). Estimated costs for restoring habitat to pristine condition (replacement costs) frequently produce values well in excess of the public's "willingness-to-pay", and therefore also do not represent a realistic valuation. The most defensible, logical, and applicable valuation for the damaged habitat characteristic of our study site was to use expenditure data for permitted wetland mitigation projects in the United States. Such data represent an empirical demonstration of willingness-to-pay value. King (1998) presented the dollar amounts per unit-area spent in efforts to restore a spectrum of wetland habitat types. The numbers represent the dollar amounts that environmental regulators, and to a degree elected governments, have allowed permit applicants to spend in attempts to replace lost wetland services and values (King 1998). We identified the dollar value

for the appropriate wetland habitat category from each of the two studies cited in King (1998) to apply for each of our habitat types under study.

Economic analyses

Estimation of the amount and the associated value of swine damage permits the application of benefit-cost analyses to evaluate the need and success of swine control from an economic perspective, or to economically compare swine management approaches. The benefit-cost model approach of the swine management involves estimating the monetary value of the benefits measured in per-ha damage saved versus the costs measured in per-ha damage lost plus control costs. The objective of minimizing opportunity costs is equivalent to maximizing net benefits (Boardman *et al.* 1996). Benefit-cost ratios (BCRs) are calculated using the standard format of the ratio of benefits to costs (Loomis and Walsh (1997), Boardman *et al.* (1996), Nas (1996), Zerbe and Dively (1994), and Loomis (1993)). If a BCR>1, then the rewards for swine removal exceeded the costs, whereas a BCR<1 suggests that swine removal conducted in that fashion was not economically efficient.

When comparing management approaches, the benefits of one approach are represented as the opportunity cost of pursuing an alternate approach. Measured this way, the benefits of following approach 1 in lieu of approach 2 are represented by per-ha value of damage saved by not pursuing approach 2. This implies that the benefits of approach 1 in comparison to approach 2 are represented by the opportunity costs of pursuing approach 1. Or seen in another way, the benefits that accrue to each approach will be measured in terms of the cost saving as compared to alternate approaches. The BCRs must be evaluated in terms of the other approaches available. The benefits accruing to approach 1 depend on the value of per-ha habitat lost in the alternate approaches not followed. For example, the benefits accruing under approach 1 in comparison to approach 2 are measured by the following equation:

$$BCR_{1,2} = \frac{\textit{per-ha damage value saved by not following approach 2}}{\textit{per-ha damage value for following approach 1}} = K.$$

In other words, the benefit in terms of damage amount of approach 1 (en lieu of approach 2) is K times greater than the cost of approach 2. For an approach to be considered feasible it should be the case that K > 1. If K < 1, then pursuing that approach is less cost-effective than the approach that is not being used under that scenario.

DISCUSSION

Each area of research has contributed substantially to the efficacy, efficiency, and perception of swine removal efforts. The PTI is an effective tool for planning and assessing swine removal efforts, as well as for follow-up monitoring to determine if and where additional control is needed. Protection and improvement habitats have been the ultimate goals of our swine removal efforts. Therefore, reliable and practical means to estimate damage levels provide true evaluations of the need and efficacy of swine control. The ability to value the habitat resource provides an effectual tool for evaluating conservation approaches. Economic analyses can greatly assist managers on how most efficiently and effectively to allocate limited funds towards habitat conservation. Ultimately, many conservation funding decisions are made on a political level by people without high levels of training or expertise in biological sciences. Placing conservation issues in an economic context can greatly enlighten the political decision making process.

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FERRET POPULATION ASSESSMENT: PROGRESS AND CHALLENGES

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ABSTRACT: Ferrets are an invasive species especially common in New Zealand farmland. Ferrets become infected with bovine tuberculosis by feeding on infected carrion, and may also be a wildlife reservoir of the disease when their density, averaged through the year, exceeds a threshold of about 3 per km^2. Reliable knowledge of ferret density is therefore useful for disease managers. Obtaining such knowledge is difficult because ferrets are highly mobile and estimates are required for large areas (>20 km^2). We describe the results of 11 field trials of a new spatially explicit capture-recapture method implemented in program DENSITY. Ferrets were captured, marked and released over 6 days in 130–170 live traps per study area (16.8–42.1 km^2). Estimated density ranged from 0.8 per km^2 (SE 0.2) to 6.9 per km^2 (SE 0.9). Relative precision (SE(Estimate)/Estimate) ranged from 6% to 29%. Home-range size varied inversely with density; this effect could be expected to bias comparisons based on conventional estimators that use an effective trapping area. Some marked ferrets were caught repeatedly at a particular site, which suggests a lack of fit to the spatially explicit detection model. However, an improved method implemented in version 3.2 of the DENSITY software appears robust to this effect. Two problems require further consideration: extrapolation from the trapped sample to a management area requires the assumption that the sample is spatially representative. Ordinarily this can be ensured by random placement of lines, but topography and difficulties of access usually make random placement unacceptably expensive. We also encountered problems with occasional dispersal movements. We suggest that ferret monitoring be undertaken at times of year when little dispersal is expected.

INTRODUCTION

Ferrets are an invasive species especially common in New Zealand farmland, where they prey on introduced rabbits and a variety of introduced and native fauna. Ferrets become infected with *Mycobacterium bovis* (bovine Tb) by feeding on infected carrion (Lugton et al. 1997). At low densities ferrets are likely to be ‘spillover hosts’ of bovine Tb. However, at higher densities ferrets have the potential to be a maintenance host of the disease. This is currently thought to occur when their density, averaged through the year, exceeds a threshold of about 3 per km^2 (Caley and Hone 2005). Reliable knowledge of ferret population density is therefore useful for disease managers.

Determining population density is difficult because ferrets are highly mobile and estimates are required for large areas (>20 km^2). Trap-catch indices have been advocated for ferrets (Cross *et al.* 1998). These rely on the strong assumption that trappability and home range size remain constant in space and time. Uncalibrated indices do not provide a measure of population density. Cross *et al.* (1998) provided a calibration of trap catch for ferrets, but as this was based on a single site at a single time it does not provide useful information about the reliability of the index.

The conventional method for estimating population density D has been to use capture-recapture or removal trapping to estimate a population size N, and to divide N by the ‘effective trapping area' ($D = N/A$). This method suffers from severe problems because A is not clearly defined, and the methods for estimating A are either *ad hoc* (boundary-strip widths from trap-revealed movements) or too expensive for general application (radiotelemetry).

New spatially explicit methods have been suggested for analysing capture-recapture data (Efford 2004a, Efford *et al.* in press a,b). These methods avoid the particular problem of estimating A by fitting a model to the capture-recapture data that has parameters only for density D and a spatial detection function. We apply the methods to data from ferret trapping and discuss issues that arise.

METHODS

1. Field trials

Eleven field trials were conducted in central Otago between February and May 2003 using Holden live traps baited with rabbit meat. Traps were set at spacings of 150–300 m mostly along tracks and ridges accessible by farm bike, with 130–170 traps per study area (16.8–42.1 km^2) (Fig. 1). Ferrets were captured, tagged in both ears, and released over 6 days. Norbury and Efford (2004) provide further details.

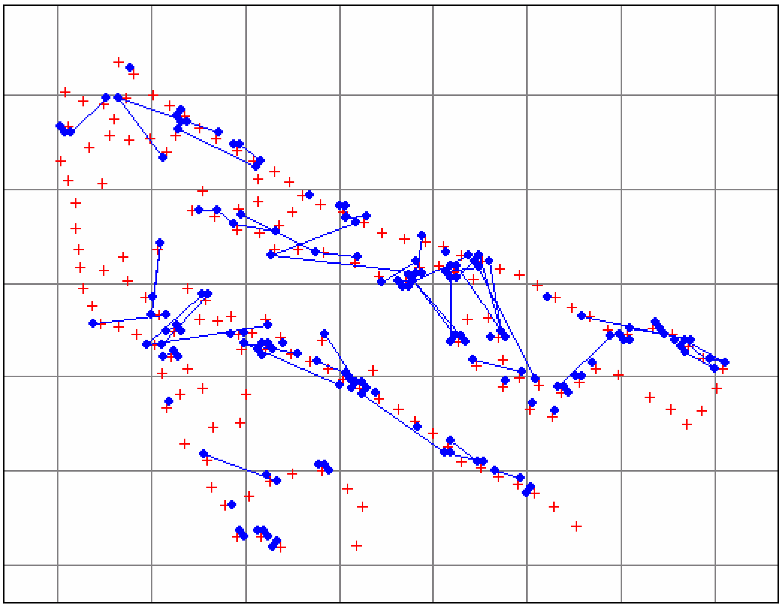

Fig. 1. Example of ferret capture–recapture on area P1. Crosses indicate trap sites (159 traps, average spacing 225 m) and dots indicate capture sites of ferrets over 6 days. Capture sites are displaced slightly from true location to reduce overlap. Lines connect consecutive captures of individual ferrets. 1-km grid.

2. Data analysis and software

We expected field data collected over each 6-day trapping session to be suitable for 'closed population' analysis in the sense that negligible recruitment or loss occurred over the period of trapping (Otis *et al.* 1978).

The spatially explicit capture-recapture approach models the observed capture data in terms of population density D and a spatial detection function $g(r)$ where r is the radial distance between a home range centre and a trap (Efford 2004a). We used a half-normal detection function, with parameters $g(0)$ (capture probability in a single trap at home range centre) and σ (spatial scale over which capture probability declines). Home-range centres were assumed to follow a 2-D Poisson distribution, and to be fixed for the duration of trapping. The model was fitted by an indirect, computer-intensive method (simulation and inverse prediction; see Efford 2004a,b for details). Simulated populations extended 3 km beyond the traps in all cardinal directions to ensure that all potentially trappable animals were simulated. Inverse prediction used conventional population estimates *N*-hat and *p*-hat to predict *D* and *g*(0), and a pooled measure of the spatial variance of individual capture locations to predict σ. We report the sampling error of *D*-hat adjusted for the spatial variance of a 2-D Poisson process (Efford 2004b).

RESULTS AND DISCUSSION

Table 1 Ferret population density estimated by spatially explicit capture-recapture for 11 sites in central Otago trapped between February and May 2003. *g*(0) and σ are detection parameters explained in the text. Standard errors (in parentheses) and confidence intervals for density were adjusted to exclude spatial variance.

Study area	Number tagged	Number of recaptures	Density km^{-2}	95% confidence interval for density	*g*(0)	σ (m)
T1	52	76	4.7 (0.6)	3.4–6.0	0.105 (0.022)	305 (20)
T2	46	63	2.6 (0.4)	1.8–3.5	0.049 (0.013)	525 (41)
B1	109	187	4.8 (0.3)	4.2–5.4	0.216 (0.031)	327 (13)
B2	62	79	1.5 (0.2)	1.1–1.9	0.037 (0.009)	765 (73)
B3	73	141	3.9 (0.3)	3.2–4.5	0.163 (0.034)	355 (22)
C1	118	98	6.9 (0.9)	5.2–8.7	0.048 (0.010)	402 (24)
C2	64	27	6.4 (1.7)	3.1–9.8	0.030 (0.010)	323 (40)
C3	43	21	3.8 (1.1)	1.6–6.0	0.014 (0.006)	439 (75)
P1	78	73	3.4 (0.4)	2.7–4.1	0.082 (0.016)	392 (24)
P2	30	39	0.8 (0.2)	0.5–1.1	0.040 (0.018)	791 (117)
P3	63	101	2.0 (0.2)	1.7–2.3	0.087 (0.016)	503 (26)

The method gave apparently precise estimates of absolute density (Table 1). Relative precision was good (SE(Estimate) / Estimate < 20%) except when few (<40) recaptures were obtained. Home-range size (measured by σ) varied inversely with density (Fig. 2). Failure to allow for the high and varying mobility of ferrets will make conventional estimates unreliable.

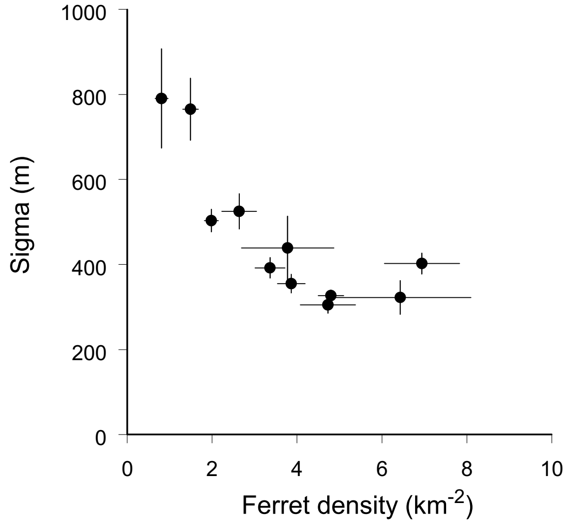

Fig. 2. Relationship between estimates of σ, a linear measure of home-range size (a circle of radius 2.45σ is expected to include 95% of activity for a circular normal home range), and ferret population density (± 1 SE). Each point represents a separate population (data in Table 1).

No correlation was found been between density and subsequent trap-catch by contractors in the same areas (Fig. 3).

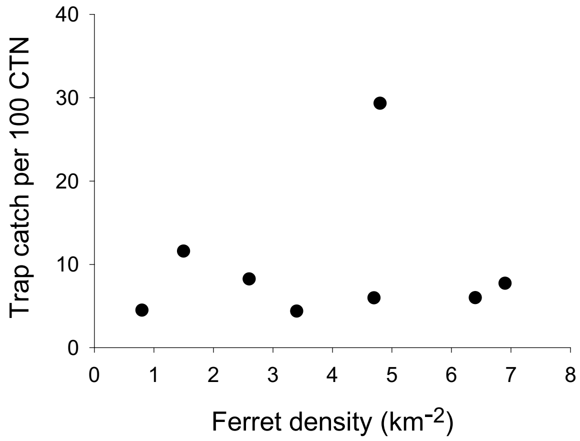

Fig. 3. Relationship between density estimated by intensive live trapping and subsequent trap catch over 3 nights removal trapping by contractors. (See Norbury and Efford (2004) for details)

Ferrets appear well-suited to spatially explicit capture-recapture in that they are trappable, easily handled, and highly mobile. Some marked ferrets were caught repeatedly at a particular site, which suggests a lack of fit to the spatially explicit detection model. Simulations lead us to believe this particular violation causes only minor bias when a suitable statistic is used to summarise movement (e.g. spatial variance of individual capture locations; Efford 2004b). However, two problems require further consideration:

1. Extrapolation from the trapped sample to a larger management area requires the assumption that the sample is spatially representative. This applies to any method based on intensive sampling of just part of the area of interest. Ordinarily, representativeness can be ensured by random placement of lines (e.g. protocol for possum trap catch index. National Possum Control Agencies 2004), but topography and difficulties of access usually make random placement expensive on the scale required for ferrets. An alternative approach is to avoid

extrapolation altogether by limiting inference to the area actually trapped. This requires us to return to a question we had hoped to avoid: how to delineate the effective trapping area. Having fitted a spatial detection model to the data we can estimate this retrospectively. In our case the model indicated a buffer ('inferred strip width') of 450–1400 m about the traps (Efford 2004b). Home-range movements ensure that the traps effectively sample ferrets living within this buffer. The buffered area included much more than 50% of each study area, and we therefore feel confident that the trapped sample was representative.

2. We encountered problems with occasional dispersal movements during a trapping session. It is unclear whether these were common enough to degrade the estimates. A simple solution would be to undertake ferret monitoring at times of year when little dispersal is expected.

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BOVINE TB PERSISTENCE IN LOW-DENSITY POSSUM POPULATIONS – THE PATCHINESS PROBLEM

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ABSTRACT: Reasons for the maintenance of bovine Tb in post-control brushtail possum populations are unclear, although crowding of residual possums on a local scale is frequently correlated with higher prevalence of the disease. Three key density characteristics of post-control possum populations that may contribute to Tb persistence are (1) the threshold density above which Tb will be maintained if the population is uniformly distributed within a controlled area, (2) the variation between patchiness across the landscape of survivors and the low-density, uniform distribution required for Tb to die out, and (3) the changes in patchiness over time, as patches of survivors increase to exceed the density threshold more rapidly than the wider population. We investigated the hypothesis that persistence of Tb in residual possum populations is influenced by their non-random (patchy) distribution. Our investigation confirmed that Tb in post-control possum populations is typically associated with patches of higher-than-average residual possum density, and provided some support for two of the three density characteristics argued to contribute to Tb persisting in residual possum populations.

INTRODUCTION

Brushtail possums (*Trichosurus vulpecula*) are the main wildlife reservoir and vector of bovine tuberculosis (Tb) in New Zealand, and infection in possums is often associated with the occurrence of Tb in livestock. Intensive control of possums under the Bovine Tb National Pest Management Strategy has led to significant reductions in possum numbers throughout all areas where Tb is endemic, and to progressive reductions in the number of infected cattle and deer herds.

Tb is a highly infectious disease and its transmission within and between host populations is density dependent. Therefore, we presume that the disease will only be eradicated from both possums and livestock if contact between individuals in infected possum populations adjacent to livestock is reduced to levels that break the transmission cycle. Prior to this study (January 2002), the default target 'density' for Tb possum populations following control (i.e. that set for control operations by most disease control managers) was a mean residual trap-catch index (RTCI) of 5%. However, while possum control operations usually achieved this target, they rarely managed to reduce possum populations *uniformly* below 5% RTCI. This is because surviving possums often occur in patches (i.e. are clustered), as a consequence of both operational limitations and the uneven distribution of toxic baits or other killing devices during control.

The importance of post-control patchiness in possum populations in maintaining Tb infection is unknown, although crowding of possums on a local scale is correlated with higher prevalence of the disease (Hickling 1995). Clearly, control programmes aimed at eradicating Tb from wildlife are at risk of failing wherever infected possums survive at local densities greater than that thought necessary to sustain Tb transmission. Hence, understanding the reasons for the location and size of patches of possums surviving control in infected populations, and the abundance of possums within patches capable of maintaining Tb, appears long overdue.

Our hypothesis was that *the persistence of Tb in residual possum populations is determined by the occurrence of patches of possums surviving control (as defined by local population density indices of >5% RTCI).* Our practical objective was to help improve the success rate in eliminating local infections of Tb in possum populations by identifying (1) the nature and size of patches of possums surviving control operations, (2) the importance of achieving uniformly low possum densities following control operations, and (3) the maximum permissible combinations of patch size and within-patch density of possums that can be tolerated under normal disease management.

METHODS

Eleven areas of forest or scrub bordering farmland were selected as study replicates, based on (1) populations that had been controlled within the previous 24 months, (2) post-control monitoring surveys undertaken within the previous 12–18 months that had recorded RTCIs of c. 3–5%, and (3) possums with confirmed Tb present within the previous 12 months. Within each replicate, we firstly undertook an initial survey of the surviving possum population by grid-based trapping and poisoning around the earlier focus of infection, and subsequently necropsied all possums captured to confirm the presence of Tb. We also indexed possum abundance at each site using trap-catch rates based on conventional 10-trap lines (NPCA 2004).

Each initial replicate was c. 400 × 400 m and nominally had 196 traps spaced at 30-m intervals. Trapping continued for 5–10 nights ($\bar{x}$ = 7.3) until two successive nights failed to catch any possums. Immediately following the trapping, a cyanide paste bait was laid between each trap site to sample any possums remaining. We assumed that our intensive trapping and poisoning effectively removed all, or close to all, possums present within each grid. At study sites where we located Tb-infected possums, we extended the trapping grids to an area of c. 1 km^2 roughly centred on the new infected-possum location (or locations).

The locations of all possum captures and kills were used to determine spatial variation in density within the residual population and the size of any patches of higher-than-expected density, while necropsy identified the point-prevalence rates of Tb infection in possums within or outside these patches.

Mean trap-catch indices (TCIs) of possums taken immediately outside the initial trapping grid were calculated using Landcare Research's trap-catch estimator – 'PestCalc' (version 1.2). These TCIs allowed us to make broad comparisons between population density indices at our study sites and those recorded following other possum control operations (i.e. RTCIs). Estimates of absolute possum numbers within each trapping grid were derived from trap-catch and cyanide-kill tallies, and these were combined with the known area of each grid to produce estimates of overall possum density.

The Spatial Analysis by Distance Indices (SADIE) method (Perry 1995) was used to quantify the spatial distribution (and degree of patchiness) of possums within 10 of our 11 study sites. SADIE procedures allowed us to produce density contour maps for each study site. The resulting maps showed where the estimated index of aggregation (I_a) was greater or lower than the overall mean (i.e. a patch of possums or a patch gap). Crude estimates of the areas of patches for all possums, and for Tb-infected possums only, were derived from the contour maps.

RESULTS

Possum numbers

TCIs varied at the 11 study sites (Table 1), with those at Waimiha, Rapahoe, Hohonu, and New Creek being above the earlier post-control density index (5%) targeted by disease control managers in the 1990s as the threshold level to sustain ongoing Tb infections in possum populations. TCIs at the remaining six study sites ranged between 0.6% and 4.7% and were similar to many within-forest RTCIs reported in recent years.

Table 1 Sampling effort, possum catch, Tb prevalence, and mean TCIs recorded at our study sites.

Study site	No. of trap and bait nights	No. of possums captured	Tb prevalence (%)	Mean TCI (%)
Waimiha	1972	29	0.0	5.3
Tautuku	1812	14	0.0	1.7
Orwell Creek	984	4	0.0	2.9
Manuka Flat	1680	16	0.0	1.7
Rapahoe	228	18	22.2	8.3
Mt Vulcan	825	7	0.0	4.7
Cloudy Hills	2446	11	0.0	-
Hohonu	2244	67	16.4	23.9
New Creek	1720	34	0.0	16.8
Karamea	1164	8	0.0	3.4
Omoto	1212	31	19.4	0.6

Tb infection

Possums with gross lesions, or with sub-clinical lesions subsequently identified at culture as infected with Tb, were found at only three of the 11 replicates (Table 1). Indices of possum abundance at both the Rapahoe and Hohonu sites exceeded the upper limit of our study's density criterion and of normal post-control possum density. Possum abundance at Omoto was much lower, and well within normal operational levels.

Patchiness

Most post-control possum populations appeared to be patchily distributed as typified by the Omoto situation (Fig. 1(a)), with the patches containing most (but not all) possums taken at each site (Table 2). Trapping and poisoning resulted in 21 Tb-infected possums being taken and most of these individuals were also in patches containing higher-than-average numbers of possums for each individual site, compared with sites where no Tb was found.

Table 2 Proportion of each grid with 'possum patches' higher than the overall average density, a crude estimate of the mean patch size, and a comparison of overall possum density with within-patch density; the shaded rows indicate sites at which Tb-infected possums were found.

Study site	Number of patches	Mean patch size (ha)[1]	Prop. of area with patches	Possum density (per ha)	
				Within patch	Overall grid
Waimiha	5	0.83	0.16	4.59	0.81
Tautuku	5	0.38	0.15	5.29	0.85
Orwell Creek	1	2.07	0.16	0.48	0.08
Manuka Flat	7	0.45	0.24	4.44	1.08
Rapahoe	2	0.95	0.18	3.70	1.80
Mt Vulcan	2	1.26	0.22	0.79	0.18
Hohonu	14	0.87	0.20	4.41	0.78
New Creek	8	0.62	0.28	4.44	1.19
Karamea	2	1.49	0.17	2.02	0.34
Omoto	10	2.70	0.23	1.11	0.26

[1] estimated from the SADIE contour maps

SADIE analyses confirmed that possums were aggregated to some extent (i.e. I_a values >1) at eight of the 10 sites examined using this technique. There were too few possums sampled at two of the sites (Orwell Creek and Mt Vulcan) to be able to conclude anything about the level of aggregation, although if the pattern found on the area sampled extended over the entire control area we would conclude that there was little or no aggregation. Although the degree of aggregation was statistically significant at only three sites (Hohonu, Waimiha, and Tautuku) and almost significant at a fourth site (Karamea), we suggest that statistical significance in this context does not equate with biological significance.

The SADIE-generated contour maps of patch clusters and patch gaps provide a biologically meaningful representation of patchiness (see Fig. 1(b)). Based on the locations of trapped or poisoned possums and typical home range sizes (1.3–1.9 ha) and range lengths (245–295 m) in forest habitats (Cowan and Clout 2000), the patch clusters identified using SADIE appear to indicate a reasonable and conservative representation of where the ranges of two or more possums overlap and where contact between individuals could be expected to occur. Given the recent presence of Tb at all sites, it appears that the aggregations represented by the SADIE contour maps typify the types of localised situations sufficient to support the ongoing persistence of Tb.

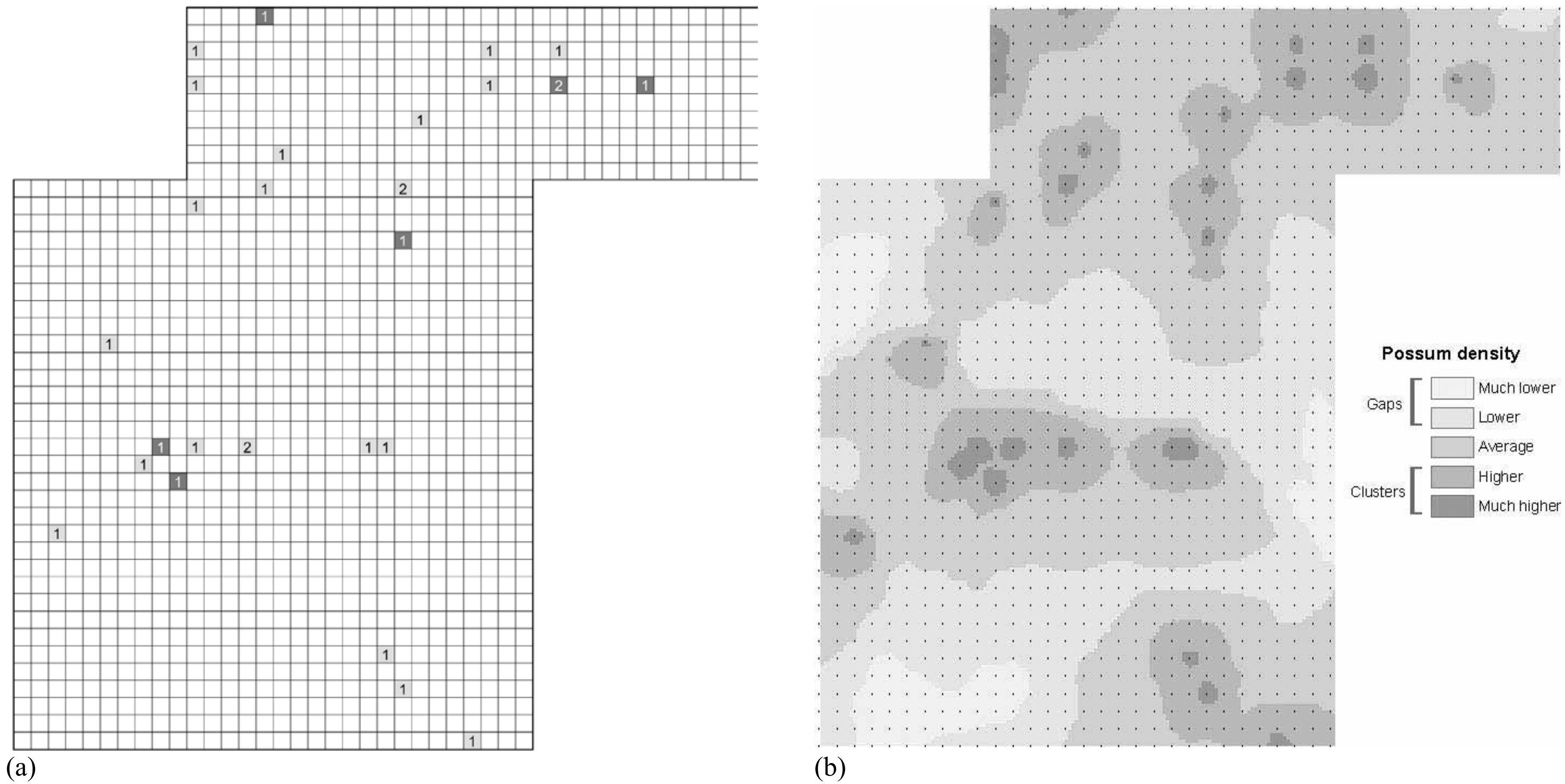

Fig. 1 (a) Location of captured or poisoned possums at Omoto, showing the clustering of possums surviving control and the distribution of Tb-infected individuals. Each square represents an area of 30 × 30 m with a trap or poison bait at its centre; lighter-shaded squares indicate locations of possums caught, darker-shaded squares indicate locations where at least one Tb-infected possum was caught, and the number in the square indicates the total 'catch'. (b) SADIE contour-map representation of the spatial distribution of possums at Omoto, showing the distribution of 'possum clusters' (darkest shadings), gaps (lightest shading), and areas where possum density is effectively equivalent to the overall average for the entire grid.

CONCLUSIONS

Possums surviving aerial- or ground-based control operations are often distributed in patches, and these can be of varying size. Disease control managers set post-control population-density targets based on mean RTCIs that are believed to reflect an overall possum density threshold necessary for Tb to die out. Despite the frequent achievement of such targets, localised patches of survivors often occur at densities that exceed the threshold for Tb establishment or persistence. Unfortunately, the current trap-line-based monitoring procedure is ineffective for identifying the presence of patches and the importance of patchiness as an issue for Tb eradication.

Possums infected with Tb and surviving control operations typically occur in patches of higher-than-average residual density. As population recovery rates are likely to be highest within such patches, the presence of patches (arising out of poor control) provides a clear reason for the persistence of the disease and its ongoing threat to adjacent livestock. While the maximum permissible combinations of patch size and within-patch density tolerable under normal management are unknown, clearly there is a need for greater emphasis on achieving uniformly low possum densities following control and so eliminating the opportunity for infected survivors to interact with other survivors and so transmit and maintain the disease within the residual population.

ACKNOWLEDGEMENT

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DETECTION OF THE RED FOX (*VULPES VULPES*) AT LOW POPULATION DENSITY

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INTRODUCTION

Since the recent introduction of the European red fox (*Vulpes vulpes*) to Tasmania, an urgent need has arisen to detect populations while they are still at low densities so that control measures can be implemented. However, detection and enumeration of rare and cryptic animals presents a particularly difficult challenge. Standard methods of surveying foxes involve observations of signs or spotlighting, although these can be inconclusive, influenced by extrinsic factors, or inefficient at low densities. Recently developed techniques such as remote photography and molecular genotyping have proved successful in monitoring a range of elusive and rare species.

We experimentally evaluated the effectiveness of spotlighting, camera trapping and genotyping of scats and hair follicles collected from bait stations in detecting a known number of radio-collared foxes. These collared foxes were considered the only foxes on our study site, and thus functioned as a virtual low-density population.

METHODS

The study site was a resource-rich agricultural property in the cool-temperate Southern Tablelands of NSW, Australia, in order to mimic the Tasmanian situation. Foxes were captured, radio-collared, marked with reflective coloured ear tags, and genotyped from tissue samples. We standardised sampling effort in terms of the approximate amount of time spent on each method of detection and the number of stations set per survey period. To ensure temporal and spatial independence of data, each station or transect was allocated to a random paddock (1-30) within the study area. Once inside the paddock, station placement targeted likely areas of fox activity such as roads, gullies and fence-lines.

Fox presence or absence was scored for each method over weekly intervals and analysed for independence using contingency tables. Log-linear models were used to test for any interactions between the presence or absence of a fox and the detection method.

PRELIMINARY RESULTS AND DISCUSSION

Camera trapping was the only systematic method to unambiguously detect collared individuals. Despite a wealth of technological problems, cameras were still labour efficient and offered indisputable evidence of the presence of collared foxes. The failure of spotlighting to detect collared foxes may be attributed either to an unrepresentative (trap shy) fox population, technical limitations, or inherent inefficiency of spotlighting in detecting individuals at low densities. Genotyping of samples has so far failed to identify any collared individuals.

Incidental sightings by researchers and farm staff during the study period constituted the greatest number of detections of collared foxes, demonstrating that chance sightings are probably the most sensitive manner of detecting the presence of foxes in a very low-density situation.

Data were collected simultaneously on the efficiency of each method in detecting un-collared foxes. All methods employed in the experiment detected un-collared foxes. Log-linear models revealed a significant (p= 0.006) interaction between the number of foxes detected and the detection method employed, and imply that spotlighting (the most efficient) and camera trapping are the more efficient methods of those compared.

In summary, the study so far has found that foxes at a ‘virtual’ low density in a resource-rich environment are extraordinarily difficult to detect with both standard and novel methods, and conceivably even more difficult to monitor with any degree of accuracy or precision.

IMPROVING THE ACCURACY OF DNA-BASED METHODS FOR ESTIMATING POPULATION PARAMETERS OF VERTEBRATE PESTS

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ABSTRACT: The use of DNA derived from non-invasively collected material such as shed hair and faeces is increasingly used to identify individuals for applications in wildlife studies. The development of highly variable microsatellite markers and advances in forensic DNA methods provide many exciting opportunities for measuring a range of population parameters in free-ranging animals. While it is now possible to generate significant amounts of data from these non-invasive sources of DNA, the biggest challenge in the application of DNA-based information is overcoming the errors inherent in non-invasive samples. Errors arise where the poor quality and limited quantity of DNA derived from field-collected material leads to heterozygotes being scored as homozygotes. If these error rates go undetected and the genotypes are directly transferred into mark-recapture models, the result will be significant over-estimates of population census size. Therefore it is essential that any study using such data determine the inherent error rate (mismatch probability), and build this into population census models. Unless such errors are corrected, DNA-based information will not provide cost-effective applications in wildlife studies.

Most methods that have been used to overcome these genotype errors involve repeating PCR amplifications for each sample in order to obtain statistical certainty of the genotype, known as the ‘multi-tube’ approach. However, the extent of replication can rarely be achieved when using DNA sourced from non-invasive samples as there usually only a small amount of material to work with and the multi-tube approach soon exhausts the finite sample. Instead, we have focussed attention on the quantity of starting DNA template and have developed methods to test the efficacy and value of non-invasive DNA-based analysis for detecting possums, *Trichosurus vulpecula,* from faecal samples collected in the Catlins Forest, Southland.

The project involves using DNA profiles from faecal pellets as an unbiased method for ‘marking’ almost all of the total possum population present at a site. By genotyping the possums caught in traps and killed by poison, and by determining the genotype of survivors of a control operation, we can quantify the proportion of the population that escapes trapping and poisoning. Our null hypothesis is that if all possums can equally be trapped, poisoned, and monitored, then we expect that all the possums initially genotyped from faecal pellets will have an equal chance of being caught and poisoned. Any divergence from this null hypothesis will indicate the likely size of any bias associated with trapping/monitoring post-control.

In order to increase the accuracy of identifying individual possums by their faecal DNA and address the problem of ‘allelic dropout’, we have developed a ‘real-time’ quantitative polymerase chain reaction (PCR) amplification using a possum-specific gene labelled with fluorescent dye and compared the amounts of PCR product to a set of standard templates of known DNA amounts. Conventional methods for estimating DNA quantity do not work for these samples, as other co-purified plant and bacterial DNA is also present after in large amounts. We used a possum microsatellite sequence (Tv12) as the target sequence with the specific TaqMan assay primers and probe designed by Applied Biosystems (Assays-by-

Design). The Tv12 microsatellite sequence (222 bp) from the Catlins sample H3T19 was amplified and cloned into the pCR 3.1 vector. The standard curve DNA used for the quantitative PCR consists of 8 dilutions of this transformant [10ng, 1.25ng, 625pg, 312pg, 156pg, 78pg, 39pg, 19pg] quantified first by absorbance in a BioSpec-mini spectrophotometer. Determining the relationship between template concentration and allelic dropout makes it possible to devise empirically based criteria for accurate genotyping. This experimentally derived dropout rate is then used to determine the number of replications per sample required in order to achieve a desired level of certainty in assigning a genotype to that sample. We can then use recently developed statistical methods that calculate mismatch probabilities (i.e. genotyping error between two samples of the same individual) in a population and have incorporated these into our statistical models.

The use of genetic tags for estimating population parameters of vertebrate pests has huge potential. However, it is critical to locate genotyping errors and define the extent of these in the resulting dataset. These errors will be specific to each species and depend on the source of samples. This approach enables cost-effective use of DNA-based information and allows studies to be designed depending on the levels of genotype discrimination required.

DNA-BASED MARK-RECAPTURE OF WILD DEER: USING FAWNS TO CAPTURE THEIR MOTHERS

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INTRODUCTION

A lack of affordable techniques for accurately estimating the density of wild animals has long been a major constraint in wildlife management. An important breakthrough has been the use of DNA fingerprinting in conjunction with mark-recapture (MR) methods of density estimation (Taberlet *et al.* 1997; Mowat and Strowbeck 2000). Provided the DNA fingerprint from each individual is unique and can be recognised on two or more occasions, mark-recapture methods can be used to estimate the absolute numbers of animals present. The main challenge is often to find ways to obtain DNA cheaply from the population. To date, most interest has centred on using hair or faeces, because use of such 'non-invasive' sources of DNA avoids the cost of capturing the animal. In pest management, however, a high proportion of the population is often killed annually, providing a potentially low cost 'recapture' option for animals 'marked' by previous or simultaneous recovery of DNA from hair or faeces. In New Zealand, this approach has already been applied to brushtail possums (*Trichosurus vulpecula*) and stoats (*Mustela erminea*) (Nugent *et. al.* 2003; Byrom *et al.* 2004).

In our previous attempt to estimate absolute densities of wild deer, however, we were unable to obtain DNA of sufficient quality to reliably identify individual deer from faeces or shed hair. We therefore explored the practicality of using parentage assessment based on a sample of killed animals, an approach first applied to estimating numbers of painted turtles (*Chrysemus picta*) in Mississippi (Pearse *et al.* 2001).

The deer killed during control usually include both adults and their offspring, with the offspring effectively representing recaptures of their parents' genotypes. The number of adult females can therefore be estimated (using the formula for a modified Lincoln-Petersen Index; from Pollock et al. 1990):

$$N_{af} = [(n_{af} + 1)(n_f + 1)/(n_m + 1)] - 1$$

$$95\%CI = 1.96 * [(n_{af} + 1)(n_f + 1)(n_{af} - n_m) (n_f - n_m)/(n_m + 1)^2(n_m +2)]$$

where N_{af} = estimated number of adult females present during a particular breeding season, n_{af} = the number of adult females present in that breeding season shot in subsequent years, n_f = the number of fawns born in that breeding season shot in subsequent years, and n_m = the number of fawn-dam matches in the shot sample. In this paper, we assess the practicality and utility of this approach as a tool for estimating key population parameters of regularly harvested species such as deer.

METHODS

The wild red deer (*Cervus elaphus scoticus*) of the 51 800 ha Murchison Mountains, Fiordland, New Zealand have been heavily controlled for over 40 years, with an estimated 424 deer remaining in early 2002 (0.8 deer/km^2 overall, 1.3 deer/km^2 of forest; Fraser and

Nugent 2003). This total includes new and unborn fawns, and was obtained using population reconstruction methods.

In 2003/04 we collected hair samples and the jawbone from most of the deer shot in the area. Females at least 2 y old in late 2002 (the fawning season) were classed as potential mothers, whilst those that had been born then were classed as their potential offspring.

DNA was extracted from the hairs using alkaline treatment, and amplified by PCR using up to 14 microsatellite markers, with the products run on an ABI3730 DNA Analyzer. Genotypes were analysed using GeneMapper™ Software Version 3.5. Mother-offspring pairs within this sample were then identified using AgResearch's proprietary Pedigree Analysis Software. Where both members of a pair had been shot at the same place on the same day, the pair was deleted from the mark-recapture analysis because marking and recapture were not independent events. The total number of adult females present in late 2002 was then estimated using the modified Lincoln-Petersen index above.

RESULTS

The sample

A total of 118 deer were collected over the 1 July 2003 – 30 June 2004 period, with 8 or more DNA markers (genetic loci) identified in 93 of these. These 93 deer included 18 adult females (potential mothers) and 30 deer <18 months (potential offspring) (Fig. 1).

Parentage assignment and density estimation

Seven mother-offspring pairs were identified. Of these, three shot together were deleted from the MR analysis, leaving a total of 15 potential mothers, 27 potential offspring, and four mother-offspring pairs. From equation 1, we estimate there were 89 ± 64 (95%CL) adult females present in late 2002. Adding back in the three adult female deleted from the analysis give a total of 92. Using an unmodified Lincoln-Petersen index gives an estimate of 104.

The average distance between the kill locations of all possible adult– subadult pairs was 10.6 km compared with an average of just 0.9 km for the seven mother-offspring pair identified (actual distances were 0.0; 0.0; 0.0; 1.3; 1.3, 1.7, and 2.3; Figs. 1 and 2).

Fraser and Nugent (2003) estimated the breeding population size in late 2002 was 304 deer, and that the long-run average annual productivity was 34%, indicating that about 100 fawns would have been born then. Because the population is much reduced, about 95% of adult females are likely to have produced young (Challies 1985), so population reconstruction suggests that about 110 adult females were present, which is within 20% of the DNA-based estimates above.

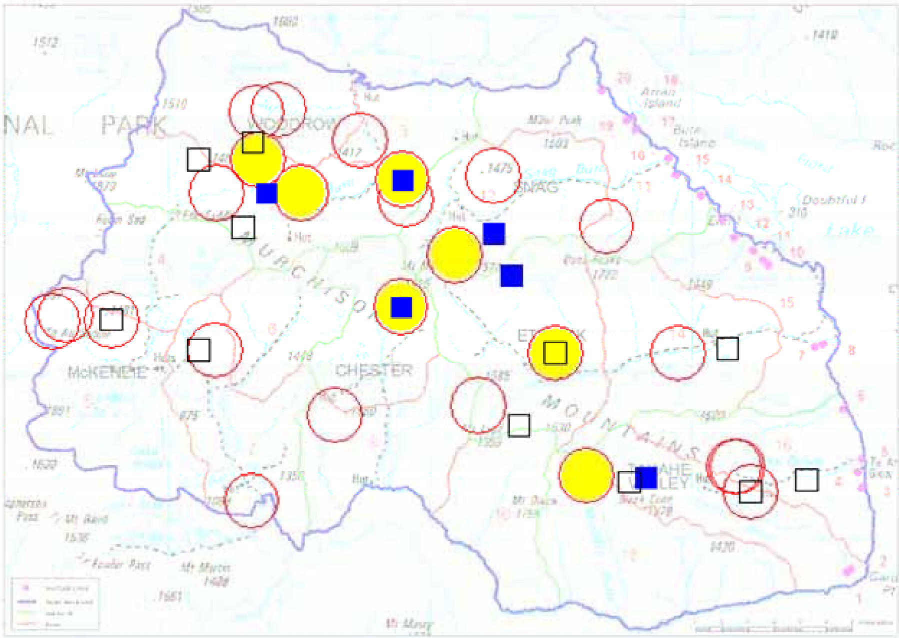

Fig. 1. Kill locations for 18 female deer >2 years of age in December 2002 (filled squares for those matched to an offspring, unfilled squares for those not matched), and 30 of their potential offspring from the 2002/03 fawning season (filled large circles for those matched to mothers, unfilled large circles for unmatched offspring. The large circles for unmatched offspring are likely to encompass the location of their surviving mother.

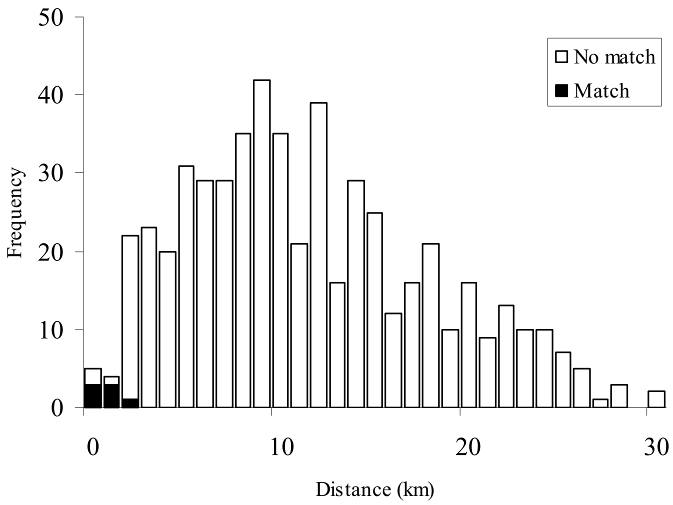

Fig. 2. Frequency distribution of the distances between all possible pairings of potential mothers and offspring, showing separately the distances between the seven matched pairs (filled bars) and the unmatched pairs (unfilled bars).

DISCUSSION

This trial indicates that offspring can successfully be used to recapture their parents, and that the resulting estimate of adult female numbers (albeit imprecise) matches an estimate derived from population reconstruction. Here we have estimating adult female density simply to demonstrate the technique, but the same logic can be used to estimate numbers of adult males, and, in conjunction with demographic data, the numbers in other age-sex classes. The necessary genotyping techniques and software are increasingly available to managers as 'black box' technologies. Like any other density estimation tool, however, practical utility will depend on accuracy (freedom from bias), precision, and cost.

Accuracy: One peculiarity of the approach used here is that adults are often 'recaptured' before they themselves are 'tagged'. Offspring are effectively tagged at conception, but as they cannot be independently sampled until they have left their mother's care, the estimate of adult female numbers is, effectively, the number of adult females present after fawns are weaned. This will be biased if the mortality rate of females that do not raise fawns to independence differs from that for those that do. However, the number of non-reproductive females is low (<10%) in deer so this is unlikely to have a major effect on accuracy for this species.

In contrast, fawns can be obtained independently of their fathers immediately after conception (i.e. fathers can legitimately recaptured via foetuses obtained from shot females), so an MR estimate for males would, effectively, be an estimate of the number of potentially reproductive males present during the rut preceding the fawning season of interest. Because reproductive success amongst male deer is usually heavily skewed in favour of a few fully mature males, there is far greater potential for bias due to differential mortality between 'tagged' fathers and reproductively unsuccessful males.

Bias could also arise from errors in identification and parent-offspring matching. In this trial, no two deer sampled had the same set of markers, so there was no bias through duplication of tags. Parentage assignment creates a higher risk of matching errors, but in this study no offspring were assigned two mothers, suggesting the risk was low.

Failure to detect some alleles (allelic drop out) can also result in failure to identify a real match between parent and offspring, or to wrongly assign kinship between unrelated deer. These potential biases can be objectively assessed (McKelvey and Schwartz, 2004), or can be overcome by repeating analyses (Paetkau 2004). In this study, the short distances between mother-offspring pairs (Fig. 2) suggests the matches are correct.

Precision: One third of the breeding population was surveyed in this trial but only 4 useful mother-offspring matches were obtained. However, continued collection of deer in 2004/05 will increase the proportion of the population surveyed, especially the proportion 'recaptured'. We expect a 2-year sample of c. 30 adult females and 50 offspring, with about 15 matches. This would give a similar estimate of c. 100 adult females but improve precision (95%CL) from 60 to 11 deer.

Cost: In this study, the cost per hair sample genotyped was about $NZ30, including parentage assignment. An extra $3000 was required to recover samples from helicopter-shot deer, while ground-shot material was (effectively) free. The average cost per sample was therefore c. $NZ55/sample, 12% of $NZ460 spent to kill each deer.

Summary: Both demographic and genetic measures suggest there were close to 100 adult females present in late 2002. Although the equivalent of one third of the breeding population is killed annually (Fraser and Nugent 2003), only about 20% of the adult female population (the reproductive engine of the population) is removed. Thus, although intergenerational mark-recapture as tested here does not directly produce an estimate of total population size, it does permit direct estimation of the minimum annual kill needed to reduce the population. It also identifies where the mothers of unmatched offspring are likely to be, so that control effort can be targeted at them.

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THE RED-EARED SLIDER TURTLE (TRACHEMYS SCRIPTA ELEGANS) IN NEW ZEALAND

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ABSTRACT: Red-eared slider turtles (*Trachemys scripta elegans*) have been present in New Zealand for over fifty years. In that time at least 110,000 hatchlings have been bred or imported. Importation was banned in 1965 but smuggling was significant until the mid-1980s. Since then, about 2000 animals have been bred in New Zealand for the pet trade each year. Demand always exceeded supply until this year's negative publicity. Red-eared turtles have strict requirements for survival and growth. Despite their high cost, it's doubtful that survival of hatchlings in captivity exceeds 5-10%. Adult animals that escape, or are released, probably cannot reproduce because of poor fertility, dry summer soils and the low temperatures in New Zealand. Because of these low temperatures, any eggs that do hatch in suitable microclimates will produce exclusively males. Many adult red-ears found in the "wild" are emaciated and infected with ulcerative shell disease, suggesting that animals frequently die within a few years of escaping captivity. I have been unable to detect evidence of reproduction or colony formation anywhere in NZ. When turtles are discovered in the "wild" they are almost always in warm water habitats previously altered or created by man (drains, farm ponds, weed infested streams). Most of the problems with red-eared slider turtles overseas have occurred in countries where millions were imported and released. This has not been the case in New Zealand. It is doubtful they could have much, if any, impact on unmodified environments in New Zealand.

INTRODUCTION

Over the past year there has been considerable misinformation about red-eared slider turtles (*Trachemys scripta elegans*) in the New Zealand media. The purpose of this presentation is to document the facts we do have about these turtles from overseas, and the research that has been done here.

History of the New Zealand market

Red ears were imported into New Zealand from Louisiana, USA until 1965. A ban on importation was introduced in 1965 because the hatchlings were found to be carriers of several varieties of salmonella not previously known in NZ. However, by the time the ban was instituted, 30,000 animals had already been imported and sold, so those alien species of salmonella were already widely spread. The imported turtles came from turtle farms where they were raised in enormous concentrations (10,000-30,000 adults per surface acre). The animals were fed processed food but large amounts of salmonella-rich offal and wild water plants from surrounding swamps were also eaten. These contaminated the stagnant water with bacteria, including multiple salmonella serotypes. Waters in surrounding swamps were also contaminated with salmonella of similar varieties. Virtually all the hatchlings were carriers of salmonella (Chiodini and Sundberg 1981). The salmonella was acquired as the eggs passed through the cloacae or were deposited in the grossly infected soils at the farms.

After the importation ban came into force, smuggling continued until the mid-1980s with 1000-2000 animals being imported per year. After that, back-yard breeders became common throughout New Zealand. After my first survey of NZ breeders in 1997, I concluded that about 2000 hatchlings were being sold per year and there was enough demand to sell another 500–1000 animals at a retail price of $90–$100 each. At that time there were four main breeders and about twenty smaller ones. My survey of breeders in 2005 came to similar conclusions. The retail price now varies from $70–$100 retail. Output is still about 2,000 animals per year that seems to be meeting demand after the recent negative publicity.

The international situation and origin of the red-ear "problem"

The Louisiana, USA turtle farms have exported between 8-12 million animals annually for many years. In later years Korea imported up to 1.3 million per year, Italy about a million and Japan 0.6 million. Taiwan, South Africa, Israel, Australia, Thailand, Cambodia, and other European Union countries were also big importers. In 1997 the importation of red-ears was banned in the European Union. China has now replaced Korea as the major importer. Red-ears have been able to reproduce in the "wild" in southern France (Cadi *et al.* 2004) and possibly Spain and Taiwan but not in northern France, central Italy (Luiselli *et al.* 1997), or England. Millions of these animals were sold in Asia for Buddhist "Mercy Ceremonies" in which the turtle is marked and then released. So, it is no surprise that large numbers of red-ears have been found in waters already altered by human activities around the world. Even if they were incapable of reproduction, and could only survive a few years, the release of millions would have a significant local impact.

Biology

Active feeding requires water temperatures above 18–20 degrees C (Ernst *et al.* 1994) and effective digestion of plant material requires hours of basking in full sun each day to produce core body temperatures around 30 degrees C. Adult red-ears prefer water 1-3 meters deep with copious amounts of vegetation. They pursue snails, insect larvae, crayfish, insects, worms, shrimp, tadpoles and other small creatures living around the margins of water plants. Live fish and birds are almost never part of their diet but they do readily consume carrion (Parmenter 1980). In the process of hunting they consume large amounts of vegetation. Favourite plants include oxygen weeds, water hyacinth and eel grass; all noxious weeds in New Zealand. In adults the diet by dry weight is 95–100% plant material (Thornhill 1982). They are known to move up to 9 km overland between habitats.

Maximum longevity in natural situations is 30 years. Most animals don't live longer than 20 years. Only 1% of hatchlings survive to 20 years. Annual survivorship of adults is about 80%. Mated females can hold active sperm for up to two years. By the end of the first year the fertility rate drops to 20% or less.

The lowest constant incubation temperature that produces hatchlings is 22.5ºC but, at that temperature, most hatchlings are deformed or neurologically impaired (Ewert *et al.* 1991). To produce any females eggs must experience constant temperatures above 28.3ºC (Cadi *et al.* 2004). To produce all females the nest temperature must exceed 30.6ºC for at least four hours a day during the middle third of development.

Successful nesting also requires soil that is moist enough to be suitable for nest building and maintenance of the water content of the eggs. Vermiculite with a water potential of −1500 kPa (.09 g water:1g vermiculite) is the driest condition in the lab that will allow the majority of eggs to escape fatal dehydration (Tucker *et al.* 2000).

Microbiology

Campylobacter and Salmonella are the most common causes of bacterial enteritis in New Zealand. About 1% of the human population are chronic salmonella carriers. Native NZ wild lizards are also known carriers of salmonella. Campylobacter is ubiquitous in NZ; contaminating dogs, cats, the vast majority of farm animals, and waterways. Chickens and ducks are the most notorious source of both salmonella and campylobacter with contamination rates of 80% (Alan 2003). Campylobacter is by far the most important cause of human disease; out numbering reported salmonella infections by about ten to one in the North. The vast majority of cases go unreported.

On a tour of turtle breeders in the North Island in 2005 I collected dirty pond water and infertile eggs from all their facilities. Three samples from each breeder were cultured onto XLD agar plates and incubated at 35ºC: pond water, pond water carried in selenite cystine broth for 3–7 days, and the yolks and shells of infertile turtle eggs. A minimum of six eggs was sampled from each breeder. The collected samples were cultured by the Whangarei Base Hospital Microbiology Department for salmonella and arizona. Campylobacter was incubated separately on other media from pond water and infertile egg samples. None of the cultures were positive for salmonella, arizona or campylobacter.

These results were surprising. One possible source of error was carrying one set of pond water samples in selenite cystine broth for over 48 hours. Although an excellent selective media for salmonella it is usually cultured onto plates after 24–48 hours. It is possible the media proved to be toxic after that time. However, the untreated pond water should have held the salmonella alive for up to three months and the eggs were used as a back-up source; all proved to be culture negative.

The results could be explained by the fact that conditions for back-yard breeders in New Zealand are much different than on the commercial turtle farms in the USA. Here water is changed frequently, tanks are refilled with chlorinated tap water, offal from cattle are not used for food and the eggs are hatched on grids or in sterile vermiculite, not in contaminated soil.

Reproduction in New Zealand

I know of two locations where red-ear eggs were able to hatch outdoors in NZ. Each nest was situated next to a large, northwest facing heat sink (rock wall/concrete wall/roofing metal) that warmed the soil through the night. Both also featured consistent moisture; an unusual summer condition in most areas of NZ. I am also aware of turtle nests hatching successfully in glass houses that were watered frequently. Except for the above examples, all breeders that discovered eggs outdoors more than two weeks after laying found they were dead.

During the summer of 1991, I constructed an artificial nest in Mangonui (Feldman 1991) in the Far North, one of the warmest areas in NZ. The nest was in an ideal location to capture the heat of the sun, facing due north on a 30 degree slope with no nearby shade. The mean low-high temperatures within the nest for January were 21ºC– 23ºC, and for February were 20ºC–24ºC. The air temperature for that summer averaged 0.8ºC below normal. At those temperatures even the most cold adapted Canadian turtles could not breed here (Bobyn 1991) but there were no eggs in my artificial nest. The presence of metabolically active eggs can raise the nest temperature by 2–7ºC in the last third of incubation (Burger, 1976), but this is too late to influence sexual determination.

Results of a turtle hunt in NZ

Once you know how, it is very easy to detect adult turtles and their nesting sites. During the summers of 1993 and 1994, during the height of the nesting season, I travelled throughout the upper North Island looking for turtles. I only investigated a few ponds in towns and cities because I assumed that there would inevitably be some escaped or released pets there. I focused on "wilder" areas looking for breeding populations in warm water habitats created by human activity. The most likely environment for them that I detected was the numerous weed-choked canals in the Hauraki Plains. In these areas the water was relatively warm and there was an abundance of water plants to eat. I found no turtles and no evidence of nesting.

During 21 years of living in the Far North I have trapped or received several adult female turtles that had found their way into area streams or neighborhoods. All were emaciated and had significant ulcerative shell disease. Clarice Ford, who receives and redistributes unwanted turtles in Auckland, states that almost all her turtles (30 per year) arrive in similar condition. Turtles deposited in the moats at the Auckland Zoo also prove to be frequently infected.

The fate of pet turtles in NZ

The vast majority of hatchlings sold in the pet trade die before one year of age. Estimates from overseas suggest survival is 5%. Survival might be higher here because the animals are much more expensive so people might take better care of them. Contrary to folklore, turtles are quite delicate and require large amounts of calcium, unfiltered sunlight or vitamin D supplements, lots of vitamin A or fresh vegetation, and an environment with no hard, rough surfaces in order to survive for long periods.

If the average turtle is eight years old when it is freed or escapes it can be expected to live for another twelve years under ideal circumstances. But turtles that are released into the wild or escape are usually discovered in poor condition; emaciated, and with multiple lesions from ulcerative shell disease. Ulcerative shell disease is caused by infection with a variety of gram negative rods that gain entry to the living bone because of injuries to the outer keratin layer of the shell. It's usually chronically progressive and ultimately fatal if not treated surgically (Feldman 1998). The origin of the injuries to the keratin are the concrete ponds the turtles are often kept in and the sharp edged rocks found in many situations in NZ, but not in their native environment. Like any chronic disease, ulcerative shell disease causes weight loss because of the inability to feed and the extra energy expenditure involved in the infectious process. I suspect that the other reason "wild" red-ears are always emaciated here is because of the low water and air temperatures in NZ. The low water temperatures inhibit feeding and the low air temperatures makes it difficult to digest the plant material they depend on for nourishment.

Control

Red-ears are easy to catch if you know their habits. Capturing them is so easy that, during the early 1980s, the main concern about red-ears was that they might be hunted to extinction. Because of that fear, considerable pressure was put on the turtle farms to release a percentage of their hatchlings back into the wild. There are various ways to capture them in different environmental conditions. Baited hoop nets are effective in feeding areas, especially if there are small amounts of current flow. Trammel nets can be used effectively in smaller, shallow water bodies where the turtles can be "herded" by disturbing the water surface. Fyke nets are effective next to sunning logs and hibernacula, especially if equipped with wings that form an underwater drift fence leading to the net (Vogt 1980). In clearer waters a set of fins and a snorkel can be used to catch large numbers of animals quickly.

Financial and social factors

The retail value of red-eared sliders sold is about \$170,000 per year. The retail value of durable goods and food sold for the ongoing care of these pets exceeds \$1,200,000 per year.

These business activities have been established in NZ for over fifty years. If there was a ban on the sale of turtles bred domestically compensation issues would probably arise. People have always been attracted to turtles. Demand in NZ has exceeded supply until this year. They are one of the preferred pets for older, asthmatic children that cannot keep mammals. Turtles that survive to adulthood are often retained and passed down from generation to generation. Although some owners of adult animals do release them into dams, rivers and lakes because of their size, many owners of escaped adult animals often contact the SPCA looking for them.

CONCLUSIONS

Except in exceptional circumstances, there is good evidence that red-eared sliders cannot reproduce in NZ successfully because of the consistently low temperatures and sparse summer rainfall in most of the country. There is some evidence that they cannot survive for more than a few years in the "wild" despite the ample supply of invasive water plants available for food. The fact that it makes the news when one is caught supports this view. However, they might be able to survive longer in parks, artificial ponds and waterways already heavily impacted by man, especially if fed by visitors. If native invertebrates exist in these altered environments it is possible that red-eared slider turtles could have an effect on their populations. Given their long history in New Zealand I suspect they would already be a problem if they were ever going to be.

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TOXIC BAIT AVOIDANCE BY MICE

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ABSTRACT: House mice (*Mus musculus*) are a widespread pest throughout New Zealand habitats, including forests and subalpine tussock areas. Some standard rodent-baiting operations are unsuccessful in controlling field populations of mice, and the possible reasons for this needs to be determined. This research investigated avoidance responses of mice to toxic baits, and aimed to identify the particular bait characteristics that mediate any avoidance. In a factorial design trial, 96 wild-caught mice were housed individually and presented with one of 32 possible bait types, for 10 nights. Bait types were all combinations of five factors: (1) toxin type (1080 or brodifacoum); (2) bait (No. 7 or RS5); (3) presence or absence of green dye; (4) presence or absence of mask/lure (0.3% cinnamon); and (5) bait size (2 g or 12 g). Other than toxin, there was no effect of bait characteristics (i.e. bait, size, dye, or lure) on bait avoidance or acceptance. All brodifacoum baits were eaten, resulting in 100% mortality. However, 1080 baits were avoided, resulting in only 8% mortality. This marked avoidance of 1080 baits by mice is likely to have been the cause of control operation failures, and until new methods are developed to improve 1080 bait acceptance in mice, this toxin should not be used for mouse control operations.

INTRODUCTION

House mice (*Mus musculus*) were carried to New Zealand as stowaways on ships in the 19th century and are now widespread throughout New Zealand, including in forests and subalpine tussock areas (Murphy and Pickard 1990). They are likely to have a significant impacts on invertebrate and herpeto-fauna and contribute indirectly to predation on other species by sustaining populations of introduced predators, such as stoats, when other food is scarce (Ruscoe 2001).

In New Zealand the large-scale eradication of introduced rodents from islands has been achieved through the use of brodifacoum, but there have been more failures with attempted mouse than rat eradications. Standard 1080 (sodium monofluoroacetate) baiting operations are used for wide-scale possum and rat control on the mainland, but have often been unsuccessful in controlling mice (Gillies *et al.* 2003a). Most animals have behavioural defences against dietary poisoning, including neophobia, the ability to detect and recognise poison, primary or unlearned food avoidance, and learned food aversions (e.g. O'Connor & Matthews 1999). There is a vast literature on the development of bait shyness and poison aversion in rodents, though less on mice (but see Humphries et al. 2000). Further, mice are generally regarded as neophilic (i.e. they have a tendency to approach unfamiliar places or objects), although there are also reports of neophobia in mice (e.g. Kronenberger and Médioni 1985).

This research investigated whether there was any avoidance response of mice to 1080 and brodifacoum baits, and aimed to identify the particular bait characteristics that mediate any avoidance.

METHODS

Wild-caught house mice were housed at the Landcare Research animal facility in individual polycarbonate cages with a wire lid, containing shredded paper for play and nesting, and fed *ad libitum* on rat and mouse pellets (Weston Animal Nutrition, Rangiora). Supplementary food (crushed grains and cereals, Lincoln Grain and Produce, Lincoln) was provided and water was available at all times. Mice were acclimatised for 1 month and weighed weekly to monitor health and well-being. All mice were weighed the day testing began and only those of stable or increasing weight were used for the trial.

In a factorial design, 96 wild-caught mice were presented with one of 32 bait types (manufactured and supplied by Animal Control Products, Wanganui and Waimate), for 10 nights. Bait types were all combinations of five factors: (1) toxin type (1080 (nominally 0.15%) or brodifacoum (nominally 0.002%)); (2) bait (No. 7 or RS5); (3) presence or absence of green dye; (4) presence or absence of mask/lure (i.e. 0.3% cinnamon); and (5) bait size ((10–12 mm (2 g) or 20 mm (12 g)). In a choice-test procedure, mice were presented with 30 g of the toxic test bait and 30 g of the standard pellet diet, for 10 consecutive nights. Three controls for nine of the bait types (including the standard diet) were randomly located in the room to measure any weight changes due to moisture, and the resulting bait intake corrected for these differences. Time to death was recorded, and at 21 days any surviving animals were euthanased humanely.

The toxin concentration in eight of the bait types was analysed at the Landcare Research Toxicology Laboratory, Lincoln. Brodifacoum baits were analysed by HPLC (Method TLM017), and 1080 baits by gas chromatography (Method TLM023). Mortality data were analysed in S-Plus using the 'GLM' procedure.

RESULTS

The baits were found to contain a mean of 0.0019% brodifacoum and 0.17% 1080. The only significant effect was toxin type ($X^2_1 = 104.9$, $P < 0.0001$). All brodifacoum baits were eaten, with a mean consumption of 13.2 ± 0.5 g over the 10 days. However, 1080 baits were avoided, with a mean of only 0.52 ± 0.04 g eaten over the 10 days. In comparison mice, over all bait types, ate a mean of 16 ± 0.15 g standard pellets over the 10 days.

This resulted in 100% mortality from brodifacoum baits but only 8 ± 0.03% mortality for 1080 baits (Fig. 1).

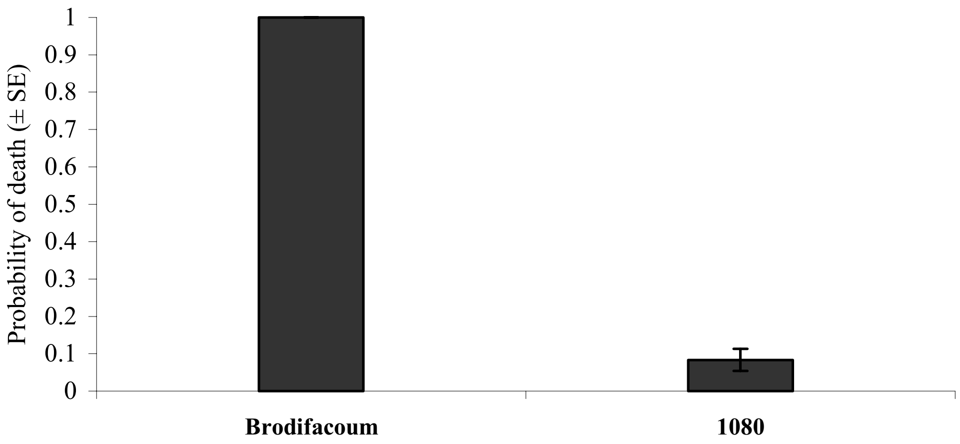

Fig. 1 Probability of death (± SE) in mice, within 21 days, for two toxins.

DISCUSSION

In conclusion, mice avoid 1080 toxin. There was no effect of any other bait characteristic (i.e. bait , size, dye, or lure) on bait avoidance or acceptance. Mice, because of their small bodyweight, are generally considered relatively susceptible to 1080, although it is less toxic to mice than to most other rodents (oral LD_{50} 8.33 mg/kg: McIlroy 1982). Gillies *et al.* (2003b) found a low non-toxic-bait acceptance by mice (compared with ship rats). The inclusion of 1080, especially at 0.15% rather than 0.08%, may have increased the avoidance of baits. However, the higher concentration is the one most likely to be used in 1080 baits for possum control operations and for future rodent control. Furthermore, the addition of cinnamon at 0.3%, does not mask 1080 for mice the way it does for possums (Henderson and Frampton 1999).

There was no avoidance of these same bait types, however, when brodifacoum was included. Although mice are generally considered to be less susceptible than rats to anticoagulants, the oral LD_{50} estimates for brodifacoum are from 0.4 to 0.52 mg/kg and are similar to *Rattus* species (O'Connor and Booth 2001). As is often found with anticoagulants, mice in this trial ate up to 20 times more bait than was required for a lethal dose (i.e. 0.43–0.65 g; Fisher 2005). Therefore, because of brodifacoum's environmental persistence (Eason *et al.* 2001) carcasses of poisoned mice are likely to contain brodifacoum residues. Despite the efficacy of the brodifacoum baits, this over-eating behaviour reinforces concerns over their field use because of the increased secondary poisoning risks to non-target species.

The marked avoidance of 1080 baits by mice found in this trial is likely to have been the cause of control operation failures, and until new methods are developed to improve 1080 bait acceptance in mice, this toxin should not be used for mouse control operations.

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AUTOMATED MONITORING FOR DETECTION OF SMALL MAMMAL PESTS

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ABSTRACT: This paper describes the current capabilities of the Scentinel® Mk4, an automated bait station and smart monitoring device for small mammals of between 40 and 2000g. It is equipped with a weighbridge, bait canisters and camera, and can be programmed to respond in different ways to visitors of specifiable weight categories. At the date of writing, we are about two-thirds of the way through an extensive field trial on farmland near Tokoroa, funded mainly by FRST and AHB.

Our aim in this study is to develop a ferret-specific version of the Scentinel, which we propose to achieve through a combination of weight and conventional tunnel design techniques. By dispensing bait only to animals that weigh more than 400 g we anticipate that it should be possible to exclude mice, rats and stoats from treatment, and by limiting the tunnel entrance size it should be possible to exclude most members of the larger species such as possums and cats. The results of this trial will show what opportunities there may be to tighten specificity in future without missing any ferrets, by, for example, raising the weight threshold or reducing the tunnel opening size, and also by choice of lure and placement of units in the landscape.

We set out 24 Scentinels at 1-km intervals, starting on February 11. In this trial we set the first weight threshold at 40 g (visitors smaller than this are ignored) and the second weight threshold at 400 g (visitors weighing between 40 and 400 g trigger the camera but not the bait, and visitors >400 g trigger both). The tunnel entrance was 105 mm diameter. When an animal weighing over 400 g enters the tunnel fully, a small quantity of bait is dispensed near its nose. In normal use the bait would have toxin added. Footprint tracking pads were used, in this trial only, to check for camera and/or weighbridge failures. Because the footprint papers needed regular changing, the Scentinels were visited weekly, but they are designed to be left for months to collect data unattended.

To test the discrimination capabilities of the Scentinel we maximized the visitation rate of all species by providing several potential lures together: an egg/oil or brain-paste liquid-food lure; an extract of ferret anal glands; and peanut butter. The latter was intended to encourage rat and mouse visits, in the expectation that visiting rodents would leave scent marks that would attract ferrets.

With over 1000 trap-nights so far, we have recorded about 900 visits, including 180 ferrets (at 17 of our 24 units), 400 hedgehogs and 60 rats, as well as a few cats, possums, mice and rabbits. Most of the hedgehogs and nearly all the ferrets, but none of the rats, were over 400 g and consequently were offered bait. More than 90% of the egg/oil baits offered to ferrets were eaten, almost always (95%) completely.

Of the few ferrets not offered bait, 3% were under 400 g, and 10% put only their front paws on the weighing platform (which triggered the camera but not bait delivery). We think that the records will indicate that most of the latter group came back later.

We have so far collected several thousands of records of weight and image by date/time and by station. Species ID is extremely good (only 2% of visitors unidentified), and we think that individual identification will be possible in many case when the records are fully analysed.

This trial suggests that it should be possible to deliver toxic baits selectively to ferrets, over the long term and at landscape scale, whilst minimising the risk of secondary poisoning (except to the relatively unpalatable hedgehogs) and the effects of neophobia. Additional data on, e.g. activity and distribution of a wide range of other species, is collected incidentally.

THE ORIGIN OF THE SPECIES: USING GENETICS IN PEST MANAGEMENT

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ABSTRACT: Key questions in pest management include the number of individuals that have invaded an area, their origin, whether invasive populations are expanding or declining, whether they are transient or resident and which individuals disperse. New methods from human forensics may illuminate the dynamics of invasive populations better than traditional approaches. These genetic analyses have recently become more accurate and feasible as a result of improved technology and statistical methods, and in combination with ecological data offer a new perspective into the dynamics of populations and the movement of individuals. Although rarely used for this purpose, such an approach may prove vital for pest and disease management. To demonstrate the application of genetics to pest management, we are using the westward expansion of the European starling (*Sturnus vulgaris*) as a test case to study an invasion in progress. We aim to provide a clearer picture of starling movements in Australia by using population genetics, and provide information to relevant agencies to improve pest management strategies.

INTRODUCTION

The use of genetics to infer information about wild populations is not a new concept but has traditionally been hindered by technical and computational constraints. Since the quality of results is often linked to the amount of genetic variation found, there is increasing demand for larger datasets. Fortunately, advances in laboratory techniques continue to increase speed and lower the cost of genetic analyses, allowing for greater numbers of individuals and genes within them to be screened. Of equal importance is the revolution in population genetic statistics resulting from increased computational power. Generally, these novel statistical methods are more useful for management than those traditionally used in genetics because they are less dependent on assumptions that are rarely met in real populations (Pearse and Crandall 2004).

Examples of applied genetics are more commonly found in the field of conservation, and are generally focused on protection of endangered populations. However, many of these techniques can be applied to pest management because they provide information that can be used to *limit* pest populations and to understand underlying dynamics leading to successful invasions. This paper explores some of the genetic tools available to assist population managers in answering questions about the number of individuals that have invaded an area, their origin, the number of invasion events and the dynamics of invasive populations. The invasion of the European starling (*Sturnus vulgaris*) into Western Australia (WA) is used to illustrate how these methods may be beneficial to population managers.

USES OF GENETIC DATA

Defining Management Units

Management and control policies may differ depending on the degree of connectivity between populations. For example, eradication may be possible in a series of small, discrete populations whereas in geographically large, genetically mixed populations, management may be the best possible outcome. In situations when population subdivision is unclear, the incorrect assessment of the number of populations may bias results (Taylor 1997). Recently described methods that cluster similar genotypes can be used to determine the number of populations sampled and define boundaries, removing the necessity to pre-define populations (e.g. Pritchard *et al.* 2000). Robertson and Gemmell (2004) used this approach to define boundaries in rat (*Rattus norvegicus*) populations on South Georgia Island. They concluded that isolated populations could be sequentially eradicated without a high risk of reintroduction. The effectiveness of eradication efforts can be checked by distinguishing survivors from new immigrants using genetic methods (see Abdelkrim *et al.* in press).

Population Demographics

It is challenging to determine appropriate levels of control effort if population size is unknown. Assessment of population size may be hampered by habitat structure, geographic extent, mobility, size of the individual, and magnitude of the population. In situations where direct census is not possible, genetic estimations of population size may be useful. Genetic data can be used to calculate effective population size (N_e), which is an estimate of the expected rate of certain genetic changes. N_e is a function of many factors including historical population size, sex ratio, breeding structure and family size (Halliburton 2004). Assuming other factors remain constant, changes of N_e imply changes of N, the total population size (Frankham 1995). Indeed, if the goal of the management agency is to model population expansion, N_e may be more meaningful than total size as it accounts for reproductive success.

Genetic tools have the ability to identify important demographic characteristics for pest animal management. For an expanding population, these tools can identify populations close to the "front" of expansion (Pearse and Crandall 2004). Genetic tools can also be used to provide feedback on the effectiveness of control programs by identifying sudden population contractions or "bottlenecks" (e.g. Hampton *et al.* 2004). Many of the methods developed to detect such events are reviewed in Emerson *et al.* (2001) and Pearse and Crandall (2004). The choice of the most appropriate method will depend on the timescale of interest (Abdelkrim *et al.* in press). Current developments attempt to model demographics of introductions over very recent history and have been used to estimate numbers of colonizing birds (*Zosterops lateralis*) (Estoup and Clegg 2003).

Population of Origin

Effective control of invasive populations may largely depend on the ability to pinpoint the source. In many situations, place of origin is unclear, or there may be multiple sources of an invasive population. A variety of methods have been developed to assign an individual to a population of origin, based on the level of genetic similarity between that individual and the individuals in the source population. The type of genetic data available, the resolution of those data and the question under investigation should be considered when choosing one of these methods. Recently, sophisticated tools such as STRUCTURE (Pritchard *et al.* 2000) and GENECLASS2 (Piry *et al.* 2004) have been used to calculate the number of populations sampled, assign individuals to populations, exclude them from populations, and identify migrants or descendants of migrants. Moreover, this method can incorporate prior information such as geographic data. These tools have the ability to be cross-validated, in order to compare the accuracy of the data output. Such approaches have also been validated using conventional mark-recapture data (e.g. Berry *et al.* 2004) re-enforcing the power of these new tools.

By virtue of their ability to assign individuals to populations, assignment programs can be used to determine the minimum number of introductions that have occurred in a particular area. Davies *et al.* (1999) used an assignment test to determine that multiple medfly (*Ceratitis capitata*) introductions had occurred in California. Single introductions might be identifiable by examining the amount of genetic variability in an introduced population as compared to potential source populations. If no variation is found in an introduced population in a gene that is variable in source populations, it may be reasonable to assume a single introduction has occurred (Hänfling *et al.* 2002), although multiple introductions of the same genotype could also result in this pattern. Conversely, invasive populations containing *greater* genetic diversity than is found in any source population may indicate multiple introductions from different sources (see Kolbe *et al.* 2004).

Characteristics of Dispersal

In order to effectively implement population control, an understanding of dispersal is vital. Dispersal can be difficult to measure but gene flow may be used as a proxy. Measures of population structure such as F-statistics (F_{ST}) or Analysis of Molecular Variance (AMOVA) (Excoffier *et al.* 1992) are frequently used to infer the relative presence or absence of gene flow between populations. F_{ST} can be transformed into the number of dispersers per generation and has been used extensively to calculate levels of dispersal. However, this model depends on a long list of assumptions that are highly improbable in real populations (Whitlock and McCauley 1999). Since invasive populations are typically small and thus are extremely likely to violate these assumptions, F_{ST} transformations are unsuitable as a literal indicator of dispersal. Despite this, there are myriad programs available that calculate dispersal rates based on transformations of F_{ST} which should be avoided unless the required assumptions are met. Additionally, these methods estimate historical rather than current rates of exchange. In contrast, BAYESASS (Wilson and Rannala 2003) departs from the traditional use of F_{ST} by using Bayesian methodology similar to the assignment methods discussed above. This program is likely to be of greater use in pest management as it addresses contemporary dispersal rates, does not require populations to be at equilibrium and can handle most types of genetic data. It should be noted that the F_{ST} methods described here measure dispersal of only those individuals who have reproduced, whereas assignment methods measure dispersal of *all* individuals sampled (Favre *et al.* 1997)

Patterns of dispersal may also provide useful information for management as they can illuminate the mechanism of introduction as well as identify particular demographic groups more likely to disperse. Using genetic analyses, it is possible to determine the sequence of a group of introductions and to distinguish primary from secondary introductions (see Sved *et al.* 2003, Kolbe *et al.* 2004). Spatial Analysis of Molecular Variance (SAMOVA) (Dupanloup *et al.* 2002) groups populations on the basis of genetic similarity and can be used to identify geographic barriers to dispersal, thus assisting in the strategic placement of control operations. Sex-biased dispersal can be detected by comparing the level of population structure between maternally inherited mitochondrial genes to bi-parentally inherited nuclear genes. Alternatively, sex-specific assignment tests (Favre *et al.* 1997) and other methods (Goudet 2002) can be used to identify sex-biased dispersal using data from bi-parentally inherited genes.

STARLINGS AS A TEST CASE

The starling (*Sturnus vulgaris*) is an ideal model for the study of invasive species as it has been introduced successfully on multiple continents including Australia. In Australia, acclimatization societies introduced starlings to Victoria, South Australia and New South Wales between 1856 and 1881 (Long 1981). Following a rapid spread, starlings became resident in most of eastern Australia but due to geographical features and control efforts, are yet to become established in WA. This provides an excellent opportunity to study mechanisms of invasion as they occur. Since starlings are highly mobile, small, and tend to inhabit areas difficult to survey, it is especially challenging to use traditional ecological methods to quantify population dynamics, identify source populations and understand population demographics. Therefore, genetic techniques discussed above will be used to address these issues. If source populations or particular groups of individuals prone to dispersal can be identified, more effective and targeted control may be possible.

Methods

Thirty to fifty individuals will be sampled from eight potential source populations in eastern Australia, from areas on the leading edge of the starling invasion in WA and along the Nullarbor (western South Australia), and a museum collection from WA. Fine scale sampling will be conducted in one area for which tracking data exists (Munglinup located west of Esperance in WA, see Woolnough *et al.* this volume). For each individual, over 20 genes will be sampled through DNA sequencing, microsatellite analysis and allozyme analysis. Additional data will also be gathered for each sample including condition, age and sex, which will be determined by dissection or genetic analysis.

Eastern Australian starling populations, which are resident and therefore expected to be stable, will be used to produce baseline population genetic data. Allozymes used in previous studies of introduced starling populations in New Zealand and the US will also be selected for this study so that changes in diversity can be compared across different sites of introduction. To ensure that microsatellite data conform to assumptions, we will use GENEPOP (Raymond & Rousset 1995) to check for evidence of null alleles and genotypic disequilibrium. STRUCTURE will be used to determine the number of genetically distinct populations and to assign individuals sampled in WA and the Nullarbor to populations of origin. Museum samples from past WA incursions will be included in this dataset to determine whether those samples form a distinct genetic group. If they do, then they will be included as a potential source population for the recent invasions. If not, we will assess whether historical and contemporary movements are consistent. We will look for evidence of multiple invasions or sequential invasion. GENECLASS2 will be used to corroborate assignments, to exclude populations that do not fit criteria, and to determine whether Western Australian populations are transient. BAYESASS will be used to calculate migration rates. SAMOVA will be used to check for discontinuities in dispersal. Sex biased dispersal will be evaluated by comparing maternally and bi-parentally inherited genes. Additionally, adults from WA identified as dispersers will be used to compare population structure between sexes. Genetic data will be investigated for evidence of population expansion or decline, because we would expect to see evidence of a bottleneck in the Australian population in general, and in any WA resident populations. We will look for genetic evidence of contemporary population expansion.

Possible Management Outcomes

If it is determined that Western Australian starling populations are from the nearest source populations across the Nullarbor, then it may be best to focus additional eradication effort on these source populations. However, the current management policy of controlling incursions in WA should be continued if Western Australian individuals or their immediate ancestors appear to be from many populations in eastern Australia. Alternatively, if Western Australian individuals appear to form a distinct population, then it may indicate that cryptic resident populations exist. If this scenario seems most likely, management may choose to increase control efforts in WA to locate and eliminate any resident populations. Additionally, if dispersal appears to be skewed toward any particular demographic group, then control efforts aimed at that group may be more effective.

CONCLUSIONS

Much of the challenge of managing wild populations stems from a lack of information regarding their dynamics. The novel statistical methods outlined in this review offer hope for improved understanding and, ultimately, more successful control of invasive species. As with all methods, independent data should be used to validate results and assumptions should be carefully checked. There exist many other examples of the application of genetic data to evaluate and control invasive populations including the comparison of historical and current levels of invasion (Hebert and Cristescu 2002), the identification of invasive species that are morphologically similar to natives (Vazquez-Dominguez *et al.* 2001) and the identification of hybridization between invasive and native species (Bond 2002). Screening communities for invading species that cannot be morphologically distinguished from natives has been suggested as a future use of these techniques (Hebert and Cristescu 2002). The application of genetic methods to pest management, although currently in its infancy, offers an important new dimension to strategic control and decision making processes.

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BAIT DELIVERY OF RABBIT HAEMORRHAGIC DISEASE VIRUS (RHDV) TO IMPROVE THE EFFECTIVENESS OF RHD OUTBREAKS ON RABBIT POPULATIONS

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In SA, naturally recurring outbreaks of RHD have held rabbit numbers down to 10-15% of pre-RHD levels in semi-arid and arid areas. However, RHD has had less impact in higher rainfall and some coastal areas, where landholders frequently complain about rabbits in late spring and early summer and claim that RHD does not occur in their area. This has stimulated mounting interest in the potential use of RHDV on bait to initiate outbreaks in such areas. Currently, RHDV is only registered for administration to rabbits by injection but this is not a practical field technique for landholders. An application for registration of RHDV-bait is currently being considered by the Australian Pesticides and Veterinary Medicines Authority and field trials have been conducted to test the efficacy of the technique.

Trials with RHDV-bait were conducted in two series: (1) in spring, when natural outbreaks in higher rainfall areas most commonly occur and hence when we considered it most likely that we would be able to initiate outbreaks with RHDV-bait, and (2) in autumn, before rabbit kittens had entered the population, and hence when outbreaks are likely to have greatest impact on rabbit numbers. The trials were designed to infect a small number of rabbits and determine: (a) whether the virus would spread to other rabbits that had not eaten the bait and initiate a localised outbreak of the disease and (b) whether the virus would spread beyond the local population to rabbits in adjoining areas. Rabbit abundance was estimated from spotlight transect counts. Sera and liver samples were taken from shot and live-trapped rabbits and analysed using RHD antibody ELISAs, RHD virus capture ELISA, PCR and genetic sequencing of PCR products.

During spring 2003, outbreaks were successfully initiated at 4 sites in the Mt Lofty Ranges and 2 sites on Eyre Peninsula using RHD virus on carrot or oat bait. Baiting reduced rabbit numbers by 0- 80%. In autumn 2004, RHDV-bait reduced rabbit numbers by 74% at one site and by only 26% at another. The recorded timing and geographical spread of rabbit deaths indicated that secondary infection occurred and that the disease spread at 3 or more sites in spring and 1 site in autumn. The level of population reduction across all sites was related to the proportion of susceptible rabbits at the time of baiting. Tissue and sera analyses indicated that some RHDV was already circulating at several sites prior to RHDV-bait release, but that RHD outbreaks subsequent to baiting were primarily caused by the release strain not by wild strains of RHDV.

One of the trial sites, Venus Bay Conservation Park, included a bettong and bilby reserve that offered the opportunity to determine whether there was a risk in exposing native herbivores to RHDV-treated bait. There was no impact on native species.

THE EFFECTIVENESS OF BROADSCALE WARREN RIPPING AFTER THE OCCURRENCE OF RABBIT HAEMORRHAGIC DISEASE IN CENTRAL VICTORIA

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ABSTRACT: After the occurrence of rabbit haemorrhagic disease (RHD) the Victorian government introduced subsidies for landholders to manage rabbits based on the destruction of rabbit harbour. Large-scale warren ripping programs were implemented across the state. At two locations in central Victoria where RHD is endemic, broadscale ripping has maintained rabbit populations at low levels over four years. Although 26-31% of ripped warrens re-opened there were on average only three active entrances/warren or 7-8 entrance/ha that needed to be treated. By fumigating or re-ripping a small number of entrances on relatively small proportions of re-opened warrens, the initial ripping investment will be protected and rabbit populations can be maintained at low levels in the long-term.

INTRODUCTION

Across Victoria twenty monitor sites were established in 1998 to collect local information on the behaviour of RHD and to monitor the effectiveness of conventional rabbit control programs. To take advantage of RHD the Victorian government introduced subsidies to support landholders in managing rabbits by concentrating on the removal of rabbit harbour. From two of the state-wide monitor sites a case study is presented comparing the activity of warrens were broadscale ripping has or has not occurred.

METHODS

For both Maryborough and Harcourt in central Victoria, two paired sub-sites (5-45km^2) similar in land type, located 4-15km apart were ripped or non-ripped and monitored at three monthly intervals over a four year period to evaluate the effectiveness of ripping rabbit warrens. Measurements of active and non-active entrances in 4-10 warren monitor plots of 1-3ha, containing 5-16 warrens commenced in May 1998. At the Harcourt site (1570ha), 1983 warrens were ripped over 871ha using a 17C traxscavator ripping 13 warrens/hr at $7.30/warren. At the Maryborough site (3500ha) approximately 6300 warrens were ripped over 1800ha using a D6 dozer ripping 6 warrens/hr at $7-$15/warren or a 12 tonne excavator ripping four warrens per hour at $18.50/warren. The higher cost/warren for Maryborough is possibly due to increased travel cost between warrens. The ripped areas included steep metamorphic hills and granite flats. The dozer and traxscavator use three tynes capable of ripping to a depth of 90cm and the excavator used a single 80-100cm tyne. Where possible, warrens were cross-ripped, back-bladed or track-rolled.

RESULTS

Historical spotlight counts obtained from a similar land type located approximately 30km from the paired Maryborough sites demonstrate the change in rabbit abundance resulting from the occurrence of RHD in early 1996. From Jun 84 to Nov 88, there was mean number of 31 rabbits/km. After the spread of RHD the mean number of rabbits spotlighted over a four year period declined dramatically to 2.5/km for ripped and 4.6/km for un-ripped areas (Fig. 1). No historical data was available for the Harcourt area but after the spread of RHD the mean spotlight counts, recorded over the same post-RHD four year period were less for ripped (5/km) than un-ripped areas (13/km)

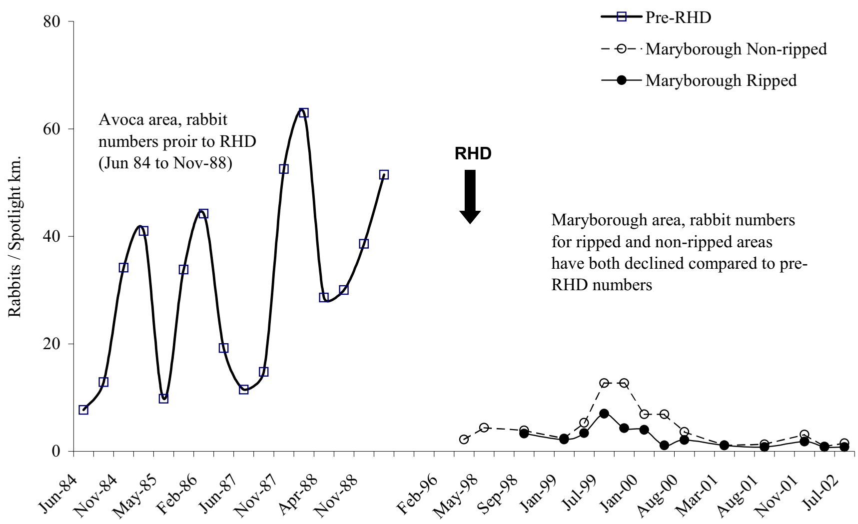


Fig. 1. Change in rabbit abundance measured by spotlight counts of rabbits before the occurrence of RHD and in the post RHD period for ripped and un-ripped areas in the Maryborough area

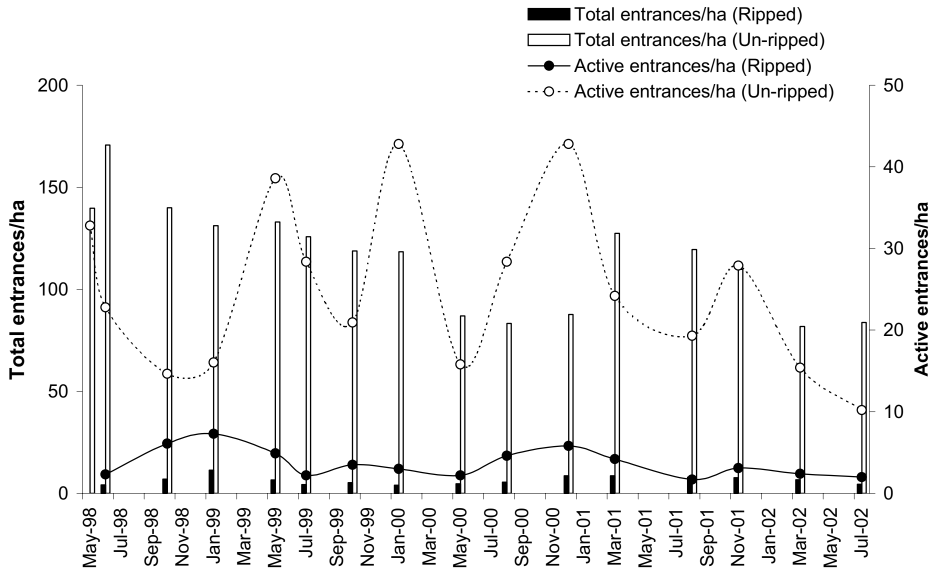
At both monitor sites, warren monitor plot density prior to ripping was similar for the ripped and non-ripped areas. The total number of entrance/ha was decreased by ripping and over the four year period (1998-02), the mean of the averaged active entrances/ha for each observation period, was less ($P<0.05$, t-Test) for the ripped than un-ripped areas. Although 26-31% of ripped warrens were re-opened, only 3 entrances per warren were re-opened compared to 7-14 entrances remaining open in un-ripped warrens (Table 1).

Table 1. The mean of the averaged warren measurements for each observation for data collected over four years from within the warren monitor plots

Site/treatment	Initial Warrens per ha	% warrens active	Total entrances per Warren	Total entrances per ha	Active entrances per ha
Maryborough					
Ripped	7.6	25	3	7	4
Non Ripped	8.4	75	14	116	25
Harcourt					
Ripped	8.6	31	3	8	6
Non Ripped	6.4	88	7	56	32

Warren densities at both locations were similar but the density of entrances was higher at Maryborough due to a greater number of entrances per warren (Table 1.). Warren ripping reduced the density of warren entrances and with very little or no follow up maintenance these reductions were maintained over the following four years. For the observed period, the respective means for total density and density of active warren entrances were reduced by 94% & 84% for Maryborough and 86% & 81% for Harcourt. For both locations the incidence of active entrances for ripped and un-ripped areas appeared to be relatively constant over time. Seasonal peaks in the incidence of active entrances are most likely associated with breeding (Fig. 2).

(a) Maryborough



(b)Harcourt

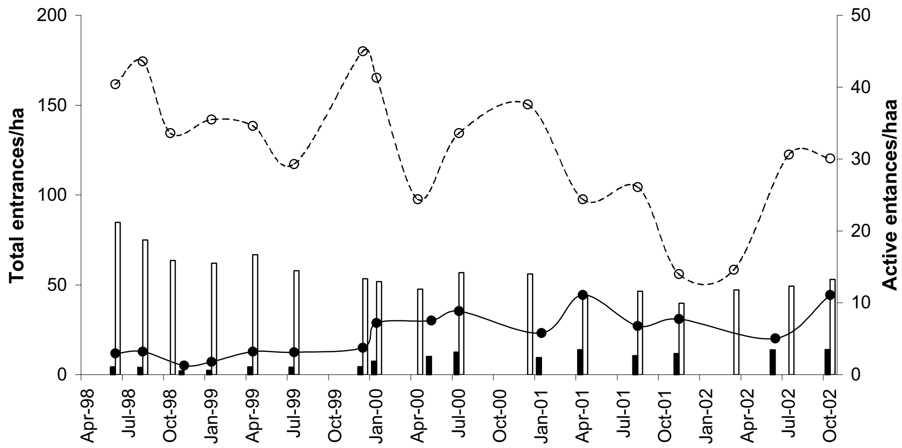


Fig. 2. For Maryborough (a) and Harcourt (b) the total number of entrances/ha (bar plots) and number of active entrances/ha (line plots) for ripped and un-ripped warrens

DISCUSSION

At the Maryborough site rabbit spotlight counts have declined to historically low levels and over four years the population has been maintained at 85-95% of the level recorded in 1995 prior to the occurrence of RHD (Fig 1). For the non-ripped areas it appears that warrens may not be occupied at full capacity and the number of active entrances remains relatively constant. In the ripped areas where warren capacity is reduced by 81-84%, there is no increase in activity. Although there have been lower than average rainfall events over the past 8 years, severe drought conditions did not occur during the observation period. The historic low population in the post-RHD era indicates rabbit nutrition may not be a major factor limiting population rebound. Antibody prevalence to RHD detected in the sera of rabbits sampled regularly during the monitor period was similar (64-70%) for ripped and un-ripped areas, indicating RHD was endemic, persisting in the field and recurring naturally (McPhee *et al*. 2001). Rabbit numbers have not rebounded and appear to have stabilised, being at an equilibrium with the impact of disease, predators or the availability of warren space.

Using active entrances/ha as a surrogate for rabbit density, a rough estimate of 1.6 active entrances equates to one rabbit during the non-breeding season (Parer and Wood 1986). The mean estimated density for the ripped areas is around 3-4 rabbits/ha but even where rabbit density is lowered by ripping, damage to plant biodiversity may still occur (Williams *et al*. 1995). Assuming 10 rabbits roughly equals 1 dry sheep equivalent (DSE), the respective rabbit grazing pressure for Maryborough and Harcourt equates to around 1.6 and 2.0 DSE/ha. The recommended livestock grazing pressure is 2.5 and 4 DSE/ha in these areas. The extra grazing pressure from rabbits in the un-ripped areas would still inflict environmental and economic damage even with the historic decline in rabbit populations.

This case study, although limited by poor replication, provides evidence that in existing rabbit populations, broadscale ripping has maintained rabbit numbers at low levels over a four to five year period. The warren re-opening rates were moderately low with only three entrances/warren or 7-8 entrances/ha requiring treatment. This requires a relatively small commitment in terms of cost and time to landholders. By fumigating or re-ripping a small number of entrances the initial ripping investment can be protected and rabbit populations can be maintained at low levels in the long-term. The challenge now is to convince government, landholders and the community to maintain the pressure on rabbit populations by increasing the control efforts when rabbit numbers are low. Persistent pressure to reduce populations further using existing control methods holds the key to reducing rabbit damage in the long term

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BURROWING RODENT CONTROL USING BIO-DEGRADABLE FOAM INJECTED INTO BURROWS

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ABSTRACT: Canada and USA have granted "Reduced Risk" registration to a Canadian invention. It is marketed as a rodenticide as EXIT™ in Canada and VARGON™ in USA. In application, the product is injected under pressure as a biodegradable foam into a rodent burrow. Any rodent that is in a closed burrow system filled with rodenticide foam will be unconscious within 2 minutes and dead by asphyxiation within five minutes. Average application time for ground squirrels and Norway rats is about 20 seconds per burrow. The product contains no toxic material and can be used anywhere there are rodent burrows. It out-performs all other rodenticides in efficiency and killing speed. It is especially useful where safety is a priority. Patents have issued or are pending in several countries. Rodent Control Inc. leases patent rights to the invention under the product name RoCon™ in all applicable jurisdictions outside of Canada and USA.

INTRODUCTION

My introduction to rodent control began twenty years ago when my wife and I moved to a small acreage in the Rocky Mountain Foothills, 15 kilometres west of Calgary, Alberta. Our acreage was overrun by Richardson's ground squirrels (*Spermophilus richardsonii*), called "gophers" on the Canadian prairie.

In 1995, David Schmunk and I started working with foam as a potential gopher control system. After three years of experimentation with various types of foams and additives, we finally had a product that worked. Any ground squirrel that was submerged in the foam would fall asleep within two minutes, and be dead within five. The foam contained no toxic substances and was completely biodegradable. We named the product EXIT.

Product

The product is marketed as an emulsion concentrate containing a foaming agent, ground mustard seed and water. The essential ingredients are the surfactant in the foaming agent, namely (alpha-olefin sulfonate, sodium), and the ground mustard seed (*Brassica hirta*/*Sinapis alba*).

The ratio of ingredients in the concentrate has been optimized to produce the highest efficacy for the lowest ingredient cost. Toxicity tests on Foam Concentrate have given an Oral LD_{50} (rat) of >5.050 mg/kg. One litre of Foam Concentrate makes 25 litres of Field Solution, which provides approximately 100 litres of foam for field use The Foam Concentrate is diluted by a factor of 25 times by weight in the Field Solution and 100 times by volume in the foam that is injected into the rodent burrows. The foam dissipates in 2 to 4 hours in the burrows and in about 20 minutes on surface. Secondary poisoning from ingestion cannot occur.

The Foam Concentrate was granted Registration as a Reduced Risk Rodenticide in Canada and USA in April, 2003. It is marketed under the trade names of "EXIT™" in Canada, and "VARGON™" in USA Rodent Control Inc. owns the patent rights granted in other jurisdictions outside of Canada and USA and leases the rights under the product name of RoCon™.

Application equipment

Application equipment consists of a Field Solution tank, a 12 volt Shurflo diaphragm pump with demand switch, hose reel with 100 feet of ½ inch hose, a thumb switch and an aeration nozzle with extension. The equipment can be mounted on the back of a pickup truck, on a small trailer towed by a garden tractor or ATV, or any utility conveyance. The 12 volt pump is powered by the battery in the vehicle used to carry the equipment or to tow it. We also use a 20 litre wheel cart with a built-in pump and 12 volt battery for use in restricted areas where noise or exhaust fumes might be a problem. The wheel cart is also used for mop-up operations or in situations where only a small number of burrows require treatment. In China, they use a gas powered backpack unit to access rat burrows that cannot be reached by truck. Perforated plastic cones are used to plug burrow entrances to prevent escape during treatment.

Application method

The recommended procedure for applying Rodenticide Foam is as follows:

1. Traverse the area to be treated and flag all open burrows.
2. Examine all burrow entrances for evidence of endangered species. Do not treat burrows where evidence of endangered species is observed.
3. Press perforated plastic cones into all burrow entrances to be treated and all surrounding entrances within 5 metres of the burrow entrance being treated.
4. Inject foam through the aeration nozzle through the perforations in the plastic cone into the burrow until foam rises to the top of the cone. If a burrow has multiple entrances foam will rise up to surface inside all cones connected to the burrow being treated.
5. Repeat 3. and 4. above until all cones have been topped up with foam.
6. Leave topped up cones in place for three minutes. They can then be removed and used again as systematic treatment continues.

It is recommended that burrow entrances be tightly packed with sod after treatment. This discourages re-invasion from outside the treated area. We found that commercial sod works best. It can be quickly cut to the proper size and it presents a barrier that ground squirrels will avoid.

Target situations and species

We have successfully used Rodenticide Foam to control ground squirrels in pastures, horse paddocks, alfalfa, corn and barley fields, cemeteries, parks, schoolyards, playing fields, rodeo grounds, boulevards, lawns, gardens, flower beds, shelter belts and historic sites. We have also demonstrated its use in eliminating Norway rats in parks, apartment blocks, boulevards, grain storage facilities, a chicken farm and a monkey zoo. Rodenticide Foam can be used anywhere that poisons pose a risk to children, pets, livestock or any not-target species. It is extremely site-specific and is applied only to the inside of target burrows. It is environmentally benign and can be used to control any burrowing rodent that inhabits a sealed burrow system.

FIELD EFFICACY TESTS

1. Rangeland and Hay Field

Dr. Gilbert Proulx of Alpha Wildlife Research and Management Ltd. performed the first Field Efficacy Tests of the Rodenticide Foam from April 26th to May 1st, 1998. He had previously assisted David Schmunk and me in our development of the product, firstly, by advising us that our original product was unsatisfactory and we should continue with our experiments, and finally that we had a product that actually worked in his laboratory tests.

Two field study areas were selected west of Calgary where ground squirrel activity was high. (1) Open range pasture, and (2) Irrigated 8 year old alfalfa field.

Protocol

Active burrows were identified by shoveling dirt into all open burrows during late afternoon and early evening on the day prior to the treatment, and early next morning (treatment day), marking the re-opened burrows with numbered flags. Rodenticide Foam was injected into the re-opened burrows through a metal grill placed over the burrow entrance to prevent escape. The application was completed when foam overflowed the burrow opening. The burrows were packed with dirt after treatment. Open burrows in Buffer Zones 30 m wide surrounding the test plots were injected with Rodenticide Foam and left open. The buffer zones were monitored continuously during the daylight hours during the field tests. Whenever a ground squirrel was spotted entering the buffer zone it was chased down an open hole and quickly dispatched with an application of Rodenticide Foam. The test plots were examined each morning for three days after treatment and all burrow openings were tabulated, treated and packed with dirt.

Results

In the Range Pasture, 192 open burrows were treated on Day 1, the "Treatment Day". The next morning (Day 2) there were two re-opened burrows which equated to a control percentage of 99%. On days 3 and 4 the control percentage was 100%. In the Alfalfa field, there were 111 re-opened burrows treated on Day 1. The next morning, (Day 2), there was one open burrow, giving a control percentage of 99.1%. On Days 3 and 4, the control percentage was 100%. In his discussion of the results (Proulx, 1998), Dr. Proulx concluded "*In contrast to other products, EXIT is safe and quick to use. While it kills animals through asphyxiation, none of its residues are toxic when ingested. Therefore, there is no danger for secondary poisoning. However, because EXIT can kill any invertebrate inhabiting a ground squirrel burrow system, users should not inject this product in burrows that may be used by endangered species.*"

2. Town of Cochrane

A field test was conducted under PMRA Research Permit 17-RP-00 in the town of Cochrane, 20 km west of Calgary in June 2000. The test examined the suitability and efficacy of Rodenticide Foam in the urban environment. It was conducted by W. Don Sutherland as senior researcher in cooperation with the town of Cochrane. Mr. Wally McCulloch, foam expert and then-Production Manager of Fire-Trol Canada assisted in the project.

Protocol

The test site selected was a vacant field close to one of the town's recreational facilities. A Treatment Plot and a Control Plot were laid out in an area of intense ground squirrel activity. The two plots were separated by a drainage ditch which inhibited migration between them. A designated buffer zone surrounded the Treatment Plot. The Treatment and Control Plots were mowed prior to commencement of the program to facilitate burrow identification. All open burrow entrances were packed with dirt and all entrances which were re-opened within 48 hours were flagged and counted. There were 284 re-opened burrows in the Treatment Plot and 342 in the Control Plot.

Rodenticide Foam application began at 7:00 AM on June 13. Two application units were used simultaneously in the Treatment Plot. Four hours later one unit was moved to the Buffer Zone to counteract continuing invasions into the Treatment Plot.

A wire basket was placed over the burrow entrances during foam injection to prevent escapes and to permit observation of ground squirrel activity during treatment. All treated burrows were packed with dirt after treatment.

Results

Table 1. Open Burrow Census– Treatment Plot

Day	Open Burrow	% Open Burrows
0	284	100%
1	3	1.1%
2	2	0.7%
3	2	0.7%

Table 2. Body Count – Carcasses Retrieved After Treatment

Day	Treatment Plot	Buffer Zone	Total
0	43	50	93
1	2	52	54
2	0	9	9
3	0	2	2
Total	**45**	**113**	**158**

Table 3. Post treatment visual census

Day	Plot	Time	Visual Count	Weather
Day 3 (June 16, 2000)	Treatment	11:32	0	Cloudy, windy Scattered rain Temp. +7˚ C
	Control	11:37	61	
	Treatment	11:45	0	
	Control	11:51	68	
	Treatment	12:00	0	
Day 4 (June 17, 2000)	Treatment	10:40	0	Sunshine Light Wind Temp. +16˚ C
	Control	10:45	96	
	Control	10:52	114	
	Treatment	11.00	0	

Efficacy

Open Burrow Census

(1) Using all re-opened burrows :Efficacy = 97.6%

(2) Using only burrows re-opened from within: Efficacy = 100%

Visual Count Census

On the basis of comparing the Visual Census of the Control Plot (maximum 114) and the Treatment Plot (maximum zero) Efficacy = 100%

OTHER FIELD TRIALS

A field trial using Rodenticide Foam was conducted near Billings, Montana in the spring of 2002. This was directed by Monty Sullins, Vertebrate Pest specialist with the Montana Department of Agriculture. 414 ground squirrel burrows were treated resulting in an average application time of approximately 20 seconds per burrow. 48 prairie dog burrows were treated for an average application time of 1 minute, 36 seconds per burrow. In numerous instances, ground squirrels and prairie dogs attempting to escape the treated burrow entrances plugged by cones were observed dying within 2 to 3 minutes.

A trial application of Rodenticide Foam for control of Norway rats in the Bird Garden of the Beijing Zoo was conducted by the Chinese Association for the Control of Rodents and Sanitary Insects (CACRSI) in 2004. The summary CACRSI report on the project concluded: (1) Based on rat density observations the killing rate was 98.85%. (2) The burrow re-opening rate after treatment was zero. (3) Rodenticide Foam is suitable for the Zoo and other places with environmental requirements. (4) Rodenticide Foam is safe, and the results are quick.

The Rodenticide Foam control method for the Beijing Zoo has since been extended to other departments.

PATENTS

Patents have issued and are pending for the formulation and method of application of the Rodenticide Foam in many countries. These include Canada, USA, Germany, France, South Africa, Australia, China and India. Rodent Control Inc. was incorporated to administer the leasing of patent rights in countries other than Canada and USA. The product name used by Rodent Control Inc. is RoCon™.

CONCLUSIONS

The efficacy rate for Rodenticide Foam for control of burrowing rodents is between 93% and 100% depending on the skill and experience of the applicator, and the characteristics of the burrow being treated. In a sealed burrow system all the rodents in the burrow will die within 3 to 5 minutes of the burrow being filled with foam. Death occurs from asphyxiation. Efficacy and killing time surpasses that of all other rodenticides. Application is site specific and is especially suitable where safety is a consideration.

ACKNOWLEDGEMENTS

I wish to acknowledge with thanks the following people who have assisted with the development and testing of Rodenticide Foam. They are: my wife Joan, our associate David Schmunk, Dr. Gilbert Proulx, Wally McCulloch, Monty Sullins and , Ms Huang Xiaoyun, Deputy Director of CACRSI

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FERTILITY CONTROL VACCINES FOR BRUSHTAIL POSSUM MANAGEMENT IN NEW ZEALAND – TARGETS AND DELIVERY SYSTEMS

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ABSTRACT: Introduced marsupial brushtail possums (*Trichosurus vulpecula*) are a major pest in New Zealand because of their impacts on conservation values and agricultural production. Immunologically based fertility control (immunocontraception) offers an effective, humane and publicly acceptable approach to possum management. Success of fertility control for possums relies on identification of suitable target antigens with a key role in the reproductive process and the development of a cost-effective and practical method of delivering vaccines to wild populations of possums.

The zona pelludica (ZP) or extracellular coat around the possum egg is an attractive target for the development of immunocontraceptive vaccines. The three major proteins of the possum ZP (ZP1, ZP2, ZP3) are ovary-specific, immunogenic, and play critical roles in the fertilisation and development of oocytes. Alloimmunisation with possum ZP2 and ZP3 proteins elicits strong humoral immune responses and reduces the fertility of female possums by 72–80%. Several regions of these ZP3 and ZP2 proteins that may be possum- or marsupial-specific and cause infertility have been identified by linear epitope mapping and amino acid alignment. Immunisation with two such peptides reduced the fertility of immunised possums females by 60–64% but had no effect in model bird and mammalian species in initial trials to assess non-target effects.

Bacterial ghost technologies are potentially a cost-effective and practical method for delivering anti-fertility vaccines in oral baits to wild populations of possums. Bacterial ghosts are non-living, empty, cell envelopes formed by the expression of a heat-inducible E-lysis gene (ϕX174) in gram-negative bacteria. These contain minimal DNA and can induce both humoral and cellular immune responses. Recombinant bacterial ghosts can express foreign proteins (up to 600 amino acids) on or within the cell envelope depending on the site-directed sequences included in the fusion. Recombinant bacterial ghost vaccines expressing possum ZP3 and ZP2 proteins stimulate humoral immune responses in serum, ovarian follicle fluid, and reproductive tract secretions of female possums when applied to mucosal surfaces of the eye and nose or administered orally. Bacterial ghosts containing possum ZP2 delivered by a mucosal route reduced the fertilisation rate of eggs of treated possums (ZP2 ghost 57.6% vs controls 90.2%, $P < 0.05$). Research to optimise antigen targets and the development of potent immunocontraceptive bacterial ghost delivery systems is ongoing.

This presentation covers a range of contracted research projects for the Foundation for Research, Science and Technology, the Marsupial Cooperative Research Centre, Animal Health Board and Landcare Research.

PARASITES – POSSIBILTIES FOR CONTROL OF COMMON BRUSHTAIL POSSUMS IN NEW ZEALAND

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ABSTRACT: Brushtail possums (*Trichosurus vulpecula*) were introduced to New Zealand from Australia about 150 years ago, and now occupy 95% of the country. More than NZ$70 million is spent annually trapping and poisoning possums for bovine Tb management and to protect native biota and ecosystems. Biological control is being researched as an alternative approach. We are evaluating the potential of the possum-specific intestinal nematode *Parastrongyloides trichosuri* to be genetically modified to act as a transmissible vector for biological control processes, such as immunosterility. Surveys based on faecal egg counts indicate that the parasite is common in possums in the North Island, but is restricted to parts of Southland and Otago in the South Island. The reasons for the restricted South Island distribution are unclear, but the simplest explanation is a recent introduction of the parasite. In the North Island, prevalence of infection varies seasonally, being highest in autumn, and is higher in older (≥2 years) than younger possums. Prevalence appears uniform spatially, at least along 24 km transects across large tracts of North Island native forest. To understand the dynamics and spread of the parasite, we released the wild-type form of the parasite into a population of free-living, parasite-naïve possums at a single site at near Pakawau, northwest South Island. In the 4 years since its release, mark-recapture live trapping has demonstrated that the parasite has persisted at the original release site. Surveys at fixed remote sites indicate that parasite-infected possums now occur over the surrounding 8,000 ha. The seasonal pattern of infection in possums at a site where they were infected naturally mirrors that of possums at the release site. We have now identified a naturally marked strain of the parasite that will be released at the original infection site (subject to approval) to study invasion of already infected populations by a novel strain. This will help us better evaluate the likely outcome of the release of a genetically modified strain and the efficacy of such a biological control system.

GENETIC CONTROL OPTIONS

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ABSTRACT: Biological control has had a chequered histroy in conservation biology with high profile successes and failure. The success of a biological control program is limited by the availability of control agents that are effective and specific. Prediction of the success of biological control programs is limited by the complexity of the introduced genome that will have many untested attributes and potentials. Genetic control targetting individual genes or processes has the potential to provide a complementary option to biological control that would, at least in theory, would have more predictable effectivity and specificity before release. In this paper we develop a generic population model and use it to compare the efficacy of alternative genetic approaches in reducing population numbers. We concentrate especially on sex-ratio distorters and show the sensitivity of the different approaches to breeding selection and population processes.

MECHANISMS LEADING TO PERMANENT INFERTILITY IN MICE FOLLOWING IMMUNISATION WITH RECOMBINANT MURINE CYTOMEGALOVIRUS EXPRESSING MURINE ZONA PELLUCIDA 3

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ABSTRACT: Immunocontraception is a promosing biological control for wild mice in Australia, having the potential to reduce the socio-economic cost of plagues with minimal environmental impact. Inoculation of BALB/c mice with recombinant murine cytomegalovirus encoding murine zona pellucida antigen (mCMV-ZP3) confers total infertility characterised by depletion in ovarian tertiary follicles by day 21 post inoculation followed by a progressive depletion in primordial follicles (Lloyd, et al., 2003). The mechanisms underlying ovarian pathology are largely unknown but are likely to involve antibody mediated and cell mediated immune responses. The immune pathology may also be facilitated by acute responses involving antibody binding to ZP in growing follicles resulting in recruitment of inflammatory cells and oocyte destruction. The aim of this study was to investigate the effect of mCMV-ZP3 infection on leukocyte infilration and expression of oocyte-derived signalling molecules in ovarian tissue.

Fifteen BALB/c female mice were randomly allocated into three groups of 5 animals. Group one received and injection of PBS, group two and three received intraperitoneal inoculations of 2 x 104 pfu of mCMV and mCMV-ZP3 respectively. Ovaries were retrieved at dat 7 post inoculation and one ovary from each mouse was sectioned for immunohistochemical analysis of resident leukocytes using mAB CD45 reative with all leukocyte lineages. The other ovary was processed for real time quantitative RT-PCR analysis of growth and differentiation factor 9 (GDF-9) and connexin 43 (Cx43) expression. mCMV-ZP3 inoculation increased the abundance of ovarian leukocytes ($p=0.08$), significantly increased expression of Cx43 mRNA ($p<0.05$), but did not alter GDF-9 mRNA expression. These results suggest that changes in expression of ovarian regulators due to ZP3 immunisation begins early after recombinant MCMV infection in mice, and implicates leukocyte infilration in the mechanism leading to permanent ovarian failure. Further experiments are underway to investigate the dynamics of leukocyte trafficking and expression of oocyte-derived signals as the course of infection progresses.

THE DESIGN AND DEVELOPMENT OF PIGOUT® - A TARGET-SPECIFIC FERAL PIG BAIT

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ABSTRACT: No commercially available feral pig bait exists in Australia or overseas, despite feral pigs being a widespread problem. Animal Control Technologies Australia (ACTA) and the Pest Animal Control Cooperative Research Centre (PAC CRC) are developing a feral pig bait (PIGOUT®) that addresses this situation by providing a highly palatable, target-specific, quality controlled and cost effective broadacre bait that lessens the risks to non-target species when compared to currently-employed baiting techniques for feral pig control.

The development of such a product will have the potential to reduce the labour investment in feral pig control campaigns while increasing target specificity. If PIGOUT® is adopted widely by landholders for large-scale, integrated control of feral pig populations, it is expected that the agricultural sector will benefit from increased lamb survival, improved pasture productivity, decreased infrastructure damage and potential control of exotic disease outbreaks. While improved profits for primary producers can only be speculative (it will vary between sites, seasons, product uptake and many other factors), the benefit to the agricultural industry is potentially great.

INTRODUCTION

The feral pig (*Sus scrofa*) population in Australia is estimated at between 3.5 and 23.5 million (Hone, 1990), with fluctuations occurring markedly due to environmental conditions. They inhabit approximately 40% of the mainland (Choquenot *et al*., 1996), and due to their extensive habitat range (much of which includes grazing and cropping lands), the cost to Australian Industry is estimated to be greater than $100 million annually (Choquenot *et al*., 1996). Feral pig impacts on agriculture include lamb predation, pasture destruction, infrastructure damage, erosion, crop destruction, and the spread of weeds and parasites (Pavlov *et al*. 1981; Choquenot *et al*. 1997). Feral pigs are also vectors for a range of diseases that have the potential (if introduced to Australia) of decimating not only commercial piggeries, but also impact on other meat-producing industries and human health (Fleming *et al*. 2000; Gee 2002).

Feral pigs also have deleterious effects on the environment through habitat modification (selective feeding, vegetation trampling, transfer of seeds in dung, digging and wallowing), as well as predation (invertebrates, small native mammals and reptiles, birds and/or bird eggs) and competition for food and habitat resources. Pigs have also been linked with the spread of the rootrot fungus (*Phytophthora cinnamomi*) responsible for the dieback disease in native vegetation (Choquenot *et al.* 1996).

Despite their impact, control of feral pigs is generally time-consuming and ad-hoc. Shooting, dogging and trapping are some of the techniques employed, however it has been recognised that broad-scale and integrated baiting campaigns are the most cost-effective method for reducing feral pig populations across large areas and subsequently reducing lamb predation and crop damage (Giles 1976; Giles 1977; Choquenot *et al*. 1996). Lethal baiting campaigns using sodium fluoroacetate (1080) in cereal grains, fermented grain, compressed bran/pollard pellet baits, fresh or dried meat, offal, carcasses, lupin seeds, fruit and vegetables are the most common technique (Bryant 2003), although yellow phosphorus (CSSP) in carcasses is also used. No single bait substrate has been proven effective due to the wide distribution and omnivorous diet of the feral pig.

Current baiting methods are highly labour-intensive, and in the case of 1080, landholders are reliant on local government officers to supply the large quantities of the toxin required to control a feral pig (72mg of 1080 in meat/offal substrate, compared to dog and fox baits of 6mg and 3mg respectively). The dose compliance of field-manufactured baits fluctuates, and if the concentration of 1080 added to the bait substrate is too low, pigs may ingest sub-lethal doses, decreasing the efficacy of the poisoning program and potentially leading to bait aversion in surviving animals (O'Brien and Lukins 1988). Inconsistent dosages may also increase risks for non-target species. Another potential threat to existing baiting methods is the current APVMA review of 1080 and CSSP, which could potentially restrict the use of both toxins for feral pig control.

As a consequence of the current difficulties faced in feral pig baiting campaigns, research is being conducted into a shelf-stable, commercially available feral pig bait, henceforth referred to as PIGOUT®. The development of such a product will have the potential to reduce the labour investment in feral pig control campaigns, increase lamb survival, improve pasture productivity, decrease infrastructure damage, increase target specificity, reduce impacts on the environment, and potentially assist in the control of an exotic disease outbreak. Field trials with PIGOUT® have also revealed a reduction in the potential impact on non-target species when compared to currently-employed baiting techniques for feral pig control. In addition, should the APVMA review result in the withdrawal or restricted use of either toxin (1080 or CSSP), any commercially manufactured, quality controlled and dose compliant bait will be likely to provide a significantly greater benefit. If both poisons are withdrawn, the palatable PIGOUT® bait matrix can be used to incorporate alternative feral pig toxins or other non-lethal (disease vaccine, contraceptive) agents.

This paper summarises the research conducted to-date with PIGOUT® baits. Trials have been conducted to determine efficacy against feral pigs, and effectiveness in providing a relatively target-specific, dose compliant and reliable tool to assist land mangers in controlling feral pig populations, while at the same time providing a safer alternative for non-target species when compared to current baiting practices.

PROJECT DESIGN

1. Development of PIGOUT® Feral Pig Bait

A target-specific feral pig bait was proposed by O'Brien (1986), basing the design on discrepancies between the ecology and behaviour of feral pigs compared to non-target species inhabiting the same areas and at subsequent risks from control campaigns. This more target-specific approach could then be combined with habitat-specific operating procedures inferred from ecological, or more recently genetic studies to further reduce non-target exposure. O'Brien (1986) suggested that feral pig-specific bait should be large and tough (to take advantage of the size and jaw strength of feral pigs), odourous (pigs have a keen sense of smell), dyed (to deter non-target species), meat and vegetable based (pigs are omnivorous, so

this deters non-target obligate herbivores and carnivores), and buried at night where possible (to target the fossicking, foraging behaviour of pigs, and decrease diurnal availability).
This research provided a starting point for PIGOUT® development, and after several iterations, PIGOUT® Feral Pig Bait has been manufactured as a tough, vegetable-based, fish flavoured, green-dyed 250g sausage encased in an edible skin (to reduce non-target access, improve ease of handling and increase effectiveness for aerial deployment). The toxic baits currently contain 72mg of 1080.

In current baiting campaigns, the toxin is distributed throughout the bait substrate, however to reduce the potential for non-target poisoning and to produce a bait that is more pig-specific, research is currently being conducted to develop a toxin delivery system that will be incorporated into the centre of the bait matrix (bait matrix itself contains no poison). Therefore, non-target animals can consume part of the bait matrix with lower risks of exposure to the toxin. Field research with both toxic and non-toxic PIGOUT® baits has indicated that most non-target animals (including stock) that visit bait sites do not consume the baits.

2. Initial palatability pen and paddock trials
Palatability trials were conducted in January 2004 at the Robert Wicks Pest Animal Research Centre (Department of Natural Resources and Mines, Queensland) to identify the most suitable bait matrix. Seven non-toxic prototype feral pig baits were tested against two controls (wheat grain and fresh meat) to ascertain initial bait acceptability and preferences. The methodology involved a paired-sample analysis of penned feral pigs, and three of the manufactured baits out-performed both fresh meat and grain in terms of feral pig first preference and time for consumption.

These three most promising manufactured baits were then trialled in a paddock situation ($100m^2$ enclosure) along with fresh meat and grain to determine bait preference in the presence of other 'natural' foods such as vegetative material. Uptake did not significantly differ, indicating that the manufactured matrices performed as well as the currently-used bait substrates. Two of these prototypes were then selected for subsequent large-scale field application.

3. Target specific non-toxic field trials
The two selected bait prototypes were aerially deployed one-week prior to an aerial feral pig cull in the rangelands of south-western Queensland (near Cunnamulla) in February 2004. Each prototype was tested against a control (fresh meat, the standard bait substrate used in the area), and different biomarkers were placed in each bait to determine level of uptake one week after bait deployment (by culling pigs and assessing biomarker residue in blood, tissue and bone). Results indicated that the non-toxic prototype matrices were readily consumed by feral pigs in the field. Target and non-target uptake was also assessed through camouflaged remote infra-red digital photography and sand plot analysis of tracks at ground-based bait stations. The results from these techniques suggested that the baits were relatively target specific, as no non-target species (native species or stock) consumed either of the bait matrices. As a result of this field trial, one bait prototype was selected based on non-toxic bait acceptance and palatability.

4. Non-target PIGOUT® field trials
Specific non-target testing of the non-toxic PIGOUT® baits has been conducted in a variety of situations including Namadgi National Park (ACT, April 2004), "Arthursleigh" sheep station near Goulburn (NSW, May 2004) and Marengo State Forest (NSW, October 2004).

The three non-toxic PIGOUT® trials were conducted in areas where non-target species would potentially come into contact with the baits, with access and uptake investigated via sand track plots and camouflaged remote infra-red digital photography. During the Namadgi and Arthursleigh trials, the non-toxic PIGOUT® matrix was compared for uptake against fresh meat and grain, and results in both trials showed low levels of interest in the manufactured baits, however fresh meat and grain baits were regularly consumed or removed from the sites by non-target species (native animals and stock).

Carnivorous mammals, including the native marsupial carnivores (ie. quolls) appear to be most at risk from traditional meat baiting campaigns for feral pigs (McIlroy 1986), however no uptake of PIGOUT® baits was observed in the trial conducted with Spotted-tail Quolls in Marengo State Forest. The replacement of fresh meat baits with PIGOUT® baits in feral pig control programs in known quoll habitats may therefore reduce the primary poisoning risks to these species.

5. Target specific toxic pen and field trials

The effectiveness of an internal polymer core to deliver a toxic dose of 1080 to a feral pig was investigated in pens at the Robert Wicks Pest Animal Research Centre in September 2004. Four non-toxic prototype cores were initially investigated, with one selected for toxin incorporation based on feral pig acceptance and uptake of a lethal dose (determined by percentage of non-toxic core consumed). 1080 was then incorporated into the prototype core, which was inserted into the PIGOUT® matrix for toxic pen trials. The toxic PIGOUT® bait was found to be efficacious in controlling feral pigs of all age classes in the pen situation, therefore large-scale toxic field trials were conducted.

The first toxic field trial was conducted on a cattle station on the southern boundary of Cape York, northern Queensland. PIGOUT® baits were aerially deployed, along with fresh meat baits (standard bait substrate used in the area). An efficacy comparison was not possible due to the low density of feral pigs at some sites, however it appeared that the aerial deployment of the PIGOUT® baits had an impact on feral pig activity. The level of population reduction was considered to be too low to provide an effective control technique, and baits were not stable after aerial deployment (potentially lowering palatability and subsequent uptake). Monitored fresh meat baits were observed to be taken by feral pigs and a range of non-target animals, however the monitored PIGOUT® baits were not removed by either target or non-target animals (although in neither case were baits placed in areas of high feral pig density). The results of this toxic field trial indicated that the PIGOUT® baits needed modifications to increase the stability after aerial deployment, and to also increase the attractiveness to feral pigs under field conditions.

A second toxic field trial (with an improved version of PIGOUT®) was conducted on Kangaroo Island, South Australia, in November 2004. Three ground-baited and three control sites were investigated, with a resultant significant reduction in feral pig activity (and potentially population decline) in baited compared to control sites. Efficacy of over 70% was achieved, and all age classes of pigs were controlled (based on track width analysis pre-compared to post-bait). Unfortunately, two non-target deaths were recorded (Brush-tailed Possum and Swamp Rat), and subsequent stability analysis of the baits (results received in February 2005) revealed some leaching of 1080 from the internal polymer core into the matrix.

The third toxic ground-baiting field trial was conducted in early December 2004 on Jawoyn Association Aboriginal Lands near Katherine, NT. This trial was compromised by the arrival of the wet season, which provided sufficient surface water for the feral pigs to disperse. Although limited lethal baiting was conducted, no estimates of population knockdown could be achieved due to low feral pig densities in both baited and control sites, although feral pig activity declined in some sites where bait uptake by this species was recorded (a known number of baits were deployed at each site and then monitored, with tracks identified on sand plots containing baits). Although this trial was conducted with the same PIGOUT® baits as used on Kangaroo Island, no non-target deaths were recorded.

The final toxic field trial was conducted in January 2005 in Welford National Park, central Queensland. The methodology involved mortality telemetry (radio-tagged pigs), which allowed for recovery and definitive information on the fate of the 50 feral pigs tagged. Results indicated that the PIGOUT® baits were target specific and highly efficacious against this population sample, as no non-targets were recorded accessing baits, and control of over 70% of the target species was again demonstrated.

Further modifications to PIGOUT® have resulted in a more stable bait matrix with improved ground impact resistance after aerial deployment trials conducted in March 2005. Additional pen trials were also conducted in April 2005 on an improved method for incorporating the 1080 toxin into the centre of the bait matrix to eliminate the degree of toxin redistribution that occurred during the Kangaroo Island baiting trial. Supplementary field trials incorporating the new toxin delivery system are proposed for May 2005 in Namadgi and Kosciosko National Parks (ACT and NSW) to further assess efficacy for feral pig control. If required, a potential aerial trial will be conducted in western NSW to obtain extra efficacy data.

DISCUSSION

The general consensus between scientists, land managers and others involved with feral pig management in Australia is that there is a demonstrated requirement for a manufactured, shelf-stable, dose compliant and quality controlled feral pig bait. Due to the geographically diverse range of feral pigs, this bait must be efficacious in a range of circumstances to allow for national acceptance and adoption. PIGOUT® Feral Pig Bait has brought feral pig management closer to this goal by providing a palatable and efficacious bait that displays all these features, and is as effective (if not more so) than currently employed baiting substrates (fresh meat and grain) in most areas investigated so far.

Additionally, there was minimal uptake of PIGOUT® baits by non-target species including native mammals, birds, reptiles, and also no uptake by domestic stock. The PIGOUT® baits have significantly lower risks to non-target species when deployed using standard practises compared with traditional grain and meat-based baits, and with an improved internal toxin delivery system, PIGOUT® baits will provide another important tool for the integrated control of feral pigs throughout Australia.

ACKNOWLEDGEMENTS

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INCREASING THE EFFICIENCY OF CONTROL OF CANID PESTS IN AUSTRALIA

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ABSTRACT: Foxes and wild dogs are estimated to cause losses of more than A$100M p.a. to agricultural industries in Australia (McLeod 2004), and their predatory activities are known to impact significantly on endemic species of mammals and birds. Continuing control of these pests is imperative, and in Australia this is most commonly achieved by use of poison baits and traps. We are working on a number of options to increase the efficiency of monitoring and suppression of these pests.

FACILITATING CANID MONITORING AND INCREASING ATTENDANCE AT 'POINT-OF- CONTROL'.

The efficiency of monitoring of canid pest abundance, and implementing methods of control if/as necessary can be improved by use of agents ('lures') that increase rates of visitation to points of control.

A significant body of literature exists on use of lures, which broadly speaking, comprise either mixtures of biological materials or synthetic chemical agents. Many authors have noted the potential advantages of completely synthetic lures, which include batch-to-batch uniformity, capacity for large-scale production, and convenience of handling.

We made direct comparison of the attractiveness of three fully synthetic lures (Abbreviated Synthetic Fermented Egg [ASFE], Fatty Acid Scent and Synthetic Monkey Pheromone; references) for red foxes (*Vulpes vulpes*), as judged by point attendance in pen situations. ASFE proved significantly more attractive than the other two formulations, and than a 'water only' control. This result was consistent with reports of other authors (Jolley and Jolley, 1992; Mitchell and Kelly, 1992; Saunders and Harris, 2000) who have previously shown high levels of efficacy of ASFE in pen trials and/or the Australian environment.

We then tested an experimental mixture of ASFE formulated for potential suitability for use as an aerosol spray in field trials in the ACT and New South Wales. Use of this formulation of ASFE with buried baits (unpoisoned FoxOff® bait matrix) significantly increased visitation of wild dogs and foxes to bait stations, and also significantly increased rate of uptake of bait by both species.

Comparison of patterns of attendance at the bait stations suggested a differential response between dogs and foxes to this lure; whereas dogs showed continuing high levels of investigation of lure treated sites over the 10 days duration of the trial, foxes showed declining levels of interest after 4-5 days.

In collaboration with Australian Wool Innovation Ltd, this experimental formulation has now been developed for release as a commercial product in Australia, under the trade-name 'FeralMone'™.

Providing new options for chemical control

The Pest Animal Control CRC is collaborating with Australian Wool Innovation Ltd and Animal Control Technologies (Aust) Pty Ltd, as well as a number of research provider/management agents, to investigate the use of p-aminopropiophenone (PAPP) as a toxicant for control of foxes and wild dogs.

Administration of PAPP to dogs using the M-44 mechanical ejector has been demonstrated to cause rapid death of animals, with onset of symptoms observable after ~30 minutes, and an average time to death of ~90 minutes. Symptoms of intoxication preceding death appear to be painless, and include loss of coordination, drowsiness and coma. Affected animals do not display hyperactivity or convulsions. These results are consistent with data from administration of PAPP to foxes by the same means (Marks *et al*. 2005).

Investigations have also shown that dogs exposed to sub-lethal doses of PAPP recover fully, with no observable metabolic or histological sequelae. Other work necessary to support an application for registration of the agent as a canid toxicant in Australia is continuing.

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DEVELOPMENT OF A HUMANE TOXIN FOR THE CONTROL OF INTRODUCED MAMMALIAN PREDATORS IN NEW ZEALAND

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ABSTRACT: Para-aminopropiophenone (PAPP) is being investigated as a toxin for mammalian predator control in New Zealand. The toxic effects of PAPP appear to be related to the rapid formation of methaemoglobin in some species, which leads to a rapid and lethal deficit of oxygen in cardiac muscle and the brain. Carnivore species appear to be much more susceptible than birds, so it potentially has a high target specificity, at least in the New Zealand context. To date, pen trials with the micro-encapsulated PAPP pellets inserted into a meat bait have been undertaken on stoats (*Mustela erminea*) and trials on other predator species are planned. A review of registration requirements by the Environmental Risk Management Authority (ERMA) has also been undertaken.

INTRODUCTION

The endemic fauna of New Zealand evolved in the absence of mammalian predators and their introduction has been responsible for many extinctions and declines. Predator control will have to be on-going if some native species, such as kiwi (*Apteryx* spp.), are to survive on the mainland (McLennan *et al*. 1996). Currently, predator control relies largely on labour-intensive trapping (Gillies *et al*. 2003, Christie *et al*. 2004), so the development of a humane predator-specific toxin would be a valuable additional control method.

Para-aminopropiophenone (PAPP) was investigated as a toxin for control of coyotes (*Canis latrans*) in the 1980s by the United States Fish and Wildlife Service (Savarie *et al*. 1983). Pest control managers in the United States expected to have limitations placed on the use of 1080, cyanide and other toxins and therefore needed to develop alternatives. The lethal response of test species to PAPP appeared to be rapid and relatively free of suffering - animals exposed to lethal doses tended to lose consciousness without painful spasms or convulsions. A significant complication however, was that many animals appeared to have a rapid vomiting response when PAPP was delivered in a bait (as compared to oral gavage). This problem impaired the development of PAPP as a vertebrate pesticide and before solutions could be fully explored, the continued use of 1080 and other toxins was approved in the United States (P. Savarie, pers comm. 2003).

The toxic effects of PAPP appear to be related to the rapid formation of methaemoglobin in some species, which leads to a lethal deficit of oxygen in cardiac muscle and the brain (Vandenbelt *et al*. 1944). Carnivore species appear to be much more susceptible than birds (Savarie *et al*. 1983; Shafer *et al*. 1983), so it potentially has some degree of target specificity.

A micro-encapsulated pellet containing PAPP has been developed by Connovation N.Z. Ltd. It delivers PAPP rapidly into the blood stream of an animal via the stomach and can be used in a meat bait. The coating of the pellet is critical for maintaining the stability and protection of the tablet core while in a meat bait, yet dissolves at a pH of 4 or less. To register the PAPP pellets for predator control in NZ, the registration requirements will have to be met of both the Environmental Risk Management Authority (ERMA) - who administers the Hazardous Substances and New Organisms (HSNO) Act 1996 - and the NZ Food Safety Authority under the Agricultural Chemicals and Veterinary Medicines (ACVM) Act 1997.

This paper reviews the ERMA requirements for registration and presents interim findings from ongoing pen trials with PAPP pellets on stoats (*Mustela erminea*). Future trials are planned on ferrets (*Mustela furo*), feral cats (*Felis catus*) and wild dogs (*Canis familiaris*).

METHODS

ERMA requirements

A review was undertaken summarising the available information on PAPP and identifying the gaps that will likely need to be filled to meet ERMA registration requirements. Biological Abstracts and Chemical Abstracts databases, and the National Technical Information Service (NTIS) were searched. Web based resources on toxic and hazardous materials were investigated through Toxline, ToxNet and the Agency for Toxic Substances and Disease Research (ATSDR) database. Preliminary discussions with ERMA have taken place and Peter Savarie from the National Wildlife Research Center, Fort Collins, Colorado, USA was contacted about his earlier studies on PAPP.

Pen trial

A preliminary pen trial was undertaken to determine whether stoats would eat a pellet containing PAPP in a meat bait, and also whether the PAPP could be released fast enough in the stomach to cause death.

Five wild-caught stoats were housed individually in cages (180 cm high, 90 cm wide and 240 cm long) containing hay and branches in a semi-open shed. Water and dry ferret pet food were provided *ad lib*, as well as a daily ration of chicken mince. During an initial acclimatisation period of at least 30 days, body weights were recorded on a weekly basis. A stoat was considered to be acclimatised when its body weight was stable or increasing, and it had a regular pattern of food consumption.

Each test bait consisted of 10 g of chicken mince implanted with 2 pellets, containing a total of 17 mg of micro-encapsulated PAPP plus anti-emetic. Two of the stoats were fasted for 24 hours before being presented with a PAPP bait in a no-choice experimental procedure. The other three stoats were fed 50g of chicken mince (50-90% normal food intake) in the 24 hours before being presented with the PAPP bait.

RESULTS

ERMA requirements

Table 1 summarises the adequacy of available information for registration of PAPP using the system provided by the HSNO Act 1996 (ERMA 2001).

Table 1: Summary of information gaps that will likely need to be filled for registration of a PAPP bait. ? = Existing data to be assessed by ERMA

Class	Recommended classification	More data?
1. Explosiveness	Not explosive	No
2. Flammability; gases	Not a flammable gas	No
3. Flammability, liquids	Not a flammable liquid	No
4. Flammability, solids	Not a flammable solid	No
5. Oxidising capacity	Not an oxidiser	No
6.1. Acute toxicity:		
- Oral	Acutely toxic via oral	No
- Dermal	No data	Yes
- Gas	Not volatile	No
- Vapour	Low vapour pressure	No
- Dusts/mists	No data	No
6.3. Skin irritants	Likely skin irritant	Yes
6.4. Eye irritants	Likely to be eye irritant	Yes
6.5. Sensitisers	Possibly low or not sensitiser	Yes
6.6. Mutagens	Low or no mutagenic activity	?
6.7. Carcinogenic	Low or no carcinogenic activity	?
6.8. Reproductive or developmental toxin	Can't classify	?
6.9. Target organ systemic toxin	Can't classify	Yes
7. Radioactive	Not radioactive	No
8. Corrosive	Possibly not corrosive	Yes
9. Ecotoxicity:		
9.1. Aquatic	Insufficient data to classify	Yes
9.2. Soil	No data	Yes
9.3. Terrestrial vertebrate	Multiple species data available	No
9.4. Terrestrial invertebrate	No data	Yes

Pen trial

Five stoats were presented with PAPP baits (Table 2). Three of the five died but two vomited and survived. There was no evidence that stoats detected the pellets and no pellets were rejected.

Table 2 Results from the pen trials. Stoats were each fed a 10 g meat bait containing 17 mg of PAPP.

Stoat	**P3**	**P2**	**P6**	**P10**	**P5**
Weight (g)	244	374	360	359	370
Sex	F	M	M	M	M
Food in prior 24hrs	No	No	Yes	Yes	Yes
Vomit	No	No	Yes	No	Yes
Time bait eaten to death (min)	52	121	Survived	129	Survived

DISCUSSION

PAPP has been widely studied as both an anti-cyanide drug (Bright and Mars 1987) and as a radioprotective agent (Blickenstaff *et al*. 1994), so there are a number of relevant studies that will help towards getting a PAPP predator toxin registered. However, some significant information gaps still exist.

The two stoats that survived after eating PAPP baits probably did so because they both vomited. Savarie *et al* (1983) also found that vomiting by a range of species was a complicating factor in their study. New PAPP pellets containing a higher dose of anti-emetic are being formulated and further trials are planned.

Carnivore species appear to be more susceptible to PAPP than birds weight for weight (Savarie *et al*. 1983; Shafer *et al*. 1983). However, many birds weigh considerably less, therefore PAPP could still be toxic to them (Table 3). The red-winged blackbird (*Agelaius phoeniceus*) had the lowest LD_{50} of the birds tested by Savarie *et al*. (1983) at 133 mg/kg. The common crow (*Corvus brachyrhynchos*) and black-billed magpie (*Pica pica*) were the next lowest, with an LD_{50} of 178 mg/kg. Using the lowest LD_{50} (133 mg/kg), 5 of 24 New Zealand native bird species that could eat a PAPP pellet in a stoat bait may be vulnerable and 16 of 24 eating a pellet from a cat bait (Table 3). Initially it is planned to register a stoat PAPP bait for use only in bait stations, so non-target impacts will be reduced. However, a PAPP bait for cats is likely to be more accessible to non-target species, including birds.

Reptiles may be another group vulnerable to PAPP. Acetaminophen (paracetamol) is used for control of brown treesnakes (*Boiga irregularis*) on Guam (Saverie *et al*. 2001) and acetaminophen, like PAPP, also induces methaemoglobin.

PAPP appears to be a rapid-acting and humane toxin for control of mammalian predators. However, there are potential non-target issues; it may be possible to lessen these by development of appropriate delivery systems (e.g. Marks *et al*. 2004; Marks *et al*. in press).

Table 3: New Zealand native bird species that might eat a PAPP pellet implanted in a meat bait. Note the non-targets do not have to eat the whole of the meat bait – they only need to eat the pellet (the cat PAPP pellets are c. 5.5 mm in diameter). * Indicates there could be some mortality

Species	**Scientific name**	**Weight** (g)	**Eat meat bait?**	**Stoat pellet** (17 mg PAPP)	**Cat pellet** (100 mg PAPP)
Brown kiwi	*Apteryx australis*	2200	?	7.7	45.5
Great spotted kiwi	*Apteryx haastii*	2400	?	7.1	41.7
Paradise shelduck	*Tadorna variegata*	1400	?	12.1	71.4
Grey duck	*Anas superciliosa*	1000	?	17.0	100.0
Brown teal	*Anas aucklandica*	500	?	34.0	200.0*
Australasian harrier	*Circus approximans*	650	Yes	26.2	153.9*
Banded rail	*Rallus philippensis*	170	?	100.0	588.2*
Weka	*Gallirallus australis*	700	Yes	24.3	142.9*
Pukeko	*Porphyrio porphyrio*	850	Yes	20.0	117.7
NZ pied oystercatcher	*Haematopus finschi*	550	?	30.1	181.8*
Variable oystercatcher	*Haematopus unicolor*	725	?	23.5	137.9*
Black stilt	*Himantopus novaezelandiae*	220	?	77.3	454.6*
Brown Skua	*Catharacta skua*	1675	Yes	10.2	59.7
Black-backed gull	*Larus dominicanus*	850	Yes	20.0	117.7
Red-billed gull	*Larus novaehollandiae*	260	Yes	65.4	384.6*
Black-billed gull	*Larus bulleri*	250	?	68.0	400.0*
Kaka	*Nestor meridionalis*	425	?	40.0	235.3*
Kea	*Nestor notabilis*	800	Yes	21.3	125.0
Long-tailed cuckoo	*Eudynamys taitensis*	125	?	136.0*	800.0*
Morepork	*Ninox novaeseelandiae*	175	?	97.1	571.4*
Sacred kingfisher	*Halcyon sancta*	65	?	261.5*	1538.5*
Tomtit	*Petroica macrocephala*	11	?	1545.5*	9090.9*
NZ robin	*Petroica australis*	35	?	485.7*	2857.1*
Tui	*Prosthemadera novaeseelandiae*	90	?	188.9*	1111.1*

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SODIUM FLUOROACETATE RESIDUE IN FERAL PIG (*SUS SCROFA*) CARCASSES – IS IT A SIGNIFICANT SECONDARY POISONING HAZARD?

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ABSTRACT: Feral pig control in Australia is heavily reliant upon poisoning with sodium fluoroacetate (1080) bait. Tissue residue levels may be considerable and pose a potential risk to non-target consumers. Tissue/fluid samples (liver, kidney, stomach, stomach contents, small intestine, large intestine, muscle and eye) from lethally poisoned feral pigs were removed and assayed for fluoroacetate concentration. The digestive system, specifically the stomach contents and stomach, consistently contained the greatest concentration of 1080 within individuals. Few non-target animals apart from introduced mammals (fox, dog, cat) appear at risk from consuming muscle tissue, however, many native species may be at risk from consuming visceral tissue (especially stomach and contents). The practical risk is probably low and reduced given the rapid decomposition of carcasses in the field. Regular consumption of poisoned pork may exceed the recommended daily intake of fluoroacetate and be a risk to human health, but there is a low probability of this occurring.

INTRODUCTION

Sodium fluoroacetate (1080) is a widely used toxin for control of vertebrate pests, in Australia. Given that a large dose of 1080 may be required to kill feral pigs, (e.g. O'Brien 1988), a high concentration of fluoroacetate residue may be found in the tissues of a poisoned animal (O'Brien *et al.* 1987). The levels of fluoroacetate found in carcasses should be investigated to assess if fluoroacetate pig baiting campaigns constitute a significant secondary poisoning risk threat to non-target species, to ensure the responsible and sustainable use of fluoroacetate. The potential for secondary poisoning of non-target species depends on (1) exposure to and consumption of fluoroacetate residue by non-target species, (2) the susceptibility of the non-target animal consuming the tissue, (3) the concentration of 1080 in tissue, and (4) the amount of tissue consumed. In this paper we present preliminary findings on the distribution and concentration of fluoroacetate in pig carcasses, and assess the secondary poisoning risk to a variety of likely non-target consumers based on their susceptibility.

METHODS

1. 1080 residues

Samples were collected during routine poisoning campaigns. Landholders free-fed areas with non-toxic grain for up to one week. Once regular consumption of the free-feed by feral pigs was occurring, 1080-impregnated fermented wheat (288mg 1080/kg wheat) was substituted. The following morning, carcasses were located and the following samples collected: liver, kidney, stomach, stomach contents, small intestine, large intestine, muscle and eye. Samples were frozen (-10^{0}C) until analysis. Fluoroacetate present in the samples was extracted in water and were then cleaned up and concentrated using anion-exchange chromatography. The fluoroacetate dichloroanilide derivative was prepared by reaction of the acidified eluent with 2,4-dichloroaniline in the presence of N,N'-dicyclohexylcarbodiimide. The resulting fluoroacetate dichloroanilide derivative was extracted with ethyl acetate and following clean up and drying was quantified using a gas chromatography mass-spectrometry system (Agilent 5973). Quantitation is by single ion monitoring of the major ion at m/z = 186, with confirmation using the 70eV electron impact mass spectrum. The level of determination for this method in animal tissue was 0.005 ug/g. Fluoroacetate results are reported as the sodium fluoroacetate equivalent.

2. Susceptibility of non-target species

The risk of secondary poisoning to non-target species was assessed through comparing the fluoroacetate residue concentration in specific tissues with the lethal dose of a number of likely non-target consumers. The lethal 1080 dose for these animals was calculated from published LD_{50} values and expected adult bodyweights (Table 2). The susceptibility of each species was based on the weight of tissue to be consumed to obtain this dose based on the maximum amount of fluoroacetate residue in various pig tissues. Animals were classified as being at potential risk if the calculated amount required for a lethal dose was <15% of their bodyweight, suggesting an ability to consume this amount in a single feed (following L. Twigg pers. comm.).

3. Carcass degradation and visitation by non-target animals

Between September and December 2004 the longevity of non-poisoned feral pig carcasses was assessed in semi-cleared grazing country at Inglewood, south-western Queensland. Their longevity was investigated through general descriptions of their state of decomposition and recording carcass weights. The species visiting and consuming carcasses were identified via remote digital or video cameras or by track plots.

RESULTS

1. 1080 residues and distribution

The tissues of six pigs poisoned from 1080 grain-baiting operations were assayed. Residues were found in all samples. The distribution of residue within each individual was largely consistent; the highest concentrations were in the stomach contents, followed by the stomach, intestines, eyeball, muscle, and liver/ kidney respectively. The actual concentrations of sodium fluoroacetate in the various tissues were highly variable, ranging between 0.0031 to 87.3ug/g in muscle and stomach contents respectively (Table 1).

Table 1 Fluoroacetate concentrations (ug sodium fluoroacetate/g sample) in tissues collected from lethally poisoned pigs in grain-baiting operations.

Pig ID	1	2	3	4	5	6
Sex	M	M	M	M	F	F
Bodyweight	38	45	41	38	17.5	18
Distance from bait station	359m	47.8m	177m	430m	190m	195m
Liver	0.102	0.047	0.031	0.328	0.761	3.070
Kidney	0.194	0.078	0.127	0.937	1.640	1.390
Stomach	60.700	10.600	11.200	20.200	29.200	49.300
Stomach contents	82.700	15.000	28.800	64.400	87.300	43.000
Small intestine	1.980	0.466	0.423	1.630	4.050	3.980
Large intestine	2.000	0.543	1.760	2.500	10.80	3.340
Eyeball	0.680	0.372	0.860	1.050	3.360	1.240
Muscle	0.211	0.084	0.419	0.703	2.600	1.560

2. Susceptibility of non-target species

The amount of sodium fluoroacetate required to receive a lethal dose (based on LD_{50}), and the amount of muscle, visceral tissue or stomach contents to be consumed to obtain this dose of fluoroacetate was calculated for a range of likely non-target species (Table 2).

Table 2 Amounts of fluoroacetate tissue non-target species would have to ingest to receive an LD_{50} (* where amount needed to be consumed for LD <15% of bodyweight)

Species	Adult body mass (g)	LD_{50}	Amount of 1080 (mg) for LD_{50}	Muscle (max) = 2.60ug/g	Visceral (max) = Stomach = 60.7 ug/g	Stomach contents (max) = 87.3 ug/g
Introduced mammals						
Fox (*Vulpes vulpes)*	5000	0.13	0.65	250g*	10.71g*	7.45g*
Sheep/cattle dog (*Canis familiarus)*	15000	0.11	1.65	634.6g*	27.18g*	18.90g*
Feral pig (*Sus scrofa*)	40000	1.0	40.00	15384.6g	658.98g	458.19g*
Cat (*Felis catus*)	4200	0.40	1.68	646.2g	27.7g*	19.2g*
Birds						
Wedge-tailed eagle (*Aquila audux*)	3200	9.49	30.37	11680.8g	500.3g	347.9g*
Little raven *(Corvus mellori*)	550	3.1	1.71	657.7g	28.2g*	19.58g*
Australian Raven (*Corvus coronoides*)	600	5.1	3.10	1192.3g	51.1g*	35.5g*
Australian magpie-lark (*Grallina cyanoleuca*)	100	8.83	0.88	338.5g	14.5g*	10.1g*
Australian magpie (*Gymnorhina tibicen*)	320	9.93	3.18	1223.1g	52.4g	36.4g*
Little crow (*Corvus bennetti*)	390	13.37	5.21	2003.8g	85.8g	59.7g
Black kite (*Milvus migrans*)	590	18.51	10.92	4200g	179.9g	125.1g
Laughing kookaburra (*Dacelo novaguineae*)	300	~6.0	1.80	692.3g	29.7g*	20.6g*
White-winged chough (*Corcorax melanorhamphos*)	330	1.75	0.5775	222.1g	9.5g*	6.6g*
Pied currawong (*Strepera graculina*)	300	13.1	3.93	1511.5g	64.7g	45.0g
Reptiles						
Monitor (*Varunus* sp.)	2.5	27.5	68.75	26442.3g	1132.6g	787.5g
Lace Monitor (*Varunus varius*)	3600	43.6	157.0	60384.6g	2586.5g	1798.4g
Sand Monitor (*Varunus gouldii*)	840	43.6	36.63	14088.5g	603.5g	419.6g
Shingle-back lizard (*Tiliqua rugosa*)	470	205.9	96.8	37230.7g	1594.7g	1108.8g
Native mammals						
Spotted-tailed quoll (*Dasyurus maculatus*)	2800	1.85	5.18	1992.3g	85.3g*	59.3g*
Northern quoll (*Dasyurus hallucatus*)	5660	6.0	33.96	13061.5g	559.5g*	389.0g*
Brushtail possum (*Trichosurus vulpecula*)	2600	0.67	1.74	669.2g	28.7g*	19.93g*

Species sensitivity (LD_{50}) and body masses obtained from (McIlroy 1982a; McIlroy 1982b; McIlroy 1983; McIlroy 1984).

3. Carcass degradation and visitation by non-target animals

Carcasses degraded rapidly, with very little edible tissue remaining 7-10 days after death. Carcasses usually showed signs of insect activity (blowfly maggots and ants) within 24 hours, and began to liquefy after 3-5 days. Lace monitors (*Varianus varius*) were the main non-target species observed consuming carcasses, often dragging the entrails from the site for further consumption. Corvids (especially crows) and raptors (wedge-tailed eagles) were also frequently observed on carcasses.

DISCUSSION

As sampling was conducted as a follow up to a routine baiting operation the amount of bait consumed by each animal was unknown. The tissue residue levels observed in this study are likely to represent the maximum from 1080 baiting at the given bait concentration (288 mg 1080/kg) since excessive consumption of bait was encouraged by free-feeding. Additionally, stomachs from pigs were consistently full, suggesting that little vomiting had occurred and therefore, a large proportion of the ingested dose would be retained in the carcass. Despite differences in methodology and bait concentration, these residue levels in muscle (2.6 ug/g) are similar to the maximum values recorded in free-ranging pigs (2.42 ug/g) (L. Twigg pers. comm.) and in penned pigs (2.9 ug/g) (P. O'Brien pers. comm.) subjected to 1080 poisoning.

Based on the residue level of 2.6 ug/g, there appears to be little risk to native Australian animals from consuming muscle from poisoned pigs. All native species examined in Table 2 need to consume in excess of 15% of their bodyweight to be at risk from eating muscle tissue. Of the introduced mammals, dogs and foxes are most susceptible requiring consumption of less than 5% of their bodyweight in muscle for a lethal dose (Table 2). However, the much higher concentrations found in the viscera and stomach contents suggest that there is a potential poisoning risk to many native animals from consuming these tissues.

Despite the potential risk, few non-target animals were confirmed to consume carcasses by remote photography. Goannas readily consume flesh including viscera, but are at low risk due to their high tolerance to fluoroacetate. However their feeding habits may increase the exposure of other species to visceral tissues, increasing their likelihood of secondary poisoning. Despite anecdotes suggesting a low impact on secondary consumers, further assessments should be undertaken to assess the extent that non-target species consume such tissues.

In the seasons tested, feral pig carcasses largely did not persist for longer than 7 days, regardless of whether it was partly consumed by non-target species or not, supporting similar work completed in Western Australia (L. Twigg pers. comm.). This suggests that, at least in warm conditions, carcasses will not persist and represent a long-term food source. Additionally, defluorination will occur within the tissues, further reducing the fluoroacetate content and concentration. Under cooler conditions 1080 poisoned carcasses can persist for extended periods (Meenken and Booth 1997). Obviously the environmental conditions need be considered when assessing the longevity of, and secondary poisoning risk associated with poisoning operations.

Feral pigs are widely harvested in Australia for human consumption. Given the residue concentrations found in muscle, is there a risk to humans from consuming poisoned pig tissue? On heating, fluoroacetate becomes unstable above 110 ^{0}C and decomposes completely at 200 ^{0}C. These temperatures are rarely reached in food cooking, particularly with the modern tendency to undercook meats for better flavour. Most cooking of meat is done in the range of 70 to 180 ^{0}C meaning much of the fluoroacetate will remain present for human consumption. Given the maximum sodium fluoroacetate concentration in muscle was 2.6 ug/g, and using an approximate human LD_{50} of 2.0mg/kg, an 80kg male would have to consume >61 kg of muscle in a single sitting to consume a lethal dose – obviously impossible. The lethal dose is only one aspect of the toxicity however. Sodium fluoroacetate has both chronic and acute effects on organisms. Assuming a meal of 300 g of poisoned pork, our 80kg male would be consuming 0.78 mg fluoroacetate, or a dose of 0.00975 mg/kg. This is above the acceptable daily intake of sodium fluoroacetate, determined as 0.0002 mg/kg/day (Reference Dose determined by the United States Environmental Protection Agency 1995).

Despite that there may be some theoretical human health risk from consuming poisoned feral pigs, is there a practical risk? Given that the residues in this study are from lethally poisoned pigs, and such pigs are generally found close to the bait station (Table 1; J. Conroy pers. comm.) it is unlikely that these pigs would be harvested. The probability of being harvested (and consumed by humans) would be greater where the animal survives poisoning operations; residues in surviving animals are lower (Gentle unpublished data) as fluoroacetate is rapidly excreted further reducing the risk. These factors suggest that unless harvesters are operating in the vicinity of a poisoning program, there is a low probability of harvesting 'contaminated' pigs. In addition we can minimise this risk further through using temporal and spatial withholding zones. Conservatively, withholding periods of 30 days would be advisable to avoid harvesting pigs from poisoned areas. However, pigs being large, mobile animals may move considerable distances from the baited site. Therefore, it may be advisable to extend withholding periods to adjacent properties to ensure that migrating pigs are not accidentally harvested.

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MINIMISING THE EFFECTS OF 1080 FOX BAITING ON NON-TARGET SPECIES AND VICE VERSA WHILE MAXIMISING THE RISKS TO FOXES IN TASMANIA

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ABSTRACT: It did not seem possible to eradicate foxes in Tasmania based on 'chasing down' individuals so a program based on endangering foxes wherever they occurred was undertaken. Based on differences in physical susceptibilities to 1080 between foxes and obvious potential non-target wildlife, 1080 baiting was chosen as the basic strategic eradication method. Key potential problems included loss of baits to wildlife and effects of baits on wildlife. Research was undertaken to tailor established methods of fox baiting to Tasmania's special conditions of much non-target wildlife and few foxes. A basic philosophy was to produce a package that was safe enough for wildlife that particular places would not have to be avoided because of wildlife.

Key criteria that were considered were amount of poison, bait type, size and delivery system and landscape density of baits. To guide more detailed research, pilot trials of acceptability of Foxoff (a commercial meat compound bait), dried kangaroo meat (DKM), fresh chicken wings, fresh liver and eggs (fresh and boiled, free and glued to bricks) to a variety of wild mammal and bird wildlife with a focus on endemic wildlife were undertaken. Pilot trials also considered presentation methods of surface lay, buried underground (at 15 cm) or in mounds and elevated on trees or wires. Direct visual observations were mainly used. These trials showed exposed baiting was untenable with more than 90% of surface and more than 50-75% of elevated baits being taken 1 week by a wide variety of wildlife. Although wildlife readily ate most baits, few species could actually eat DKM until it softened with moisture, usually only nibbling the edges of large pieces (40 g). Buried baits were taken at a frequency of 10–15% with 1 week. Foxes on mainland Australia readily take buried DKM and Foxoff.

On the basis of urgency, our pilot studies, mainland Australian research on fox baiting and advice from fox experts it was decided to start an operational 1080 poison program in parallel, to further research. Operational baiting was to start using combinations of DKM with Rhodamine B tracer and Foxoff with bead tracers buried at 15cm (under sand pads where convenient) at a landscape density of 5/km^2. It was surmised foxes would have home ranges of at least 2 km^2 and thus would be exposed to many baits. Checking was initially to be every two days and baits would be retrieved after 2 weeks. A dose of 2.5 mg/bait was used, an amount that on represented several lethal doses for most foxes so at least some baits would remain dangerous during toxin breakdown before retrieval. Individuals of carnivorous wildlife species (Tasmanian devil, spotted-tailed quoll and eastern quoll) would have to eat at least several fresh-layed baits within two days before they would be endangered although omnivores (Tasmanian bettong and long-nosed potoroo could be killed with one bait. A random selection of retrieved DKM baits was checked for residues of 1080 and baits were placed experimentally to check breakdown over time.

More detailed research on what wildlife took baits, the effects of depth of burial, landscape density of baits, and pads and scent attractants was undertaken and assessment of population effects of operational baiting on key wildlife species was planned, to occur when baiting coincided with populations of sufficient densities. Where a gap in knowledge of fox responses to our proposed baiting methods was identified, research on foxes in similar habitats on mainland Australia undertaken.

After several weeks of 1080 baiting in Tasmania operational loss of baits was very low (usually 2–4%). Frequent checking handicapped baiting coverage while often not giving accurate information on what species took baits so checking ceased until retrieval. Foxoff was difficult to retrieve because of 'mushing' but DKM baits could be retrieved even if quite rotten. Since there was a public commitment to retrieve all possible baits, we stopped using Foxoff.

Residues of 1080 in retrieved DKM baits/time varied widely between baits, most importantly meaning that after 2 weeks less than 20% of DKM baits contained an LD_{50} for foxes. The main feature seemed to be the dryness of the DKM; if it was rotting it was less likely to have useful amounts of 1080. The amount of 1080 was increased to 3mg/bait and landscape densities to 10/km2 in an attempt to have more baits dangerous to foxes after two weeks. Experimental bait take by wildlife was only slightly higher if buried at 10cm (the mainland norm) so that depth was also adopted. This more aggressive baiting combination was encouraged by independent review of the program.

Although the usual temporal pattern of take of buried baits by foxes is well known (it starts immediately and stays moderately high), take by wildlife in Tasmania starts very low, drastically increasing once baits were in the ground more than two weeks. It seems dasyurids cannot efficiently find buried baits until they rot (by which time 1080 residues are usually very low).

Capture-mark-recapture studies of bettongs and brushtail possums before and after poisoning in both baited (including Foxoff) and control areas showed no change in size and persistence of individuals was normal. Operational baiting did not occur in large areas of moderate or high density quoll populations, thus CMR studies were inconclusive (small samples and high variance). Persistence of individual quolls, including females with pouch-young, was normal, even after repeated baiting. Population studies of Tasmanian devils were hampered because of the spatially coincidence of Devil Facial Tumour Disease with study areas but persistence of individuals (non-diseased) appeared normal even after repeated baiting and eating of baits (rhodamine in scats). Baiting occurred over less than 15% of the range of any Tasmanian wildlife species so it can be concluded that short term effects of fox baiting on local populations of wildlife were very small and on state-wide populations negligible.

DEVELOPING A STRATEGIC FOX ERADICATION PROGRAM IN A SCEPTICAL SOCIAL ENVIRONMENT

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ABSTRACT: From 1998 to late 2003 there was concrete evidence showing a small number of red foxes exist in Tasmania. This spate of evidence led to the Fox Free Tasmania program tasked with eradicating foxes.

The history, effects and the difficulties of controlling foxes on mainland Australia are accepted but many Tasmanians remain sceptical about foxes in the state.
Despite at least five incursions into Tasmania since 1864, foxes apparently never established and therefore both they and their impacts are not noticed and the risks not accepted by much of the public. The abundance of foxes in many areas of mainland Australia gives the impression they are easy to find; an attitude transferred to Tasmania by visitors. Combined with homocentric media programs about modern forensics, this impression completely over-rides the realities of finding, let alone counting, very rare animals. This builds on a basic scepticism that comes from decades of 'crying wolf' with reports of Thylacines. Indeed, the issues create considerable confusion in that many people that dismiss foxes accept there are still Thylacines, completely contradicting the weight of evidence. Occasional hoaxes create further suspicion.

Political polarisation in the community (most recently about forestry) leads to escalating claims to the point where much of the community does not know what or whom to believe. An additional 'political' problem has been that the basic strategic fox eradication tool is 1080, a very contentious pesticide in Tasmania.

This combination of factors led to a key problem in that, before support is offered, many people demand a standard of proof such that foxes would have to be well established! This attitude extends into the essential tail-end requirement of eradication; making sure there are none left and has been used by politicians and lobbyists against the government in general and program in particular. The resulting public furore presents real problems with public acceptance of the taskforce, despite polling showing most Tasmanian's accept something should be done if foxes are there. Lack of acceptance means problems with flow of reports and volunteers, permission for access to private land, and political 'nerves' in supporting the program.

A police inquiry only about alleged deliberate import of foxes failed to identify any culprits but was miss-represented by some press, politicians and lobbyists as a failure to find evidence of foxes, further discrediting the program.

To try and deal with public suspicions, the Fox Free-Taskforce uses standard operating procedures, treating credible evidence as would be court evidence. Hard evidence such as

footprints, scats and carcasses undergo independent, specialist examination and sighting reports are physically followed-up where circumstances warrant.

Evidence was made public and reactions varied. Predicably, sighting reports were treated with great suspicion but, surprisingly, so was good quality, hard evidence. Clear footprints, a confirmed scat a fresh dead fox on the roadside and even the shooting by a hunter of a fox containing an endemic rodent still did not overcome Tasmania's super-scepticism. Evidence was often publicly dismissed as a hoax, even as conspiracy to provide jobs for the taskforce. However, the real overriding reason seems the very basis of scepticism – "I'll believe it when I see it".

Extensive public consultation was undertaken about the impacts of foxes, the need for monitoring and an integrated eradication program including 1080 baiting. Following specific research, baiting techniques established on mainland Australia were modified to suit Tasmania's unique non-target carnivore conditions (many Tasmanian devils, quolls and omnivores and few foxes) and strict procedures established for baiting. Efforts were made to measure the effect of baiting on native carnivores. The exact location of every bait was recorded and attempts made to recover them, something no other large scale fox baiting program has ever attempted. Regular public updates have been given, including the decrease in evidence in most baited areas.

Despite this, suspicion about 1080 remained high and permission to poison was often refused.

Employment of an experienced pest management expert from Victoria and independent review of the whole program by a respected mainland fox control expert were made both to improve the taskforce's performance and reassure the public of a professional approach.

A public survey was conducted to check attitudes and the results were positive. Several changes were made. To spread ownership of the issue, attempts were made to involve the public in monitoring, searches, shooting and even baiting with mixed success. Possible public perception of the taskforce as a very well funded discreet operational unit, cf an 'extension' unit, may be part of the problem.

Unrealistic expectations by the public (easily fed by media, lobbyists and politicians), people unconvinced by even concrete evidence and an impatience to 'move on' contrasts with elements of the public extremely concerned about foxes. The major problem remains convincing the public of foxes at very low densities and being able to monitor for long enough to be sure they are not established. As the response winds down, re-igniting the program via evidence triggers becomes the major problem in a sceptical public environment, made even worse by recent, dubious claims of photos of a Thylacine and flamboyant offers by media of rewards for proof a living Thylacine.

RAT ERADICATIONS – HOW TO GET IT RIGHT WITHOUT A RECIPE

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ABSTRACT: Eradication of invasive alien species on islands is growing worldwide. Robust and meticulous planning has been the key element in the success of rodent eradications run by the New Zealand Department of Conservation. Every project has its own issues that need local solutions and our planning process will deliver these. It is risky to think that a standard recipe approach will work but the process and principles are transferable. The basic principles to achieving eradication must be met in every case for all target species. A feasibility study is often the best way to investigate these principles. Such studies must consider the ecological and social context and foresee as many of the operational planning issues as possible to enable a decision to be taken on whether to commit resources to further eradication planning. The ability to successfully prevent reinvasion through biosecurity is of prime consideration at this stage. Adequate resources, strong organisational and public support and exceptional project management skills are all necessary to enable a project leader to build a capable team, motivated to succeed. Ongoing peer review of planning is critical including testing assumptions and new ideas, field testing critical systems and equipment, including back-up gear and contingency plans. Peer review culminates in a final audit before the operation is declared ready to proceed, signalling the end of the planning phase. The team running the project's operational phase are given the autonomy to make decisions and to get on with the job, supported by, but without interference from those less informed back on the mainland. In the post operational phase, formal debriefs and reporting focus on lessons for future projects. Good information management throughout the project is vital to successful review.

INTRODUCTION

Eradication of invasive alien species on islands is growing worldwide (Veitch & Clout, 2002). New Zealanders have a reputation for being innovative and successful in this field, achieving rodent eradications on islands up to 11,300 ha in size (Towns & Broome, 2003). This paper focuses on rat eradication projects on islands using aerially-sown poison baits where eradication is achieved through a single "king hit" of poison. Eradication projects for other species usually require a prolonged intensive effort to get the last animal or plant, meaning factors around sustaining effort and detecting target species need to be added to the process described here.

The Department of Conservation (DOC) Island Eradication Advisory Group (IEAG) provides assistance to DOC pest eradication projects (1999-2005). DOC takes a strategic approach to eradication planning with each island being part of a wider process of developing the technology (Cromarty *et al.* 2002).

Every project is unique and must be planned from first principles. DOC's planning process has allowed us to do this successfully and this process is transferable to other rodent eradication projects.

In summary the process can be outlined in six steps: (Fig. 1).

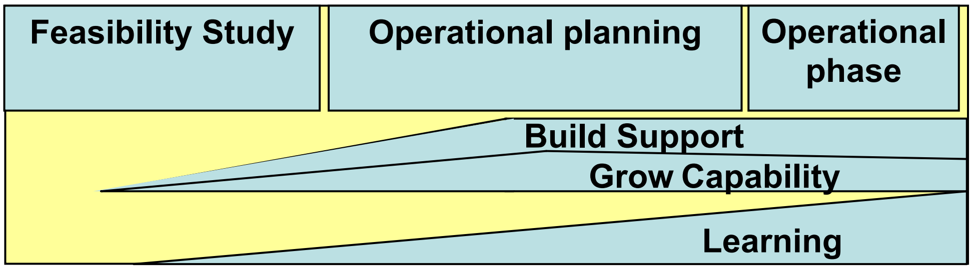

Fig. 1. Six eradication project management phases.

FEASIBILITY STUDY

A feasibility study to scope and size the project addresses three questions:

1. Why do it?
Ideally the project is initiated within a context of island restoration with long-term goals established. The benefits of eradication need clarity from the outset. Specific measurable benefits help evaluate a project against financial and environmental costs. This is critical for building project support.

2. Can it be done?
We use five principles to achieving eradication that must be met in every case, for all target species (Parkes, 1990, Bomford and O'Brian, 1995):

1. All individuals can be put at risk by the eradication technique(s);
2. They can be killed at a rate exceeding their rate of increase at all densities;
3. The probability of the pest re-establishing is manageable to near zero;
4. The project is be socially acceptable to the community involved;
5. Benefits of the project outweigh the costs.

At the feasibility study stage there is uncertainty how closely these principles can be adhered to. Declaring what is known from other projects, inferred from trials or assumed from other available evidence, allows a judgement call on the basic question "can it be done?"

To address eradication principle 3 above, a feasibility study should look carefully at island biosecurity. Removing pests can make the island more vulnerable to other invasive species. For example the eradication of Norway rats from Raoul Island may have significantly increased the chances of mouse survival and colonisation, should an incursion occur.

3. What will it take?
A project brief exploring as many of the planning issues as possible enables the project to be properly sized. Accurate sizing allows:

- for adequate resources and timeframes to solve issues;
- management of stakeholders' cost and time expectations;
- better management of the operational planning task itself;
- identification of dependencies in the planning such as trials preceding key decisions on eradication design;
- projects beyond the organisation's capability to be identified and abandoned early before too much money is spent or expectations raised.

Where a project is abandoned at this stage, the feasibility study highlights barriers. These circumstances could change in future and allow the project to proceed.

BUILD SUPPORT

Strong organisational and public support will enable a project leader to build a capable team, motivated to succeed. Gaining support and building a team requires long lead-in times and careful communication to manage expectations proactively from the outset of the project.

1. Internal support

This requires key people being "sold" on the goals of the project and regularly briefed on progress toward those goals. Organisational confidence in the project to the highest levels was identified in a New Zealand Government study of innovation in the Public Service (Wright and de Joux 2003). The authors included a case study of the 2001 Campbell island rat eradication project

A team approach gives the best chance of success. The team involves everyone in the project, including advisors, critics, decision makers, service and support staff as well as those doing the work on the ground, and in the air. Internal support building should reach at least as far as the highest level of decision making in the project and always to the "grass roots" level.

Support from higher level managers can influence project resources. The people and money must be available to carry out all tasks efficiently whilst not providing incentives for shortcuts.

2. Public support

Public support is of equal importance. Public or community opinion often strongly influences politicians and decision makers. Building public support is dependant on full and frank consultation about the project that listens to and addresses concerns. This takes time, rushing it can be detrimental to the desired outcome. Our advice is 'start early'. Where the project is proposed within the context of island restoration goals already agreed with the community, things can go more smoothly.

GROW CAPABILITY

In an eradication context capability means: skills and experience; attitude and motivation; time and resources.

The IEAG takes a multi-project approach, giving project managers experience in each other's projects and involving them in advisory group discussions to expose them to the group's culture of:

- robust and meticulous planning;
- open debate where all points of view are heard; and
- a customer focus on meeting the needs of the project manager- so s/he feels supported rather than intimidated by the group.

This approach helps equip project managers with the right attitude and motivation to achieve eradication. Their challenge is to provide the leadership to achieve this for the rest of their team. Project teams must understand and agree with an eradication plan, know the importance of their role and how integral their effort is to achieving a successful outcome. Sometimes the IEAG intervenes on behalf of the project team to get the resources or support for the project. Allowing time to focus on the project is particularly important in the final stages where unexpected issues must be accommodated without affecting the quality of the project.

OPERATIONAL PLANNING

Most effort in aerial rat eradication projects goes into planning because there is little opportunity to analyse data and adjust actions once the operational phase has begun. The poisoning must be designed to eradicate all rodents without need for follow up as it is extremely difficult to even detect, let alone "mop-up" surviving rodents especially on large islands. This means it has to be planned correctly.

DOC's operational plans cover the eradication design, team members' roles and responsibilities, how consent conditions will be complied with, and all the logistical planning of how the people and equipment will get to and from the island (including removal of waste). They link to other documents such as safety plans, media management, assessment of environmental effects, and monitoring plans.

The IEAG places strong emphasis on minimising the risk of failure. The consequences of failure are so high that all measures must be taken to reduce its likelihood. Our planning aims to minimise the risk of failure by:

- **Using proven eradication design (methods)** The eradication design is continually assessed against the principles of eradication and recent best practice lessons from eradication and research projects.
- **Avoiding unnecessary complications**. Total coverage of the island by aerially sown baits generally carries the least risk of failure. Each alternative technique adds to the risk of failure. While compromises are made to safeguard people and wildlife, alternative ways to mitigate these risks whilst still aerially sowing baits are preferable.
- **Conducting trials, testing assumptions and new ideas** to reduce uncertainty around effectiveness or potential impacts. For example any new or unproven equipment is field tested before the operation to iron out any teething problems.
- **Anticipating potential problems** and planning to meet or eliminate them should they arise. This 'frees up' the project manager during the operational phase to focus on the goals of the project and to deal with the truly unexpected that inevitably arises.
- **Peer reviewing operational planning** is not a discrete step which is "ticked" as completed, the IEAG becomes involved throughout the planning process as an independent part of the larger project team. This helps identify risks and provides the climate of open discussion and support project managers need. The independence and experience advisory group members bring to these discussions keep issues in perspective and relate them to how they might affect the risk of failure.
- **Readiness checks.** Peer review culminates in a final audit before the operation is declared ready to proceed, signalling the end of the planning phase. These checks use IEAG members and experienced project managers to carefully go though the total package of planning documents. Project team members are also questioned to verify nothing critical has been overlooked.
- **Obtaining consents.** Local authority consents invariably end up being publicly notified despite verbal assurances to the contrary. Allowing time for this process to avoids timeframes becoming squeezed at the critical point just prior to the operational phase. Consent conditions that put the viability of the operation at risk can be avoided by involving the project manager in the consent process to negotiate workable conditions.

Island biosecurity measures should be in place prior to the operational phase to prevent new pests being introduced with equipment and people involved in the operation.

OPERATIONAL PHASE

The planning phase of the project grows capability in the team to carry out the operational phase of the project. This team have the autonomy to make decisions and get on with the job, supported by, but without interference from those less informed back on the mainland.

The operational team should stick to the plan where possible. Having experienced people on-site for discussions which support the project manager's decision making helps avoid ad hoc changes that increase risk. These are not extra team members, they can for example be part of the bait loading crew when not involved in discussions.

The logistics of getting bait to islands means the total quantity of bait available is finite once sowing begins. Careful monitoring of bait use during sowing ensures early detection and fixing of bucket calibration problems so that enough bait remains in reserve to re-sow gaps discovered in the navigational guidance printouts.

LEARNING

In the post operational phase, formal debriefs and reporting should focus on lessons for future projects. Each DOC project has piggy-backed on the experience of those before it and plays a part in identifying lessons for future projects. This is doubly important for projects that fail.

Good information management throughout the project is vital to successful review. If the project manager cannot accurately state what was actually done, any review of the project will be disadvantaged.

There is worldwide interest in the eradication of invasive species. Good documentation is essential to communicate the lessons from both successful eradications and failures to plan and build support for other projects. Retaining the use of the tools currently available to us also requires good reporting on these projects.

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A REVIEW OF COMMENSAL RODENT ERADICATION ON ISLANDS

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ABSTRACT: A large majority of recorded vertebrate and plant extinctions since 1600 have been of island species and introduced mammals are responsibility for the vast majority of these extinctions (Groombridge 1992). Commensal rodents (*Rattus* spp. and *M. musculus*) are the most wide-spread and damaging of the introduced mammals (Atkinson 1985). They are directly responsible for an estimated 40% of global bird extinctions and the extirpation of many seabird populations (King 1985). However, commensal rodents can be eradicated from islands (Towns and Broome 2003), after which populations of native species can recover (Towns *et al.* 1997). We reviewed all known commensal rodent eradications from islands with the intent of facilitating future island conservation actions. The complete data set can be viewed at http://www.islandconservation.org/eradicationdb.html, and will be later available in an online island eradication database. Data collected included records of island size, country, vegetation, target species, eradication methods (including toxin and trapping specifications and application methods) as well as non-target species, costs and agencies involved.

To date, we have found at least 274 commensal rodent eradications on 233 islands, mostly in New Zealand and Australia. The first eradication was in 1951 on 3.3 ha Rouzic Island. The majority of eradications (63%; n=173) have occurred on small islands (<50 ha), while only 13 eradications (<5%) have removed commensal rodents from islands >500 ha. The largest successful campaigns took place on Campbell Island (11,300 ha) for *R. norvegicus*, Raoul Island (2938) for *R. exulans*, St. Paul Island (800 ha) for *R. rattus*, and Enderby Island (710 ha) for *M. musculus*, although the largest intentional eradication of mice was on Mana Island (217 ha). The most common method of eradication has been poisoning with the second generation anticoagulant brodifacoum (64%; n=129, out of records for which data on method used were available). Impacts to non-target animals continues to be a major factor in restricting efforts to eradicate rodents outside of New Zealand (no native terrestrial mammal fauna) with relatively few eradications attempted or successfully completed with endemic rodents (e.g. endemic *Peromyscus* on Anacapa Island) that are at high risk of inadvertent extirpation. Impacts from commensal rodent predation and, more recently, the benefits of eradications have been increasingly documented (e.g. see Veitch and Clout 2002; Pascal *et al.* in press). These impacts and benefits, combined with the continued success of eradication campaigns on larger islands, demonstrate the value and role of commensal rodent eradications in the conservation of biodiversity (Towns *et al.* in press). This powerful conservation tool is becoming a standard management procedure on islands and will become

more widespread as more efficient eradication techniques and improved methods to prevent re-invasion of islands by commensal rodents are developed (Dilks and Towns 2002).

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LOCAL ELIMINATION OF POSSUM POPULATIONS – FEASIBILITY AND BENEFITS

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ABSTRACT: Recovery of possum populations after control occurs through immigration from adjacent areas and breeding of survivors and immigrants. If local elimination can be achieved, the population recovery will depend solely on immigration and therefore should be substantially slower, particularly in very large areas. Modelling predicts that local elimination of possums followed by 'perimeter' control (LEPC) is likely to be a more cost-effective control strategy than the current 'knockdown-maintenance' approach. Furthermore, immediate relief would be gained from all possum damage, while conventional maintenance control may, for example, take an estimated 4–8 years to eradicate bovine Tb from a residual population. Our ability to control possums has improved in the last three decades such that it now appears that local elimination is, technically, a realistic goal, and evidence will be presented that it is possibly already being achieved occasionally. Constraining factors include: unreliable monitoring at ultra-low densities, inappropriate selection and use of control options, lack of incentive under the present contracting system, initial cost, contracting capacity, and the future availability of 1080. However, these difficulties can be overcome, and should be if it is accepted that local elimination is sometimes a desirable and feasible goal.

INTRODUCTION

Control of possum populations in New Zealand will be required in perpetuity unless possums can be completely eradicated, or they are deemed to no longer be pests. Presently, neither of these is at all likely, provoking the question: can long-term control of possum populations be achieved more efficiently? Current strategy to maintain a low density entails the initial reduction of a population followed by intermittent control, ranging in frequency from 'almost continuous' to once every 7 years (Parkes and Murphy 2003). The efficiency of control can be improved by (1) better predicton of where and when control is required, (2) reducing per capita cost of control, or (3) reducing the rate of recovery and hence frequency of control. To date most research has focused on better targeting and increasing kill rates, although current efforts to develop a reproductive control for possums will likely focus on reducing recovery rates. In this paper we explore a potential new strategic approach to increased cost efficiency – complete 'localised elimination' of possums followed by 'perimeter control' to reduce immigration into the area. For convenience, this strategy will be referred to as LEPC. The term 'local elimination' is used to distinguish this strategy from 'eradication' as the latter is defined as the permanent removal of all animals.

Eradication is a successful strategy for islands where the 'obligate conditions' (Parkes 2005) are most easily met: namely, (1) all pests must be placed at risk of death, (2) they must be killed quicker than they breed, and (3) the probability of recolonisation must be zero. Possums have been eradicated from 10 islands ranging in size up to 2321 ha (i.e. Rangitoto Island).

On the mainland, it is usually impractical to prevent recolonisation without building an expensive possum-proof fence. This has ruled out eradication as an option for most mainland areas, so the 'maintenance control' paradigm has become standard practice. However, major improvements in effectiveness now make it reasonable to consider local elimination (both with or without control of immigration) as an alternative strategic option that is intermediate between maintenance control and eradication.

IMPROVED TACTICAL ABILITY

Possum control by poisoning has become considerably more effective over the last 30 years due largely to improvements in bait quality and delivery. For example, average reductions of 70% were achieved in aerial 1080 operations in the 1970s (Batcheler 1978), but by the late 1990s kills usually exceeding 90% were achieved where improvements were being used (Henderson *et al*. 1999). These improvements have been gained, firstly, by ensuring that all possums are exposed to bait, whether these are aerially sown (Morgan 1994) or presented in bait stations (Thomas 1998). Secondly, the factors affecting bait consumption have been analysed enabling the establishment of specifications that maximise the likelihood of possums' ingesting lethal quantities of toxin (Henderson *et al.* 1999). While the influence of factors such as rainfall (Bowen *et al.* 1995), temperature (Veltman and Pinder 2001) possum 'condition' (Bamford and Martin 1971) and, possibly, availability of 'competing' natural foods (Morgan *et al.* 2000) cannot be controlled, understanding of these influences enables pest managers to schedule operations to minimise their negative effects. Many control operations are now so effective that the standard trap-catch monitoring technique used often detects few or no surviving possums. Data received from several pest managers demonstrate that, for both ground-based and aerial control operations, many operations are now reducing possum numbers to extremely low levels if not actually eliminating them locally (Table 1). Post control monitoring intensity was very high in some cases, increasing confidence in the results, and in at least two operations (Hopkins and Hochstetter) considerable additional trapping by a research team failed to detect any survivors. Local elimination of possums therefore appears a realistic operational aim.

Table 1 Sample of aerial and ground control operations monitored since 2000 in which very low or nil survival was recorded using the Residual Trap Catch Index (NPCA 2004).

Operation	Area (ha)	Trap-nights	RTCI %
a) Aerial operations			
Bideford – July 2000	2907	660	0
Tongariro – September 2001	19 980	1020	0.1
Kahutara – March 2003	910	450	0
Titiraupenga – July 2003	10 150	600	0
Waikaremoana – July 2004	9219	1170	0.1
Kahutara – September 2004	1337	630	0.1
b) Ground operations			
Hopkins – July 2003	1500	2700	0
Matea – July 2003	14 787	2550	0.2
North Taupo – July 2003	2164	1740	0.2
Hochstetter – September 2003	450	420	0
Bideford – November 2003	1188	690	0
Te Wharau – April 2004	1224	600	0
Kahutara – 2004	2988	2250	0
Holdsworth – 2004	1185	1800	0
Raetea – 2004	920	600	0
Matea – 2004	2799	1800	0.2

A key factor determining the likelihood of success is the use of 'best practice' in all aspects of control. This has been defined for aerial 1080 control operations based on the identification and specification of all the key parameters that determine, firstly, whether possums encounter a potentially lethal bait, and secondly, whether they eat it (Morgan 2004b). The use of quality assurance procedures to ensure that such specifications are met is becoming routine for aerial 1080 operations, but the approach should be applied to all control methods used in future improvements, including the strategy proposed here.

IS LOCAL ELIMINATION A VIABLE ALTERNATIVE STRATEGY?

The cost-effectiveness of LEPC will depend on biological characteristics of the possum population that determine immigration, the size of the 'sink' area (i.e. where control is done) relative to that of the 'source' area (i.e. the adjacent area from which immigrants will come), the cost of achieving complete elimination relative to the cost of maintenance control, and the cost of preventing or at least reducing immigration rates.

We used a deterministic model to illustrate this strategy and to investigate the influence of these variables on its cost-effectiveness. We assumed the sink area to be circular and the source to be a surrounding annulus. To predict possum population recovery we used the asymmetric growth equation (Barlow and Clout 1983) in which population growth is given by:

$$N_{t+1} = N_t + (r_m N_t(1 - (N_t/K)^{\theta})) \quad (1)$$

where: N_t = population density at time t, r = intrinsic rate of increase, K = equilibrium density (i.e. 'carrying capacity'), and θ = exponent determining the shape of the curve.

Average values used initially were:
K = 10 possums/ha; N_t = 0.5 possums/ha after a 90% kill (therefore, assuming a pre-control density of 5 possums/ha); r_m = 0.34 (i.e. an 'average' rate of increase, Hickling & Pekelharing 1989); θ = 2 (Barlow and Clout 1983).

The contribution of immigration, adjusted for the effectiveness of control around the sink perimeter, is described by:

$$I(j + a) = ((J * Jd * Js) + (M * Md * Ms)) * S \quad (2)$$

where: I(j + a) = total immigration , J = density of juveniles in source, Jd = proportion of juveniles dispersing annually, Js = proportion of juveniles in source that disperse into the sink, equivalent values for mature possums (M), and S = proportion of juveniles and adults surviving perimeter control.

Average values used initially were:
J = 0.94 possums /ha, as juveniles comprised 19% on average in 14 populations studied (Brockie *et al*. 1981), and therefore M = 4.06; Jd = 0.3 (Cowan and Clout 2000); Md = 0.05 (an assumed 'generous' value making calculations conservative); Js and Ms = 0.25 assuming equal dispersal in all directions; S is assumed to be 50% or 20%.

Combining equations 1 and 2, the proportional contributions (based on area) of breeding in the sink and immigration from the source is then incorporated:

$$N_{t+1} = N_t + (r_m N_t(1 - (N_t/K)^{\theta})) + (((J * Jd * Js) + (M * Md * Ms)) * S*a/A)) \quad (3)$$

where: A = sink area, a = source area.

In comparing the cost-effectiveness of LEPC against standard control, some assumptions must be made concerning cost. Typically, aerial control involves prefeeding bait at 2 kg/ha followed by application of toxic bait at 2 kg/ha and presently costs approximately $25/ha (C. Speedy, pers. comm.). Subsequent maintenance control of the population costs between $25/ha and $75/ha per occasion depending particularly on terrain and methods used among other factors (C. Speedy, pers. comm.). Conservatively, we use a value of $35/ha for present purposes, and assume that typically maintenance control will reduce the residual population by 70% each time it is applied. The most likely reason for possums surviving aerial control operations is considered to be failure to encounter bait, either because of incomplete coverage or because they were living predominantly in the canopy (where baits are scarce) during control. We propose that it may be feasible to eliminate all possums by using two successive aerial 1080 operations, separated by about a month, in which flight paths are orientated at 90° to each other so as to maximise the chance of all possums being exposed to bait. The cost of elimination is therefore assumed to be $50/ha (although in practice it may be less as administrative costs are unlikely to double).

Reduced immigration might be most economically achieved by use of one or two parallel lines of 'long-life', 'low-labour' devices around the perimeter of the sink. For example, a 1080 gel bait has been shown to remain palatable and toxic to possums for at least 26 months (Morgan 2004a), a cholecalciferol formulation, better suited to prolonged placement due to its relatively low environmental hazard, is under development, and kill-traps are now available that would need to be checked only infrequently. The range of such tools will likely expand as the emphasis shifts from short-life tools to reduce high-density populations to long-life tools for efficient control at very low density. The total cost of maintaining the specified level of control of immigrants would be dependent on the duration of effectiveness of devices and the predicted time until the population in the sink recovers to a threshold. Therefore, assuming the specified level of perimeter control would be achieved by replenishing control every 2 years (although control effectiveness may decline with time due to factors such as weathering of bait or malfunctioning of traps), four perimeter control operations would be needed, for example, where recovery of 9 years is predicted. The cost of perimeter control will also be a function of the area of the sink, decreasing proportionally with increasing sink size. Therefore, the additional cost of perimeter control is given by:

Cost of perimeter control per ha of sink = (Perimeter (km) * Cost/km perimeter * No. of control operations needed within predicted recovery period)/Sink area (ha). (4)

Using the typical values for parameters relating to equations 1–4, three of the most influential and easily measurable parameters (kill, sink area, and cost of perimeter control) were varied to determine the cost–benefit of local elimination/perimeter control (LEPC) strategies relative to that given by standard knockdown/maintenance control. We have assumed the cost of using long-life devices to control 50% of immigrants along a perimeter as $200–300/km, and $300–450/km for 80% control. Figure 1 shows the difference in recovery time after four different control strategies were applied to a sink of 5 km radius and with an immigration source 1 km wide. To exemplify the comparison of cost–benefit ratios, we have assumed an arbitrary threshold of 1 possum/ha as the trigger for control. Standard control achieving an initial kill of 90% would need maintenance operations at 2-yearly intervals following initial control. Under LEPC where 50% of immigrants are controlled on the perimeter (31 416 m), control devices would need to be replenished four times (at an assumed cost of $300/km) before the population recovered to an arbitrary threshold of 1 possum/ha. The added cost ($30.40/ha) of achieving local elimination and 50% perimeter control is predicted to delay recovery until 9 years after control. This represents a 72% improvement in cost–benefit ratio compared with standard control (Table 2). Similarly, 80% perimeter control costing $450/km will delay recovery until 12 years improving the cost–benefit ratio by 108%.

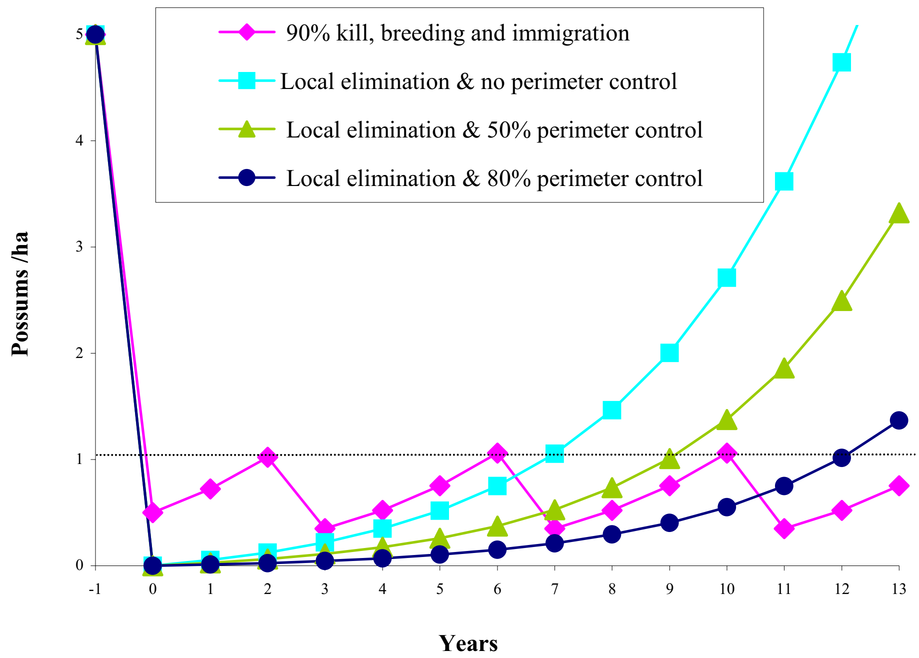

Fig. 1 Recovery of possum populations after a 90% reduction to a threshold density of 1 possum/ha under four alternative control strategies. Immigration is assumed from a 1-km-wide annulus around a sink of radius 1 km. Formulae and population parameter values used are given in the text above.

Other combinations of kill, sink area, and perimeter control-cost are presented in Table 2 and cost–benefit compared with that achieved under standard control. Using the same initial kill as the above example (i.e. 90%), local elimination alone (i.e. without any perimeter control) was cheaper than standard control giving a 10 or 73% increase in benefit–cost ratio for sinks of approximately 300- or 8000-ha areas respectively. When perimeter control was added, increases of up to 121% were achieved depending on both sink area and cost of perimeter control. Even when compared with a higher level of initial control (95%), local elimination is still more cost-efficient if perimeter control exceeding 50% can be sustained. The number and cost of maintenance operations in standard control greatly influence the relative efficiency of alternative strategies. Where maintenance control costs are greater than the conservative value of $35/ha used, substantial further improvements in relative efficiency are gained: for example, following a kill of 95% in a source of radius 5000m, 80% perimeter control (at $450/ha) gives an improvement of 188% in benefit–cost ratio over standard control involving maintenance operations costing $75/ha.

Table 2. Cost–benefit ratios of alternative control strategies relative to standard control based on local elimination (LE) and perimeter control (PC) for specified values of: (1) kill given by standard control, (2) sink radius and source annulus, and (3) cost of 50% and 80% perimeter control

Parameter values								
Kill (%)	90	90	90	90	95	95	95	95
Sink radius (m)	5000	5000	1000	1000	5000	5000	1000	1000
Source annulus (m)	1000	1000	1000	1000	1000	1000	1000	1000
50% PC	200	300	200	300	200	300	200	300
80% PC	300	450	300	450	300	450	300	450
Benefit:cost								
Standard Control	1	1	1	1	1	1	1	1
LE	1.73	1.73	1.15	1.15	0.96	0.96	0.73	0.79
LE+50%PC	1.77	1.72	1.05	1.00	1.12	1.08	1.05	1.00
LE+80%PC	2.27	2.14	1.40	1.23	1.66	1.56	1.41	1.30

IMMEDIATE RELIEF FROM DAMAGE

Apart from the appreciable long-term economic benefits predicted by an LEPC strategy, an additional major benefit is gained due to the immediate and complete relief from further possum damage. For example, modelling of the transmission of bovine Tb indicates that initial control followed by maintenance control that suppresses the population below 1–5% RTCI (i.e. about 1 possum/ha) will typically take 4–8 years to eliminate Tb (D. Ramsey unpubl. data.). In contrast, an LEPC strategy would eliminate Tb from possums immediately, removing the risk of spread to livestock. Likewise, protection of conservation resources that are damaged at all but the very lowest possum densities (e.g. mistletoe and kauri snails) would be achieved immediately by LEPC, while maintenance operations following standard control may not suppress the population for long enough to provide adequate protection.

CONSTRAINTS TO ACHIEVING LEPC

Local elimination is unlikely to emerge as operational practice under the present system of contracting whereby contractors are typically paid after monitoring has shown a performance target has been met. Clearly their focus is on minimising the effort (and therefore the kill) required to reliably achieve the target. There is no reward for contractors in overachievement. Managers, on the other hand, cannot realistically set a ‘zero survival’ target even if they were prepared to pay for the additional control effort required because the current trap-catch based monitoring method (and even potentially much more efficient methods such as interfence-based indices) are too imprecise to confirm when elimination has been achieved. Initially, at least, implementation of the LEPC strategy would be more likely to succeed if contractors and pest managers combined skills in prescribing the best approach to achieving elimination, agreed on a realistic price, and arranged monitoring of the contractor’s compliance with the prescription rather than monitoring performance. Longer-term contracts would also facilitate a longer-term strategy for a particular area, as would the use of progress payments, especially in coping with the initial higher costs of control required by local elimination.

The primary practical constraint to local elimination is whether 100% of possums within and area can be put at risk, and whether all of those put at risk can be killed. Bait sowing technology has advanced to the point where total coverage of all possum homes ranges can be assured (Morgan 2004c) but there is emerging evidence of some form of 'temporal refuge', where possums escape exposure during a brief poisoning or trapping period possibly because, for example, some individuals are exclusively arboreal at the time. Research is currently underway (Morgan 2004c) to determine the extent of this problem and to find ways to overcome it. Furthermore, although possums encounter baits, they may avoid them because of previous misuse of poison baits resulting in well-entrenched bait shyness (Morgan *et al.* 2002). Other practical constraints may arise if perimeter control is very expensive due to topography or vegetation type: areas with at least a substantial proportion of the perimeter as bush-edge habitat would be most suitable.

While the range of control tools available to contractors has increased in recent years, the future availability of 1080 is presently a source of some concern, particularly as it is the only poison available for aerial distribution in baits. In response to ongoing public concerns, use of 1080, the major tool used against possums, is presently being reviewed by ERMA. Any major restrictions on its future use would severely impact on the collective capacity to control possums.

CONCLUSIONS

Empirical evidence from recent control operations suggests that LEPC may be feasible. The strategy is most likely to succeed initially where: (1) high levels of bait-shyness are unlikely to have resulted from past control, (2) access to and topography of the area and its perimeter facilitate complete control coverage (i.e. all targeted possums are exposed to the control tool(s)), (3) control tools (including biocontrol in future) and their application methods are sufficiently well developed that key specifications for success can be defined and monitored, (4) longer-term 'collaborative' contracts are used to encourage the specification of a strategy using the best available tactics for the particular site, and (5) contractor performance is assessed against the agreed tactical specifications. Predictions from a simple deterministic model (which could usefully be further examined with stochastic models) suggest that the strategy offers substantial increases in long-term cost-effectiveness of possum control, a very desirable aim given the likelihood that possum control will, at present, be required in perpetuity.

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CONSERVATION ACTION IN THE GALAPAGOS: LARGE-SCALE INTRODUCED HERBIVORE ERADICATIONS

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ABSTRACT: Introduced mammals are major drivers of extinction and ecosystem change. Introduced herbivores are particularly destructive to island ecosystems: the introduction of goats, pigs, and donkeys to islands worldwide has resulted in widespread primary and secondary impacts via overgrazing, often leading to ecosystem degradation and biodiversity loss. Building on island conservation techniques partially developed in New Zealand, we report on a series of large-scale introduced herbivore eradications on the Galapagos Islands. Eradications have been completed or are underway on large islands be leveraging and integrating (1) aerial hunting by helicopter, (2) the use of specially trained hunting dogs and ground hunting techniques, (3) the integration of global positioning system and geographic information system technology, and (4) improved Judas goat techniques. Over 41,000 goats were removed from Pinta Island (5,940 ha), and over 18,000 pigs from Santiago Island (57,941 ha) – both the largest insular removals to date. Goats are currently being removed from Santiago and Isabela Islands (472, 350 ha) – a project of unprecedented scale. Leveraging new technologies and techniques should drastically increase both the island size where eradication is feasible and the efficiency of the campaign, the latter saving precious conservation dollars.

INVESTING IN CONJECTURE: ERADICATING THE RED-EARED SLIDER IN QUEENSLAND

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INTRODUCTION

The Red-eared Slider Turtle (REST) (*Trachemys scripta elegans*) is recognised as a threat to biodiversity when introduced to areas outside its natural range (IUCN/SSC 2004). REST occurs naturally in the Mississippi River (Ernst 1990). Thus, the discovery of two adult, apparently free-ranging animals in Pine Rivers Shire, southeast Queensland, Australia in January 2004 prompted investigation by agencies responsible for vertebrate pest management. Residents found the turtles wandering on a warm, rainy evening following a very dry period. They realised the turtles were unusual, their identity as REST was confirmed.

Three categories of potential risk from the presence of REST were identified: Biodiversity impacts. Studies and observations from parts of the world where REST are naturalised raised concerns that the spread of REST could precipitate a decline in native Australian Chelonians (e.g., Cadi and Joly 2003, 2004). Mechanisms for this could include (a) competition for food and living space. REST have a high reproductive output compared to Australian Chelonians, (b) introduction of exotic reptile diseases (c) impacts on fisheries. REST are omnivorous, and their diet may include fish and crustacean (Parmenter and Avery 1990), and (d) human safety impacts. The extensive trade in hatchling REST ('penny turtles') has created a public health risk from the spread of salmonella (Connor 1993; Mermin *et al.* 2004). This has resulted in a ban on sale or distribution of hatchling REST in the USA (Connor 1993).

A pest assessment carried out by the Queensland Department of Natural Resources and Mines rated the risk of REST establishing in Queensland as extreme. A climatic model suggested that REST have the potential to establish over a large part of Australia, possibly including inland waterways. The precise risks posed by REST in the Australian environment are not known since the species is not widespread in Australia, and has not been studied. A project team with representatives from the State Department of Natural Resources and Mines, Environmental Protection Agency, Department of Primary Industries (Fisheries), the Queensland Museum and Pine Rivers Shire (local government), and the Australian Quarantine Inspection Service (federal government) was established.

RESULTS

Where did they come from?

It is illegal to keep REST in Australia. Nevertheless, animals have, in the last 20 y, been 'swapped' by collectors, and sold outside the formal pet trade (J. Cann pers. comm.). REST are probably dumped by some pet owners who become bored with their animals, are not prepared to keep the turtles for their full lifespan (more than 25 years - Frazer, *et al*. 1990; Gibbons, 1990), or realise that they are illegal to keep. With several million REST exported from the United States each year[1,2,3] it is inevitable that some reach Australia. The Australian

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[1] Hoover, 1999 reported that 8.4 million REST were exported from the USA in 1996, with export showing a consistent increasing trend

[2] More 1 million sliders were imported annually to the Republic of Korea prior to 2001.

Quarantine Inspection Service report that a few REST are intercepted at ports (N. Charles, pers comm.). This informal trade was confirmed as the likely source of REST at Mango Hill[4].

Trachemys scripta elegans: An adaptable and robust animal

The Red-eared Slider is one of the numerous subspecies of the Pond Slider (*Trachemys scripta*). REST are primarily animals of mild temperate climates. Other subspecies of *Trachemys scripta* occur in subtropical and tropical Central America. REST have proven very adaptable, and have become established in more than 20 countries representing cool temperate and tropical climates, and everything in between (Ernst 1990; Moll and Moll 1990; Silva and Blasco 1995; Cadi *et al.* 2004; IUCN/SSC 2004). REST are generalists in many respects. REST will live in a variety of still or very sluggish water bodies. They are able to tolerate water of variable quality, and will live in water contaminated with levels of thermal pollution, radioactivity, chemicals, and organic waste that are not tolerated by other vertebrates (Gibbons 1990). REST readily occupy constructed or highly modified water bodies, such as farm dams, ditches, and urban ponds in the anthropogenic landscape (e.g., Gibbons 1990; Parker 1990; Spinks *et al.* 2003; Rose and Manning 1996). The ability to survive on almost any food gives REST a competitive advantage. REST consume both plant and animal material, although the diet of juvenile animals generally consists of a greater proportion of animal material than in adults (Clark and Gibbons 1969; Hart 1979; Parmenter and Avery 1990).

REST can lay up to three clutches, about 75 eggs a season, compared with a maximum of 30 (typically 10-15) eggs per season in most Australian freshwater turtles (Goode and Russell 1968; Cann 1998). In addition, female REST are able to lay fertile eggs for up to five years after a single copulation with a male (C. Limpus, pers comm.).

Responding to the Red-eared Slider Incursion

Manage or eradicate?

There have been few attempts to manage REST as a pest and there is a complete lack of published information on the species in the Australian region (Bomford 2003). Despite a lack of information and shared experience a decision to either eradicate or strategically manage REST had to be made. Very different approaches and resources would be needed to achieve each of these objectives. With limited resources, the project team dealing with REST needed to establish achievable objectives to be reached by economical means.

Pursuing eradication at a broad scale on a 'mainland area' is not generally a realistic objective for a pest management program. Pursuing this can waste valuable resources (Bomford 2003). However, a still, well-defined water body can be regarded as a type of island. Thus, it was felt that a small window of opportunity for eradication might exist if:

- REST were confined to a very limited number of 'islands' (water bodies);
- Immigration and emigration from these water bodies could be controlled and
- An effective capture technique could be developed.

The team's first priority was to gather information on the extent of the REST incursion to judge the feasibility of eradication. The team gathered information in two ways. First, comprehensive education and community engagement programmes were run in the Pine

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[3] Telecky (2001) estimated that US turtle farms produced 52 million REST for export between 1989 and 1997.

[4] As a result of investigations, a court case is pending. This issue therefore cannot be discussed further here while the matter is before the court.

Rivers Shire, where the first sliders were found, and in surrounding areas. This programme was promptly broadened to incorporate southeast Queensland, and eventually the rest of the state. A 'hot-line' was established, and persons having seen or captured sliders were encouraged to contact the project team. All responses were investigated. These surveys suggested that self-sustaining wild populations of REST in Queensland are small and restricted to less than ten relatively small stationary water bodies, all in close proximity to one another. All but one are small farm dams that are not linked to other water bodies by flowing water or well-defined watercourses. The exception is Halpine Dam, a larger, old farm dam- spring fed, and with very high water quality.

Preventing accidental spread of REST

Southeast Queensland is undergoing very rapid population expansion. A large number of properties being developed support small 'farm dams' or ornamental ponds. Most of these are drained, and then filled prior to construction. In many instances, local government require such water bodies to be drained so that native turtles can be recovered and relocated. Protocols for recovering turtles have not included a screening process, since the presence of exotic turtles was not known or suspected until very recently. Property developers have been required to recover all turtles and relocate them. In the Pine Rivers Shire, where the first wild populations of REST were found, as many as 300 farm dams are drained and filled each year. With 11 local government areas within a 100 km radius of the Brisbane CBD, it is likely that well over 1000 farm dams are being drained in the southeast each year. Without a screening process, relocation of turtles during property development has the potential to be a major vector for spread of REST. The project team is working with local governments to ensure that turtles taken in recovery programmes are properly screened for REST before release.

Recovering illegal pets

The project team work through interest groups and use the media to encourage the public to hand in REST that are being (illegally) kept. Recently, the Australian government declared a six-week 'reptile amnesty' during which persons keeping illegal reptiles could surrender these without penalty. Six REST were handed to authorities in southeast Queensland during the amnesty. The project team has been able to use the high level of media interest and public interest in REST to convey the message 'hand them in', and an explanation for why REST should not be kept as pets.

Attempting eradication

The project team decided that with little evidence of a widespread incursion, the small number of water bodies affected by REST could be treated as 'islands', and eradication attempted. For eradication purposes, highest priority is being given to and most intensive effort is directed toward established REST populations. Evidence suggesting the presence of wild REST populations is checked as it is received. If the evidence is a sighting, the observer is questioned and visual observations are made. Nearly all 'sightings' are confirmed as native turtles. When REST are handed in, we attempt to judge whether they are animals that have been living in the wild, or recently abandoned, unwanted pets. Experience has shown that some of the animals surrendered, though claimed to be 'wild' are clearly pets. It may be that persons keeping REST illegally feel a need to claim their animals were wild caught in order to avoid prosecution. In several cases, pet REST appear to have been deliberately released in areas where they are certain to be picked up and handed in- schoolyards, for example. Indications that REST are recently released pets include a lack of algae and bacterial growth on the head and shell (indicates that animal has been living in chlorinated water) and a readiness to take food by hand or in the presence of a person. Wild animals generally have heavy growth of algae and bacteria on their shells, and they will not take food offered by hand.

If a sighting is confirmed as a REST, or if a surrendered animal indicates the possibility of a wild population, still water bodies within a (roughly) 2 km radius are mapped. Surveys are then conducted in those closest to the original sighting/hand-in. Visual observations are made at water bodies in the peak periods for basking - between about 08:00 and 11:00 and again between about 15:00 and 16:30. Water bodies are also hand-trawled with a seine net. A breeding population is indicated by the presence of multiple individual REST of different ages. We also treat a water body as supporting a breeding population if new hatchlings or eggs or adults males and females are found. The strategy then depends upon the dimension of the water body, type and density of aquatic vegetation and tenure of the property.

The preferred method for eradication is to drain the water body, remove all REST, then fill and compact. Understanding the behavioural differences between native Australian freshwater turtles and REST was critical to success. We found that when a water body is drained native turtles will initially rest on the bottom or burrow only a short distance (perhaps about 40 cm) into the silt on the bottom. REST will burrow more than 1.5 metres into the silt on the bottom of a water body. Unlike local native freshwater turtles, REST could not reliably be recovered by shallow probing with hand tools. We were forced to use heavy earth moving equipment to de-silt the dams. The muck was spread on a slashed field, turned and raked with a tractor, and REST were removed by hand. We also found that disturbance provokes a distinctive response in REST. Once again, procedures that are appropriate when dealing with native freshwater turtles can lead to failure when attempting to remove REST. To capture native turtles, the seine net is run through the water while driving turtles away from banks or aquatic vegetation by splashing and beating the water. 'Beaters' drive the turtles towards a point in front of the net. The ends of the net are brought round and the turtles are captured as they attempt to swim in front of the seine. We learned through bitter experience that this technique is completely unsuitable for REST. A swift and quiet sweep of the seine net is required, as REST will drop to the bottom and burrow into the mud if disturbed. Thus the net will pass over the top of the animals that may not emerge again for many hours.

The process of draining water bodies also seems to provoke an idiosyncratic response in REST. We found that once draining commences, REST will disperse from the dam, generally at night. Cash and Holberton (2000) made similar observations in an American study, where up to 75% of the slider population in a test pond migrated when draining commenced. We therefore secured sites with barrier fences when draining water bodies, or working with nets for prolonged periods. Placing pitfall traps on the inside of the fence was an effective means of using the dewatering process as a capture technique. Wherever practical, we recommend that barriers be erected as soon as REST are discovered, and that they remain around water bodies that have been treated.

Fyke nets were also tested. These were laid in chest-deep water, parallel with the shore. They proved ineffective for capturing turtles in this position. However, fyke nets were used successfully to capture REST dispersing from dams during de-watering. The nets were used in conjunction with a barrier fence.

Large water bodies that cannot be drained and filled or netted with seine nets present a special problem. There is one such lake in the Mango Hill area. We capture REST in large water bodies using cathedral traps. Cathedral traps, consist of a baited 'crab pot' that sits on the bottom of the water body. A column of trawler mesh runs from the crab pot to the surface of the water and is supported by floats. This allows turtles to rise to the surface for air once they are captured. Traps baited with beef, fish and/or bread, are left overnight and checked the following mid-morning. REST enter cathedral traps quite readily, but persistence and large numbers of traps are required to capture REST when only small numbers are present. In these situations, intensive trapping with cathedral traps is followed up with prolonged passive trapping with 'basking traps'.

Basking traps consist of a floating square of cylindrical plastic (PVC) pipe, from which a mesh basket hangs suspended. Galvanised wires 'ramps' extend from the outside edge of square to the water's surface. These allow turtles to climb onto the PVC pipe. Because it is a rounded, smooth surface, when the turtles move, they slip into the suspended mesh basket. Unable to climb out, they are held until they can be collected (REST) or released (native turtles). The traps are moored with a rope attached to a weight, and they are placed in water that is about 1.5 – 2 metres deep. We have found that these traps become increasingly effective the longer they are left in place. As they weather, and take on a more natural appearance, they are more readily accepted as basking sites. Incorporating some natural materials into the design may also assist. We have found that basking traps are a best used in combination with other observation and capture methods. They are useful where REST are present in small numbers and are particularly valuable as a surveillance tool following removal of REST using more intensive methods.

Successful removal of REST from water bodies will still leave the problem of preventing re-infestation by hatchlings. Although eggs are usually laid close to the home water body, REST may disperse up to 2 km to lay eggs (Gibbons, Green and Congdon 1990). Conducting visual searches for turtle nests is time consuming and inefficient, even when conducted by trained observers. Searching large areas is impractical. This is a labour intensive strategy that does not give an acceptable level of certainty. The inability to efficiently locate REST eggs near breeding populations appeared as if it would be an insurmountable obstacle to eradication. However, we are developing a novel solution.

Innovation

"Sniffer dogs" have been widely used for search and rescue, detecting drugs, explosives and human remains (USDA 2003). Detector dogs are used in Guam and the Marianas to find and remove invasive Brown Tree Snakes *(Boiga irregularis*) at entry and departure points (Engeman *et al.* 1998). Studies of the effectiveness of dogs as detectors consistently show that, used correctly, dogs are generally reliable and superior to visual detection methods (Smith *et al*. 2003). A sniffer dog, handled competently, has the potential to rapidly and efficiently affect searches for REST eggs and nests, improving success, reducing human labour requirements and providing greater confidence in the results of the programme. Staff of 'Multi-National K-9' were chosen to train a suitable dog for the REST project. MK9 trainers have provided dogs to security services and police worldwide, for explosive and drug detection, search and rescue and forensic work.

A detector dog has been working for only a few weeks, but has already found several empty REST nests, and proven several other areas clear of REST. We suspect that any viable clutches of eggs have already hatched, and that egg laying will not occur again until spring. Thus, our detector dog will find his greatest use from early September.

Prospects for Successful Eradication

The team has had to interpret the available information on the species for local conditions that are very different from those that that exist through most of the Red-eared Slider's natural range. We have tried to make insightful observations while testing our approach to REST management. Much of what we have observed has improved our effectiveness. Despite this, we lack key pieces of information. We still do not know: when egg-laying commences and finishes, how many clutches of eggs are usually laid in southeast Queensland, and how tolerant REST are of salt water. Having these pieces of information would help us to frame our searches for REST geographically and temporally.

Relying on an informed public has proven an effective means of identifying potential wild populations of REST, and recovering REST being kept as pets. We have checked dozens of sightings, and surveyed areas where REST have been found 'at large'. We have confirmed and successfully delineated only one wild population of REST. Eradication of this population is proceeding, with 150 REST removed from six water bodies with a total surface area of less than 7 hectares. We believe we have recovered all REST from four of these water bodies, two of which have since been filled and compacted, with a third to follow. Two more have been drained, de-silted and isolated from re-infestation with barrier fencing. The techniques used on these small water bodies are not appropriate for the largest, Halpine Dam. Halpine Dam appears to have a small population of REST, an unknown proportion of which have been removed using intensive trapping. A combination of extended visual observation, passive trapping and searches with the detector dog will be used to verify the absence of REST. The effectiveness of our verification methods for turtles in the aquatic environment is unclear. At this time, we would be unable to declare with certainty that the Halpine Dam does (or does not) still harbour REST. Verification in water bodies that, for one reason or another cannot be drained, remains our greatest problem. However, the detector dog gives us the ability to reduce or prevent breeding in the infested 100 ha area at Mango Hill.

If the current infestation is regarded as an island, it could be argued that for the current wild population of REST, two of three key requirements for successful eradication can be met. We believe we can control immigration, and emigration of REST in the affected area. However, we are unable to say with certainty that we will detect the last REST - a third requirement for eradication. It may be possible to provide more certainty if we are able to develop more effective lures, baits and capture methods.

Although we have investigated a large number of REST observations, we have not identified any infestations additional to the original. We are therefore cautiously optimistic about succeeding. We are also aware that the discovery of REST in one or more very large water bodies, for example a city water supply impoundment, would make eradication impossible. If this happens, we will have to reassess our objectives to determine what level of *management* would be possible for this pest.

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PROTECTING PENGUINS FROM FOXES ON PHILLIP ISLAND

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ABSTRACT: Foxes threaten populations of little penguins on Phillip Island, Victoria. Current fox control procedures may be holding the fox population below its carrying capacity, but the effort is difficult to sustain in the long-term. Given the degree of isolation of the population, eradication may be achievable but will require an increased effort in the short-term.

INTRODUCTION

Red foxes *Vulpes vulpes* were first reported on Phillip Island, a 100 km^2 island at the entrance to Western Port, Victoria, in 1907 (Glidden 1968). Within 10 years, their threat to local seabirds (little penguins, *Eudyptula minor*, and shearwaters, *Puffinus tenuirostrus*) and domestic animals was recognised (Gabriel 1919) and the local council employed two staff on a casual basis to control fox numbers. This program ceased due to the world war in 1939. Following WW2, fox control was undertaken opportunistically by several local residents. Fox depredations continued, however, and in 1955 the local council introduced a bounty scheme that ran up to 1984. Despite these efforts, penguin colonies on the island were gradually reduced in number and extent until by c.1980, only the largest colony at the western end of the island remained (Dann 1992). This colony has become a major tourist attraction known as the Penguin Parade. In 1980, a fox control program was initiated by the Penguin Parade to protect the colony. Early in 2005, this program killed its 1000th fox. Now, the control program is to be expanded into an eradication program to create a 'Fox-free Phillip Island'. On reaching the 1000th fox milestone and at a point of a change in direction for the program, we reflect on the efficacy of past procedures and what we have learnt about the foxes of Phillip Island.

Features of Phillip Island that influence fox behaviour and control procedures include; a 500 m separation to the mainland; connected by a bridge in 1945; the island comprises 60% farmland, 25% housing estate and roads, and 15% coastal veg./ woodland; there are 5 to10 thousand resident human population swelling to c.60,000 during holidays; there are few native ground mammals (swamp wallaby, echidna, eastern water rat); but abundant introduced species (rabbits, hares, black rats and house mice; and seabird populations include ~60,000 little penguins (resident year-round) and >1 million short-tailed shearwaters (migratory, resident Sept-May).

METHODS

Fox control techniques employed, control and monitoring efforts of the Phillip Island fox control program have varied over time, being dependant on fox activity (particularly responsive to penguin kills), and the preferences and priorities of staff. For most foxes killed, the basic records kept include; date, location, technique, sex, weight, body length and stomach contents. Additional data recorded in later years include; effort (person-hours), age (based on growth layers in teeth and reproductive condition such as numbers of developing fetuses). Near-daily records are also kept of fox activity in the vicinity of the Penguin Parade (tracks on beaches), fox sightings, and penguins killed by foxes. Specific research projects conducted on the Phillip Island foxes include; a genetics comparison with mainland foxes

(Lade *et al.* 1996), remote video monitoring of bridge crossings (Kirkwood and Leschinski 2002), diet studies (Kirkwood *et al.* 2000, in press), assessments of mechanical ejectors (van Polanen Petel *et al.* 2002, 2004a), and bait uptake (Kirkwood unpublished data).

RESULTS

The number of foxes killed per fox year (October to September) increased from 1979/80 to 1996/97 and declined thereafter (Fig. 1). In the 1980s, most foxes were killed at night during spotlighting, whereas in the 1990s, hunting with hounds during daylight accounted for the greatest proportion of foxes killed. Baiting with 1080 was successful up to 1995/96 but thereafter few foxes were killed by baiting.

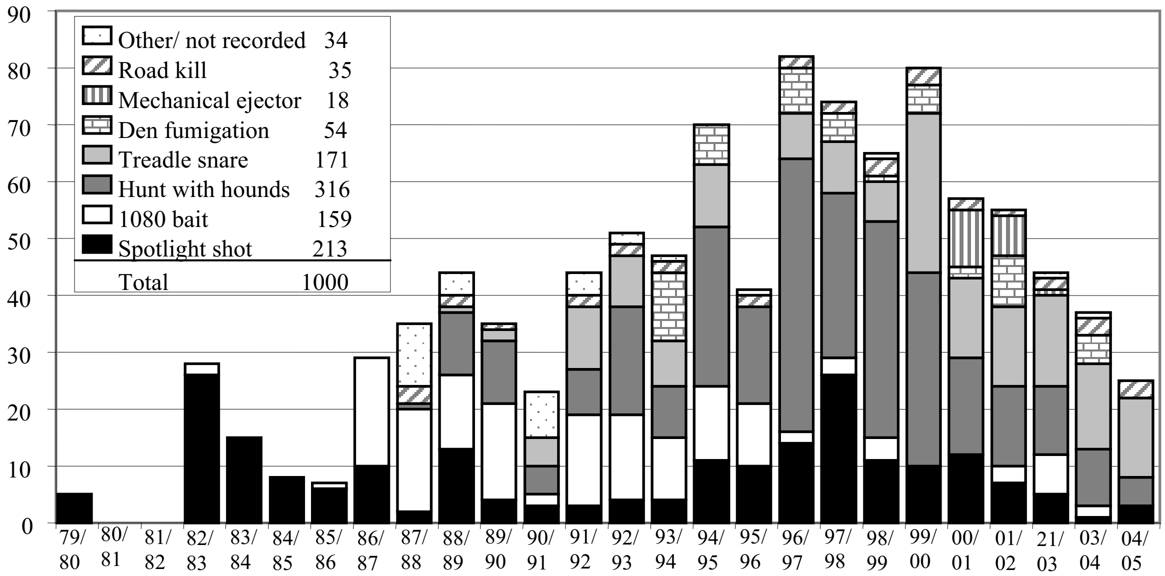

Fig. 1 Method of kill and year ('fox year', October to September- mean birth-date of foxes on the island is ~ 1 October) of 1000 foxes killed on Phillip Island. Note that the 04/05 data is to mid-January only.

Fox control effort increased during the 1980s and early 1990s. In the early 1980s, the program operated at only the western end of the island with two staff conducting spotlighting at night. By the late 1990s, the effort was island-wide, involved over eight staff members and a range of techniques. Although there are scant data to quantify effort, it probably declined from the late 1990s. Key staff retired and others moved to other duties, perhaps partially in response to declining catch rates and reduced fox activity around the penguin colony. A comparison between the financial years of 2000/01 (when a baiting research project was undertaken and the keeping of detailed records commenced) and 2003/04, demonstrates an overall drop in effort of 73% (Table 1). Throughout the program, the most sustained technique has been hunting with hounds, and the least, poison baiting.

Table 1. A comparison between 2000/01 and 2003/04 of foxes killed, effort (person hours) and effort per fox in the four main techniques employed on Phillip Island.

2000/01	**Foxes killed**	**Effort (hrs)**		**Hours per fox**
Treadle	17	915		57
Dog hunt	21	1332		63
Spotlight	12	283		24
Baiting (cyanide)	8	1150		144
Total	**58**	**3680**		**63**
2003/04			**effort cw 2000/01**	
Treadle	16	314	34%	20
Dog hunt	4	464	35%	116
Spotlight	2	191	67%	96
Baiting (1080)	0	29	3%	-
Total	**22**	**998**	**27%**	**45**

Sixty-eight % of foxes killed were in their first year (Fig. 3). Aging of foxes has enabled estimates of minimum fox populations in past years (Fig. 4). Accordingly, between 1996 and 1999, the number of foxes was at least 120 to 140 (i.e. 1.4 foxes per km^2).

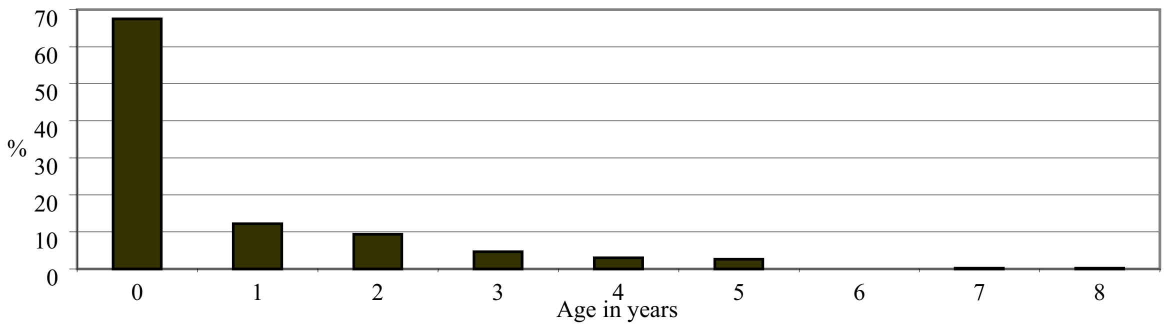

Fig. 2 Percentages of foxes in each age class killed on Phillip Island.

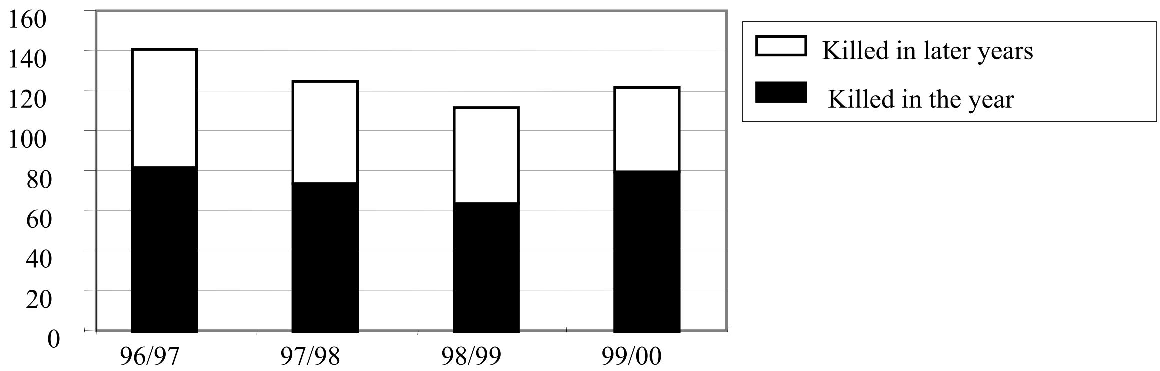

Fig. 3 Numbers of foxes known to be alive in each fox year (October to September) calculated by adding foxes killed in the year and foxes killed later, aged and determined to have been alive in the year (e.g. a 3 yr fox killed in 00/01 was alive in the preceding three years). Data are presented for the period 1996 to 1999 when effort was believed to be consistent and high.

The number of penguins killed by foxes fluctuates between years (range 4 to 331, Fig. 4). The fluctuations are due to individual foxes adopting surplus killing strategies in some years;

over 30 penguins may be killed in a single night. Most kills are in Autumn, when young foxes leave natal territories.

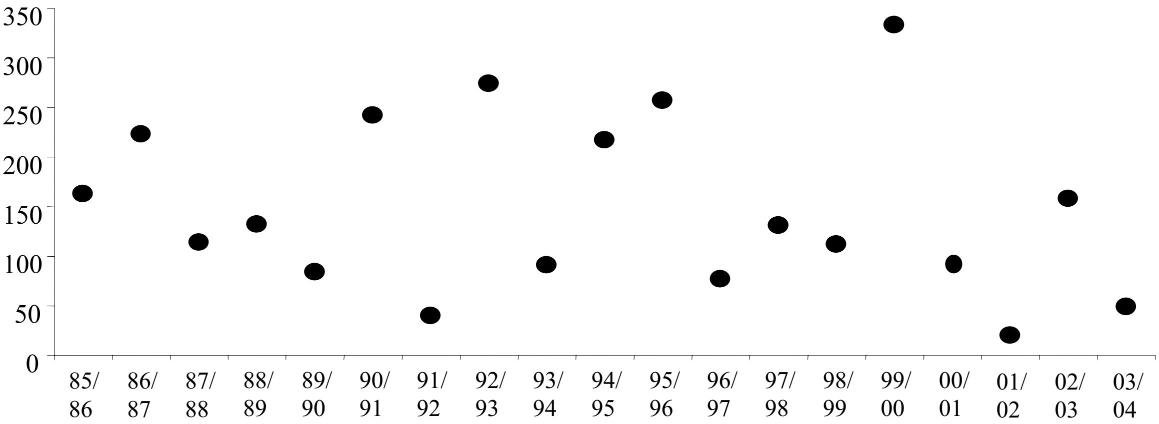

Fig. 4 Penguins killed by foxes per fox year (October to September).

A DNA study recorded only slight separation between mainland and island fox populations, demonstrating a degree of isolation, but suggesting occasional migration to the island (Lade *et al.* 1996). From 196 nights of video surveillance on the bridge to the island, no fox crossings were recorded (Kirkwood and Leschinski 2002). An assessment of stomach contents of foxes demonstrated that the main prey is shearwaters (47% Frequency Of Occurrence), rabbits (30%) and mice (15%) (Kirkwood *et al.* 2000). Rabbits sustain the fox populations during winter, when shearwaters are absent.

A 2003/04 study comparing bait uptake by foxes on Phillip Island and on the adjacent mainland (Bass Flats) provided evidence that the fox population on the island was below its carrying capacity or had more abundant food resources (unpublished data). Over a 20-night period on Phillip Island, foxes visited 30% of free-feed stations and fed at 5%, whereas on Bass Flats, foxes visited 78% of stations and fed at 67%.

DISCUSSION

There has been almost 100 years fox control on Phillip Island. Between 1980 and early 2005, a targeted control program killed 1000 foxes. Most were killed through shooting (spotlighting and hunts with hounds) rather than baiting, which is commonly considered to be a more time-effective technique. Reasons why efforts were directed toward shooting include: successes were common, a carcass was produced, it involved a team approach, and staff enjoyed hunting. By contrast, reasons for baiting effort not being sustained include: fear by management of killing a domestic dog, complicated administrative procedures associated with baiting, perceived poor rates of bait uptake when trialed, and the fact that a carcass was not recovered.

Key lessons from the control program to date include;

1. Fox control procedures are unlikely to be sustained at high-levels indefinitely.
2. Unless staff resources are dedicated to the task, other responsibilities will erode control effort.
3. Unless managed otherwise, staff will favour techniques that they enjoy.
4. Penguin protection from foxes on Phillip Island requires fox eradication.
5. Current fox control procedures on PI will not lead to eradication.

A new eradication strategy has been drafted by an external expert (Steve McPhee, Agricultural Technical Services) and adopted by the Board of the Phillip Island Nature Park. Key features of the strategy include;

1. Commitment to a 5-year plan.
2. An associated high-profile publicity/ communications program.
3. Employment of two dedicated staff.
4. Island-wide baiting programs.
5. Acquire trained dogs for den searching.
6. Minimise the chance of migration to the island.

ACKNOWLEDGEMENTS

We thank-all the past and present crew of the Phillip Island fox control team and acknowledge the continuing support from Vertebrate Pest Research Unit, DPI, Victoria.

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PROTECTING ENDEMIC PLANT SPECIES BY REMOVING FERAL GOATS (*CAPRA HIRCUS*) FROM GUADALUPE ISLAND, MEXICO

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ABSTRACT: Guadalupe Island, 26,000 ha, 1.300 m elevation, is an oceanic island located 250 km off the Pacific Coast of Mexico. The island's flora, with 34 described endemic species, and fauna, with 9 described endemic birds have been devastated by introduced goats (*Capra hircus*) and cats (*Felis catus*). The Guadalupe endemic variety of Monterey pine *Pinus radiata* var. *binata*, one of only three natural populations of this globally important timber species, has been reduced to 220 adult trees, all over 100 years old. The endemic Guadaluoe cypress forest, *Cupressus guadalupensis*, has been reduced from 4,000 ha to 85 ha. Because of this, eradicating the introduced mammals is a conservation priority. In 2004 a collaborative goat eradication program was begun by the Grupo de Ecologia y Conservacion de Islas, mexican Environmental Ministry (SEMARNAT), mexican navy (SEMAR) and Island Conservation. Because the island has only limited year round water sources we began the project using corral traps at these sites. Over a period of 13 weeks (16 June – 27 september) these traps captured 1,190 goats. Capture rate was greatly reduced during periods of increased moisture (heavy fog and ligh rain). As the efficacy of these traps decreased we switched to ground hunting. Between 16 August and 17 December 1,752 goats were killed by a team of 4 to 6 hunters. Leg hold traps were also used and caught 37 goats, 36 of which were radio collared and released as Judas goats. An aerial hunting program was conducted in November 2004, utilizing a Bell 206 helicopter with a Mexican pilot and a New Zealand hunter. In 30 hours of flying time over 6 days this team killed 3,261 goats, 52.2% of the total animals to date.

Regression analysis of number of animals killed per hour indicates that there could be fewer than 500 animals remaining. Ground hunting with the assistance of Judas goats continues. The helicopter will return in spring 2005, after the winter rainy season. We hope to finalize the eradication in summer 2005. Monitoring begun prior to the goat eradication has already demonstrated recovery of native plants, with more than 1,000 new seedlings of *Pinus radiata* counted inside goat-proof fenced exclosures and the discovery of one endemic species thought extinct on the island (*Satureja palmeri*) and at least four other species thought extirpated.

OUT ON THE BORDER: KEEPING STARLINGS OUT OF WESTERN AUSTRALIA

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ABSTRACT: The European starling, *Sturnus vulgaris*, is listed as one of the world's worst 100 invasive alien species by the IUCN (World Conservation Union). Starlings represent a significant biosecurity risk to agriculture, the environment and the community of Western Australia (WA). Fortunately for WA, the Nullarbor Plain represents a natural barrier restricting the westward movement of starlings, but it is not completely starling-proof. Currently, there are sparse numbers of starlings across the Nullarbor Plain and two 'founder' populations of starlings near Esperance, on the eastern edge of WA's Agricultural Region. The Western Australian Department of Agriculture (DAWA) and the Agriculture Protection Board (APB) have successfully strategically managed starlings since 1971. More recently, some applied research strategies have been initiated to assist best practice management. This paper briefly outlines the past, current and future management and research strategies used to keep WA free from starlings.

INTRODUCTION

The IUCN (World Conservation Union) consider European starlings (henceforth referred to as starlings) to be one of the world's worst 100 invasive species, and only one of three birds to share this dubious honour (Lowe *et al.* 2000). Since the 1850s, the starling has become a global pest through human assisted introductions, with approximately 30% of all available terrestrial habitats now inhabited by this bird (Fear 1984). It has demonstrated its capacity for continental colonisations, with North America colonised in a little over 100 years (Long 1981). In Australia, starlings were introduced to Victoria (1856-1871), New South Wales (1880) and South Australia (1881) by acclimatisation societies (Long 1981). These introductions were successful, and like North America, the starling rapidly became established in south-eastern Australia (Figure 1). Fortunately for Western Australia (WA), the Bureau of Agriculture placed the starling on the list of prohibited imports in 1895, and despite a subsequent unsuccessful attempt by the WA Acclimatisation Committee to introduce them in 1898 (Long 1988), starlings have yet to successfully colonise WA. The main reason the westward continental expansion of starlings has been halted is because of the natural barriers of the Nullarbor Plain, which literally translates as treeless plain, and the arid interior of Australia.

Starlings have the ability to move vast distances over reasonably short periods of time. For example, starlings annually migrate from Poland to Algeria, a distance of 2700 km (Feare 1984). In Australia, one example of a large-scale movement was by a starling banded in Mallala, in South Australia, which was then recaptured four months later at Mundrabilla on the Nullarbor Plain in WA, a distance of 986 km (Pryde and Massam, unpublished). There have also been other records of large-scale unassisted movements of starlings arriving in WA, such as the 1936 record of a starling shot at Gingin, approximately 80 kilometres north of Perth (Long 1981). Prior to 1971, apart from an occasional bird, such as the Gingin example, starlings were not an issue for WA, but since this time they became a major focus of pest animal management strategies.

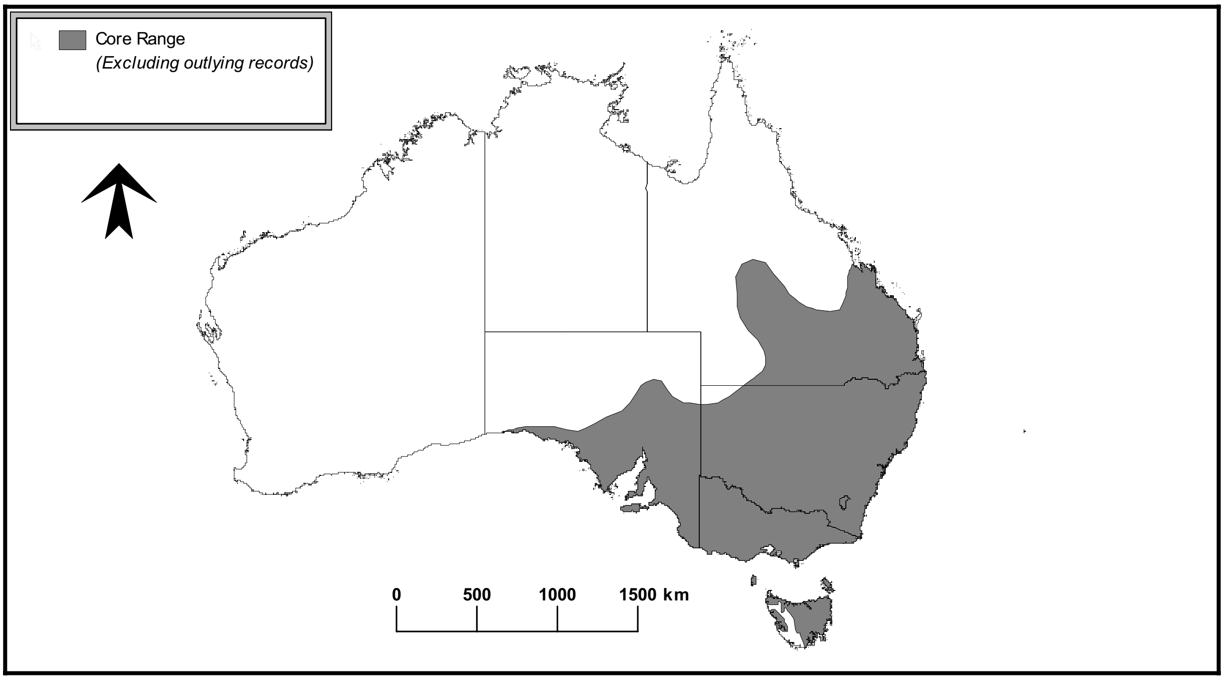

Fig. 1. Stylised current distribution of European starlings in Australia, excluding outlying populations in Far North Queensland and Western Australia. Map adapted from the Atlas of Australian Birds, Birds Australia (www.birdsaustralia.com.au, retrieved 23/02/05).

OPERATIONS

The 1970s – Beginning of starling management in WA

The period of the early 1970s coincided with the improvement of the National Highway across the Nullarbor, from a gravel road to a bitumen road. We speculate that this, combined with high rainfall episodes, resulted in improved westward passage of starlings because of increased water and food resources associated with increased road traffic and infrastructure development across the Nullarbor Plain. In October 1971, 26 starlings were destroyed in the Condingup area, east of Esperance (Fig. 2). This represented the first serious threat of a founding population of starlings in WA.

Small numbers of starlings were shot, netted and trapped at Condingup from 1971 to 1976. In response to this incursion, and with considerable foresight, the Agriculture Protection Board (APB) of WA implemented a preventative strategy in 1975 and began the long campaign of starling control based at Eucla (Fig. 2). This highly successful and proactive control operation is one of the few examples of a long-term commitment to prevent the establishment of a serious vertebrate pest. Over 30 years, the starling control program based out of Eucla has removed 53,646 potential invaders.

The 1980s and 1990s – Problems and solutions

Despite the considerable professional activities of the Euca-based control team, starlings were again found at Condingup in 1982. Based on the number of birds taken between 1982 and 1984 (N = 164), it could be debated that this population was part of the original population first detected in 1971 rather than a new infestation. Because starlings are moderately sized (around 70 grams), and can become very cryptic in behaviour once persecuted, at very low density (less than 10 birds) they can be almost impossible to detect without considerable skill, effort, local knowledge and time. It is possible that the original population was reduced to just a few birds and that in the intervening years (1977 to 1982) successfully bred to a detectable population size. Alternatively, these birds represented a second invasive wave of starlings. The size (number of birds) and flock structure (e.g. age composition) necessary for a successful founding population is not well understood.

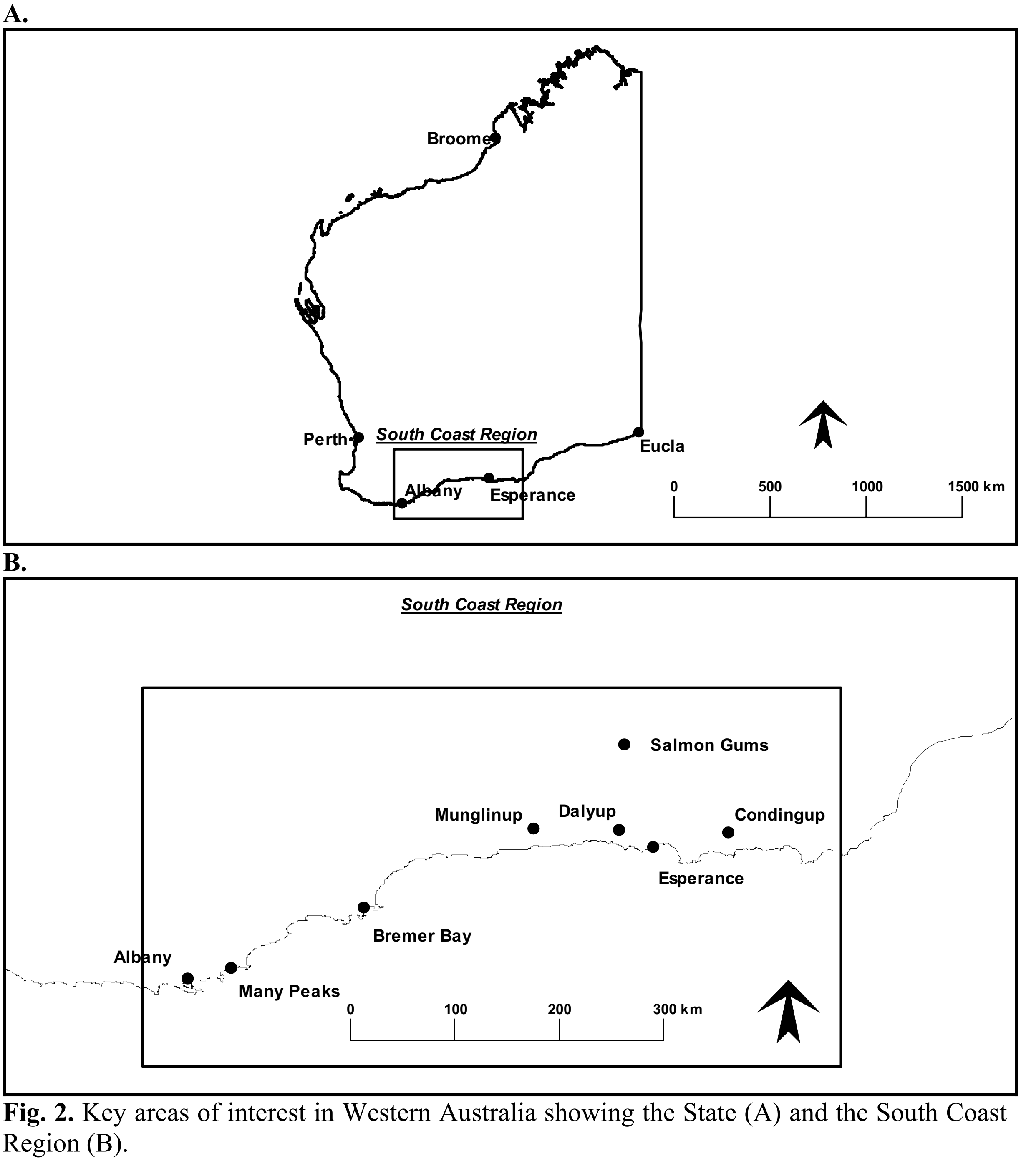

Fig. 2. Key areas of interest in Western Australia showing the State (A) and the South Coast Region (B).

The 1980s saw an increased urgency to control and eradicate starlings in WA. Not only were starlings found again at Condingup in 1982, but in 1986 new populations were also found west (Dalyup) and north (Salmon Gums) of Esperance (Fig. 2B). These populations were rapidly and successfully controlled.

One of the most alarming starling incidents to date occurred in 1987, when a flock of starlings was confirmed at Many Peaks, east of Albany (Fig. 2). This is the furthest west a population of starlings has become established in WA. Using many techniques, combined with a great deal of planning, patience, surveillance and team work, this single cohesive flock was eradicated in a six month campaign. In terms of control techniques, considerable success was gained with both mist and cannon netting (Table 1), with shooting proving to be successful to remove the final birds. When a second flock was discovered at Many Peaks in late 1988, shooting was successfully used to remove these birds. The apparent key to success was that the known roost area was not disturbed during the control effort, which limited the risk of the birds being dispersed through persecution and allowed the control team members to keep the flock under constant surveillance.

Table 1. Success of control methods, as a percentage, used in the outbreak in the Bremer Bay (Hendry's and Dillon Bay localities only; 1988 to 1991) and Many Peaks (1987 to 1988) region of Western Australia. Note that 'effort' may not necessarily be uniform between control techniques. *Many Peaks data did not separate adults from juveniles. †Another flock of 23 birds (not indicated in the table) was discovered after the first flock. These birds were subsequently shot.

Age	Control Method	Many Peaks*†	Hendry's	Dillon Bay
Adult	Shooting		87.3	95.8
	Lure Cages		10.9	4.2
	Netting (Mist & Cannon)		0.0	0.0
	Destruction of Nests		0.0	0.0
	Other		1.8	0.0
	Total Number of Birds		55	24
Juvenile	Shooting		14.5	13.3
	Lure Cages		33.9	33.3
	Netting (Mist & Cannon)		0.0	53.3
	Destruction of Nests		50.0	0.0
	Other		1.6	0.0
	Total Number of Birds		62	15
Adult and Juvenile (Combined Data)	Shooting	16.3	48.7	64.1
	Lure Cages	0.0	23.1	15.4
	Netting (Mist & Cannon)	83.7	0.0	20.5
	Destruction at Nests	0.0	26.5	0.0
	Other	0.0	1.7	0.0
	Total Number of Birds	43	117	39

Also in 1988, another population of starlings was discovered at Bremer Bay (Fig. 2). Again, a major incident response was initiated and the population was eradicated. The Bremer Bay campaign was a longer effort, taking 34 months and it required considerable resources and staff to achieve success. Again, a variety of techniques were used to achieve eradication (Table 1). In this operation, shooting was the most effective means of removing adult starlings, whereas the juvenile birds (and nestlings) were more susceptible to trapping, netting and destruction at nests. These, and other data from ongoing control efforts, demonstrate that trapping clearly has an age-bias towards naïve juvenile birds over the more cautious adults.

Contrasting the Bremer Bay and the Many Peaks incidents, the value of using more than one control technique is apparent (Table 1), since not all control techniques are necessarily equal or applicable in different habitats. The development of control techniques is also an area in need of further research. It is also evident that local eradication of founding populations of starlings is achievable, given the right conditions, skills, resources and commitment.

Past and current challenges

The Bremer Bay and Many Peak control efforts are clear highlights in the successes of starling management in WA. However, the challenges of persistent incursions at Condingup, and more recently, Mungliup, are ongoing. Since starlings were first found at Condingup in 1971, control efforts have destroyed starlings in 24 out of 34 years, including the 5-year starling-free hiatus between 1977 and 1981. Up until 2004, 1,195 starlings have been destroyed at Condingup alone. More recently, control efforts began on a major population at Munglinup, since it was first detected in 2001. Between 2001 and 2004, 671 birds were destroyed at Munglinup. The eradication of this population represents a logistical, technical and resource challenge for the Department of Agriculture and the community of WA.

A key question is: why were some control operations successful in eradicating populations of starlings and others apparently not as successful? There is no simple answer to this. The successful control programs at Many Peaks and Bremer Bay were generally dealing with one coherent flock of starlings. The Munglinup population for example, has at least nine flocks of birds operating independently of each other (Woolnough and Rose unpublished). Flock complexity, combined with confounding variables such as habitat complexity, ethical and health and safety restrictions in the use of some techniques, cross land tenure issues, staffing, and resourcing issues make the management of control options even more challenging for operational and management staff.

RESEARCH AND DEVELOPMENT

Research related to starlings in WA has generally been reactive rather than proactive. New incursions and the potential risk of a founder population becoming well established have driven research, with pulses of research in the late 1980s and now since 2002. Although a precautionary principle would suggest proactive research is preferable (Calver *et al.* 1999), there have been some recent successes with research that will potentially have important benefits to starling management in WA.

Judas Starlings

In 1989, a trial investigated the Judas technique for European starlings (see Lowe 1990). It was initiated as a potential tool for use in the Bremer Bay incident. This trial was largely unsuccessful for two reasons. The major limitation, at the time, was the excessive weight of the radio transmitter package (approximately 5 g). Further, the excess weight of the radio-package generally impeded flight capabilities of the radio-tagged birds. The second reason was that captive birds were used as Judas animals. Captive birds were used because they could be easily transported and released at the site of infestation and quickly locate the rogue flock. In reality, the prolonged period of captivity affected their behaviour such that they were probably incapable of free-ranging activities without a period of 'retraining' or adjustment. As a result the Judas technique was not developed further.

Taking advantage of the increased miniaturisation of radio packages (1.4 g *cf* 5 g used in the previous study), the Judas technique was revisited in 2002. Prior to field trials, a comprehensive captive trial investigated the optimum way to attach radio transmitters to starlings. Results suggested that a modification of the Rappole harness was the best all-round attachment technique (Woolnough *et al.* 2004) and subsequent field trials proved its success.

Two recent field trials, using wild caught Judas birds, demonstrated that the Judas technique could be used in conjunction with the suite of techniques used to control starlings.

Molecular Tools – An integrated approach to pest management

Apart from the obvious conclusion that the original source of starlings in WA was eastern Australia, most likely South Australia, we currently have very little understanding of where starlings in WA come from, and by which route and when they arrived. Understanding the population dynamics of the source population offers great potential to improve the effectiveness of control and preventative strategies for WA. If the locality of the source of the infestation can be identified, broad-scale control options such as avicides (e.g. Lapidge *et al.* this volume) might be utilised to reduce the threat of potential invasions.

In collaboration with the University of New South Wales and the South Australian Animal and Plant Control Commission, we are currently using molecular techniques to determine the genetic profiles of birds to be used as tools to map the genetic demographic structure of the European starling throughout Australia (see Rollins *et al.* this volume). Information derived through this research programme will be used to develop more target-specific and habitat-specific control procedures.

The long-term goal is to marry molecular approaches with control technique development in an integrated approach to pest animal management. Combined with a strategic plan and stakeholder engagement, an integrated approach should ultimately lead to the prevention of European starlings becoming an established economic, social and environmental pest in WA.

FUTURE CHALLENGES

Like other examples of border protection, the key challenge is convincing the community, industry and governments that the costs of prevention far outweigh the potential costs of the pest becoming established. In 2003/2004, the Department of Agriculture spent AUD$418,000 on the operational control of starlings. Even though this figure is considerable, it has essentially remained static for nearly 20 years, and therefore represents a real decline in available resources. This is the modern reality of competing needs and priority setting for government agencies. The challenge then becomes how to engage the broader community and industry to address the ‘actual’ decline in funding. Without ongoing commitment and financial support, the reality will be that starlings will become widely established in WA.

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We would like to thank the many staff (too numerous to mention) from the Department of Agriculture and Agriculture Protection Board that have worked on the starling programme since 1971. These staff members have contributed to a long and generally successful campaign, and are the source of the data reported in this paper. We also thank Ken Rose, Laurie Twigg and Peter Thomson for comments on early drafts, Colin Parry for providing personal notes on the Many Peaks incident, and Ted Knight for his recollections of the same incident. We would also like to acknowledge the current starling team of Bianca Donald, Ken Franklin, Ray Gwynne, Ted Knight, Harry Little, Ron Pryde and Noel Rennie (South Coast Region), Doug Bryan, Harvey Gurney and Lynton Gurney (Eucla), Win Kirkpatrick, Tim Lowe and Ken Rose (Research), and William Sherwin, Ron Sinclair and Lee Ann Rollins (Molecular Ecology).

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RISK ASSESSMENT FOR THE IMPORT AND KEEPING OF EXOTIC VERTEBRATES

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ABSTRACT: An analysis of historical records of the exotic birds, mammals and finfish introduced to Australia shows that several factors distinguish between species that successfully established wild populations and those that failed. For example, for all three taxa a good climate match to Australia, a large overseas geographic range and a history of successfully establishing exotic populations overseas are correlated with successful establishment in Australia. These factors are used to develop more quantitative models to assess the risk of establishment. The number of introduction events is also strongly correlated with establishment success for all three taxa. This means that if more exotic animals are kept in more places, they are more likely to establish wild populations.

Although too few exotic reptiles and amphibians have been introduced to Australia to enable comparable analyses to be conducted, adequate sample sizes exist for the USA and Britain. These data are being analysed to see if the same factors are correlated with establishment success for these taxa.

Our decision models are more quantitative, more transparent and more scientifically based than processes previously used by government agencies to conduct risk assessments on exotic vertebrates. However, the models still contain qualitative components requiring subjective expert judgements, so they are potentially subject to bias. Because of these subjective components, and because of the potentially expensive environmental and economic consequences of a wrong decision, we strongly recommend that those who conduct risk assessments using the models have appropriate expertise and are also independent and unbiased, with no vested interest in the outcome.

INTRODUCTION

Many exotic vertebrates have established wild populations on mainland Australia: 25 mammals, 20 birds, 4 reptiles, 1 amphibian and 31 finfish. An additional 7 birds, 1 rodent and 2 reptiles have established on offshore islands. Many of these species are now major pests, costing Australia $100s of millions in lost agricultural production and land and water degradation, and many threaten our native species by habitat destruction, competition and predation. Eradication of newly established exotic vertebrates has rarely been attempted and even more rarely achieved. Red-eared sliders (*Trachemys scripta* – a species of freshwater tortoise) have recently established exotic populations in Australia. Exotic fish species are establishing at an increasing rate (Table 1).

Table 1 Number of exotic freshwater finfish species established in Australia

Date	Number of species	Source
1967	9	Weatherley and Lake (1967)
1997	19	Arthington and McKenzie (1997)
2004	31	Lintermans (2004)

It is highly undesirable for Australia to allow any new vertebrate pest species to establish. But many potential pest species are already being kept in captivity in Australia and there are frequent applications from zoos, wildlife parks, aquaria and private keepers and traders for permission to import and keep new species. So clearly we need robust risk analysis and risk management systems to identify which species pose a high risk of establishing should they be released in Australia, and if they do establish, which species pose a high risk of becoming agricultural or environmental pests. A robust risk assessment process will enable us to make sensible decisions about which species to let into Australia. And for species that are already kept here, or new ones that we allow in, we'll be able to decide which ones need to be kept in highly secure collections.

Risk assessment involves identifying hazardous events (in this case the establishment of new exotic vertebrate pest species in Australia) and estimating the likelihood that such events will occur and the probable consequences if they do. Is it possible to identify exotic species that pose a high risk of establishing wild populations if they are released or escape? Many ecologists claim scientific theory and knowledge is still far from the stage where it is possible to make certain predictions about introduction success for individual species (Enserink 1999; Williamson 1999; Ehrlich 1989). These ecologists question the feasibility of reliably predicting which exotic species could establish in a new country and the impacts they would have if they did establish. Fortunately we think these ecologists have been unduly pessimistic and that their conclusions were premature. Recent quantitative studies on the characteristics of exotic species indicate there are a suite of attributes that are correlated with establishment success (Kolar and Lodge 2001; Bomford 2003).

METHODS

We have conducted quantitative analyses of past introductions of exotic birds, mammals and freshwater fish to Australia (Duncan *et al.* 2001; Bomford 2003; Forsyth *et al.* 2004; Bomford and Glover 2004). We are currently conducting an analysis of exotic reptile and amphibian introductions to the USA and to Britain. In each study we compare the attributes of species that established with those that failed to establish. We then compare the attributes of those that become pests with those that are present but not pests. We have found a suite of factors that, taken together, are good predictors of establishment success and pest potential. We have used the results of these quantitative analyses, supplemented with published information on analyses of overseas introductions and ecological theory, to develop more quantitative risk assessment models for the import and keeping of exotic vertebrates in Australia.

RESULTS

This paper brings together the findings of several published and unpublished studies on risk assessment modelling for exotic vertebrates. The general findings from our analyses are presented here with selected examples of the results of our data analyses. More comprehensive details of our results are available in our referenced publications (Duncan *et al.* 2001; Bomford 2003; Forsyth *et al.* 2004; Bomford and Glover 2004) or will be presented in future publications.

Establishment success

Five key factors are correlated with establishment success:

1. Introduction effort

For introductions of exotic birds and mammals to Australia, the number of individuals released, the number of introduction sites and the number of introduction events are significantly correlated with introduction success (Duncan et al. 2001; Forsyth et al. 2004). For 352 freshwater finfish species introduced around the world, the number of introduction events is significantly correlated with introduction success (Figure 1). All fish species that have been introduced more than ten times have established at least one exotic population. These data tell us that if more exotic animals are kept in more collections and in more places, then more exotic species are likely to establish wild populations. Animals may escape by accident or during floods or fires or by intentional release by people who know longer want to keep them but do not wish to kill them, or by people who actually want to try and establish wild populations.

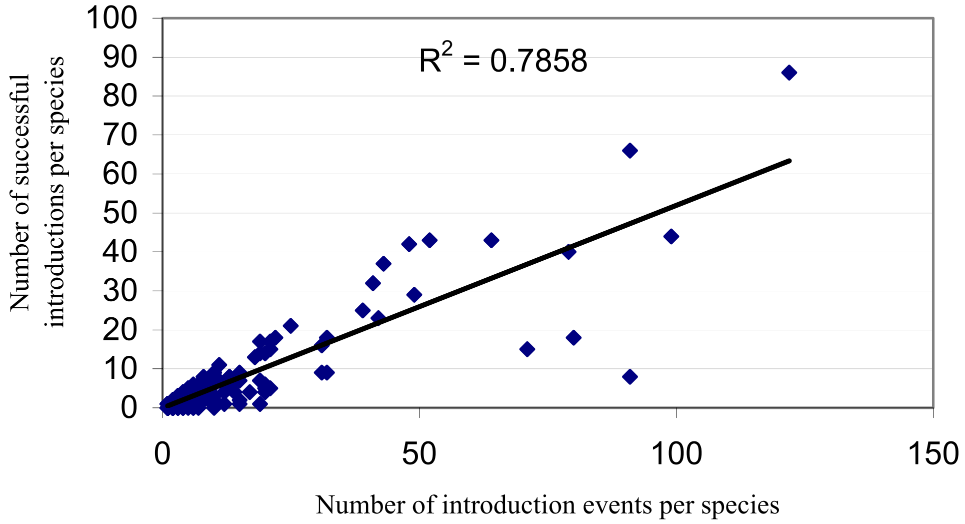

Fig. 1. Number of introduction events for 352 freshwater fish species around the world and number of successful introductions. Success is correlated with introduction rate. (Data collated from Arthington et al. 1999).

2. Climate match

A climate match between species' overseas geographic range and Australia is correlated with establishment success for exotic birds, mammals and fish introduced to Australia (Duncan et al. 2001; Forsyth et al. 2004), and for exotic reptiles and amphibians introduced to Britain (Figure 2).

3. History of establishing exotic populations elsewhere

A history of establishing exotic populations elsewhere in the world is correlated with establishment success for exotic birds, mammals and fish introduced to Australia (Duncan et al. 2001; Bomford 2003; Bomford and Glover 2004; Forsyth et al. 2004). The same correlation is present for exotic reptiles and amphibians introduced to the USA and Britain (Figure 3).

4. Taxonomic group

Mammals and fish both have higher reported establishment success rates around the world than birds, reptiles and amphibians. Generally about one-third of the bird species that have been introduced around the world have established at least one exotic population whereas the figure for both mammals and fish is about two-thirds (Bomford 2003; Bomford and Glover 2004). The figure for reptiles and amphibians is highly variable but averages around 40%.

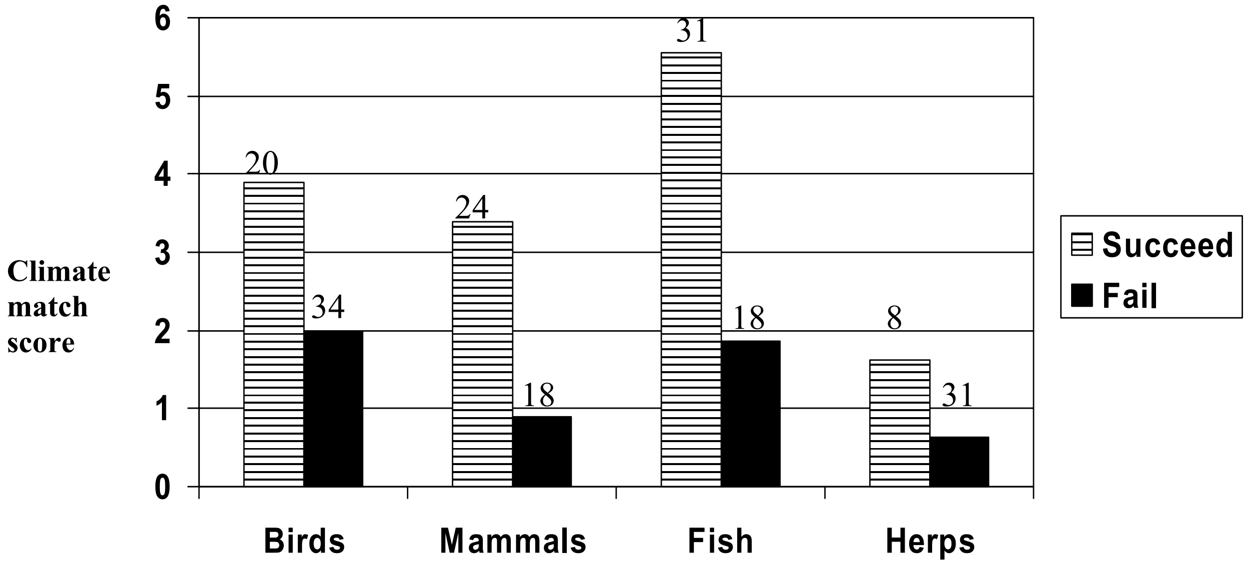

Fig. 2. Average scores matching the climate in species' overseas geographic ranges to Australia for exotic birds, mammals and freshwater fish, and to Britain for exotic reptiles and amphibians (herpetiles), which either successfully established or failed to establish in the wild following their introduction. Sample sizes (number of species) on top of columns. Successful species have better climate matches (Bomford 2003; Bomford and Glover 2004).

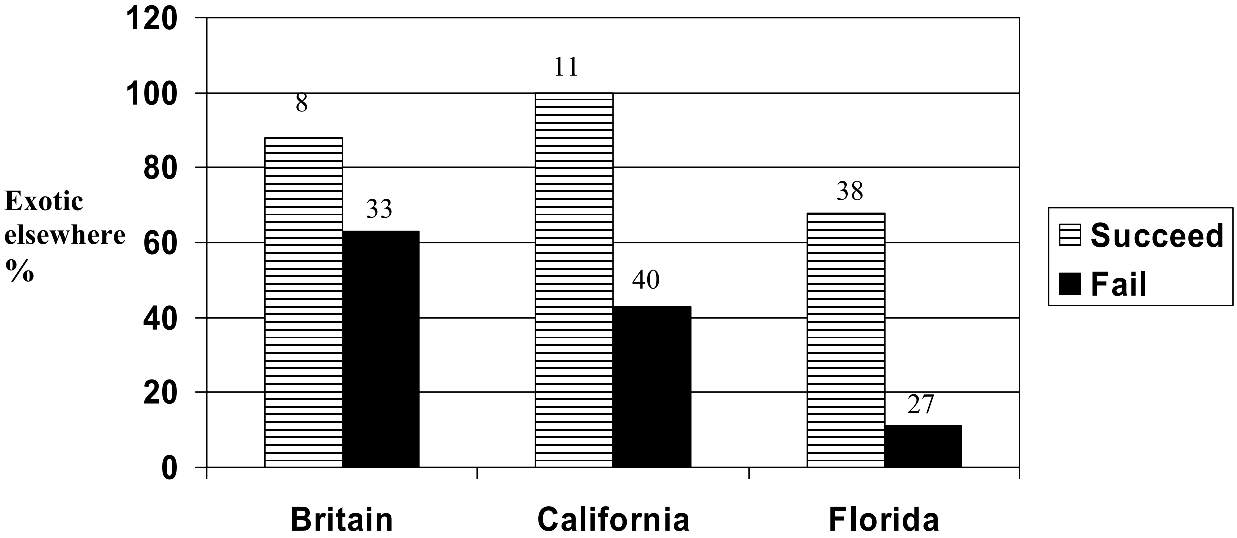

Fig. 3. The percentage of exotic reptiles and amphibians introduced to Britain and the USA that have established exotic populations elsewhere. Species that successfully established in the wild are more likely also to have established an exotic population in another country. Sample sizes (number of species) on top of columns (Data collated from F. Kraus unpub.).

Both family and genus are significantly correlated with establishment success for exotic fish introduced around the world, with success rates ranging from 88% for Gobiidae and Cobitidae (Table 2) down to 0% for Pangasiidae and Adrianichthyidae (Arthington et al. 1999; Bomford and Glover 2004).

Table 2 Introduction success rates around the world for the five most successful families of exotic freshwater fish. (Data collated from Arthington *et al.* 1999.)

Family	**Number of recorded introduction events**	**Number of successful introduction events**	**Success rate %**
Gobiidae	16	14	88
Cobitidae	8	7	88
Poeciliidae	172	144	84
Clupeidae	10	8	80
Loricariidae	5	4	80

5. Overseas geographic range size

Overseas geographic range size is correlated with establishment success for exotic birds, mammals and fish (Bomford 2003; Bomford and Glover 2004).

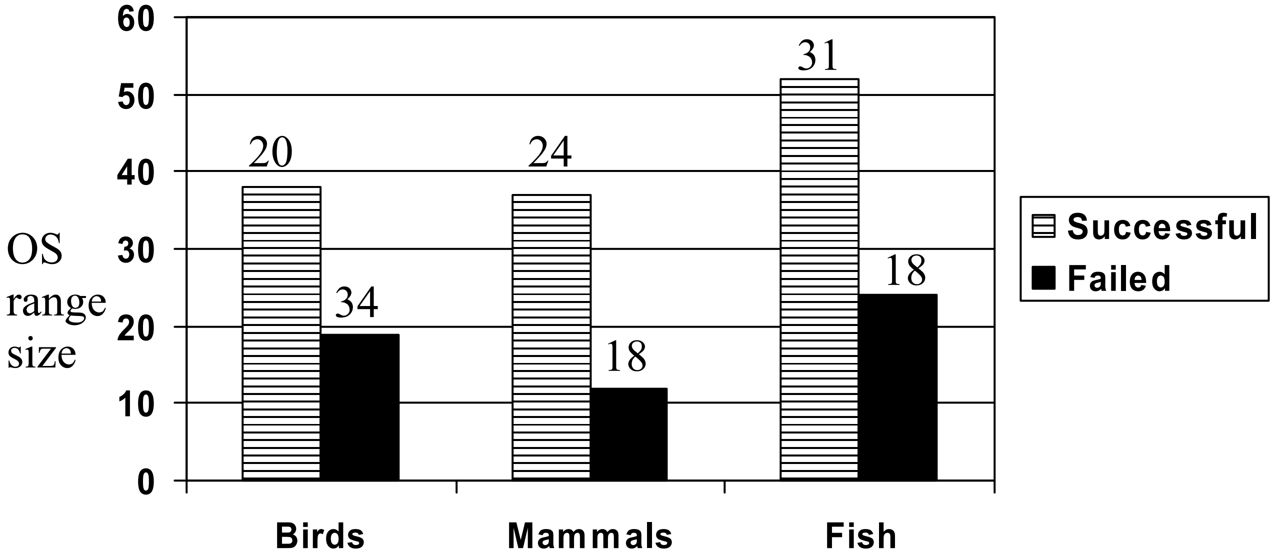

Fig. 4. Average overseas geographic range size for exotic birds, mammals and fish introduced to Australia. Bird and mammal ranges in millions of square kilometres (Source: digitized from Long 1981 and Lever 1985). Fish ranges in number of latitude by longitude degree grid squares in which the fish is recorded present (Source: Fishbase 2004). Sample sizes (number of species) on top of columns. Successful species have larger overseas range sizes.

There are many additional factors that have been hypothesized to enhance the probability of establishment but for which scientific supporting evidence is currently lacking or equivocal. These factors include:

- Rate of population increase
- Broad environmental tolerances
- Broad diet
- Genotypic variability
- Ability to live in disturbed habitats
- Behavioural flexibility
- Gregariousness
- Dispersal ability.

Pest potential

The component of the risk assessment process that attempts to predict pest potential is far less quantitative and more uncertain than the component predicting establishment success. Often little is known about the impacts of exotic species that have already established so predicting the impacts of species that might establish in future is far more uncertain, particularly for fish, reptiles and amphibians, which are the least studied taxa. The following three factors are generally considered to contribute to the risk that an established exotic species could become a pest:

1. Pests overseas

Most exotic species that are considered pests in Australia are also considered pests in at least parts of their overseas range (Bomford 2003; Bomford and Glover 2004).

2. Climate match

Where there is a high climate match to areas in Australia where threatened ecological communities or species occur or where potentially vulnerable agricultural industries are located, this should indicate a higher level of risk. For example coyotes and pumas, which are both considered to be pests of livestock in the United States, have good climate matches to the Australian rangelands.

3. Taxonomic group

Exotic mammals are more often pests than exotic birds (Long 1981, 2003; Lever 1985; Bomford 2003). Certain families of mammals and birds contain a high proportion of species that are agricultural or environmental pests. Exotic mammals most likely to cause damage to agriculture or forestry are: Canidae (foxes and dogs), Mustelidae (stoats and ferrets), Cervidae (deer), Bovidae (cattle, sheep and goats), Leporidae (rabbits and hares), Equidae (horse family) and Muridae (rats and mice) (Lever 1987; Long 2003). Exotic birds most likely to cause damage to agriculture or forestry are: Psittaciformes (parrots), Fringillidae (old-world finches), Ploceidae (sparrows and weavers), Sturnidae (starlings and mynas), Anatidae (ducks, geese and swans) and Corvidae (crows) (Long (1981).

Too little information is available to enable us to draw generalisations about the species attributes associated with the impacts of exotic fish, reptiles and amphibians because these taxa have been poorly studied. There have, however, been some spectacular negative environmental consequences from some individual species introductions. For example, the introduction of Nile perch to Lake Victoria in Africa resulted in the extinction of over 200 species of native cichlid species (Kaufman 1992). Individual exotic reptile and amphibian species have also had devastating impacts, such as the introduction of the brown tree snake *Boiga irregularis* to Guam (Fritts and Rodda 1998) and the cane toad *Bufo marinus* to Australia (Freeland 1984).

Modelling

In our risk assessment model we weight individual variables according to the degree to which they influence the risk. The factors affecting establishment are used to determine establishment risk that is rated as extreme, high, moderate or low. Then the factors influencing the likelihood of becoming a pest following establishment are used to determine the pest risk which is also rated as extreme, high, moderate or low. Our new models are much simpler and more quantitative than the previous processes used by government agencies to place exotic vertebrates in threat categories. We plan to test our models by assessing their predictive accuracy on independent data sets of exotic vertebrates introduced to other countries.

There will be always be uncertainty in predicting establishment risk and pest potential. The possible development of new, unpredictable behaviour patterns, and of phenotypic or genotypic shifts, plus the possibility of climate change, brings a strong element of uncertainty to risk assessments.

CONCLUSIONS

Our decision models assess the risks that exotic species could become future pests if they are imported and kept in Australia. The decision-making process is transparent. The scientific basis for the factors included in the models and their weightings are fully referenced to our own and other published quantitative studies wherever possible. All the factors included in our models need confirmation by rigorous scientific studies and all have exceptions and chance events play a large part in the success of any individual introduction. Further testing and refinement of the models is planned.

Although our decision models are more quantitative, more transparent and more scientifically based than previous processes used by government agencies to conduct risk assessments on exotic species, they still have a subjective components requiring expert judgements, and are hence potentially subject to bias. Also the data required to accurately use the models may be difficult to find and interpret which adds an additional subjective component. Because of these subjective components to the risk assessment process, and because of the potentially environmentally and economically expensive consequences of a wrong decision, it is essential that those who conduct risk assessments using the models have appropriate expertise, and are also independent and unbiased, with no vested interest in the outcome. Hence we strongly recommend that those who conduct these risk assessments are directly employed by government agencies, not by applicants wishing to import or keep exotic species.

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ANIMAL WELFARE ISSUES ASSOCIATED WITH MARKING WILD ANIMALS FOR IDENTIFICATION

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ABSTRACT: Identification of wildlife aids biological study and conservation management, and usually involves the application of an artificial mark. Marking can affect the animals involved through the act of marking itself, the wearing of the mark and the procedures required for observing the mark. Effects on subject animals include alteration of: appearance; behaviour; interactions with their own or other species; health and fitness; capacity to survive and reproduce; population dynamics; ecological balance and other factors.

The act of marking usually requires capture, and some degree of restraint and handling, all of which can be stressful to wild animals. In addition, the mere presence of humans in the environment may disturb the natural behaviour of the species of interest and other animals. The application of many marks involves tissue damage, and may, therefore, cause pain. More permanent methods such as branding, tattooing, tagging and surgical implantation are generally more stressful and cause more pain than superficial methods such as painting and hair clipping. Mark application can also increase the risk of infection and, if healing is protracted, can potentially alter the animal's behaviour and energy use.

As well as causing direct bodily harm (e.g. chaffing, constriction), the presence of a mark may alter the animal's appearance and behavioural parameters such as movement, foraging, feeding, courtship, migration and habitat use. In addition, intra- and inter-specific interactions may be affected e.g. predator-prey relationships. Such alterations can impact on an animal's capacity to survive and reproduce.

Repeated human presence, capture and handling for observation of marks can cause persistent low level stress, which may make marked animals more vulnerable to the effects of other natural stressors. Adverse effects may be evident immediately or appear long after the procedure is performed. There is generally a trade-off between remote identification (less disturbance) and the longevity of the mark, e.g. paint marks tend to be highly visible from a distance, but require recapture and refreshment if they are to be used for longer-term studies. Although permanent marks such as brands and tattoos do not require refreshment, they are often small, and recapture is required for subsequent identification.

Researchers have an ethical and scientific responsibility to select the most appropriate method for marking wild animals, and to employ the most effective and humane ways of applying the chosen mark. The most appropriate method will vary according to the species and population to be marked, the environment, season, research group and other factors. Therefore, wildlife scientists must develop a sound background knowledge of the population under study, and recognise the advantages and disadvantages of different marks and marking procedures for that specific population.

Wildlife scientists need to weigh the anticipated benefits of the research against the probable adverse consequences for the animals. Application of the General Safeguards (outlined in Mellor *et al.* 2004), together with those safeguards specific to each marking method should

help maximise the benefits of marking programmes, while minimising potential animal welfare compromise and other negative effects.

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ETHICAL RESPONSIBILITIES OF SCIENTISTS MARKING WILD ANIMALS FOR IDENTIFICATION

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ABSTRACT: Marking individuals or groups of animals is an integral part of wildlife research and conservation management and usually involves the application of an artificial mark. However, marking can have adverse effects on individual animals, populations, non-target species, ecological balance, the environment and other factors. In addition, it is very likely that research that has a significant effect on the subjects will generate invalid data. Therefore, wildlife scientists have an ethical and scientific responsibility to weigh the anticipated benefits of the research against the probable adverse consequences, and to minimise, or at the very least, quantify any negative effects on the study animals.

In order to fulfil these ethical and scientific responsibilities, wildlife researchers should follow the General safeguards for marking wildlife (Mellor *et al.* 2004). These guidelines are applicable to all marking methods, associated procedures, species and research protocols. They include: sound justification for proposed research; development of clearly defined aims and objectives; thorough knowledge of the species and population to be marked; careful selection of the most appropriate marking method, and employment of the most effective and humane ways of applying the chosen mark; systematic evaluation of the effects of the chosen method in captive animals or allied species, before the method is used in wild populations; monitoring and assessment of the effects of marking on wild populations; development and refinement of methods to minimise any adverse effects of marking on the subject animals; proper training and proficiency in applying the mark; dissemination of information pertaining to marking methods and their effects.

In addition to adherence to the general safeguards, researchers must also be aware of, and comply with the specific safeguards associated with each marking method employed. Researchers should also comply with all relevant legislation and regulations, seek the advice of experienced peers, and receive and offer constructive criticism from and to colleagues regarding the efficient and ethical use of animals. The smallest number of animals that will satisfy the goals of the study should be used, and the research potential of each animal should be maximized e.g. using toe-clip material for genetic analyses. Scientists should research and develop new marking techniques or refinements of existing techniques, especially after injury or mortality of study animals has occurred. Finally, researchers have an ethical obligation to publish any innovations or information regarding negative effects of marking methods, and to train and supervise all assistants to apply the same ethical and scientific standards.

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CAN WE FIX IT? YES WE CAN! MAKING VERTEBRATE PEST CONTROL ETHICAL

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Vertebrate pests must be controlled – but control must be ethical. In this paper, we summarise current thinking on principles for humane vertebrate pest control and give examples of how these principles can be, and are being, followed.

Ethical pest control is control that is necessary and is justified. Necessity means whether the control itself is necessary, and whether the pests must be killed in order to achieve control, or non-lethal methods would suffice. If the benefits of any action outweigh the harms, we normally consider that action to be justified. To be truly justified, though, the benefit must be maximised fully and the harms minimised. How can we maximise the benefits and minimise the harms of pest control?

Principles to maximise benefits and minimise harms of vertebrate pest control

Guiding principles have previously been suggested to ensure that pest control operations are necessary, and that harms are minimised and benefits maximised (see review by Littin *et al*. 2004). These have recently been expanded upon following an Australian workshop (Humane Vertebrate Pest Control Working Group 2004). In another paper in this session, O'Connor, Warburton and Fisher have reformed and reinforced these principles. The following suggested 'checklist' of principles, to ensure that pest control is ethical, is derived from these three sources:

1. The aims or benefits and the harms of each control program must be clear.
2. Control should only be undertaken if it is likely that the aims can be achieved.
3. Control strategies/methods must be appropriate, effective and feasible to ensure that the goal/ aims are achieved, the benefits maximised and the negative impacts minimised.
4. The most humane methods feasible must be used to implement the strategy.
5. The methods must be applied in the best possible way to ensure that the goal/ aims are achieved, the benefits maximised and the negative impacts minimised.
6. The outcome must be measured to ensure that the goal/aim was achieved, rather than merely a reduction in the number of pests.
7. Once the desired aims or benefits have been achieved, steps must be taken to maintain the beneficial state.

A further principle was suggested by the Humane Vertebrate Pest Control Working Group (2004):

8. Where there is a choice of methods, there needs to be a balance between humaneness, community perception, feasibility, emergency needs and efficacy.

If step 4 is to be achieved, a further three principles have been suggested (see Littin *et al*. 2004):

1. the relative humaneness of all current methods must be assessed in the practical circumstance of their use;
2. active attempts must be made to improve the humaneness of all current methods; and

3. an active research program to develop new more humane methods must be implemented.

Humane alternatives must also be cost-effective in order to be accepted.

Ways in which principles are already applied

Several of these principles are already followed in the planning of some pest control operations, often to achieve other aims (for instance, to satisfy community concerns or budgetary restrictions), sometimes inadvertently and without a realisation of the ethical or animal welfare implications.

The development of Threat Abatement Plans (Australia), Regional Pest Management Strategies (New Zealand) and Integrated Pest Management Strategies (US and elsewhere) are areas in which several of these principles are already being followed to some extent, particularly principles 1, 3, and 6. ‘QA’ and best practice requirements incorporate principle 5. It is the application of principle 4 that requires attention and focus.

Ways forward

Principle 4 will become easier to apply as research into cost effective alternatives and the amelioration of the negative impacts of pest control advance. Other advances can help progress this aim. For example, the New Zealand National Animal Welfare Advisory Committee has recently approved guidelines for the humaneness testing of capture and kill traps for vertebrate pests and Littin *et al*. (2002) suggest guidelines for assessing the humaneness of vertebrate pesticides.

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ETHICS AND THE KILLING OF WILD SENTIENT ANIMALS

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ABSTRACT: The ethical principles advocated for managing and using domestic and captive animals are increasingly seen as inadequate for guiding the management of wild animals. A growing number of people find it difficult to support vertebrate pest control, particularly because of their negative perceptions of killing. Although there is general acceptance that animals, whether domestic or wild, should be killed as humanely as possible, there is less agreement about whether some animals should be killed at all. In population ecology we know that population size is a balance between reproduction and mortality and that as populations increase, limits are set more often through increasing mortality than reducing reproduction. Here we explore whether such dynamics can be the basis of an ecological ethic, where our actions are determined by ecological, individual animal welfare, and human values.

INTRODUCTION

The way we choose to value and treat the environment, including wild and pest animals, depends on the interactive effects of culture, society's expectations, our familiarity with animals and their environments, and our understanding of ecological principles. An appreciation of the complexities of ecology, especially, is being lost with increasing urbanisation. A growing number of people have a "Disney" view of animals, which probably drives increasing opposition to lethal vertebrate pest control. As professionals involved in vertebrate pest control we have a responsibility to not only acknowledge the public concerns but also to inform and educate the public of the realities involved in protecting the environment to ensure balanced policies governing vertebrate pest management are implemented. To quote Rollin (2004), "Every profession including medicine, law, agriculture [or pest control] is given freedom by society to pursue its aims. In return society says to the professions, that it does not understand well enough to regulate 'you regulate yourselves the way we would regulate you if we understood what you did. But we will know if you don't self-regulate properly, and if this happens then we will regulate you despite our lack of understanding'." So how should we, the vertebrate pest control profession, regulate ourselves? One approach, explored here, is to develop an ethic to guide our actions.

Unlike farm and pet animals, no obvious "duty of care" applies to wild animals except in a conservation sense of care for populations (Reynolds 2004). Nevertheless society expects that whenever we undertake pest control it should be done as humanely as possible. However, the more challenging issue is whether we should be controlling wild animals - is it right to control one population in order to preserve another (e.g. kill stoats to protect kiwi)?; or to kill sentient animals to protect non-sentient plants (e.g. to kill possums to protect rata)? This paper tries to clarify some of the ethical challenges facing vertebrate pest control in Australasia.

PHILOSOPHICAL APPROACHES

Although there are a plethora of terms and subtle definitions in philosophy, we adopt here three major philosophical approaches to environmental ethics as outlined by Kirkwood

(2000). The first is the anthropocentric, or human-centred, ethic based around the value of the environment as it contributes to actual or potential human benefits such as goods, services, and cultural or aesthetic values. There is a further anthropocentric stance based on the premise that humans should avoid harming animals because it engenders callousness in the humans themselves.

The second is the animal rights ethic. Strict animal rights or liberation proponents believe animals must not be exploited regardless of the benefits to humans or the environment (Regan 1992). More commonly this ethic focuses on individual animal welfare which is based on minimising harm, pain or suffering of sentient animals (Singer 1990). Animal welfare is normally about protecting or enhancing the fitness or state of the animal, but in vertebrate pest control animals are often killed – their welfare is deliberately compromised (i.e. it is deprived of life, and its death can be painful).

The third is the biocentric or ecocentric ethic, based on the inherent or intrinsic value of the environment and its constituents (species, populations, or ecosystems). Many of our beliefs and activities in wildlife management are aimed at preserving the environment, as expressed in the lines of Leopold's (1949) land ethic: "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise".

Wildlife species are given moral standing in the biocentric ethic by virtue of their role in natural systems, in the animal right ethic by virtue of their sentience, and by society in general for a multiplicity of reasons (Peterson 2004). It is the conflict between the welfare of individual sentient animals (animal rights ethic) and concern for the ecosystem as a whole (biocentric ethic) that has formed the core conflict for us in wildlife management. Certainly we are not the only ones to find this difficult, with philosophers continuing to debate these issues. For example Marks (1999) recommended we develop an ecocentric ethic in vertebrate pest control that still requires us to consider the welfare of pest species. Although Marks emphasised that this ethic should not ignore the rights of individuals but that they would not be paramount, others, including Eggleston *et al.* (2003), consider this approach inadequate because it always relegates animal welfare to a secondary concern. Alternatively, Singer (1997) states that the ethic of concern for all sentient beings is the most defensible basis for resolving conflicts between the interest of humans and wild animals. Callicott (1980), however, resolutely opposes this animal liberation ethic because it provides for no discrimination between wild and domestic animals, or between overabundant and rare animals, or between native and exotic animals. Other philosophers debate the conflict between the biocentric and anthropocentric ethical positions. For example, Macer (1998) considers it more ethically acceptable to kill animals for survival of ecosystems than for the pleasure gained from hunting.

The three philosophical approaches each give different insights. The anthropocentric (people), the animal rights (animals), and the biocentric (environment). In vertebrate pest control programmes, it is suggested that all three stances are important because the interest of the people, animals and the environment are inextricably linked. However how much weight should be given to each of these components? In this contribution, we begin the development of a pest control ethic by suggesting that the animal rights ethic is currently given too much weight and we use population biology to argue that this weighting can, and should be significantly reduced.

ROLE OF POPULATION BIOLOGY

Vertebrate pest populations are generally characterised by having relatively high reproductive rates, but as populations increase towards maximal levels population density is regulated usually by a sequence of: (1) increased mortality rate of immatures; (2) increase in age of first reproduction; (3) reduction in reproductive rate of adult females; (4) increase in mortality rate of adults (Eberhardt 2002). Consequently many vertebrate pest populations have high numbers of individuals dying, as part of the natural process of population regulation. For example, annual mortality rate of juveniles can range from 7 to 89% and similarly for adults (Sibly et al. 1997; Table 1).

Table 1 Examples of annual juvenile and adult mortality rates (from [1]Sibly *et al.* 1997, [2]Efford 2000, [3] M. Efford pers. comm.)

Species	Juvenile mortality (%)	Adult mortality (%)
Feral cat (*Felis catus*)[1]	73	43
Himalayan tahr (*Hemitragus jemlahicus*) [1]	24	27
Red deer (*Cervus elaphus*) [1]	7	9
Feral pig (*Sus scrofa*) [1]	53	53
Fox. (*Vulpes* sp.) [1]	80	45
Brushtail possum (*Trichosurus vulpecula*)[2]	-	45
House mouse (*Mus musculus*)[3]	>90	>90

Therefore, although the animal rights ethic morally condemns pain and death it is irreconcilably at odds with the ecological facts of wildlife population dynamics (Callicott 2003). Given that high mortality rates can result from natural processes, is killing then morally unacceptable? Singer (1997) introduces the concept of self-awareness, suggesting that most animals don't see themselves existing over time or having a future. Further, for most non-social animals there is little evidence that the death of an adult individual has an effect on other animals in the population (an exception is if a female adult is killed when she has surviving dependant young). Therefore, as long as animals are killed humanely we suggest their death does not pose an unacceptable ethical challenge because it is an essential, ecological process. However, some would argue this stance is a naturalistic fallacy (i.e. IS does not imply OUGHT). Moreover, if fewer individuals are killed from the control, over the long-term, than if natural regulation was allowed to occur, then there may be an ethical benefit from pest control (Varner 1994).

We believe that the vast majority of wildlife managers agree killing must be done humanely. However, because we recognise that none of the current methods are totally or consistently effective, there is an ethical cost of pest control. The size of this ethical cost depends on whether it is measured against an ideal of instantaneous death, as for farm animals, or some lesser requirement (e.g. compared with natural deaths; Warburton & Choquenot 1999).

Although we have provided arguments to support pest control (killing), we believe such actions can only be justified if the outcome of the control achieves the pre-determined environmental, animal or human health goals. Control must only be undertaken if key strategic principles can be adhered to (Littin *et al.* 2004). Killing if done humanely can have little ethical cost. Therefore if such pest control achieves the desired benefits, we believe killing individual pests is ethical acceptable. Ineffective pest control that realizes none of the benefits from removing pest animals, but incurs ethical costs of killing, therefore must be considered ethically unacceptable.

ETHICAL BALANCE

We believe there is a need for a balance between biocentric, animal rights, and anthropocentric ethics. The issue of vertebrate pest control is not merely a conflict between a human-centred ethic and an animal rights ethic, it is a triangular debate in which human interests, a biocentric ethic, and an ethic of concern for all sentient beings must play a role (Singer 1997). Similarly, Norton *et al.* (1995, cited in Kirkwood 2000) advocated a pluralistic approach with the acceptance of both environmentalism and concern for the individuals, recommending a shift in emphasis from one to the other depending on the situation.

We believe that a supporting ethic for vertebrate pest control should have less emphasis on the animal rights ethic and a better balance between the biocentric and anthropocentric ethics. Finding a balance between these two ethical positions requires finding the balance between the intrinsic value of the environment and human centred interests. Once this balance is achieved what management is required can be identified and any resulting pest control would therefore be ethically justified (with the caveat that pest control is done humanely).

To develop a sound basis for vertebrate pest control a four-step process needs to be implemented:

1. Precisely define an agreed (between ecologists and society) management goal (in precise and concrete terms explaining why wildlife is being managed and what it will achieve: Caughley 1988)
2. Implement appropriate control strategies that ensure goal is achieved.
3. Use humane methods/tactics to achieve the strategies.
4. Measure the outcome to ensure goal has been achieved.

Step 1 is likely to pose the greatest challenge, and currently is often poorly done, as it will be determined from a biocentric and anthropocentric ethical balance. We believe that only if these four steps are successfully implemented will vertebrate pest control be ethically acceptable in the future. Those involved in vertebrate pest control have to begin questioning their assumptions about the environment, animals and people which shape what we and others take to be acceptable in killing animals. This contribution is the first step in examining our beliefs.

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BIRD PEST POLICY AND MANAGEMENT IN QUEENSLAND: RISK MANAGEMENT OR RISK TAKING?

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ABSTRACT: Strategic pest animal management programs require the identification of issues, the coordination of responsibilities and the provision of resources. Bird pest policy and management in Queensland and Australia has not followed this approach. Exotic bird pest management has suffered from a lack of coordination, an indecisive national government position and reluctance and lack of capacity to accept responsibility for action. This has resulted in a situation where most pest bird issues are poorly addressed and new threats ignored. The overlap of issues and confusion concerning native and exotic bird species has further complicated the issue.

There is now recognition in Queensland that bird pest management must be better addressed and a program, coordinated across a range of departments, is being trialled. This program is in its infancy and its success will require the resolution of a number of issues including: how the state will deal with the keeping of many exotic bird species, developing capacity and responsibility for the eradication of recently naturalised species and the management of widespread exotic species being left to under resourced local governments.

INTRODUCTION

The current interest in invasive species management within Australia has raised the profile of a range of previously neglected species. This has also highlighted cases where the management of existing pest species such as pest birds are poorly addressed. In Queensland the negative impacts of bird species has been considered minor in the past in comparison to pests such as wild dogs, feral pigs and rabbits. This lack of concern has resulted in exotic birds intentionally being left out of the main pest management legislation in the state and their management coordinated by another agency (i.e. the Environmental Protection Agency). This agency although having experience with native birds is not resourced for the management of exotic pests.

The recent establishment of the Australasian Bird Pest Network and the development of national management guidelines for bird pests of horticulture have provided a welcome refocussing at the national level (Tracey *et al*. 2005). Coupled with a renewed effort to coordinate activities at the state level, bird pest management in Queensland is in a position to move forward. Addressing the view that this renewed action is too late is the first hurdle to overcome. The aim of this paper is to provide a case study of how to improve an inadequately addressed area of pest management.

BACKGROUND

A review of invasive species management in Queensland in 2001 found that exotic birds were one group of invasive species, which were poorly managed. A range of introduced bird species were thought to be spreading in Queensland, with negative impacts on native wildlife and human health, for example, common Indian mynas (*Acridotheres tristis)*, starlings (*Sturnus vulgaris*) and more recently blackbirds (*Turdus merula*). In addition, several hundred different non-native bird species have the potential to become pests if they are imported into Australia and escape captivity. There is already a considerable diversity of exotic birds held in Queensland, some of which are considered to have a high pest potential.

Recent research shows that a number of native and exotic bird species cause localised pest problems. A Department of Natural Resources and Mines state-wide survey (Oliver and Walton 2004) found that 3% of primary producers and 6% of people in urban centres considered birds the pest of most concern. Horticulturalists considered them the second most significant (13% of producers) pest group, however few formal studies of these impacts have been carried out. In the recent community survey the common Indian myna was considered the worst Australian pest and three of the top ten pests were birds (ABC 2004).

Although birds were listed in the Queensland Pest Animal Strategy there were no specific actions directed to birds in this document (Queensland Government 2002). The main pest management legislation in the state is the *Land Protection (Pest and Stock Route Management) Act 2002* managed by the Department of Natural Resources and Mines. The predecessors to this Act traditionally covered pests with economic impacts. A recent review included both environmental and social impacts, to better reflect the current public view of pests. Nevertheless the current Act still excludes birds and this department provides little educational material, little to no funded research and no on-ground control.

Currently no Queensland state agency has undertaken management programs for naturalised exotic birds. Some local governments have investigated the extent and impacts of exotic bird species, including surveys of the Indian myna by Caloundra and Brisbane City councils and trials of myna traps by Cairns City council. However, no local government has undertaken significant control activities of an exotic pest bird.

Keeping birds in Queensland

The agency in Queensland, which has accepted responsibility for bird management, both native and exotic, is the Environmental Protection Agency (EPA). As the management of potential pests generally recognises the legitimate use of some species (both recreational and commercial) it must provide scope for this use to occur through a licensing system. The licensing of aviculturalists to keep native and exotic birds is under the *Nature Conservation Act 1992* and its associated regulations. The primary consideration as to which native species can be kept is conservation of the species, including the potential threat of take from the wild. Little consideration has been given to pest impacts of native species should they be released outside their native range.

In contrast, the keeping of exotic bird species in Queensland is primarily based on a risk assessment approach. Since 1992 a small group of extreme risk species (formerly 5 now 10) have been prohibited and are not allowed in the state. Until recently a further 87 species were allowed to be kept without a licence. In 1997 an administrative moratorium was placed on the importation of all exotic bird species not already listed as “domestic animals” under this Act. This effectively halted the legal importation of exotic birds into Queensland. This moratorium stayed in place subsequent to the dismantling of the National Exotic Bird Registration Scheme (NEBRS). In 2002 the EPA undertook to allow the keeping of an additional 108 species in Queensland. At the same time 5 species were placed into the “prohibited wildlife” category. The *Nature Conservation Act 1992* was also amended making it an offence to release a live exotic animal to the wild.

The reassessment of these species occurred as they were all listed on the NEBRS schedule. The researcher examined the ecology and life history of the entire range of species and ranked these species in terms of the likelihood that they would establish in the wild in Queensland. The threshold points in this system recognised the current status of bird species in the state e.g. were they in the trade and were they naturalised. This decision was based on a comprehensive assessment of pest status and a range of other issues, but it used a different model of risk assessment than has previously been used (Bomford 2003).

While this assessment has been labelled as risk management, some consider it risk taking. They argue that under this Act over 200 species of birds can now be kept without a permit in the state. Given the past history of releases from captivity (Duncan *et al.* 2001) this poses an increased threat to the state. To date there is no state agency plan in place for responding to new exotic bird incursions.

CASE STUDY - Red Whiskered Bulbul
The red whiskered bulbul (*Pycnonotus jocosus*) is a prohibited species in Queensland in recognition of its high pest potential. This southern Asian species was introduced into Sydney in 1880 and later in Melbourne. Bulbuls have subsequently spread along the east coast from Sydney, becoming common in urban areas inhabiting parks, gardens and along creeks. The only known wild population in Queensland is in the city of Mackay. This population, intentionally established from aviary releases, has been present in the city for approximately 15 years. However, no control activities have been undertaken on this species to date and its further spread is likely.

COMPONENTS OF AN EFFECTIVE SYSTEM

In 2004 a whole of government exotic pest bird project commenced to assess if the legislative changes for exotic birds can be improved. This project was set up by a new cross government committee called the Interagency Pest Management Committee, which has a mandate to improve invasive species management across the state. This committee recognises that while one state agency may be listed as responsible for a pest group, other agencies are likely to have skills, resources and even legislative responsibilities that might assist.

Although in its early days this project has identified that an effective state based program for bird pest management, consistent with the management of other pest animal groups, should include:

- coordination of local, state and Australian government agencies;
- prevention of the establishment of new pest species;
- early detection and eradication of newly established species; and
- management and control of widespread pest species.

Several of these components are in place but to date they have not been well resourced or implemented. For example although the current legislation provides a head of power for the EPA to respond to exotic birds naturalisations, this agency does not have a record of carrying out these activities. It is therefore not resourced with skilled staff or funding to allow it to respond adequately to these species, although its staff do have expertise in the management of problem native species such as white ibis (*Threskiornis molucca*), rainbow lorikeets (*Trichoglossus haematodus*) and Australian magpies (*Gymnorhina tibicen*) which could be used for exotic birds. A major deficiency with the current activities in Queensland has been the devolution of research and control programs down to local governments. This contrasts with the delivery of research, information and awareness activities, financial assistance, control on government lands, planning and coordination for more recognised pest species such as pigs and feral cats by state agencies. This again will require increased resourcing by state agencies.

The outcome of this approach to exotic bird management in Queensland may not be clear for a number of years but it is hoped that an improved coordination will result in improved resourcing and management across the state.

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NATIONAL GUIDELINES AND RESEARCH PRIORITIES FOR MANAGING PEST BIRDS

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ABSTRACT: There are over 100 bird species from Australia and New Zealand that can cause significant losses to fruit, nut, grain, rice and aquaculture industries, create conflicts in urban areas, damage infrastructure, reduce aesthetic values, and pose risks to the environment and to human health. Despite numerous concerns raised by industry and the general public there is very little objective advice and few simple, universally applicable solutions available. Pest bird research programs have traditionally received limited funding and lacked the capacity to comprehensively assist with management decisions where problems occur. Cooperation between federal, state and local government, universities, private organisations and industry is imperative to ensure practical solutions are pursued and limited resources are used effectively. We support the need for national guidelines for managing pest birds and propose future directions for research. To allow land managers to effectively manage pest birds, support is needed to improve our ability to predict patterns of bird movements and damage, develop simple techniques for estimating the extent and severity of damage, assist in economic decision-making, improve the adoption of strategic management, reconcile legislation and responsibilities for managing pest birds and increase the cooperation and commitment by industry and government. Although specifically aimed at reducing the impacts of birds to Australian horticulture, the principles, strategies, management techniques and research directions proposed in the draft national guidelines are applicable for dealing with most pest bird situations in Australasia. The initiatives adopted to encourage cooperation between organisations and to ensure direct involvement by land managers are discussed.

INTRODUCTION

Over the past decade, the Bureau of Rural Sciences has produced a series of national pest management guidelines for major vertebrate pests of agriculture including feral horses (Dobbie *et al.* 1993), rabbits (Williams *et al.* 1995), foxes (Saunders *et al.* 1995), feral goats (Parkes *et al.* 1996), feral pigs (Choquenot *et al.* 1996), rodents (Caughley *et al.* 1998) and wild dogs (Fleming *et al.* 2001). These guidelines follow the principles of adaptive and strategic management (Walters and Holling 1990; Braysher 1993) and were developed and endorsed by industry and the Vertebrate Pest Committee of the national Standing Committee on Agriculture. At present there are no national government or industry-supported guidelines for pest birds and as a result research lacks coordination and direction. Although largely unquantified, pest birds are likely to cause significant economic, environmental and social impacts and are considered to be an increasing problem, particularly given the recent expansion of a number of horticultural industries. Despite this, there is a dearth of information relating to bird ecology, impacts and damage reduction options. This paper outlines draft guidelines for managing the impacts of pest birds to horticulture, identifies research priorities and describes a process to encourage their adoption.

A STRATEGIC FRAMEWORK

The draft national guidelines for pest birds in horticulture follows the same strategic framework adopted for other major pest animals. We advocate careful planning and outline the tools needed for horticulturists to achieve effective management. The guidelines will:

- describe the strategic approach for best practice management,
- review the extent and severity of damage caused in Australia,
- review the movements, breeding, social organisation and preferred habitats and foods of the top 20 pest birds of horticulture,
- describe the techniques for measuring and monitoring bird damage,
- provide a scientific assessment of control techniques, including scaring, population reduction (poisoning, shooting, trapping and contraception), habitat manipulation and decoy feeding, netting and other forms of exclusion, chemical repellents, and biological control,
- describe the economic principles of pest bird control,
- outline the current legislative controls relating to pest birds,
- consider the practicalities of dealing with pest bird issues amongst other management priorities and discuss ways of improving communication between researchers, advisors and growers,
- demonstrate strategic management by illustrating examples of successful local and regional approaches to managing pest bird issues, and
- outline the information deficiencies and priorities for future pest bird research.

RESEARCH PRIORITIES

One of the constraints on industry funding for pest bird research in Australia has been a lack of clarity about where the priorities lie and whether investment in research will bring enough returns to justify the expenditure. There are several deficiencies in current knowledge that restrain the effective management of pest birds. To allow horticulturists and other pest bird managers to effectively manage pest bird damage, firm recommendations and a coordinated progression for future research is required. The following research directions have been identified after reviewing gaps in knowledge and are the culmination of many discussions with key stakeholders, including researchers, federal, state and local government agencies, industry representatives and land managers:

- Improved use of existing control techniques on the main pest bird species.
- Development of simple and efficient techniques for estimating the extent and cost of damage.
- Improved support for economic decision-making and more detailed information on the costs and relative effectiveness of management techniques.
- Improved adoption of available technology and understanding the barriers to adoption.
- Improved knowledge of bird ecology, diet and patterns of movements and damage.
- Reconciling legislation and responsibilities for pest birds.
- Improved cooperation between national and state agencies, industry and land managers.
- Enhanced commitment from government and industry.
- Demonstrate relevance of ‘best practice’ management to land managers.
- Increased support for developing and registering products that can be used by land managers.

TOWARDS A COOPERATIVE APPROACH

The adoption and applicability of national guidelines and priorities for research relies on the effective communication between key collaborators and must directly involve end-users. Cooperation between federal, state and local government, universities, private organisations, industry and land managers is a major component of this project. Ownership by land managers and the continued involvement by all collaborators throughout the process is essential to ensure: practical solutions are pursued and are nationally relevant; research is not duplicated; and optimal adoption of proposed management strategies. Several initiatives have been implemented to start this process, including the Australasian Pest Bird Network, the National Pest Bird Survey and the pest bird bibliographic database.

1. Australasian Pest Bird Network

The Australasian Pest Bird Network (APBN), hosted by NSW DPI, was launched in August 2004 to promote and facilitate collaboration and information sharing on pest bird management issues between federal and state government agencies, industry bodies and private organisations. The APBN encourages discussion on pest birds, keeps members up-to-date with current research, and provides an avenue for canvassing management and research directions and disseminating and requesting information on pest birds in Australasia. In comparison to larger email discussion groups this network targets a much smaller number of people (current 150) with a specific interest in pest birds and their management, and is committed to ensuring industry is represented. The APBN provides an avenue for industry to be directly involved in developing the national pest bird guidelines, and includes representatives from Horticulture Australia, the Grape and Wine Research and Development Corporation, the Grains Research and Development Corporation, Cherry Growers of Australia Inc, the Australian Nut Industry Council, Apple and Pear Growers Association of South Australia, Australian Olive Growers Association and the Australian Blueberry Growers Association. Key international contacts from the United States, South Africa and the United Kingdom ensure members are informed of the latest research.

A range of issues have been discussed by the network including: management and trapping of cockatoos; methyl anthranilate; interagency responsibilities for pest birds; the National Pest Bird Survey; fenthion; game hunting and introductions of exotic birds (pheasants, partridges and guinea fowl); and, Indian mynas (alphachloralose, introductions in SA and Tas, climate and bioclim mapping). Regional or state coordinators of the network are regularly informed on pest bird management, policy and research, and are a point of contact in each jurisdiction (Table 1). Anyone wishing to distribute or obtain information or canvass research ideas about pest birds can post a message by sending an email to: pest.birds@dpi.nsw.gov.au or contact John Tracey to become a member.

Table 1. Regional Coordinators of the Australasian Pest Bird Network

Location	Key Contact	Organisation	Phone	Email
ACT	Mary Bomford	Bureau of Rural Sciences	02 62724263	Mary.Bomford@brs.gov.au
NZ	Jim Coleman	Landcare Research	+64 3 325 6701 x2257	colemanj@landcareresearch.co.nz
TAS	Graham Hall	Dept of Primary Industries, Water & Environment	03 6397 6591	Graham.Hall@dpiwe.tas.gov.au
WA	Marion	Dept of Agriculture	08 93662301	mmassam@agric.wa.gov.au

Location	Key Contact	Organisation	Phone	Email
	Massam			
SA	Ron Sinclair	Animal and Plant Control Commission	08 83039506	sinclair.ron@saugov.sa.gov.au
VIC	Ian Temby	Dept Natural Resources & Environment	03 92964636	ian.temby@nre.vic.gov.au
QLD	Jim Thompson	Natural Resources, Mines and Energy	07 34055544	jim.thompson@nrm.qld.gov.au
NSW	John Tracey	NSW Dept of Primary Industries	02 63 913952	john.tracey@agric.nsw.gov.au

2. National Pest Bird Survey

The national pest bird survey (available from www.agric.nsw.gov.au/reader/bird-damage-form.htm) commenced in November 2004 to involve horticulturists in future research and management directions. This survey requests information on bird damage levels, the species involved and the costs of current management, and seeks feedback on priorities for future research and development. This will provide an insight to the problems posed by bird pests in horticulture at a national level, and will identify crops and regions most affected by birds. The results of the survey will be verified by comparing growers estimates with direct measurements where techniques are available, and non-response bias will be estimated through phone questionnaires.

3. Bibliographic Information Package

A bibliography of key scientific papers and reports on bird pests has been collected from contributions from relevant experts and researchers in Australia and New Zealand and has been regularly updated since 1999. This information package was intended as a resource for land managers and researchers with an interest in bird pests. It contains references from areas such as biology, feeding habits, habitat preferences, breeding and movement behaviour, distribution, damage assessment, and management of the key bird pest species to agriculture, the environment, and in urban areas. While the emphasis is on Australasia, key international references are also included. This database now includes over 6000 key-worded references and is freely available from the authors.

CONCLUSIONS

Bird damage is a significant problem for many primary producers in Australia. There are many bird species that are known to cause damage that possess marked differences in feeding strategies, breeding behaviour and movement patterns. There is high variability and uncertainty of bird movements and subsequent damage levels between and within seasons, and a range of factors that influence damage at the property, regional and national scale. Land managers are also faced with increasing social, environmental and legal restrictions of available techniques, particularly where native species are involved. Little objective advice is available and management solutions are seldom suited to all bird species, crops and situations. Despite a large number of techniques and devices available, these are rarely subject to objective assessment. As a result of all these factors, managing pest birds is one of the more problematic issues facing land managers.

Despite these concerns, many industry and government organisations have been reluctant to invest in research into reducing damage caused by birds. This may be partly due to the current lack of information available on the severity and distribution of the problem and a lack of efficacy data and cost:benefit analyses for damage reduction strategies. A strategic approach to managing pest birds is encouraged, with consideration of the species involved and accurate estimation of the extent and costs of damage before and after implementing control. There are several deficiencies in current knowledge that restrain the effective management of pest birds, as outlined above. The new Australasian Invasive Animal Cooperative Research Centre will offer a means of overcoming these deficiencies in collaboration with industry and government partners. Research priorities and draft national guidelines for pest birds will be made available for comment to relevant groups via the Australasian Pest Bird Network and industry communication networks.

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CORELLA PROBLEMS IN WESTERN VICTORIA: CHRONOLOGY OF THE MANAGEMENT OF A NATIVE PEST SPECIES

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ABSTRACT: Long-billed Corellas (*Cacatua tenuirostris*) are mainly confined to south-eastern South Australia and south-west Victoria. The effects of post colonial land changes in these regions caused a dramatic decline in abundance and distribution of the Long-billed Corella such that by the 1960s there was concern about its the long-term viability. More recently the population has increased to a situation where they are regarded as pests.

This paper outlines the chronology of various approaches to management of the Long-billed Corella in western Victoria. This case study identifies that future Long-billed Corella management needs to be framed by a nexus of diverse information and suggests that pest management requires a more participatory approach identifying methods that reduce crop damage in contrast to the dominance of lethal control of birds. This requires a paradigm shift for both government and community in relation to the locus of control informing pest management.

INTRODUCTION

After the mid 1800s Long-billed Corellas (LBC) went through a period of rapid population decline until the 1950s. Since this time there has been an increase in the species' abundance and distribution associated with a change in diet from native to exotic foods (Emison *et al.* 1994). Increases in the amount of cropping within the species range have led, in the last 30 years, to conflicts between birds and farmers (Bomford and Sinclair 2002). In addition, urbanisation of birds has increased conflicts within various communities. This paper provides an historical overview of the chronology of management and outlines a diversity of control techniques, most of which have been unsatisfactory. We argue that the future for corella management lies in differentiating between the various perceptions of this economic pest, which will be better understood by an appreciation of the human dimensions of the problem. This, we argue, requires a greater facilitatory role for government agents, which differs substantially from their traditional advisory and operational functions.

Control and Management

Table 1 identifies the chronology of management from late 1800s to 2005 which emphasise lethal control, no doubt because the assumption was that a direct correlation exists between bird abundance and crop damage; however, Braysher (1993) has questioned this assumption for a range of pest species. As early as Emison *et al.* (1981) stressed the importance of ascertaining economic loss directly attributable to LBCs but the repeatability and validity of any such investigations have been limited. Undoubtedly LBC management has been influenced by political pressure to resolve landholders' concerns. This has led to an emphasis on lethal control programs because, as an outcome, it satisfies landholders' traditional paradigm for pest management. However, this view of pest management often fails to address damage reduction.

Since 1999 a trapping and gassing program has dominated corella management in Victoria. Although removing birds from the population (Fig. 1) the cost of the program is high (Fig. 2). Due to recent funding constraints, and a directed change in the role for government agents, there has been a reduction in the government funded programs with greater importance given to sharing costs between stakeholder and government. The current program has been guided by government's response to problems such as 'cockatoos', which is

- Native wildlife is a community asset and perceived wildlife problems are to be considered in the context of the species' ecology the community's activities;
- Communities are to be considered part-owners of perceived problems and solutions;
- Landholders are to be assisted, through education and other means, to devise and adopt viable wildlife impact mitigation measures as standard management practices; and
- Government promotes partnerships with industry, for the management of wildlife impacts, leading to more robust means of addressing barriers to agricultural or other industry production.
- In summary, Government has shifted from direct on-ground management to:
    - leading, and facilitating, community effort to seek viable control methods;
    - assisting people in building these methods into strategies incorporated into their enterprise management, and
    - facilitating community adoption of appropriate strategies.

The goal is to educate farmers about bird behaviour and identify practicable solutions for landholders to reduce damage. The current program is regarded as successful because it reduces stakeholder anxiety by identifying that the 'corella problem' can be managed and 'solutions' exist, but success is dominated by estimates of bird deaths and not a reduction in crop loss. There is currently community concern that responsibility for LBC management is still seen as a role for government and as roles change landholders may not be willing to embrace the government's initiative when they have to bear the cost of trapping and destruction.

Table 1 Chronology of management of the LBC in SE Australia

Time period	**Observation / Action**	**Outcome**
Late 1800s	Long-billed Corellas identified as a concern to farmers	Poisoning birds with 'pickled' (mercury based fungicide) seed wheat used to control rabbits
1960–1976	Damage to sunflowers in western Victoria	Shooting a popular control method.
1977	Government tested Measurol™ as bird repellent	Inconclusive results
1981	Long-billed Corella declared 'unprotected' for cereal growers.	Shooting with permit expanded in specific shires where landholders and managers were shooting birds throughout the year. Concern from conservation groups that Long-billed Corella populations were threatened
	Emison et al. (1981) promoted evaluation of timing, distribution and economic extent of crop damage.	Estimated crop losses for oats averaged \$6800 per farm but no indication of farm size or the time period. Crop loss for sunflowers estimated as from 10% to 100%.
	CONCOM agreed not to relax policy prohibiting export of native wildlife	Decline of interest in trapping for sale
1983	Du Gueslin et al. (1983) reported 17 cases of bird poisoning in Victoria.	Government investigated control methods to alleviate landholders desire for illegal poisoning
	NSW professional trappers licensed to take birds in Victoria	2 785 birds trapped. Political pressure to allow export of birds but no relaxation of CONCOM policy.
1985	Department of Conservation, Forest and Lands (DCNR) continued to trial methiocarb	Results inconclusive but (60% (n=20) of farmers believed repellent was effective. Concern that inappropriate handling of methiocarb affected farmers' health.
1986	DCNR repeated methiocarb experiment but with less replicates. Horsham Region Land Protection Advisory Committee (HRLPAC) (1986) provided data on bird damage in the Horsham region. Public meeting held in South Australia to review corella control / damage (Best et al. 1986)	Results inconclusive. Estimated cost of Measurol™ treatment \$6.60 ha^{-1}, which was less than the HRLPAC (1986) \$8.40 ha^{-1} estimate for shooting and scaring. Costs associated with crop protection were \$749 per landholder and crop losses were \$22.00 ha^{-1} to \$43.30 ha^{-1} for barley and \$13.00 ha^{-1} for oats and wheat. Fisher (1986) estimated average crop loss as \$2000 per property. Trapping and export promoted as a suitable control measure (Ackroyd 1986).
1988	Formation of the Cockatoo reference group based in Horsham	Increased community participation in management
1990	Poisoning continued in the south Wimmera with loss of three Brolgas (a vulnerable species in Victoria). Temby (1990) concluded that no repellent worked reliably for a wide range of crops and situations. de la Motte (1990) stated that trapping and export of pest birds would have no significant benefit for Australian farmers. He made an exception for LBCs. Emison (1990) concluded that trapping did, in some cases, disrupt large flocks.	

Table 1 Chronology of management of the LBC in SE Australia (cont.)

Time period	Observation / Action	Outcome
1992	DCNR trapping and gassing trials undertaken and evaluated.	Trapping unsuccessful in terms of catching large numbers of birds. Not possible to ascertain whether this method dissipated large flocks. Trapping program improved co-operation between government and landholders.
1995	Instigation of Environment and Natural Resources Committee (ENRC) to 'inquire into problems in Victoria caused by Long-billed Corellas, Sulphur-crested Cockatoos and Galahs' Field trials of MA in western Victoria found that 0.8% (w/w) MA on oats was an effective repellent (Kentish et al. 2003)	ENRC (1995): • supported shooting as a method of scaring birds • recommended that alpha-chloralase be investigated to assist with bird control • supported trapping and gassing programs and that this technique's effectiveness be evaluated • did not support capture and export of birds • did not support poisoning to kill wildlife
1999	Contrary to the advice provided by the ENRC (1995) Minister for Conservation and Land Management approved the use of poisons to aid cockatoo control. Further trapping and gassing program undertaken by the Department of Natural Resources and Environment to supplement, and provide an alternative to the chemical control program.	Political decision to poison created concern from community groups (Birds Australia 1999). 1 066 Long-Billed Corella and 48 non-target birds killed. Farmers considered poisoning a vital tool for crop protection but expressed concern about the limited advice on suitability, appropriate concentration, application techniques and timing of poisoning. See Fig. 1. Program did not significantly reduce bird population but considered successful in dissipating and dispersing large flocks. Farmers were sceptical of trapping because of low success. Commented that technique reduced crop and tree damage
1999-2003	Trapping and gassing program dominated government's approach to corella management in Victoria. Technique promoted in response to landholders desire to poison birds. Education /extension of landholders to improve farm hygiene practices.	2002 post-trapping farmer survey indicated insufficient birds were being killed. Few landholders could estimate crop loss (considered less than 20%). Community concern about the reduced funding for trapping program.
2003-2005	Training of landholders / managers in trapping and gassing technique. Promotion of non-lethal techniques to reduce bird damage of crops.	Shift of operation of trapping and gassing from government to landholders

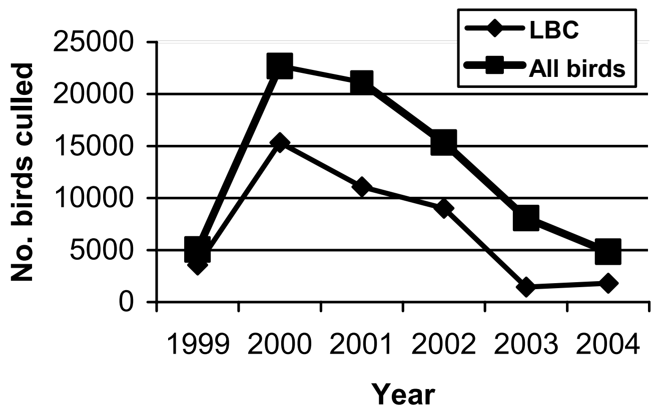

Fig. 1 Number of Long-billed Corellas (LBC) and all birds trapped per annum

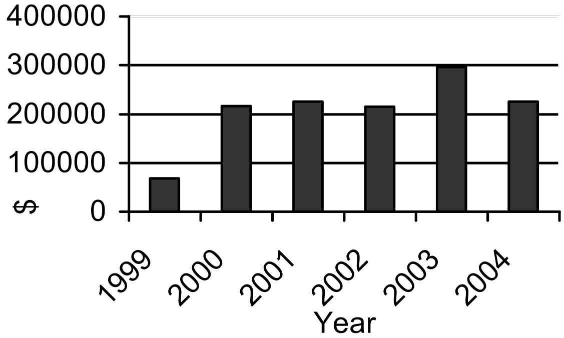

Fig. 2 Annual cost of trapping and gassing program

The government's current approach of sharing responsibility may assist affected stakeholders to manage LBCs but to some extent the government's response can be seen as shifting responsibility from bureaucracy to client. This shift of power may benefit government but is an additional cost for stakeholders. Government will no doubt be challenged when they promote their 'solution' to stakeholders' problems without a thorough investigation of the diversity of social landscapes. Unfortunately to date there has been little research as to the acceptance by the community of such a radical change in responsibilities.

DISCUSSION

LBC management has been dominated by lethal control; however Bomford and Sinclair (2002) suggest that attempts to reduce bird pest populations have largely been unsuccessful in reducing crop damage to acceptable levels. Wildlife managers face increased urgency to take action to reduce conflicts between people and over abundant species of wildlife. As such, government agents find themselves working within systems where the ecological, economic, sociological and political subsystems interface (Decker and Chase 1997). This case study shows that although a diversity of lethal approaches have been trialled there is still little empirical data to demonstrate any effectiveness in reducing economic damage in the long term. There has been a great reliance on anecdotal information and the use of bird mortality as the dominant measure of success of control.

Stakeholders are now seeking greater involvement in wildlife management issues (Chase *et al.* 2000) and government agents are at the forefront of juggling conflicting and contrary views, while attempting to base decisions on appropriate knowledge. Understanding the human dimension in wildlife management is critical if effective pest management strategies are to be perceived as appropriate by stakeholders (Decker and Chase 1997). It is necessary to provide opportunities for communities to participate within decision-making processes so that they perceive that their views have been incorporated into management polices. Unfortunately little work on the scope of human dimensions has been undertaken in Australia (Jones *et al.* 1998; Miller 2003).

Changes in government policy creating greater community ownership of the LBC problem through more facilitatory roles for government agents requires a fundamental paradigm shift in understanding the locus of control. Although government might be ready to make such a change there is limited evidence to suggest that stakeholders are equally enthusiastic about changes to their role. We suggest that before government initiates moves from their traditional authoritarian role to a more facilitatory position there is an urgent need to understand whether community agreement exists for this paradigm shift in control and management of the problem.

CONCLUSION

It appears that to promote a more human orientated approach to understanding the economics of the 'corella problem', a construct that needs to be clearly differentiated from the management of LBCs, requires government to work within communities addressing the benefits and costs of alternative solutions, promoting economic measures of success of pest management, and managing for changes in the locus of control. This requires an appreciation that:

- there are many different valid perceptions of the problem;
- outcomes require solutions that are agreeable and practical to all stakeholders;
- it is important to monitor conflict and to continuously adapt outcomes to changing situations and social climates; and
- issues will continue to be contested and problematic as social landscapes expand and perceptions change.

Acknowledgement of these points requires a shift towards greater understanding of the desirable social and economic outcomes for pest management issues and not just lethal control of the animal.

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INTERSPECIFIC AGGRESSION IN MAGPIES: IMPACTS ON OTHER BIRDS IN NEW ZEALAND

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ABSTRACT: Australian magpies (*Gymnorhina tibicen*) can be highly aggressive and many reports of them attacking other birds in New Zealand exist. Furthermore, anecdotal reports of sudden declines in bird numbers are often associated with the arrival of magpies into an area. Until now, however, no studies have attempted to determine the impact they may have on other birds in New Zealand. Here we assess (in three separate trials): (1) changes in the abundance of other birds over three years of large-scale (900 ha) magpie control, (2) if other birds avoided flying or foraging close to territorial and flocking magpies, the proportion of passing birds that were attacked and the behavioural context of those attacks, and (3) whether magpies are serious predators of nesting birds in rural ecosystems. In the first trial, reducing magpie numbers on large blocks of farmland significantly increased index counts of five introduced (blackbird *Turdus merula*, song thrush *T. philomelos*, myna *Acridotheres tristis*, skylark *Alauda arvensis*, and starling *Sturnus vulgaris*) and one native species (kereru *Hemiphaga novaeseelandiae*) by small amounts in treatment cf non-treatment blocks. In the second trial, significantly fewer birds foraged in pasture close (i.e., ≤50m) to magpies than in pasture with no magpies, and fewer birds were also recorded flying near (i.e., ≤50m) territorial breeding magpie groups but not non-breeding flocks. Excluding harriers (swamp harrier; *Circus approximans*), only 8% of birds recorded within 50m of territorial breeding groups were observed being attacked. Territorial breeding groups attacked 39% of passing harriers. Magpies in non-breeding flocks did not attack other birds, except harriers (attacked in 17% of appearances). During attacks, the victim was either swooped or chased; no physical contact was ever observed. Attacks were most frequent when numerous birds occurred near magpies and species recorded in the highest frequencies were generally attacked most. In the third trial, time-lapse recording techniques were used to identify predators at bird nests in rural areas. Magpies were responsible for one of 23 lethal events. Ship rats (*Rattus rattus*; eight events), harriers (eight events), cats (*Felis catus*; five events) and a pukeko (purple swamphen; *Porphyrio porphyrio*; one event) were the other predators filmed preying on nest contents. Our data suggest that reported magpie attacks on other birds are heavily biased towards sensational events that are rare. However, magpies may displace other birds on a local scale, possibly because magpies occasionally chase them or prey on their nest contents. We suggest that in New Zealand, targeting introduced mammalian predators would probably be more beneficial than magpie control for restoring bird communities, because controlling magpies on large blocks of land was expensive and resulted in only modest increases in some (mostly introduced) species.

FACTORS INFLUENCING THE SPATIAL DISTRIBUTION OF INTRODUCED BIRDS ON ARABLE FARMS IN NEW ZEALAND

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ABSTRACT: In New Zealand, the agricultural and horticultural industries view many introduced bird species as significant crop pests. In the arable sector, for example, introduced passerine species, such as house sparrows and greenfinches, cause substantial damage to high-value speciality crops, e.g., radish seed. Bird control techniques currently used by farmers such as scarers, shooting, repellents and pesticides are generally inadequate – they are either economically or environmentally unsustainable or simply ineffective. As very little is known about introduced bird populations and their ecology in New Zealand's modified landscapes, it is difficult to determine the impact of different management strategies on their populations or how these strategies might be improved.

In this study, we investigated whether variation in bird abundance on arable farms during the breeding season could be explained by variation in habitat composition at different scales. Bird surveys were carried out early and late in the breeding season on 20 randomly selected 1-km × 1-km squares on arable farms in the Canterbury Plains. Two approximately parallel transects, divided into 10 × 200-m sections, were established in each 1-km square. All birds seen were recorded. Bird abundance within the squares (1-km-square scale) and within individual sections in each square (the 200-m-section scale) was estimated using distance sampling software for 11 introduced species: starling *Sturnus vulgaris*, blackbird *Turdus merula*, song thrush *T. philomelos*, skylark *Alauda arvensis*, house sparrow *Passer domesticus*, dunnock *Prunella modularis*, yellowhammer *Emberiza citrinella*, chaffinch *Fringilla coelebs*, greenfinch *Carduelis chloris*, goldfinch *C. carduelis*, and redpoll *C. flammea*. Habitat composition was also recorded for four habitat categories: farm practice (arable, pastoral or mixed); boundary features (shelterbelt, hedgerow or only fence/ditch); man-made features (road/farmyard); and crop type (grazed pasture, ungrazed pasture, cereal or other arable crop). Generalised linear mixed models were used to identify habitat features that could explain variation in abundance at the 1-km-square scale (i.e. between the squares) and at the 200-m-section scale (between sections within squares), early and late in the breeding season for each species.

In general, farm, man-made and crop habitat composition were poor predictors of bird abundance at both the 1-km-square and 200-m-section scales. At both scales, boundary habitat type was the best predictor of bird abundance. The abundance of six species (greenfinch, chaffinch, redpoll, yellowhammer, blackbird and dunnock) at the 1-km-square scale was associated positively with the area of shelterbelts (a hedgerow or treeline more than 2 m tall) and/or hedgerows (less than 2 m tall) present. At the 200-m-section scale, all species, except skylarks, were more likely to be present on sections with a shelterbelt. Skylarks, in contrast, consistently avoided shelterbelts or hedgerows at both spatial scales. Starlings avoided 200-m-sections that were classified as arable- and mixed-farm types but were positively associated with grazed pasture, at both scales. House sparrows, in contrast, were more likely to be present on 200-m-sections with cereal present than on those without cereal. Chaffinches, dunnocks and song thrushes were less abundant in 1-km squares with more man-made features (roads or farmyards) present.

Our results suggest habitat composition is an important contributor to variation in the abundance of 11 common introduced bird species on arable farms at both the 1-km-square and 200-m-section scales. Boundary habitat features are the best predictors of bird abundance during the breeding season, indicating that modifying boundary habitat composition may help to control bird pest populations at different spatial scales. In areas where starlings and house sparrows are significant pests, reducing the area of grazed pasture and cereals respectively on farms growing other high-value crops that are prone to bird pest damage may also help to reduce losses to birds. There is a need for experiments to test the feasibility of using habitat manipulations as an alternative bird management strategy to current short-term control techniques.

COST-EFFECTIVENESS OF BIRD REPELLENTS FOR CROP PROTECTION

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ABSTRACT: Chemical bird repellents are touted as an effective and "clean, green" solution to bird pest problems. We evaluated the cost-effectiveness of some purported bird repellents for crop protection. They cost from about \$200/ha to more than \$30,000/ha for a single application. Most would require repeated application, and therefore cost at least twice this amount. If a crop was worth \$10,000/ha, the loss to birds without treatment was 10%, and the treatment was 100% effective, then the cost of treatment must be less than \$1,000/ha for it to be cost-effective. If the value of the crop, loss to birds, or effectiveness of the treatment was less, as it is likely to be, then the maximum cost of the treatment must also be less to be cost-effective. Based on current treatment costs, most of the bird repellents evaluated are unlikely to be cost-effective, except perhaps on high-value crops suffering high levels of bird damage. A simple pre-treatment cost–benefit analysis such as proposed here would indicate when a treatment was likely to be cost-effective, and should always be undertaken before the use of any bird repellent or other bird control technique.

INTRODUCTION

Bird damage is one of the greatest problems facing growers of fruit, vegetable, grain, and seed crops worldwide. However, because of the difficulty of assessment, losses to birds have seldom been quantified. Most estimates have placed losses at less than 20% in fruit and vegetable crops, and less than 5% in grain and seed crops (e.g. Dolbeer 1981; Porter *et al.* 1994; Mason and Clark 1997; Boyce *et al.* 1999; Coleman and Spurr 2001; Avery 2002). Chemical repellents are considered potentially effective and environmentally sensitive means of reducing bird damage (Avery 2003). However, they will be cost-effective only if their cost is less than the economic benefit resulting from their use (Dolbeer 1981; Avery 1992).

METHODS

The bird repellents investigated here include the only two registered and commercially available in New Zealand (Avex™ and Mesurol®), two registered and commercially available overseas (D-TER® and Rejex-it™), and four that have been trialled in the laboratory and/or field (cinnamamide, d-pulegone, neem oil, and ortho-aminoacetophenone (OAP)). Avex™ is similar to Flight Control™, D-TER® to Curb®, and Rejex-it™ to Bird Shield® and Avignon®.

The cost-effectiveness of each bird repellent was calculated from the cost and effectiveness of the treatment, the value of the crop to be protected, and the loss to birds if the crop was not protected. The cost of raw materials was obtained from suppliers or the literature, and the cost of field application from local spray contractors. Costs were influenced by application rates and the number of applications required, and these were also obtained from suppliers or the literature. In the case of d-pulegone, neem oil, and OAP, application rates were based on concentrations applied to food in trials with captive birds because, to our knowledge, they have never been sprayed onto crops as bird repellents. There was little in the literature on the effectiveness of field applications of bird repellents, so our calculations were made using a range of values from 25 to 100% reduction in bird damage. The value of various crops was obtained from farm industry organisations or the literature. All values are in NZ dollars

(2004) unless otherwise stated. As noted in the introduction, little information was available on losses to birds, so we used a range of values from 5 to 30%.

RESULTS

Costs

The total cost of a single application of the bird repellents evaluated ranged from $224/ha for neem oil to just over $30,000/ha for OAP (Table 1). In practice, most of the repellents would probably require more than one application. For example, the active ingredient in neem oil (azadirachtin) is degraded by ultraviolet (UV) light, and topical applications are usually effective against invertebrates for only 4–8 days (Mordue and Blackwell 1993). Thus, weekly application of neem oil for 8 weeks (about the length of time that some maturing arable crops, for example, are vulnerable to bird damage) would cost about $1,800/ha. Methyl anthranilate (MA), the active ingredient in Rejex-it™, also breaks down in UV light. Application of Rejex-it™ reduced grazing on grass by Canada geese (*Branta canadensis*) for less than 1 week (Cummings *et al.* 1995a), and damage to blueberries by birds such as cedar waxwings (*Bombycilla cedrorum*) for less than 2 weeks (Cummings *et al.* 1995b). Avery *et al.* (1996a) applied Rejex-it™ to blueberries weekly for 3 weeks, at a total cost of US$4,942/ha, without reducing bird damage. Weekly application of Rejex-it™ for 8 weeks on maturing arable crops in New Zealand would cost $6,800–$13,400/ha, depending on the application rate used (recommended rates range from 23.5 kg/ha on grass to 47 kg/ha on fruit). The manufacturers of Avex™ recommended that it be applied every 3–4 weeks, but the duration of effectiveness has not been substantiated in field trials. Two applications over an 8-week period would cost about $700/ha, three applications $1,050/ha, and so on. The manufacturers of Mesurol® recommend that it be applied every 2 weeks, so four applications over an 8-week period would cost about $1,300/ha. Cinnamamide was applied at 2-week intervals to young oilseed rape in the UK (Gill *et al.* 1998). Fortnightly application for 8 weeks on maturing arable crops in New Zealand would cost about $70,000/ha, based on current prices for small quantities. The duration of effectiveness of d-pulegone and OAP is not known, but even a single application would be prohibitively expensive, based on current prices for small quantities. In contrast to the above, the supplier of D-TER® claims that it would remain effective for 8–12 weeks. Consequently, a single application, costing about $3000/ha, should (if effective) be sufficient for maturing arable crops in New Zealand.

Effectiveness

The effectiveness of field applications of bird repellents has been highly variable, and influenced by factors such as crop type, stage of the crop, number of applications, and weather after application. In general, bird repellents have been most effective on sown seed, seedlings, and ripening fruit, and less effective on maturing grain and seed. For example, Mesurol® (or its active ingredient methiocarb) reduced losses of sown pea seed by 99% (Porter 1977), ripening blueberries by 99% (Holland *et al.* 1980), and ripening cherries by 90% (Porter *et al.* 1994), but maturing white rice by only about 55% (Guarino 1972) and maturing wild rice by 0% (Moulton 1979). Its ineffectiveness on maturing wild rice may have been because it adhered mainly to the hulls, which the birds did not eat. Likewise, D-TER® was more effective on exposed grain (e.g. millet) than on grain surrounded by leaves (e.g. rice) (Bruggers 1979). Also, Mesurol®, Avex™, cinnamamide, d-pulegone, D-TER®, and neem oil were ineffective on seed crops of European red radish, which have seeds inside pods (author's unpublished data). Flight Control™, the US equivalent of Avex™, reduced bird

Table 1 Comparison of costs for a single application of some potential bird repellents for crop protection

	Primary repellents (painful or irritating on contact)						Secondary repellents (causing illness or discomfort after ingestion)	
	Cinnamamide	D-pulegone	D-TER®, Curb®	Neem oil	Rejex-it™ AG-145 Bird Shield®	OAP	Avex™, Flight Control™	Mesurol®
Active ingredient	Cinnamamide	D-pulegone	Aluminium ammonium sulphate	Azadirachtin	Methyl anthranilate	Ortho-amino-acetophenone	Anthraquinone	Methiocarb
Registered as a bird repellent	No, trialled on crops in UK	No, trialled only on captive birds	Europe, Australia	No, but as insect repellent in India	USA	No, trialled only on captive birds	USA, NZ	USA, Australia, NZ
Length of effect	<2 weeks? (UV stable)	Probably short (volatile)	8 weeks? (UV stable)	<1 week against insects (UV degraded)	<1 week (UV degraded)	Unknown	3–4 weeks? (UV stable)	2 weeks?
Phytotoxic?	No	Yes?	No	No	No?	Unknown	No	No?
Supplier[1]	Biolab Scientific, Auckland, NZ	Penta Manufacturing, USA	BHPM, Penola, Australia	Suntec (NZ), Tokomaru, NZ	Becker Underwood, USA	Sigma Aldrich, USA	Elliott Chemicals, Auckland, NZ	Bayer, Christchurch, NZ
Cost/kg[2]	$8,750	$560	$75	$25	$35	$7,500	$215	$200
Application rate	2 kg/ha (97% active)	10 kg/ha? (85% active)	20 kg/ha ×2 sprays (98% active)	8 kg/ha? (20% active)	23.5–47 kg/ha (14.5% active)	4 kg/ha? (98% active)	1.5 kg/ha (50% active)	1.5 kg/ha (75% active)
Cost/ha[3]	$17,500	$5,600	$3,000	$200	$825–$1,650	$30,000	$323	$300
Effectiveness (% reduction in loss to birds)	>80% in lab, ≤44% in oilseed rape field trial (Gill et al. 1998)	≥80% in lab, untested in field (Avery et al. 1996b)	Effective on ripening grain in Africa (Bruggers 1979, Avery 2003)	Effective in one lab trial (Mason & Matthew 1996)	Effective in some field trials on turf and fruit, but inconsistent (Avery 2003)	Effective in lab, untested in field (Clark 1997)	Effective on turf, seedlings, ripening grain, and fruit (Avery 2003)	Effective on sprouting crops, ripening grain, and fruit (Avery 2003)

[1] *Suppliers contacted for costs (other suppliers exist).*
[2] *Cost/kg of cinnamamide, d-pulegone, and OAP are for small (25–1000 g) quantities of laboratory grade materials.*
[3] *Cost/ha at application rate above, excluding cost of sticker/spreader ($2/ha), if needed, and field application ($24/ha).*

numbers and/or bird damage on turf by 95% (Devers *et al.* 1998), maturing ratoon rice by 80% (Avery *et al.* 2002), lettuce seedlings by 40% (York *et al.* 2000), and maturing wild rice by 0% (Avery *et al.* 2000). Rejex-it™ reduced bird damage to blueberries by 75% in one trial (Avery 1992) and 0% in another trial (Avery *et al.* 1996a). The effectiveness of D-TER®, d-pulegone, neem oil, and OAP has yet to be demonstrated in field trials.

Cost-effectiveness

If a crop was worth $10,000/ha (the approximate value of European red radish seed and some varieties of grapes, for example), the loss to birds without treatment was 10%, and treatment was 100% effective, then farmers must spend less than $1000/ha for a bird repellent to be cost-effective (Table 2). If the value of the crop, loss to birds, or effectiveness of the treatment was less, then the maximum cost of a bird repellent must also be less to be cost-effective. For example, if the crop was worth only $2,000/ha (the approximate value of wheat) and the loss to birds without treatment and the effectiveness of the treatment were the same as above, then farmers must spend less than $200/ha on a bird repellent for it to be cost-effective. If the loss to birds without treatment was only 5%, and the treatment was only 50% effective, then wheat farmers must spend less than $50/ha on a bird repellent for it to be cost-effective.

Table 2 Maximum total cost per hectare allowable for a bird repellent treatment to be cost-effective on a crop yielding $10,000/ha[1]

Loss to birds	Effectiveness of treatment (i.e. reduction in loss to birds)			
	25%	50%	75%	100%
5%	<$125	<$250	<$375	<$500
10%	<$250	<$500	<$750	<$1000
20%	<$500	<$1000	<$1500	<$2000
30%	<$750	<$1500	<$2250	<$3000

[1] For crops yielding other returns, multiply the figures above by the value of the crop divided by $10,000 (e.g. multiply by 2 for crops worth $20,000/ha, and by 0.5 for crops worth $5000/ha).

Based on the above, most, if not all, existing bird repellents, even if they were effective, would not be cost-effective for reducing even quite high levels of bird damage, even in high-value crops. For example, for Mesurol® and Avex™ to be cost-effective, the loss to birds would have to be more than $325–$350/ha (3.25–3.5% of a crop worth $10,000/ha, or 16.25–17.5% of a crop worth $2,000/ha), and a single application at 1.5 kg/ha would have to be 100% effective, which is possible in some crops such as grapes, but unlikely in others such as wheat. The loss to birds would have to be more than twice the above if two applications were necessary, and so on, for these bird repellents to be cost-effective. Neem oil would be cost-effective if the loss to birds was more than $1,800/ha (i.e. more than 18% damage to a crop worth $10,000/ha, or 90% damage to a crop worth $2000/ha), and eight weekly applications at 8 kg/ha were 100% effective. However, the effectiveness of neem oil as a bird repellent has yet to be demonstrated in field trials. D-TER® would be cost-effective if the loss to birds was more than $3,000/ha (i.e. more than 30% damage to a crop worth $10,000/ha, or 100% damage to a crop worth more than $3,000/ha), and application of the product (a double spraying at 20 kg/ha) was 100% effective. These levels of bird damage seldom occur, and as with neem oil, the effectiveness of D-TER® has yet to be demonstrated in field trials. Rejex-it™ would be cost-effective if the loss to birds was more than $6,800/ha (68% of a crop worth $10,000/ha) and eight applications at 23.5 kg/ha were 100% effective, which is unlikely, as noted above. Cinnamamide, d-pulegone, and OAP could never be cost-effective unless their cost was significantly reduced.

DISCUSSION

In general, the bird repellents evaluated mostly cost too much relative to the value of the crop, and their effectiveness was too low and too variable to be cost-effective. Possible exceptions are Mesurol® and Avex™ when used on high-value crops suffering high levels of bird damage, but even then their use is limited because they are not registered for use on food crops (e.g. grapes) because of residue problems (Porter et al. 1994). A pre-treatment cost–benefit analysis would indicate whether a proposed bird repellent treatment was likely to be cost-effective. Admittedly, it can be difficult to predict bird losses and the effectiveness of a treatment, but even crude estimates based on historical evidence are better than none (Dolbeer 1981). A simple pre-treatment cost–benefit analysis should always be undertaken before the use of any bird repellent or other bird control technique for crop protection.

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EGG OIL: A TOOL FOR THE MANAGEMENT OF PEST BIRD POPULATIONS

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ABSTRACT: Few effective tools are available for management of pest populations of introduced or native birds in Australia and New Zealand, though they cause a range of problems in rural and urban areas. The United States Department of Agriculture has demonstrated that the application of various oils to eggs during the nesting season can manage the populations of such invasive species as the Canada goose and ring-billed gull. Due to high rates of recruitment, targeting the reproduction of pest birds during the breeding season may potentially result in longer term reductions in density and may also overcome animal welfare concerns associated with lethal control of adult birds. We are testing this approach for its value in managing the nuisance population of Australian white ibis (*Threskiornis molucca*) in Sydney. Australian white ibis are native wetland birds of Australia, which prior to 1950 were rarely recorded in the Sydney region. They first started breeding in Sydney during a severe drought in the late 1970s and have adapted extremely well to the urban environment. Their numbers continue to escalate in the Sydney metropolitan region, reaching pest concentrations in several areas. Impacts range from public safety issues relating to injury, disease transmission and fouling, to displacement of other species and considerable tree damage caused by their nesting. Management includes trapping in some areas, but is largely concentrated on nest and egg destruction, which is highly labour-intensive and essentially temporary, as the birds rapidly rebuild and lay again.

In recent seasons the Australian white ibis population in Centennial Park, Sydney, has been managed by nest destruction. Many of the birds build on islands in the Park's ponds, which provides a suitably protected environment for the study of their management in an urban area. During the 2004-2005 breeding season we conducted a pilot study comparing the effect of spraying ibis eggs at weekly intervals with corn oil or canola oil with the breeding success of eggs in unsprayed nests. Small volumes (5ml/egg) of human food grade oils were used, so there were no environmental toxicity implications for this approach. Two islands in one (Willow) pond were initially selected for the most rigorous investigation. Nests were tagged and eggs were inconspicuously marked, and those on one island were not sprayed while nests on the second island were sprayed with either canola or corn oil. This approach was later extended to two further ponds. On the three ponds, 48% of the eggs were untreated, and 48% of these hatched. Canola oil was sprayed on 24% of the eggs, and corn oil on 28%. No eggs sprayed with either corn or canola oil hatched. In addition to the controlled experiment a further 222 eggs were sprayed weekly with food oil and no hatchings occurred. The birds incubating sprayed eggs on Willow Pond sat on average 50% longer than those incubating unsprayed control eggs. This incubation past the due hatching date could reduce the annual number of clutches attempted by Australian white ibis, which may otherwise rear up to three clutches.

In summary, weekly treatment of Australian white ibis eggs with food oils entirely eliminated hatching and extended incubation periods on average by 50%. Spraying the eggs of pest bird populations with food oil appears to be a simple, inexpensive and effective tool to assist in managing these populations, and is likely to be generally applicable to all pest bird species whose nesting sites can be readily accessed. During the next breeding season this study will be extended to multiple nesting locations and aim to determine the optimal effective spraying regime for management purposes.

STARLICIDE® – THE BENEFITS, RISKS AND INDUSTRY NEED FOR DRC-1339 IN AUSTRALIA

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ABSTRACT: Common or European starlings are a significant introduced pest bird of agriculture in Australia that account for estimated production losses of at least $10 M per annum. The species is widespread in south-eastern Australia, and has been reported to inflict high levels of damage to viticulture, horticulture and livestock production industries, as well as being an environmental and social nuisance. Attempts to manage the economic impacts of starlings in Australia involve netting, scaring devices, shooting, and habitat manipulation. A lethal agent used in America and New Zealand, DRC-1339, is currently not registered in Australia. DRC-1339 (3-chloro-4-methylaniline hydrochloride), commercially known as Starlicide®, has been successfully used for over 35 years and is a particularly well studied invasive animal toxin. Pestat Ltd is currently reviewing the potential non-target impacts and relative susceptibility of DRC-1339 to Australian bird species, based on published data for similar overseas species. A multi-state and -industry feasibility study of the likely safety for use and market potential of DRC-1339 as an avicide in Australia is currently occurring. Field trials of non-toxic bait media and seasonal variability in bait take at three distinct climatic regions of Australia where starlings are a problem will shortly commence. This is a recently-funded work in progress, and as such only the pilot study design will be presented in this paper.

INTRODUCTION

Common or European starlings (*Sturnus vulgaris*) are a significant introduced pest bird of agriculture in Australia and overseas. The species is now widespread in south-eastern Australia (Fig. 1). Starlings have been reported to inflict high levels of damage to grapes and stonefruit crops, causing an estimated average loss of 10% of total yield (Bomford and Hart 2002). As well as physical damage, the species has been implicated in eating and fouling cattle food and water at feedlots, fouling sheep fleeces, usurping natural nest hollows and competing with native birds, spreading proclaimed weeds, acting as a disease vector and causing economic and aesthetic damage by roosting in and fouling human structures (Bomford and Sinclair 2002). Bomford and Hart (2002) reported that starlings were the worst introduced bird pest of agriculture in Australia, and accounted for losses of at least $10 million per annum. It was further estimated that annual research costs for starlings and other pest birds amounted to $3 million per annum (Bomford and Hart 2002). Additionally, the government of Western Australia has maintained an ongoing starling prevention programme since 1971, committing $418,000 in 2003/2004 (Woolnough *et al.*, this volume).

Attempts to manage the economic impacts of starlings in Australia involve numerous control methods. These include exclusion netting, scaring devices, shooting, trapping, repellents and habitat manipulation. Of the lethal means, shooting is reported to be the 'most ineffective bird control technique in Australia' (Fleming 1990) and previously trialled avicides, principally α-chloralose, have returned little success (Bomford and Sinclair 2002) and are currently unregistered for use. Perhaps the most effective management technique for controlling starlings is exclusion netting, which when applied correctly can prevent damage from all pest birds, is humane and socially acceptable (Bomford and Sinclair 2002). The high investment cost of netting means that only highly valuable crops receiving high levels of damage are likely to return the investment on the procedure (Sinclair 1990).

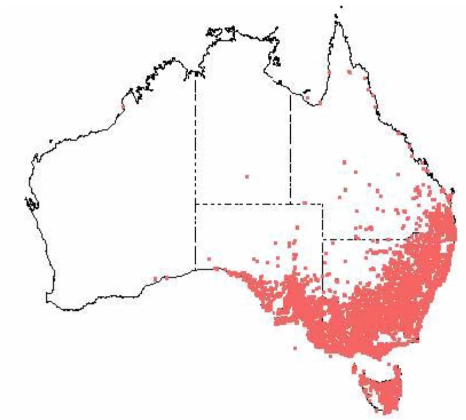

Fig 1. Map of common starling distribution in Australia (Birds Australia website 2004).

Australia is not alone in battling the damaging effects of starlings. As well as using the above mentioned techniques, the United States Department of Agriculture (USDA) has used DRC-1339 or Starlicide® since 1967 for starling control at feedlots, and later in vineyards. With different bait media and methods of presentation the toxin is also used to manage blackbirds, rock doves, corvids and gulls for the purposes of protecting human health and safety, agricultural crops and threatened or endangered species. DRC-1339 is an acute toxin causing irreversible kidney and heart damage in sensitive birds, resulting in a quiet and painless death normally 1-3 days after ingestion (APHIS Tech Note). Due to its extensive use in the USA, non-target risks of DRC-1339 have been comprehensively studied, resulting in estimates of median lethal dose (LD_{50}) for more than 60 species of birds as well as many mammals. Furthermore, in 36 years of widespread use in the USA DRC-1339 has not been responsible for any known secondary poisonings of mammalian or avian scavengers or predators, with the possible exception of a single crow. Pestat Ltd has recently signed a Memorandum of Understanding with the USDA's National Wildlife Research Centre, and as a consequence is able to access this agency's wealth of published and unpublished data on DRC 1339. DRC-1339 is also registered for use in New Zealand, where it has been used successfully to control rooks.

RESEARCH PLAN

The aim of this project is to undertake a multi-state and -industry feasibility study of the likely risks/benefits and market potential of DRC-1339 as an avicide in Australia. This will involve three distinct activities, each of which will represent a stringent objective milestone that will ensure that the Australian potential of DRC-1339 is not over-promised. The three activities are:

Desktop risk analysis

Undertake a comprehensive desktop exercise to assess predicted susceptibilities of bird Families in Australia based on data for the 60+ bird species already examined by USDA.

Potential non-target exposure risks of DRC-1339 result from a combination of bird distribution, intrinsic susceptibility, and diet and feeding habits. Beak and cranium morphology are two further attributes that affect non-target exposure and that could be used to limit impact through starling-targeted feeders in areas where they are required. The breadth of USDA toxicity data, combined with Australian bird data, will allow a highly detailed risk analysis to be undertaken so as to elucidate areas/species where the project lacks background knowledge of the potential risks associated with use of the toxicant.

Stakeholder survey

Undertake a stakeholder survey of Grape and Wine Research and Development Corporation (GWRDC) grape growers, Meat and Livestock Australia Ltd (MLA) feedlot owners and Horticulture Australia (HA) fruit growers to benchmark their starling problems (along with that of other pest birds), gauge their interest in use of DRC-1339, document their concerns and estimate the market potential for DRC-1339-based product/s. This activity will be undertaken through existing lines of communication between the Research and Development Corporations (RDC's) and their stakeholders. At this point a cost-benefit analysis will be undertaken to assess the feasibility of importing, registering and commercialising DRC-1339 in Australia.

Non-toxic field trials

If activities 1 and 2 yield promising results, including limited and acceptable potential non-target species exposure risks and an indication of significant industry demand for the product, then the project will proceed to field trials of non-toxic bait media and timings in three distinct climatic and land use regions of Australia where starlings are impacting on agriculture. Trial sites will include semi-arid Ceduna (mean annual rainfall 290 mm), the Mediterranean climate of the McLaren Vale (mean annual rainfall 640 mm) and temperate Orange (mean annual rainfall 940 mm). Trials will commence in summer to coincide with large congregations of starlings that form near Ceduna, then continue into the autumn grape ripening season when the maximum impact on viticulture occurs, and will continue through until the end of the breeding season in October 2005 (approximately). Throughout all trials, starling numbers will be estimated and visitation rates to different bait substrates measured. At the same time non-target visitation to bait stations will be monitored. Animal Ethics Approval for these trials will be sought.

DISCUSSION

The design of this pilot study is one that will involve agencies from three states working with private industry and an international collaborator in a Commonwealth Government-backed assessment of the Australian need for an avicide that has been used for several decades in the USA and is registered for use in New Zealand. The study aims to assess likely target specificity, stakeholder interest, market potential, possible bait substrates, appropriate application rates and timings, and the requirement for starling-targeted feeders all in the next 12 months at three separate sites. At the completion of the pilot study, project collaborators will determine whether to proceed with preparing a business case involving further research with the view to registration, or to discontinue investment in DRC-1339 due to a lack of target-specificity, stakeholder interest or our inability to attract starlings to a suitable bait material.

It is not the intention of this feasibility study to undertake intensive lethal pen or field trials of DRC-1339, nor to seek its registration. Should each of the steps of the feasibility study listed above provide promising results, then additional support will be required from industry.

Further funding would be necessary to undertake the more expensive Australian research component (need to know how, when and where to best target the birds in order to minimise their damage in each particular situation/location), non-target testing, bait stability testing and registration processes. It is also noted that at this point interested third party organisations not initially involved in the pilot study will be invited to become involved. Also at this time, a mutually agreed commercial partner will be engaged to take the product to market.

In summary, DRC-1339 is a product successfully used in America and New Zealand and its potential use in Australia should be investigated. This feasibility study will objectively assess the benefits and risks of DRC-1339 to allow an informed decision on whether Australian registration of the product is warranted. In addition, there is little doubt that extremely useful data relevant to invasive species management will be generated by both the non-target risk assessment, industry perception of bird problems and current controls and the field trials of non-toxic bait media. The authors look forward to presenting findings in the literature and at future meetings.

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MANAGING URBAN NOISE IMPACTS FROM BIRD SCARING DEVICES; A NEW AND BALANCED APPROACH

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ABSTRACT: Noise generated by bird scaring devices used by growers attempting to protect their crops often creates conflict with residents at urban/rural interfaces. The Environment Protection Authority of South Australia has developed guidelines for the use of these devices with input from a working party of community, primary producer and local and state government representatives. The guidelines incorporate the concept of a performance-based objective (PBO) to delineate "unreasonable interference" and use the Accumulated Peak Level (APL) as the appropriate measure of impulsive noise generated by devices like gas guns. Separate APLs have been set for primary production zones and interface areas between primary production and residential, rural living or buffer zones. A different PBO is set for electronic bird scaring devices that generate high tone noise modulating in frequency and amplitude.

A central concept in the guidelines is that noise-generating devices are likely to be most effective when used strategically and as part of a multi-faceted approach to bird management. To assist growers, the guidelines include an outline of a bird management plan and provide access to information on developing such a plan. This paper summaries the processes in the development of the guidelines and the basis of the principles therein.

INTRODUCTION

Poor developmental planning can result in a conflict that arises from a lack of balance between primary producers desire to use noise in an attempt to protect their crops from bird damage and local individuals and communities whose amenity is threatened by noise trespass. The problem is not new but is common throughout the world. Two factors seem to have increased the severity of the problem in recent years. The first is changes in land-use with more intensive horticulture and viticulture creeping in towards peri-urban areas. The second is the expansion of residential areas out from urban areas through rezoning and the growing number of people seeking a semi-rural life-style by taking up residence in or adjacent to areas zoned for primary production. This conflict not infrequently results in court action and may involve the community and a range of private and state and local government instrumentalities. There has been general frustration among all stakeholders at the lack of a standard technical-based approach to find an acceptable solution to the problem.

In South Australia, the *Environment Protection Act* (1993) specifies an environmental duty of care that requires a person not to undertake an activity that pollutes, or might pollute, the environment. Noise is a form of pollution that can result in environmental harm. In the past, noise from audible bird scaring devices has been addressed in an Environment Protection Authority (EPA) policy which set limits on the level of noise that could be produced during the 'night' (essentially preventing use of the devices after 8 p.m. or before 7 a.m.) and as a mandatory provision attracted a penalty under the Act for non-compliance. However, there was no specific direction provided for the use of the devices during the 'day' (7 a.m. to 8 p.m.) although their use during this time still had to comply with the environmental duty of care.

Draft guidelines for the use of audible bird scaring devices were introduced in 1995 to assist local government prepare by-laws and policies relating to audible bird scarers. These guidelines limited the number of devices per unit area (e.g. 1 device per 10 ha), the maximum frequency for discharges (e.g. 6 shots per hr) and set minimum separation distances to the nearest residence (e.g. 200 to 300 m). These conditions were generally consistent with those used interstate and overseas but they have not solved many situations of conflict and there was a clear need to review the whole situation. This paper summarises the consultation process and the new guidelines that resulted from that consultation which, through setting of a performance-based objective, aim to indicate the standard of care required of users of audible bird scaring devices to comply with the legislative duty.

METHODS

Consultation

To assist in developing the guidelines, a working group was formed with participants from the community (primarily residents' groups opposing the use of gas guns), primary producer industry groups (representing viticulture, tree fruits and general horticulture interests) and local and State government. An independent facilitator conducted the meetings. An acoustic engineer with extensive experience of presenting technical evidence in court relating to issues with audible bird scarers made an introductory presentation to the working group. In addition, numerous documents from Australia, NZ, UK, USA and Canada on bird scarer noise policy and management were consulted.

The working group initially explored all the issues relevant to the group or organization each member represented. These issues were further developed into a list of 10 principles around which the guidelines were formed. In essence the principles aimed to set a balance between the rights of primary producers and those of the community living with this difficult issue.

Setting a performance-based objective – the Accumulated Peak Level

The most commonly used audible bird scaring devices are the propane powered gas guns that generate characteristic low frequency impulsive noise. A search of world literature found limited information on the relationship between impulsive noise and health effects. However, a study (Bullen *et al.* 1991) of the impact of impulsive noise from Holsworthy artillery range south of Sydney, on the neighbouring community is regarded as a world standard. Bullen *et al.* (1991) found that the Accumulated Peak Level (APL) was the superior measure in relation to estimating community reaction (degree of annoyance) to impulsive noise and that LinPeak was the most appropriate descriptor of such impulsive noises. The APL is a single number that represents the cumulative impact on people of the number of shots and their level of noise over the course of a day. Effectively, it is the logarithmic addition of noise levels from successive shots measured at a receiver. LinPeak is an unweighted linear measure of the absolute noise level and can be regarded as the actual impulse without modification.

A value of APL responds to an expected percentage of the community being 'seriously affected'. Environmental policy generally accepts a 10% level of seriously affected rather than no effect at all, to account for economic and technical considerations, and variation in individual responses noise. The balance between these considerations changes according to the location of the receiver. The 10% rule would apply to the protection of a resident in a residential zone but there would be a different balance for a resident in a horticultural zone (the balance being in horticulturists' favour) and for a resident at the interface of a horticultural zone where there is a need for both land users to compromise.

Electronic bird scaring devices do not generate impulse noise rather intermittent bursts of noise that are high in tone and modulating in amplitude and/or frequency. A suitable descriptor for this type of noise is the equivalent noise level (L_{Aeq}), which is effectively an average noise level over the period of time that a device is operating. An EPA noise policy provides a means for adjusting noise levels (i.e. a 5 dB(A) penalty) that exhibit electronic device type characteristics.

Management guidelines

The working group accepted that a grower should have a bird management plan if the grower's operation of audible bird scaring devices might have an adverse impact on the surrounding community. The plan should outline the grower's integrated bird scaring and management strategies and should contain certain elements (e.g. separation distances and hours of operation) that can demonstrate how the performance-based objective will be achieved. Where devices on multiple properties contribute to an excessive APL at a single residence, each property should participate in an area bird management program/plan that must achieve a cumulative maximum APL through a coordinated approach amongst the properties.

RESULTS

Consultation

It was not always possible to achieve total consensus on all issues. Community representatives particularly disagreed with the threshold APL set at 10% 'severely affected' – they argued for a 0% severely affected level but most realised this was impractical given that residents are exposed to noise from sources other than bird scarers. There was also a degree of concern from local government about the need for additional resources to support administration and compliance resulting from implementation of the guidelines.

Performance-based objectives

The guidelines provide separate PBOs (Table 1) for impulsive noise from gas guns and for non-impulsive noise generated by electronic devices that have been set for primary production zones and interface areas between primary production and residential, rural living or buffer zones.

Table 1. Maximum performance-based objectives for (A) impulsive noise as produced by a gas gun, and (B) electronic noise amplified through speakers, generated as part of an integrated bird scaring strategy, according to the location of the receiver.

Type of noise	**(A) Impulsive**	**(B) Electronic**
Location of receiver	**Maximum APL (dB)**	**Maximum L_{Aeq} (dB(A))***
Primary production zone	118	57
Interface between primary production zone and residential or rural living zone or buffer zone	115	52

* Subject to adjustment for annoying characteristics under the Environment Protection (Industrial Noise) Policy 1994

Notwithstanding compliance with the APLs in Table 1, the guidelines set maximum values that should not be exceeded by any single impulsive device (Table 2).

Table 2. Maximum values associated with single impulsive device.

Parameter	Maximum value
Maximum noise level from any shot	100 dB(LinPeak)
Maximum number of shots in any hour	6

As a rule of thumb:
- a gas gun located more than 300 m from a residence in a primary production zone operating at six shots per hour for ten hours of the day should achieve the performance-based objective,
- a gas gun located more than 500 m from a residence in a residential, country township or rural living zone operating at six shots per hour for ten hours of the day should also achieve the performance-based objective.

Care should be taken where the topography is substantially different, or where weather conditions may assist in propagating noise.

No change was made to the provision that at 'night' (after 8 p.m. or before 7 a.m.), noise from bird scaring devices must not exceed a noise level of 45 dB(A).

Management guidelines
In order to assist growers to achieve compliance with the PBOs, an outline of the elements of a bird management plan is provided in an appendix to the guidelines. It is expected that each property will have a specific plan that may require review from season to season and from one crop or part of the property to another. The guidelines also provide examples of approaches that could be built into area bird management plans to achieve compliance. These include joint rationalisation of the number of devices, their relative locations and their discharge rate and timing, rotation of use of devices to different properties or portions of properties during the day, and an increase in the range of and variation in use patterns of alternative bird management measures, including visual as well as auditory techniques.

DISCUSSION

The draft guidelines known as Environment Noise Guidelines: Audible Bird Scarers[5] was released for public comment in 2003, and amended in light of comments received.

It is the intention of the EPA to link the draft guidelines to a new Environment Protection (Noise) Policy currently in its final stage of drafting under the Environment Protection Act 1993.

Such a link would enable direct legal action to be taken to secure compliance with the guidelines with significant penalties should these requirements continue to be breached.

The adoption of an APL as a performance-based objective together with a requirement for a bird management plan will shift the emphasis in regulation of noise from audible bird scaring devices from a change in behaviour (e.g. the number of discharges per hour) to one of reducing the impact (i.e. the cumulative effect on any 'receiver'). This shift will introduce a fairer means of dealing with multiple impacts and more closely reflect the duty of care

[5] http://www.epa.sa.gov.au/pdfs/bird_scarers.pdf

established by the Act. It also aligns with the direction that can be expected to emanate from courts as they consider the sort of evidence available from relevant research.

However, the approach may result in less clarity for a grower or for nearby residents, as to what behaviour is acceptable. The guidelines (especially those for operating gas guns) address that concern by providing rules of thumb for device operators.

The working group considered that more stringent restrictions should be applied when inappropriate/ineffective use of devices (generally when used on their own for extended periods of time) causes unacceptable problems for residents. In fact, one of the basic premises in the guidelines is that audible bird scaring devices are likely to be most effective when used strategically and as part of an integrated bird management program. Where devices on multiple properties measurably impact on a resident(s), the guidelines require preparation of an area bird management plan and that will need the cooperation and coordination of all growers concerned. The advantage of such an approach is that it may result in more effective bird management over an area, rather than just over a property. In addition, a coordinated approach may more effectively address the issues of habituation of birds to scaring and the fact that scaring simply relocates the problem to another property. The working group recognised the problematic nature of the development and implementation of area bird management plans but considered in such situations, the pro-active involvement and leadership of industry groups and local and State government authorities was important.

The guidelines recognize that amendments may be required following research or as additional information becomes available as the guidelines are put to the test by local government.

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WILDLIFE, LIVESTOCK AND FOOT-AND-MOUTH DISEASE: MODELS FOR FERAL GOATS AND SHEEP

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ABSTRACT: Foot-and-mouth disease (FMD) is a disease of ungulates that causes severe economic hardship to countries where outbreaks occur. Sheep and goats have been implicated in the spread and maintenance of FMD in many countries where FMD is endemic. In Australia, feral goats are widespread, locally abundant and often coincident with merino sheep, the most numerous domestic livestock.

In the absence of FMD, epidemiological models are an aid to contingency plans for controlling the disease. In this study, the population dynamics, biological and behavioural parameters of feral goats and merino sheep were used to build two-species temporal and spatial compartmental models (susceptible– latent– infected– recovered, SLIR) of FMD virus (FMDV) transmission in an environment with high densities of both hosts.

To construct a stochastic spatial model of FMDV transmission between species, a resource selection function was first fitted in a geographic information system (GIS) to observational data of feral goats. The resource selection function was then used to set the probabilities of occurrence of feral goats in 1 ha areas of the study site. Sheep were deemed to be equally likely to occur in any part of their paddocks.

Contacts between individuals goats and between sympatric groups of goats and sheep were frequent and exceeded 1 per day for all these types of contact, while contact between herds of goats were rare as were contacts between groups of sheep. The temporal models of FMDV transmission showed that the rate of contact within and between species was such that FMD was predicted to spread rapidly throughout infected herds or flocks. The models indicated that vaccination of sheep where feral goats are present had no effect on persistence of FMD in the two populations unless the herds of goats in contact with infected flocks of sheep were culled to a low level prior to the reintroduction of vaccinated sheep.

The spatial model predicted that FMD would die out in a community of merino sheep and feral goats in less than 90 days because of the low rate of contact between herds of goats and between herds of goats and sheep flocks. Therefore in the event of an FMD outbreak, it is important that reintroductions of sheep are not permitted until at least 90 days after completion of culling.

These results allow improved contingency planning for FMD outbreaks in areas with high livestock and feral goat densities. However, alternative contact rates and models should be examined for drier environments where movements of feral goats are more extensive and likely constrained by water bodies, and contact between herds of goats will be different.

WEATHER AND THE LONG-DISTANCE MOVEMENT OF RABBIT HAEMORRHAGIC DISEASE VIRUS

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ABSTRACT: Rabbit haemorrhagic disease virus (RHDV) escaped from a quarantined field trial in Australia in 1995 and spread through much of the Australian wild rabbit population within a year. On several occasions during this period RHDV established new foci of infection several hundred kilometres from previously reported outbreaks. These discontinuous range expansions were often associated with unusually heavy rainfall and/or with the movement of small low-pressure systems across the Australian continent. Vertical and horizontal air movement within low pressure systems could move vector-borne or aerosolised micro-organisms long distances, following which they might be returned to earth by downdrafts associated with heavy rain. This paper discusses two of these movements and the associated weather conditions. An understanding of long-distance movements of RHDV could contribute to our knowledge of the epidemiology of RHD, but it may also have wider implications, related to exotic disease control, to the determination of appropriate conditions for confining potential new candidate biocontrol agents under quarantine while they are being field tested prior to their possible release, and to the understanding of the epidemiology of any disease which is spread by wind-borne vectors or aerosol.

INTRODUCTION

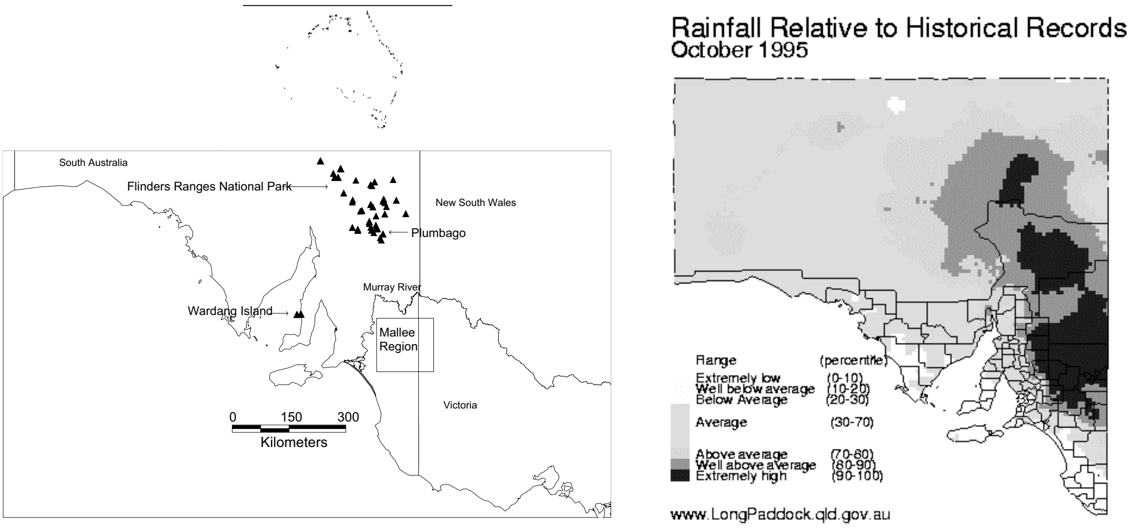
Rabbit haemorrhagic disease virus (RHDV) escaped from a quarantined field trial on Wardang Island in Australia in 1995 and spread throughout much of the Australian wild rabbit population the following year (Kovaliski 1998). On several occasions RHDV established new foci of infection several hundred kilometres distant from previously reported outbreaks. Some of these discontinuous range expansions were associated with unusually heavy rainfall and/or with the movement of small low-pressure systems centred on the Australian mainland. Disease can be spread long distances by the wind (Pedgley 1983). The convection and advection of air within low pressure systems has the potential to move vector-borne or aerosolised micro-organisms long distances, following which they could be returned to earth by downdrafts generated by heavy rainfall or by the active flight of the vectors, thereby establishing new foci of disease some distance from previous outbreaks. This paper discusses some of the observations throwing light on these suggestions.

OBSERVATIONS

Escape of RHDV off Wardang Island in September 1995

RHD escaped from quarantine on Wardang Island in September 1995, and the first outbreaks on the adjoining mainland were observed the following month (Kovaliski 1998). The distribution of new RHD outbreaks, and the areas receiving above average rainfall, in October 1995 are shown in Fig. 1. Most of the RHD outbreaks occurred in areas near Plumbago and the Flinders Ranges National Park that received unusually heavy (>80 percentile) rainfall. This raised the question, was there a causal connection between these outbreaks and rainfall, and, if so, what was the underlying mechanism?

The weather conditions associated with the movement of RHDV from Wardang Island to the area around Plumbago and the Flinders Ranges National Park are unclear (Wardhaugh and Rochester 1996). Fig. 2 shows the low-pressure system that produced most of the rainfall shown in Fig. 1*b* (for example, at Yunta – near Plumbago – it produced 2, 6 and 34mm on 20, 21 and 22 October respectively). The presence of RHD in the area around Plumbago and the Flinders Ranges National Park was not confirmed until 28 October, but circumstantial and unconfirmed reports suggest it may have been present in both areas in mid-October, before this low developed. If this is true, RHDV must have been transported to these areas before the low shown in Fig. 2 developed, but this low may then have resulted in the regional dispersal of virus already in the area and the intensification of RHD epizootics to the point that they were noticed and brought to the attention of the authorities. However, if these unconfirmed reports are in error, it is possible that RHDV was both transported to the Plumbago–Flinders Ranges area and disseminated by the system that produced the rainfall on 20–22 October.



(*a*) (*b*)

Fig. 1. (*a*) the location of RHD outbreaks for October 1995, and (*b*) South Australian rainfall percentiles for the same month.

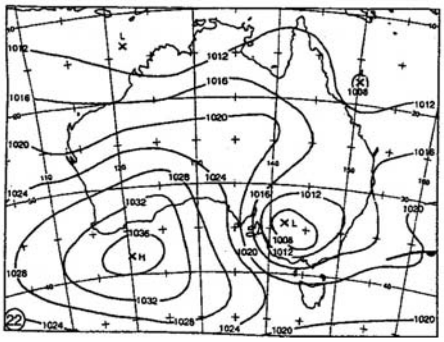


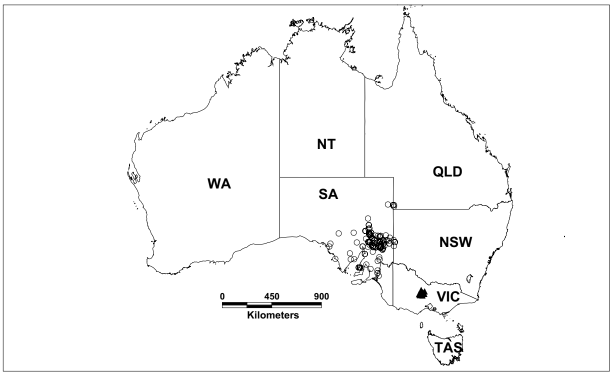
Fig. 2. Synoptic weather map for 22 October 1995.

Small low-pressure systems producing rainfall and centred near a disease outbreak would appear to have the potential to spread virus present either as an aerosol or on a vector. Cloud cover would reduce degradation by ultraviolet light, and high humidity could lengthen the time the virus survived outside a host. The virus could be transported into the atmosphere by the ascending air associated with low pressure systems, be transported radially by atmospheric convergence or divergence, and be returned to ground level by downdrafts generated by heavy rainfall or, in the case of vector-borne virus, by the flight of the vector. In addition to movement generated by air circulation within the low-pressure system, movement of the system as a whole could potentially transport viral particles large distances before their return to earth. A low pressure system centred over Australia would be less likely to transport an airborne virus offshore than one centred south of Australia, which is the more common position of the low pressure systems affecting southern Australia.

Could this provide a plausible meteorological mechanism for other long-distance movements of RHDV apparent in the early history of RHD outbreaks? The hypothesis that there was a causal connection between the long-distance dispersal of RHD and low-pressure systems would be supported if other examples could be found where the occurrence of new RHD outbreaks in areas remote from previous outbreaks was correlated with the presence of low-pressure systems and heavy rainfall. Several long-distance movements of RHD occurred in the year following the escape of RHD off Wardang Island (see maps in Kovaliski 1998), and one of these will be considered below.

Appearance of RHD in central Victoria in March 1996

Eleven RHD outbreaks occurred near Bendigo in central Victoria in March 1996, several hundred kilometres from other known occurrences of virus (see Fig. 3*a*). The first was reported on 1 March 1996, the second on the 6th and the remainder from the 19th to the end of the month. RHD kills rabbits within 1–4 days of infection (Cooke and Berman 2000; Cooke 2002), so the virus must have spread to Victoria in February 1996 or earlier. Above average rainfall occurred in the same area in February (Fig. 3*b*) and in January (not shown). One candidate weather system is shown in Fig 4*a*; this produced heavy rainfall (43mm in total) at Bendigo on 27 and 28 February. However, it is doubtful if this system could have transported sufficient virus hundreds of kilometres to produce noticeable mortality as soon as 1 March, or to produce 11 noticeable outbreaks in one small area near Bendigo without producing outbreaks in other areas as well. It is more plausible to suggest that a small amount of virus was transported by an earlier weather system to establish a single, unnoticed, outbreak near Bendigo, which was amplified and spread over the surrounding area by subsequent systems to produce a more noticeable epizootic.



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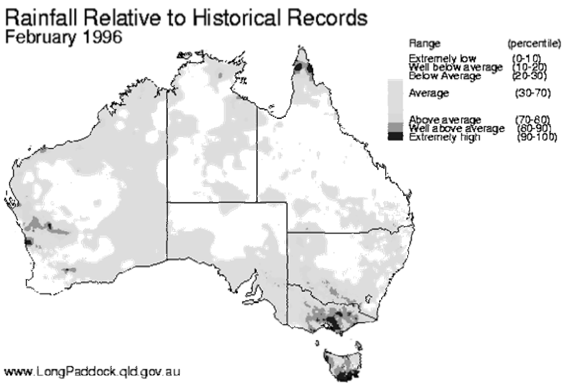

(*b*)

Fig. 3. (*a*) the location of RHD outbreaks for March 1996 (solid triangles are new outbreaks for the month and open circles are earlier outbreaks), and (*b*) rainfall percentiles for February 1996.

The level of RHD outbreaks in Australia was low over the 1995/1996 summer (Kovaliski 1998), with ten outbreaks in December 1995, eight in January 1996, and only one in February 1996. It is therefore possible that the disease arrived in the Bendigo area some weeks before March 1996 and persisted at a low level, without causing noticeable mortality, until conditions improved. Such improvement may have been provided by rain that fell in February 1996, as this was largely confined to Victoria (see Fig 3*b*), the only part of Australia where RHD outbreaks occurred in March 1996. Rainfall in eastern Australia in January 1996 was more widespread, and fell in some areas where RHD had previously occurred apparently without causing new outbreaks (data not shown). In this case RHDV may have been carried to the Bendigo area by low pressure systems on 8–9 February (28mm rain at Bendigo) (data not shown), or 31 December 1995/1 January 1996 (47mm rain at Bendigo) (Fig. 4*b*), with the outbreaks noticed in March being generated by the favourable conditions accumulating from the 8–9 and 27–28 February systems. The system shown in Fig. 4*b* tracked across RHD-infected areas in South Australia and then over central Victoria.

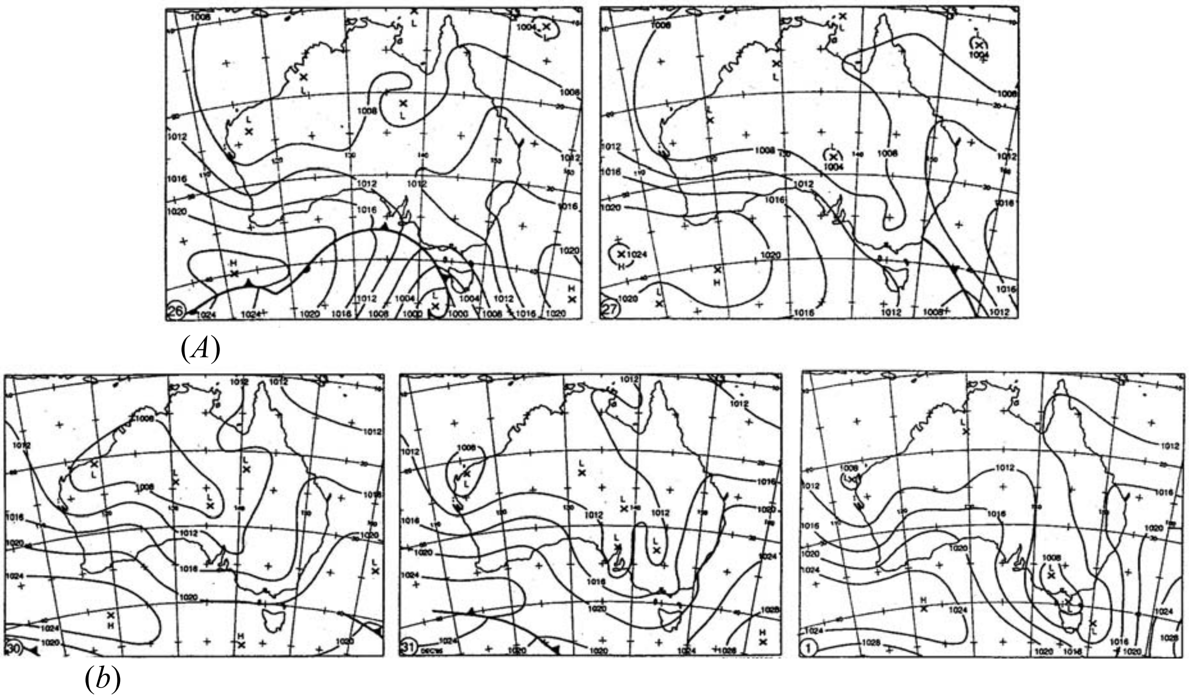

Fig. 4. Synoptic weather maps for (*a*) 26 and 27 February 1996 and (*b*) 30 December 1995 to 1 January 1996.

DISCUSSION

Though not conclusive, the evidence presented here supports the existence of an association between the observation of major dispersal events of RHD, low-pressure systems and above average rainfall. However, a closer examination of the meteorological data associated with these observations suggests that the processes underlying them proceed in two stages, the first being a relatively inconspicuous dispersal event whose timing may be uncertain, and the second a more noticeable local/regional intensification and multiplication of outbreaks in response to heavy rainfall associated with a low pressure system centred nearby. The probability that the stage 1 transport of virus to the outbreak area is affected by a similar weather system as well is unclear, but given the apparent capacity of stage 2 events to produce multiple new outbreaks, this possibility cannot be discounted.

Rainfall has the capacity both to return airborne micro-organisms to earth, and possibly to create conditions favourable for the proliferation of some potential insect vectors in the same area. The association of some dispersal events with heavy rainfall suggests that mosquitoes may be involved as a vector, a possibility also considered by Wardhaugh and Rochester (1996) in relation to the October 1995 outbreaks. The mosquito *Culex annulorostris* can transmit RHDV under laboratory conditions (Cooke 2002).

The hypothesis that RHDV may have been transported by low-pressure systems will be tested by modelling air parcel movement for relevant systems to establish whether plausible meteorological mechanisms exist for the long-distance transport of RHDV by these systems. In addition, it may be possible to infer whether the virus was transported on insects or as an aerosol from a study of the air temperatures and wind speeds associated with the putative movements and an understanding of the meteorological and other requirements for airborne movement of the various candidate organisms.

The work has the potential to contribute to our understanding of the epidemiology of RHD, but it may also have wider implications. An understanding of the interaction between weather and the movement of animal diseases over long distances has relevance for contingency planning for exotic disease control, for the establishment of appropriate conditions for confining new candidate biocontrol agents under quarantine while they are being field tested prior to their release, and for the understanding of the epidemiology of any disease spread by flying vectors or aerosols.

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Ron Sinclair, Greg Mutze and Tony Henson contributed information and their recollections, and Greg commented on the manuscript. John Kovaliski provided the maps of monthly RHD outbreaks.

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VARIATION IN ACTIVITY OF RABBIT HAEMORRHAGIC DISEASE DUE TO RABBIT POPULATION DENSITY AND A BENIGN CALICIVIRUS

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ABSTRACT: Studies commenced in 2001 to determine whether conventional rabbit control programs affected the subsequent impact of rabbit haemorrhagic disease (RHD). Eight sites were chosen in semi-arid and moist temperate areas. At each site, higher-density populations were paired with nearby populations where density was reduced by chemical/mechanical rabbit control. Rabbits were classified as having antibodies to virulent RHD, to an RHD-like non-pathogenic calicivirus (benign CV) or no antibodies (sero-negative). The prevalence of RHD antibodies was similar across regions but there were more sero-negative rabbits in semi-arid (43-54%) than temperate areas (19%,) and fewer rabbits with benign CV antibodies in semi-arid (6-10%) than temperate areas (38%). This effect was evident in both juvenile and adult rabbits. Rabbit control programs reduced rabbit density, increasing the proportion of sero-negative rabbits and reducing RHD sero-prevalence in juvenile rabbits (<1300g) but not in adults (≥1300g). Hence, rabbit control slowed the circulation of RHD in juvenile rabbits but ultimately a similar proportion of rabbits were infected. Because primary infection occurs at a later age and mortality is higher in older juveniles, rabbit control does not reduce the impact of RHD. We found no effect of rabbit control on the interaction between RHD and benign CV that could be exploited to improve the effectiveness of rabbit control.

INTRODUCTION

The occurrence of RHD in Australia provides a unique opportunity to capitalise on the reduction in rabbit numbers caused by the disease. Management of rabbits can be improved by gaining a better understanding of how the virus behaves when conventional rabbit control impacts on rabbit populations. But understanding the epidemiology of RHDV is complicated by the existence of non-pathogenic or benign forms of calicivirus (Capucci *et al*. 1996) that were widespread in Australian rabbit populations prior to the spread of RHD in 1995 (Cooke *et al*. 2000). In Australia a pre-existing, benign CV is reported to provide higher levels of protection from the lethal RHD for rabbits living in cool, moist, temperate areas than to rabbits living in semi-arid or arid zones (Cooke *et al*. 2002). Understanding the behaviour of both virulent RHD and benign CV may enable more effective use of our conventional control techniques if those techniques affect the transmission or impact of either disease. This study examined the impact of rabbit control on antibody prevalence in the northern, semi-arid areas and southern, cool-moist, temperate areas.

METHODS

Eight study sites were monitored in South Australia and Victoria (Fig. 1). Each site consisted of two sub-sites of >5 km^2: a higher-density population sub-site, paired with a nearby sub-site where rabbit population density was reduced by warren ripping, destruction of surface harbour, baiting and fumigation Rabbit abundance and serological status were monitored at four monthly intervals over two years.

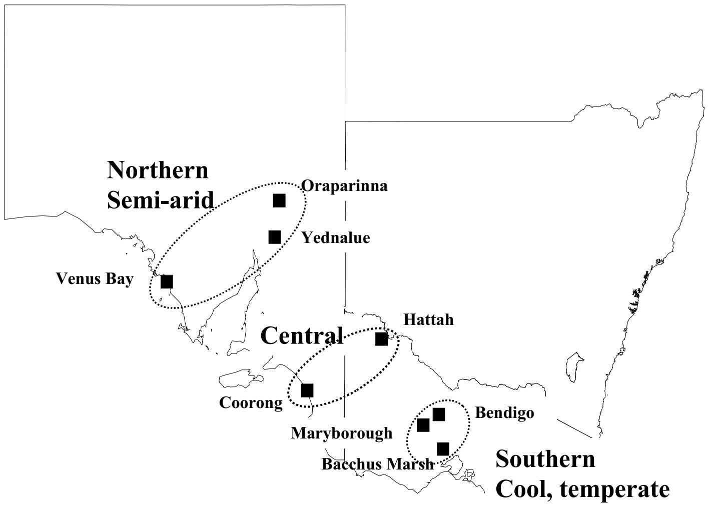

Fig. 1. Locations of the paired monitoring sites

Indices of rabbit abundance were obtained from replicated spotlight counts of rabbits along vehicle transects (5-20km). Data were expressed as rabbits/km to allow comparison between sites with different transect lengths.

Rabbit serum and tissue samples were collected from samples of 15-30 shot or live captured rabbits at each sub-site. Sera were tested using enzyme-linked immunosorbent assays (ELISAs) for antibodies raised against RHDV. Quantitative analysis of competition ELISA and ELISAs for IgG, IgA and IgM antibody isotypes (Capucci *et al.* 1991a,b) enabled the classification of antibody status into three groups: sero-negative (no antibodies detected), antibodies to RHD and antibodies to a non-pathogenic or benign CV (Cooke *et al.* 2000). Benign CV antibodies can only be detected in rabbits that have not been infected with RHD (ie RHD antibodies mask the presence of any antibodies to the benign CV). Therefore, we considered RHD prevalence as the proportion of all rabbits tested with RHD antibodies, whereas the prevalence of benign CV immunity was taken as the proportion of RHD-negative rabbits that had benign CV antibodies.

At each sub-site, at all observation periods the proportion of animals within immune classes, log10 transformed number of rabbits/spotlight km and the proportion of rabbits <1300g were calculated. Then for each sub-site the average over observation periods of the calculated values was used as data in the analysis, but excluding times when less than five rabbits were captured. Sub-site means were then analysed as a three, region by two treatment factorial analysis of variance with two error terms. The region main effects were compared to a between site error term. The treatment main effect and interaction between region and treatment where compared to a between sub-site within site error term. Since no interactions between region and treatment were found (P>0.05) only main effects are presented.

RESULTS

Estimates of rabbit abundance and the proportions of rabbits within different immune classes appeared to cluster around three regions: the semi-arid northern region, (Oraparinna, Yednalue and Venus Bay), the central region (Hattah and the Coorong) and the southern, higher rainfall region of central Victoria (Maryborough, Bendigo and Bacchus Marsh) (Fig. 1).

1. Rabbit abundance

There were more rabbits in the southern temperate region (8.5 rabbits/spotlight km) than in the central (1.3/km) or semi-arid northern regions (2.4/km) (P=0.017, using log10 transformed values of the arithmetic means). Control efforts were successfully applied; reducing rabbit populations by 76% on log-transformed values (P<0.00025, 95% CI 64-84). On a numeric scale, this equated to a mean reduction from 6.82/km in the uncontrolled areas to 1.97 rabbits/spotlight km in controlled areas. There were no significant regional differences in the proportional reduction achieved by control efforts (P=0.146).

2. Antibody status of rabbits

Influence of region

For both juvenile and adult rabbits, the proportions of populations classified with virulent RHD antibodies were similar for all regions (Fig 2). There were more rabbits classified as sero-negative in northern (54%) and central (43%) regions than in southern areas (19%), at the expense of fewer rabbits classified with the benign CV antibodies in northern (6%) and central (10%) regions than in southern areas (38%).

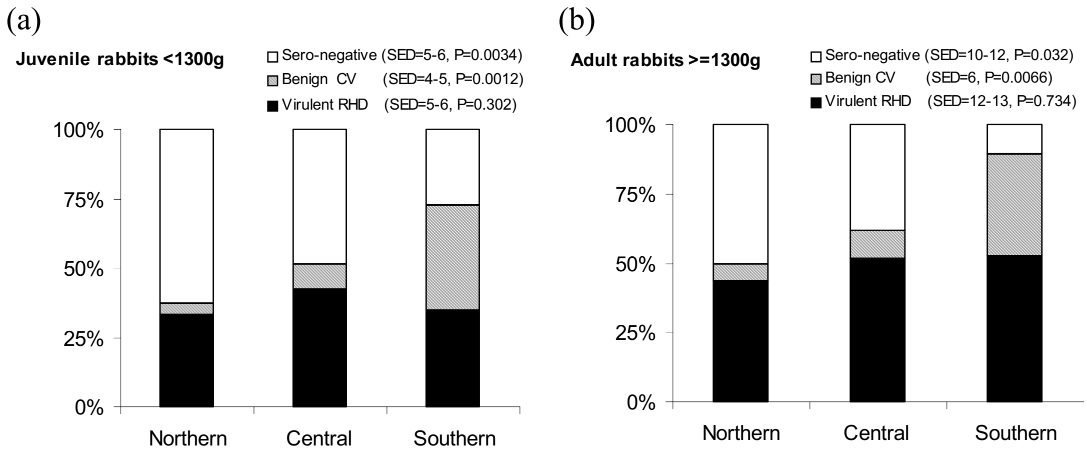

Fig. 2. The proportion juvenile (a) and adult (b) rabbits with no antibodies (sero-negative) or with antibodies to benign CV or RHD, in northern, central and southern regions.

Influence of rabbit control

Rabbit control significantly reduced the proportion of young rabbits classified with virulent RHD antibodies and increased the proportion of young rabbits that remained sero-negative. The overall proportion of young rabbits classified with antibodies to benign CV appeared to be little effected by rabbit control. However when the effect of control was restricted to the southern region, where benign CV was common, there was an indication (P=0.06) of a relatively large decrease in incidence of the benign CV classification in juvenile rabbits. Overall, there was no significant effect of rabbit control on the antibody status of adults (P>0.1, Table 1). However in two cases where seroprevalence of RHD antibodies in non-controlled populations was already low, RHD was much less prevalent in adults from controlled lower-density populations.

Seasonal effects
At all sites, RHD showed distinct seasonal patterns of activity that were generally consistent with previous studies. Antibody prevalence increased to almost 100% during some outbreaks and declined when young susceptible animals were recruited into the populations. In the arid and central regions, outbreaks of RHD occurred in sero-negative rabbits during late winter/spring. Virus activity was very low in summer but significant disease activity also occurred during autumn and early winter in arid pastoral areas. In the higher rainfall districts of southern Victoria, distinct outbreaks of RHD occurred in spring and summer but most animals infected were already carrying antibodies from infection with benign CV earlier in the season.

Table 1. The effect of rabbit control on the proportions of young and adult rabbits with CV antibody classes: sero-negative (no antibodies), antibodies to benign CV or RHD.

Measurement	No control	Control	SED	Pvalue
Young rabbits <1300g				
Sero-negative (%)	38	54	4.6	**0.019**
Benign CV (%)	19	17	3.6	0.503
Southern Region only	45	31	5.8	0.060
Other regions	4	8	4.5	0.381
RHD (%)	43	29	4.8	**0.040**
Adult rabbits ≥1300g				
Sero-negative (%)	29.2	35.7	4.2	0.182
Benign CV (%)	18.1	19.1	2.9	0.741
RHD (%)	52.7	45.2	4.1	0.124

DISCUSSION

In this study, conventional rabbit control programs reduced the proportion of young rabbits with protective RHD antibodies, but had no consistent effect on the antibody status of adults. From this we conclude that lowering rabbit density delays infection with RHD, (i.e. increases the mean age at which juvenile rabbits are first infected) but that the virus continues to circulate in lower-density populations and ultimately infects approximately the same proportion of the population. Because young sero-negative rabbits are more likely to survive infection than older sero-negative juveniles or sero-negative adults (Robinson *et al.* 2002), it is likely that conventional rabbit control increases the overall mortality rates from subsequent RHD outbreaks, albeit by slightly increasing the life-span of the individuals before infection. Hence rabbit control slows the circulation of RHD but does not reduce its effectiveness. Exceptions to this generalisation may occur where transmission of RHD in the area is already poor.

In the southern region there are also indications that rabbit control reduced the proportion of rabbits with benign CV antibodies. Failure to detect a more general effect may have been because so few rabbits had benign CV antibodies in the central and northern regions. Antibodies to the benign CV can currently be detected only by an indirect method: they react strongly to only one of four ELISAs that were developed to test for antibodies raised against RHDV. This leaves open the possibility of misclassification of some rabbits with low antibody titres so that results must be viewed cautiously where the prevalence of benign CV antibodies is very low. Nevertheless, as previously observed by Cooke *et al.* (2002), there was a significantly higher incidence of benign CV antibodies in rabbits from moist temperate areas than those from drier areas. The level of protection offered by benign CV from RHD infection is unknown, but recent trials suggest that they may reduce mortality in the field by as much as 50% in some circumstances (G. Mutze and R. Sinclair, unpublished data), which would greatly reduce the impact of RHD.

At the commencement of this study, we believed that if rabbit control (reduced density) affected one virus more than the other there would be implications for optimum timing and frequency of control. For example, rabbit control might leave recovering populations largely susceptible to both diseases and epidemic RHD might then spread back in more quickly than benign CV. We found no such effect of rabbit control on the interaction between RHD and benign CV that could be exploited to improve the effectiveness of rabbit control. Prevalence of both viruses appeared to be reduced amongst young rabbits in lower density populations, but each virus was affected to a similar extent

Our results suggest that current rabbit control operations during summer, in South Australia and north-western Victoria, make good use of the seasonal reduction of rabbit populations by RHD during spring. However, in the higher rainfall districts of southern Victoria, RHD activity often occurred in summer, so rabbit control should be conducted only in late summer or early autumn, after RHD outbreaks but before the breeding season commences. Finally, our results show that from a very young age the majority of rabbits in southern Victoria have antibodies to either or both of the benign CV and RHD. Despite the limited impact of RHD for rabbit control in this area, the potential for improvement from further releases of RHDV appears to be limited.

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EVALUATING VACCINATION STRATEGIES FOR CONTROL OF BOVINE TUBERCULOSIS (*MYCOBACTERIUM BOVIS*) IN BRUSHTAIL POSSUMS USING A SPATIALLY EXPLICIT MODEL

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ABSTRACT: Bovine tuberculosis (*Mycobacterium bovis* - Tb) is endemic in wild brushtail possum (*Trichosurus vulpecula*) populations in New Zealand. The mainstay of Tb eradication strategies has been the use of lethal control, usually using poison baits in an attempt to keep possum population densities below the theoretical threshold for disease eradication. However, vaccination of possums using bacille Calmette-Guérin (BCG) has been shown to afford some protection to possums from Tb infection with an efficacy of 70% being demonstrated in wild individuals vaccinated by both intranasal aerosol and conjunctival instillation (Corner *et al.* 2002). Hence BCG is being considered for more wide-scale use to help control the disease. However, little information exists on the duration of protection afforded by BCG in possums and how decay in vaccine immunity might affect vaccination strategies. We explored the potential for vaccination to complement or replace existing lethal control strategies using a spatially explicit stochastic model of possums and Tb. The model simulates events (i.e. birth, death, infection, dispersal) for individual possums located uniquely in a two-dimensional landscape. The model is partially based on the deterministic, non-spatial, Anderson/May type SI (susceptible/infected) compartment model of Barlow (2000) and hence, uses many of the same parameters. However, the spatial model differs from this model in other several important respects. Firstly, spatial structure is modelled explicitly and hence, disease transmission occurs at a local scale and is based on the probability of contact between infected and susceptible individuals, which is dependent on the degree of home range overlap. Secondly, the model includes both sexes to account for sex-specific dispersal behaviour.

We used the spatial model to examine disease control strategies involving the use of either BCG vaccination or lethal control as well as the integration of vaccination with lethal control strategies in different temporal sequences to determine how vaccination could replace or complement existing disease control strategies. Additionally, we examined how changing the efficacy of BCG vaccination affected each vaccination strategy. Vaccination efficacy was expressed in terms of the probability of non-response, the minimal time of protective immunity provided (the "guarantee time"), and the rate of decay in immunity once the guarantee time had elapsed.

In general, vaccination was a less efficient strategy for eradicating Tb when used alone compared with lethal control. Vaccination applied each year having a <20% non-response rate and lifelong immunity had a 95% probability of eradicating Tb within 8 years while the comparable strategy using lethal had a 95% probability of eradicating Tb within only 4 years. Similarly, vaccination applied following a single application of lethal control was required to have <20% non-response rate and life long immunity to deliver the same benefits (probability of eradication in a given time frame) as the similar strategy using lethal control. If the vaccine had a non-response rate >20% then similar benefits to lethal control could only be achieved by applying vaccination each and every year. However, even in this case the vaccine was required to have a guarantee time of 3 years with a half-life after this period of at least a year.

In conclusion, lethal control strategies were theoretically shown to be a more effective disease control strategy than vaccination. Strategies that used combined lethal control and vaccination generally required more effort to achieve the same outcome than strategies using lethal control alone. Hence, combined strategies are likely to be less cost-effective than the use of lethal control. However, lethal control may induce immigration and other compensatory responses by survivors. We did not model these effects, which are likely to degrade the effectiveness of lethal control compared with vaccination. Further investigation is therefore required to determine the usefulness of strategies involving vaccination.

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DO FERAL PIGS PLAY AN IMPORTANT ROLE IN NEW ZEALAND'S TB PROBLEM?

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INTRODUCTION

Despite sometimes having a high prevalence of bovine tuberculosis (Tb), feral pigs are generally regarded as spillover end-hosts unable to sustain the disease in the absence of infection in other species. Although intraspecific transmission occurs in captivity (Ray *et al.* 1972), transmission between feral pigs must be rare because there are few places in the world where Tb has persisted in feral pigs in the absence of infection in other species (Nugent et al. 2003a,b). The clearest evidence for end-host status is the decline in prevalence in pigs following the removal of infected cattle and buffalo from parts of the Northern Territory of Australia (McInerney *et al.* 1995). Countering this widespread belief, new evidence suggests Tb may have persisted in wild boar long isolated from livestock in Spain (Aranaz *et al.* 2004), and there is increasing suspicion that although not maintenance hosts in their own right, feral pigs do play some role as part of a wildlife complex in sustaining and spreading Tb in New Zealand. This paper summarises relevant insights from observations made during recent ecological and epidemiological investigations in New Zealand, focussing on three main areas: (i) additional evidence against intraspecific transmission between pigs; (ii) likely routes of transmission to and from pigs and their role in interspecific transmission; and (iii) the likely spatial scale and pattern of interspecific transmission involving pigs.

MAIN FINDINGS

Pigs readily become infected with Tb when infected brushtail possums (the primary wildlife host of Tb in New Zealand) are present (Lugton 1997). For example, all of 16 uninfected pigs released into Hochstetter Forest, West Coast (where 2-53% of possums were infected during the 1990s; Coleman *et al.* 1999), in 2000 became infected within about 2 months of release (Nugent *et al.* 2002). Likewise, on Muzzle Station, North Canterbury (where Tb is also present in possums but at lower levels), we detected Tb in 58% of 65 pigs (and 71% of the 31 pigs > 1 year old) during 2002-2004. However, no transmission of Tb to or between pigs was observed there when 8 or more Tb-free 'sentinel' pigs were held in continuous contact (for up to nine months) with 1 or more Tb-infected pigs in two 1 ha pens that excluded possums, ferrets, and livestock. The effective density of infected pigs in these pens exceeded 100/km^2, at least ten times higher than the density of wild pigs outside the pens. The well-fed pigs inside the pen did not cannibalise the carcasses of two pigs that died during the trial.

To assess potential routes of interspecific transmission, the fate of pig, deer, possum, and ferret carcasses have been monitored in five separate investigations. Pigs usually find and scavenge a high proportion (>50%) of possum carcasses within their home ranges, especially in winter (Barber, 2004; Nugent *et al.* 2004). This indicates that where pigs are abundant most infection in possums is likely to spill over into pigs. Video footage of pig families feeding simultaneously on a single possum carcass indicates how the numbers of wild animals infected with Tb could sometimes be amplified through scavenging. However pigs rarely cannibalise the remains of other pigs or feed on the carcasses of ferrets so pig-to-pig or ferret-to-pig transmission via scavenging is unlikely to be an important route of infection for pigs (Yockney and Nugent 2003, Byrom 2004). Conversely ferrets frequently fed extensively on pig carcasses, and possum occasionally did so as well (Byrom 2004; Yockney and Nugent 2003). In one instance, a family of six ferrets together ate all of the edible tissue on a pig's head (Yockney and Nugent 2003), indicating further potential for amplification of infection. Possums have also been recorded feeding on deer carcasses, usually only briefly but sometimes for extended periods (Nugent et al. 2003b), and on ferrets (Ragg *et al.* 2000; Byrom 2004), indicating potential for transmission of Tb from these predominantly spillover hosts back to a known wildlife maintenance host.

Pigs can potentially spread Tb long distances. One of the female pigs that became infected in the Hochstetter Forest trial (see above) left that area about six months after release, and was shot nine months later 35 km away in an area not known to contain infected possums. The timing of the shift, and the absence of infection in three other 5-month-old pigs (probably her offspring) shot with her, makes it likely that this sow was infected before dispersing, and carried the disease with her. For the released pigs in that study that did not disperse, a radius of about 6 km around the kill site encompassed 95% of all previous locations; i.e., even resident pigs can easily carry Tb up to 6 km (Nugent *et al.* 2002). Consistent with this, Tb prevalence in pigs in the Hauhungaroa Range, central North Island, declined from high to low levels when sampled across 7km of forest with few possums that lay immediately east of an area with high possum densities and levels of infection (Nugent *et al.* 2003).

CONCLUSIONS

Because the prevalence of Tb in pigs is often high, and because it has not been particularly difficult to obtain video footage of possums scavenging pigs or deer (Yockney and Nugent 2003), the risk of pig-to-possum transmission is likely of sufficient magnitude to be of management concern (unless very few of the interactions between possums and infected pig carcasses result in transmission). We therefore consider it likely that pigs will have contributed significantly to the historical spread of Tb in wildlife by transporting Tb long distances ahead of the Tb 'front' in possums, resulting occasionally (through scavenging of pigs by possums) in the establishment of new outlying foci of infection in possums. Both natural movements by pigs and transport of live or dead pigs by hunters would contribute to such spread.

Where Tb is already established in wildlife, we believe pigs are also likely to sometimes play an important role in spreading Tb from forested areas to farmland, via a four-species chain (possum-pig-ferret-livestock). The final link in this hypothetical chain is based on previously reported observations of close contact during interactions between ferrets and livestock (Sauter and Morris 1995). The observations above indicate that the first two links of this chain have high probabilities of occurrence, possibly even increasing the incidence of disease in wildlife through group scavenging. Transmission from ferrets to livestock must also be common, as ferret control reduces the incidence of infection in cattle even when possum are not controlled (Caley *et al.* 1998) and Tb has been detected in about 50% of cattle herds known to have infected ferrets present during the cattle-testing year (Caley 2003).

This chain of interspecific transmission is likely to be of greatest consequence when infected possums have been eliminated from farmed areas through possum control but are still present in adjacent unfarmed areas where possums are not controlled. Because both ferrets and pigs have large home ranges and disperse long distances, a transmission pathway like this would tend to produce outbreaks of infection in livestock within a radius of perhaps 10 km around any area in which infected possums are present, even where the possum density within that area is held at very low levels. The pattern intuitively expected would be one of widely dispersed and unconnected herd breakdowns not closely associated with the forest-pasture margin, each herd breakdown lasting only 1-2 Tb-testing cycles.

As one example consistent with this predicted pattern, Tb has occurred sporadically between 1999 and 2003 in unconnected cattle herds spread widely through developed farmland near Featherston, east of the continuous scrubland and forests of the Tararua Range, lower North Island. Some of these sporadic breakdowns occurred after possum densities on the farmland had been reduced to very low levels (post-control trap catch rates of <1% in recent years) and moderate to low densities in the scrub and forest immediately to the west (trap-catch rates of 0.3-4.0%). Surveys in 2003 and 2004 did not detect Tb in c. 120 possums, yet Tb was detected in three ferrets in 2003 (but in none of 35 ferrets surveyed in 2004), and in 15% of 27 pigs surveyed in 2004 (unpubl. data).

Together, these observations suggest that pigs probably play a much more important role in the Tb problem in New Zealand than previously suspected, not as a maintenance host but as an amplifying and dispersive link in several chains of interspecific transmission. The management significance of this role is likely to increase with the decline in reactor herds under the NPMS. If so, key implications are (i) combined pig control and surveillance ahead of the Tb front in possums would probably help slow the rate of Tb spread in some places or at least better define where possum control was needed, and (ii) removal of distant reservoirs of Tb in possums could have a greater impact on the frequency of sporadic Tb-breakdowns in cattle and deer farms within possum-controlled areas than would intensifying possum control on those farms.

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THE ROLE OF FERRETS IN LANDSCAPE-SCALE SPREAD OF BOVINE TB IN THE HIGH COUNTRY OF NEW ZEALAND'S SOUTH ISLAND

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INTRODUCTION

Estimating the extent of disease transmission among and within species is a prerequisite for effective control of undesirable diseases such as bovine Tb (Caley and Hone 2004). In the northern South Island high country (NSIHC), control and eventual eradication of bovine Tb poses some major challenges. In this region, three species (possums (*Trichosurus vulpecula*), feral pigs (*Sus scrofa*), and ferrets (*Mustela furo*)) are frequently infected and play varying roles in both the persistence and spread of the disease in a vast and largely unforested landscape. Understanding the routes and frequencies of Tb transmission between these species is likely to be crucial in designing the most efficient and effective programmes for disease management in this area (Byrom 2004; Nugent *et al.* 2003; Yockney and Nugent 2003).

Ferrets are generally regarded as a spillover host of bovine Tb in New Zealand (Byrom 2001). However in some areas, rapid expansion of Tb-endemic areas has been linked to long-distance movements by ferrets and subsequent transmission of infection to cattle and deer, and/or spread of infection to other wild animals (including other ferrets) at new locations (Livingstone 1996). Furthermore, observed behaviour of ferrets and other wildlife species at ferret carcasses suggests that transmission of Tb could occur through scavenging of infected material (Ragg *et al.* 2000). However, the frequency, nature and duration of such interactions with ferret carcasses remain largely unquantified.

The aims of this study were twofold. First, to quantify the potential for young ferrets (nominally infected with Tb) to transport the disease during dispersal in the NSIHC. Second, to determine which species of wildlife are most likely to encounter and scavenge on ferret carcasses in the NSIHC, and so characterise the likely fate of Tb present in infected carcasses (and potential routes of transmission back to other wildlife species). This information is critical in assessing whether ferrets play an important role in the persistence and spread of Tb in the landscape, and therefore in determining how much emphasis should be placed on ferret control in vector management programmes in New Zealand.

METHODS

Movements of young ferrets

In January 2003, 22 young ferrets (13 males and 9 females) were live-trapped at Muzzle Station in the NSIHC and radio-collared with 25-g Sirtrack mortality-sensing ferret collars. Sites at which ferrets were collared covered approximately 8 km of accessible river flats and terraces of the Clarence River known to be occupied by pigs, ferrets and possums. Young ferrets were captured late enough in the season to be independently trappable (Caley and Morriss 2001), but still in family groups and close to their mother's home range (Byrom 2002). Collared ferrets were radio-tracked at least once a week from January to late March 2003 to determine their survival and to calculate distances moved away from the mother's home range. Dispersal distances for all surviving ferrets were calculated as the straight-line distance between first and final locations for each ferret.

Of the 22 young ferrets originally radio-collared, 10 (7 males and 3 females) survived until early April 2003 when they were captured, euthanased, and necropsied to determine their Tb status. Peak dispersal occurs in mid-to-late February (Caley and Morriss 2001; Byrom 2002), so these ferrets were assumed to have completed their dispersal movements. Pooled lymph nodes from each ferret were frozen at –4°C immediately after necropsy until they were sent for culture. Ten radio-collared ferrets (5 males and 5 females) died during January–March 2003. Two other radio-collared ferrets (one male and one female) were lost within 1–4 weeks of collaring and it was assumed either that the collar had malfunctioned or that these individuals had moved very long distances out of tracking range.

Fate of ferret carcasses
Four carcasses of radio-collared ferrets that died were monitored using infrared-triggered camera systems to determine the nature, frequency and duration of behaviours of wildlife species visiting the carcasses. A further nine ferret carcasses (obtained elsewhere on Muzzle Station) were video-monitored in summer and early autumn (January–May 2003) to increase the sample size to 13. A further 20 ferret carcasses were video-monitored in winter and spring (Aug–Oct) 2003. Each carcass was staked to the ground with a peg to prevent it being removed. Carcasses were monitored for at least 3 days in summer and for at least 1 week in winter. The type of behaviours observed at each carcass and the duration of each behaviour were recorded for each visit by each wildlife species. The minimum number of individuals of each species visiting each site was also recorded.

RESULTS

Movements of young ferrets
Dispersal distances of the 10 ferrets that survived until early April 2003 ranged from 0 to 10.7 km (median 2.5 km) from their likely location of birth (Fig.1). Of those 10 ferrets, three males were infected with Tb and had moved straight-line distances of 1.5 km, 3.5 km, and 10.7 km. The four radio-collared ferrets video monitored after death had travelled 0.4, 0.5, 1.0 and 2.4 km. Two of these were scavenged by other ferrets.

Fate of ferret carcasses
Cameras recorded for a mean of 4.4 days at each carcass in summer (total recording time 57 days on 13 carcasses), and 7.1 days per carcass in winter (142 days on 20 carcasses). Fifteen different species visited ferret carcasses. Sheep (*Ovis aries*) and cattle (*Bos taurus*) and five wildlife species (Australasian harriers (*Circus approximans*), ferrets, possums, cats (*Felis catus*), and hedgehogs (*Erinaceus europaeus*)) approached to <1 m of ferret carcasses and interacted with them in some way. In summer, most visits were by ferrets and possums; in winter most were by possums and cats. Pigs did not visit ferret carcasses in summer or winter, despite being present in the general area.

When ferret carcasses were encountered by other wildlife species, many of those encounters resulted in behaviours that could be considered ‘risky’ in terms of Tb transmission (i.e. rolling on the carcass, sniffing, licking, or actual scavenging). The average duration of each interaction was half a minute or more. In summer, 8 of 13 ferret carcasses (62%) were scavenged. In winter, 4 of 20 carcasses (20%) were scavenged. Australasian harriers and hedgehogs were the only species that scavenged ferret carcasses in both summer and winter. In addition, ‘risky’ behaviours occurred occasionally after the carcass had been ‘opened up’ by scavengers such as harriers or ferrets: in summer, two possums sniffed ferret carcasses after the gut cavities had been opened up by scavengers; in winter, two possums and at least five cattle sniffed similar carcasses. Possums were not observed scavenging ferret carcasses in this study, but Ragg *et al.* (2000) believe an instance of this occurred in their study.

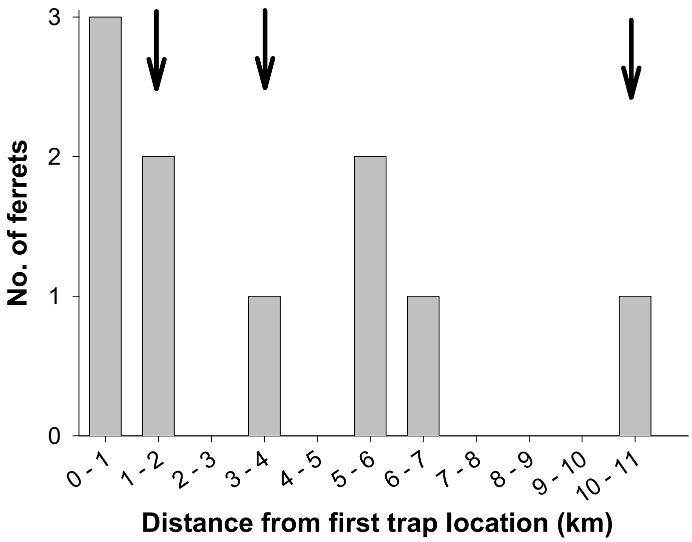

Fig. 1 Dispersal distances of 10 young ferrets in the northern South Island high country in Summer 2003. Arrows show the distances dispersed by three infected male ferrets.

DISCUSSION

Caley and Hone's (2002) hypothesis that Tb is often acquired by ferrets through scavenging infected material soon after weaning suggests that it is possible for young ferrets to pick up the disease before leaving their mother's range. This study confirms that ferrets in a Tb-endemic area can easily transport Tb long distances, up to 10 km in this instance. Furthermore, ferrets dispersing from within a Tb-endemic area could contract the disease 'on route' and still pose a risk far from the original source.

Assuming diseased ferrets are capable of transporting Tb outside the boundary of Tb-endemic areas, what is their potential for creating new foci of infection? Based on the recorded interactions with ferret carcasses, the risk of transmission of Tb from dead ferrets to pigs and possums appears negligible. The potential risk to other wildlife species, such as ferrets, cats, and perhaps Australasian harriers, was moderate, at least in summer. 'Opening up' of carcasses by harriers, ferrets and cats might increase their infectiousness to possums (through scattering viable bacilli around the carcass), but if infected carcasses become available only at a low density in the landscape, the probability of creating a new focus of infection in possums would be extremely low.

Landscape-scale cycling of Tb by ferrets

The role of ferrets in cycling bovine Tb in the landscape depends on five factors:

1. The likelihood that ferrets will contract the disease by scavenging on infected material (the focus of Yockney & Nugent's 2003 study).
2. Their ability to transport the disease large geographic distances (this study).
3. The probability that ferrets will transmit the disease to other wildlife species if they die (this study).

4. The population density at which the disease can be maintained in a ferret population independent of other wildlife sources (Caley 2002).
5. The probability that live or dead ferrets will transmit the disease to livestock (only partially addressed by this study).

Yockney and Nugent (2003) showed that ferrets were one of the main wildlife species to scavenge potentially infected pig remains in the NSIHC in summer, and that the disease could readily be ‘amplified’ through whole family groups of ferrets feeding on pig carcasses (factor 1). In addition, results from this study and simulation modelling (Nugent *et al.* 2003) confirm that infected ferrets are capable of transporting the disease large geographic distances in the NSIHC (factor 2).

However, the probability of the disease being transmitted back to other species of wildlife through scavenging (particularly by key species such as pigs and possums) appears to be low in summer, and even less in winter (factor 3), given the extremely low probability of those species scavenging the carcass. Nonetheless, where both ferret numbers and Tb prevalence in ferrets is high, occasional transmission to possums may be of management significance when it results in a new outbreak of Tb ahead of the Tb front in possums.

The risk of infecting other ferrets is higher, and will vary depending on the population density of ferrets at which Tb can be maintained independent of other wildlife sources of the disease (factor 4) (Nugent *et al.* 2003; Caley and Hone 2004). Caley (2002) hypothesised a threshold population density for disease maintenance in ferrets of about 2.9/km^2. Results from live-trapping for young ferrets in this study suggest that ferret densities were only moderate for typical rabbit-prone country. At higher population densities of ferrets, both the number of infected carcasses becoming available annually to be scavenged, and the probability of them actually being fed upon, would probably be proportionally greater.

A study of the behaviour of livestock around ‘sick’ ferrets (where drugged ferrets exhibiting behaviours similar to Tb-infected animals were ‘nosed’ and sniffed by livestock; Sauter and Morris 1995) shows how Tb could potentially be transmitted from ferrets to livestock (factor five Cattle investigated ferret carcasses in winter in this study, sniffing and making nose contact on several occasions (and on at least five of those occasions, after potential exposure of Tb bacilli had occurred through scavenging by other species), showing that dead ferrets also pose some risk. Transmission from ferrets to livestock must occur, as ferret control reduces the incidence of infection in cattle even when possums are not controlled (Caley *et al.* 1998). However that probability that an infected ferret will infect livestock remains largely unquantified, making it difficult to assess the management significance of this transmission pathway. Overall, ferrets appear likely play an important role in New Zealand’s Tb problem, not only as a maintenance host when their densities are high, but also (like pigs) as an intermediate host responsible for sometimes amplifying and spreading Tb, particularly to livestock.

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A SUCCESSFUL UNSUCCESSFUL FERAL ANIMAL MANAGEMENT PROGRAM

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ABSTRACT: In June 1999 the then Parks and Wildlife Commission of the Northern Territory (PWCNT) declared a "Pest Control Area" covering most of the Victoria River District (VRD), at which time the projected donkey and horse populations were estimated at 93,000 and 63,000 respectively. Control notices requiring the removal of specified numbers of donkeys and horses were issued to 27 of the 50 holdings included within the declared pest control area. Notices issued in 1999 totalled to a required off-take of 55,000 donkeys and 44,000 horses in the following 12 month period. The effectiveness of the program was not assessed until late 2001, when a follow-up survey of the VRD was undertaken. This survey indicated that the donkey population had increased to 103,000 donkeys and that the horse population had declined to 40,500 horses. During this period a total of 58,000 donkeys and 7,500 horses had been removed. The number of donkeys removed in this three year period exceeded that required in the initial notice, however the donkey population had increased by 10,000. This increase was a consequence of a failure to achieve the required off-take in the specified 12 month time frame; actual removal amounts for donkeys in the three years were 5100 in 1999, 19,800 in 2000 and 33,100 in 2001. The inconsistent horse population data indicates that the 1999 estimate was incorrect. The program has continued and is now in its sixth year. Up to the end of 2004 a total of 152,000 donkeys and horses have been removed to achieve a projected real population reduction of 40,000 donkeys based on the 2001 population estimate, to give a current donkey population estimate of 63,000 donkeys in the VRD. The current predicted horse population is 30,000 horses across the district. While the program cannot be considered to have been successful to date from a numerical perspective, the program has been highly successful from a number of other perspectives. This program is the first of its type in the Northern Territory that has been funded primarily by the landholder, rather than fully funded by the Northern Territory Government. Generally, landholder acceptance and commitment to the program has been positive, however, the program has clearly identified that landholder agreement and acceptance of the timeframe has to be established before commencing. Failure to obtain total landholder participation contributed substantially to the extended timeframe of the program. Also contributing to the extended timeframe was a failure to recognise and meet the resource requirements of the program, restricting the level of control that could be taken in any one year. One of the most significant ongoing positive outcome of the program has been the integration of control across both pastoral and indigenous lands.

ANIMAL CONTROL TECHNOLOGIES AWARD 2005

The Animal Control Technologies Award was initiated in 1995 to encourage better links and understanding between those researching pest animals and those who are implementing management programs. It is a contribution to helping fundamental researchers appreciate the scale and difficulties of practical programs and also helps those at the workface to understand the complexity of the research behind new technologies and complex pest problems.

Animal Control Technologies provides travel, accommodation and dinner costs for the winner to attend the Vertebrate Pest Conference. Conference registration fees are waived and the winner must present a short paper on his/her work in the field.

The award recognises members of the effector agencies, leading farmers or coordinators who have played practical roles in tackling major programs, whether these be on rabbits, foxes, camels, cats or rodents on private or crown land. State finalists are nominated by the VPC member in each state or territory on the basis of an outstanding record of local leadership in achieving an integrated best practice approach to vertebrate pests. The national winner is selected by a panel comprising the Conference Chairman, Chairman of the VPC and the MD of Animal Control Technologies.

Previous winners:

1995 Hobart	Dean Wainwright	APB WA
1998 Bunbury	Ian Qualman	Corong APCB SA
2001 Melbourne	Stuart Barcla	"Roscoe Downs" Cunamulla Qld

The 2005 winner is Keith Saalfeld of the Northern Territory Department of Infrastructure & Environment. Keith has played a key role in the survey and management of pest herbivores over vast areas of the Northern Territory.

All State finalists for this award are to be congratulated for achieving a high standard of sustained commitment to best practice and effective outcomes in an often difficult social, regulatory and technical environment. This year the panel would also like to acknowledge three other nominees who only just missed selection in the very strong 2005 nomination round. These highly regarded nominations were:

John Matthews: DPI Vic for work on coordinated programs over many years in the Casterton area of Victoria and implementation of numerous policy guidelines,

Rob Coventry: Elliston LeHunt APCB SA for systematic expansion of a group control program over vast areas of the lower Eyre Peninsular

Lisa Thomas/Rhett Robinson: Dubbo RLPB NSW for combined lamb and Mallee fowl protection around Dubbo in NSW

Animal Control Technologies would like to congratulate all nominees for the 2005 Award

DO INTRODUCED PREDATORS COMPETE WITH NATIVE CARNIVORES?

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ABSTRACT: The spotted-tailed quoll (*Dasyurus maculatus*) is a medium-sized marsupial carnivore that has declined in abundance and distribution since European settlement in Australia, and is now listed federally as an endangered species. Introduced predators are thought to have contributed to this decline. Foxes and feral cats occupy a similar dietary niche to that of quolls, and may be directly aggressive to them. The impacts of dingoes and other wild dogs are also of interest, as they have the potential to compete with quolls, but may also suppress populations of cats and foxes. Here I report on the extent of overlap in resource use between sympatric populations of quolls and eutherian predators. The study was conducted in Marengo and Chaelundi State Forests, north-eastern New South Wales, between January 2003 and October 2004.

The diets of quolls, foxes and wild dogs were investigated by analysis of scats. Considerable dietary overlap occurs, with mammals constituting over 80% of the diet of all three species. Medium-sized mammals such as rabbits, possums, bandicoots and small macropods are the most frequently consumed prey for all three predators. However, some niche separation is apparent, with quolls frequently consuming arboreal prey (greater gliders), which are relatively inaccessible to foxes and dogs. Although foxes and dogs are heavily reliant on medium-sized prey, dogs supplement these with large prey such as kangaroos, whereas foxes more frequently consume small prey such as rodents and *Antechinus*.

Telemetry has shown that female quolls occupy exclusive home ranges of 1-2 km^2, while males have home ranges of up to 7 km^2 or more, which overlap extensively with those of other males and females. Both sexes occupy multiple dens, which may be in hollow logs, tree hollows, rock crevices or burrows. Spatial overlap in the home ranges of quolls, foxes and feral cats is extensive, indicating that quolls are not necessarily excluded by the presence of introduced predators.

Microhabitat use by quolls was studied using spool-and-line tracking. Twenty-five quolls were tracked over an accumulated distance of 10,140 m. Although *D. maculatus* is partially arboreal, very little activity (1%) was recorded in trees. Rather, quolls focused most of their activity on the ground (61%) or on top of fallen logs (37%). Mean height above ground was 28 cm. These results suggest that coexistence of quolls and canids is unlikely to be facilitated by vertical partitioning of the habitat.

In conclusion, extensive niche overlap occurs between spotted-tailed quolls and eutherian predators, indicating a high potential for exploitation competition. Direct interference or interspecific aggression has not been recorded in this study, although it is possible that direct encounters are avoided by temporal separation. Future research should focus on predator removal experiments to determine whether competition occurs.

PREDICTORS OF CLUTCH PREDATION OF BANDED DOTTERELS IN BRAIDED RIVERS OF THE MACKENZIE BASIN, NEW ZEALAND

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ABSTRACT: Introduced predators are a serious threat to New Zealand's indigenous fauna. Reducing the abundance of predators is the main method used for protection, but it is not a guarantee for sustaining prey populations because it can also depend on the abundance of the prey themselves; the abundance of other prey species, particularly pest species; or the nature of the habitat that the prey species occupy.

We explored the temporal and spatial patterns of clutch predation of banded dotterels (C*haradrius bicinctus*), and recorded nest habitat, nest density, and predator and rabbit (the main prey of predators) abundance to find predictors of clutch predation. We did this for 753 clutches in total at 7 nesting sites on 3 braided rivers of the Mackenzie Basin, South Island, measured over 3 consecutive breeding seasons. This ecosystem contains avian biodiversity that is globally and regionally significant, and often threatened. The avifauna, including dotterels, nest on the open riverbed gravels and are vulnerable to mainly cats, ferrets, and hedgehogs. Dotterel populations are abundant and appear to be stable despite these predators, and there is a large amount of clutch survival data available for this species. The relative ease of obtaining field data makes banded dotterels a good model on which to base generalisations that may have wider application for mitigating predation of other ground-nesting species in this ecosystem.

Immediately before the study, rabbit populations were reduced by rabbit haemorrhagic disease (RHD). Clutch predation rates (mean, 50%) were as unusually high then as those recorded in the past during rabbit control programmes in the riverbeds (mean, 57%). Clutch predation rates during years of high rabbit abundance average 27%. This suggests prey-switching by predators in both instances. In subsequent years, sites with localised rabbit control that was confined to the riverbeds experienced a drop in predation rate, whereas sites with widespread RHD-induced declines in rabbit numbers (this study) experienced an increase in predation. This implies that the relationship between rabbit population declines and predation of dotterel clutches is scale-dependent.

When RHD arrived, the Department of Conservation (DOC) kill-trapped predators on some of the sites to protect birds from prey-switching. Trapping nearly halved clutch predation, although this effect may have been confounded by variation in nest density. Clutch predation was lower where nest density was higher, suggesting safety in numbers. This relationship held if sites with predator control were removed. Clutch predation was also lower on the less stable non-vegetated shingles closer to the river channels compared with the more stable vegetated river margins which predators used more often. Rabbit and predator abundance were poor predictors of clutch predation post RHD.

These results indicate critical times and places of high clutch predation risk in braided river ecosystems. Ways to minimise these risks include focussing predator control during periods of rabbit decline, maintaining predator control for more than one breeding season if the rabbit declines are widespread, and applying greater control effort at sites with relatively low nest density (to expand the nesting range) and along nesting areas on stable riverbed margins.

Applying greater predator control effort at sites with low nest density raises difficulties. Funding constraints force DOC to focus control at sites that contain endangered species. Evidence from this study shows that such sites also happen to contain higher densities of dotterel nests, which we have argued imparts some natural protection against predation because of safety in numbers. This poses the question of whether shifting some of the control effort to the more vulnerable lower nest density sites will provide greater overall conservation benefits for the wider avian community than the current strategy. Is the likely reduction in protection of endangered species offset by these wider putative benefits? At the very least, it will cast a wider protective net over the nesting range of banded dotterels. These are important questions for the DOC to consider when planning predator control strategies.

PREDATION OF MOUNTAIN BEECH SEED BY AN INTRODUCED RODENT

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ABSTRACT: The functional response of post-dispersal seed predators (house mouse, *Mus musculus*) to absolute densities of southern beech seed (*Nothofagus solandri* var. *cliffortioides*) was studied in laboratory and field trials. House mice showed a Type II (hyperbolic) functional response to seed availability and this was not modified by the presence of an alternative food source (naturally occurring lepidopteron larvae). Using field enclosures erected in a beech forest, we provided a single mouse (n = 40) with a set quantity of beech seed for 24 hrs. Between 10 and 2000 seeds were offered. We then recovered the uneaten seed and husks and counted them. Maximum daily intake rate of beech seeds during field trials averaged 1042 seeds mouse^{-1} although mice ate close to 100% of seeds when up to 800 seeds were offered. This is theoretically sufficient to provide house mice with both the energy and protein required for growth and reproduction.

We explicitly incorporated the functional response into the numerical response of house mice to beech seed, measured for field populations monitored in Fiordland National Park, New Zealand. A numerical response that incorporated beech seed intake rate that was modified by density dependent mechanism(s) fitted the data better than either a numerical response related to absolute seed availability or *per capita* seed availability.

We developed a model that simulated beech seedfall, house mouse population growth and seed reserve depletion over one year. Seed became available in late summer and autumn and the house mouse population grew according to the predicted numerical response. Seed reserves were depleted according to the population's total response (individual intake rate multiplied by the prevailing population density). We found that previously reported declines in house mouse populations in beech forests during spring and summer is likely related to spring beech seed germination that renders seed no longer available as a food source for house mice. Our simulation model suggested that it is not possible that house mouse populations would completely eat-out beech seed reserves prior to germination in a year of large seedfall, but it may be possible in low seedfall years. 'Masting' behaviour in New Zealand native beech trees is therefore sufficient to satiate an eruptive population of an exotic mammalian omnivore, despite the lack of a long co-evolutionary interaction.

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IMPACT OF RABBIT GRAZING POST-RHD IN CENTRAL OTAGO, NEW ZEALAND

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ABSTRACT: Rabbits are pests in many areas of New Zealand because they have a negative impact on agricultural production and conservation values. The production impact is predominantly on pastoral enterprises where rabbits reduce profitability of wool growing by directly competing with sheep, and from the cost of control of the rabbits. However, there is a scarcity of quantitative information on the extent of these impacts and how they vary with rabbit density (Norbury *et al*. 2002). Arguably this information was not required in the past when the consequences of no control rapidly became expressed in unacceptable rabbit numbers. However, since the introduction of a biocontrol agent, rabbit haemorrhagic disease (RHD), to New Zealand in 1997 rabbit numbers have been suppressed in many areas (Parkes *et al*. 2002). This has meant that traditional forms of rabbit control – poisoning and shooting in New Zealand – have declined (Parkes and Norbury 2004). Control by habitat manipulation such as warren ripping is a common post-RHD control strategy in Australia where its benefits are additive to those from RHD, but the method has little relevance in New Zealand, where rabbits rarely live in warrens. The question remains whether the costs of such traditional control in the presence of the effects of RHD are warranted by the marginal benefits to production that might accrue. We need to understand the relationships between rabbit densities, sheep numbers and pasture production to make a rational judgement.

We undertook a replicated experiment that measured the impacts of sheep and rabbits at a range of densities on pasture biomass in semi-improved pasture in the rabbit prone region of Central Otago, New Zealand.

Rabbit abundances were indexed at each of the two sites using nighttime spotlight counts along permanent transects, while sheep density per unit area was obtained from landholder records. Pasture biomass (and composition) were estimated quarterly at 20 points per site using a modification of the comparative yield technique. Each point contained plots that were: (1) grazed by all herbivores, (2) excluded all herbivores, and (3) grazed by rabbits. The rate of increase (r) of pasture biomass under various combinations of season, site, and rabbit and sheep density was modelled. Models were fitted to the data using Markov Chain Monte Carlo methods, and the parameters of the fitted model were used to predict the likely rate of increase in pasture biomass under realistic levels of sheep stocking, and rabbit density.

Rabbit abundance varied markedly throughout the study as a result of RHD; increasing from 7–17 after the initial epidemics to 62–71 rabbits per spotlight kilometre across the two sites, but then declined to 1–5 rabbits per spotlight kilometre following subsequent RHD epidemics. The relationship between the predicted rate of increase of pasture biomass in the presence of sheep, and rabbit density was negatively correlated. For example, in spring in the presence of average sheep stocking rates, an observed reduction in rabbit densities from c. 70 to 5 rabbits per spotlight kilometre, resulted in an increase in the predicted rate of increase of pasture biomass of 57%.

In the areas of semi-arid New Zealand where RHD has held rabbits at very low densities year round (e.g. the Mackenzie Basin), the marginal benefit to pasture growth of conventional control would not likely be justified by the cost. For example, the increase in the predicted rate of increase of pasture biomass from reducing rabbit densities from 5 to 0 rabbits per spotlight kilometre was only 9%. However, in the Central Otago study sites where rabbit densities fluctuate widely in response to annual RHD epidemics, it is much less clear whether conventional control is justified.

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GROUND DISTURBANCE BY FERAL PIGS: ECOSYSTEM ENGINEERING OR JUST ROOTING AROUND?

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INTRODUCTION

Wild pigs have a range of direct and indirect effects on indigenous plants and animals that are collectively perceived as environmental impacts. While the impact that pigs have on the viability of the native animals and plants that they prey upon has rarely been assessed, there are no clear cases where these impacts threaten species viability. Of more general concern is the impact that ground disturbance (rooting) caused by pigs is perceived to have on ecosystems where it occurs, particularly where these ecosystems are in conservation reserves (Choquenot *et al.* 1996).

Recent research has highlighted the importance of interaction between above- and below-ground components of terrestrial ecosystems for changes in the structure and functioning of above-ground vegetation communities (Wardle *et al.* 2004). Focusing on the subsoil side of these interactions, direct removal of carbon and other nutrients from root material by parasites, pathogens and root herbivores operating in the rhizosphere can limit plant growth. In contrast, mycorrhizal fungi and other mutualisms enhance uptake of limiting nutrients by plants, enhancing their growth. Indirect feedback loops can also operate through the role that the detrital food web plays in releasing nutrients sequestered in dead organic matter and microbes.

Ground disturbance by pigs could lead to the selective removal of specific elements of the below ground subsystem (i.e. mycorrhiza, macroinvertebrates), or their indirect elimination through modification of physical and chemical soil characteristics. In either case, these changes could reduce the efficiency or entirely disengage any or all of critical feedback mechanisms linking above- and below-ground ecosystem components. If feedbacks are disrupted over periods sufficient to affect structure and functioning of above-ground vegetation, ground disturbance by pigs may lead to permanent replacement of components of the vegetation, or reduced resilience of the vegetation community to natural or human induced disturbance. To develop pig control strategies which protect the long-term viability of a vegetation community, pig abundance would need to be linked to the extent of ground disturbance, ground disturbance to changes in soil nutrient pool, and changes in the soil nutrient pool to vegetation growth and survival. We describe a preliminary model that links pig abundance to the extent of ground disturbance. The model is used to identify key parameters for estimation, and to indicate the spatial scale at which changes in key soil characteristics pools might need to be assessed.

MODELLING GROUND DISTURBANCE

To link ground disturbance to existing pig population models, we sited our modeled system in Australia’s semi-arid rangelands, but drew parameter estimates from studies conducted in a more diverse range of environments. For this reason, the model should be viewed as hypothetical. Most ground disturbance observed in the rangelands is associated with the floodplains that surround major drainage lines and their associated channels and anabranches, and in ephemeral swamps (Choquenot *et al.* 1996). Hence, the amount of susceptible ground area at a given location in the rangelands will generally be determined by the spatial extent of these habitats. A compartmental model of ground disturbance by wild pigs in the rangelands is shown in Fig. 5.7. According to the model, any area of susceptible ground in a given area will either be disturbed by wild pig rooting (*R*) or will be undisturbed (*U*). Areas of ground change from being undisturbed to disturbed at rate *m*, and revert to being undisturbed at rate *n*. The model can be formulated as two linked differential equations:

$$dU/dt = U + n[R - m\ (R / R + U)] - m(U / R + U)$$
$$dR/dt = R + m(U / R + U) - n[R - m\ (R / R + U)] \qquad \text{Eqs 1}$$

According to Hone's (1988) study conducted in a temperate montane setting, *m* for a given patch of ground will depend on pig density, aspect, the rockiness of the ground, the presence of trees and shrubs, altitude, the proximity of drainage lines and the amount of grassland in the immediate area. However, because no similar data are available for the rangelands, the model developed here focuses on how this rate might vary with pig density and pasture biomass. Giles (1980) found that the amount of below-ground vegetation consumed by wild pigs in the rangelands increased when pasture availability declined. This suggests that the per capita rate at which wild pigs will root up ground will increase as prevailing pasture biomass decreases. Assuming that the rate of ground disturbance (*m*) is related to pasture biomass (*PB*) below some critical level of availability (PB_c), variation in m can be described by:

$$m = m_{\max}\left(1 - \frac{PB}{PB_c}\right)^W \qquad \text{Eq. 2}$$

where $m_{\max}$ is the maximum per capita rate of ground disturbance, and *w* is a coefficient that constrains *m* to its maximum value when pasture biomass is below the level where wild pigs can no longer consume it (i.e. they have to satisfy most of their food requirement from below-ground sources). The numerical response of wild pigs to pasture biomass described in Choquenot (1988) indicated that wild pig abundance declines when pasture biomass in the previous quarter falls below 251 kg ha^{-1}. Assuming that wild pigs will tend not to expend energy to forage below-ground while aboveground pasture biomass is sufficient for them to generate a positive rate of increase, 251 kg ha^{-1} is a plausible estimate for PB_c. The functional response estimated by Choquenot (1988), suggested that wild pigs were unable to consume pasture once its biomass fell below 92 kg ha^{-1}, which corresponds with a value of 6.8 for the coefficient *w*.

The maximum rate of ground disturbance by wild pigs will occur when pasture biomass declines to very low levels of availability. Under these conditions, $m_{\max}$ could be estimated from the rate at which ground is disturbed, and known wild pig density. Hone (1988) suggested from his study of ground disturbance that around 10% of a 13 km^2 area of montane forest in southeastern Australia was disturbed by wild pig rooting. McIlroy *et al.* (1989) estimated that wild pig density in a nearby area was 1.8 pigs km^{-2}. Hone (1988) did not age the ground disturbance he measured, and so could not determine the rate at which undisturbed ground was disturbed by pigs. However, Hone (1987) estimated that 8 months after wild pig density in the area had been reduced by more than 90%, the incidence of ground disturbance had declined by 22%. This rate of reversion corresponds to a daily rate (*n*) of 0.0009, implying that it may take 3.03 years for disturbed ground to reverts to its undisturbed condition. By using this rate of *n*, and ascribing values of of 1.8 km^{-2} to wild pig density, 251 kg ha^{-1} to PB_c and 7.9 to *w*, the model described in Eqs 1 can be used to predict variation in the percentage of an area disturbed by wild pig rooting as a function of pasture biomass and m_{max}. Using a pasture biomass of 100 kg ha^{-1} (i.e. where wild pigs still have access to above-ground vegetation, but would be under food stress), a value of m_{max} that produced an equilibrium level of ground disturbance of 10% was derived iteratively (m_{max} = 5.57) (Fig. 1). This value implies that when little above-ground pasture is available to pigs, they will disturb 5.57 m^2 day^{-1} in searching for below-ground food resources. The relationship between pasture biomass and m for this value of mmax is shown in Fig 2.

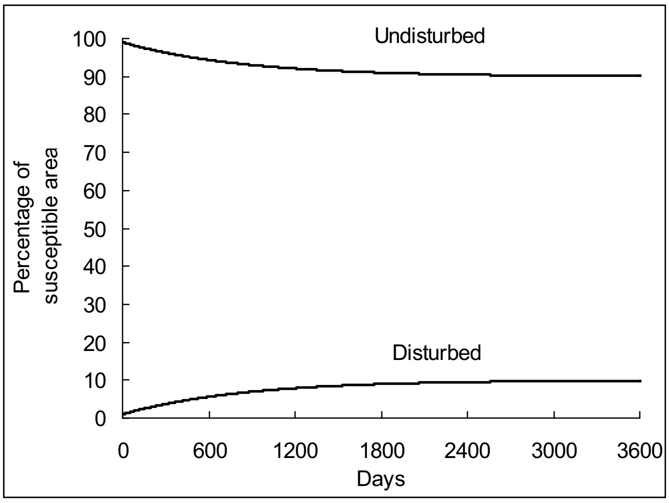

Fig. 1. Variation in the percentage of susceptible area that is disturbed and undisturbed over 10 years, predicted from the compartmental model described by Eqs 1. Initial percentage of disturbance is set at 1%, after which the level of disturbance moves to steady equilibrium at 10% of the susceptible area. At this point, the rate at which undisturbed ground is disturbed equates with the rate at which disturbed ground reverts to undisturbed condition. Pasture biomass is assumed to be 100 kg ha^{-1}, and wild pig density 1.8 km^{-2}.

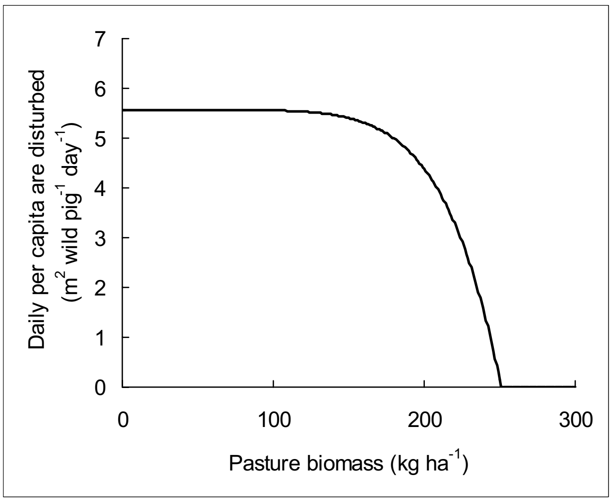

Fig. 2. Variation in the per capita rate at which new ground is disturbed by wild pigs, as a function of pasture availability. The relationship is predicted from Eq 5.9 using parameter estimates of m_{max} = 5.57 m^2 wild pig^{-1} day^{-1}, PB_c = 251 kg ha^{-1}, and w = 6.8.

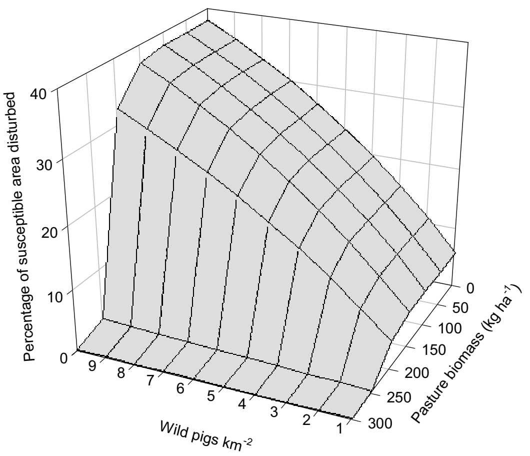

Fig. 3. Variation in the percentage of susceptible ground that is rooted after 10 years, as a function of wild pig density and pasture biomass, predicted from the compartmental model described by Eqs 1. The simulations used to produce the figure were initiated with 10% of the susceptible area disturbed.

Fig. 3 shows variation in the predicted percentage of susceptible ground that is disturbed after 10 years with incremental changes wild pig density and pasture biomass. Both factors have a major influence on the area of ground disturbed by wild pigs, suggesting that interaction between pigs and pasture must be taken into account when predicting how wild pig management will influence their environmental impacts. The effect pasture biomass had on the level of ground disturbance became stronger as pasture availability increased from levels where pigs could begin to replace below-ground food resources (92 kg ha^{-1}) to levels where they could fully replace below-ground food resources (251 kg ha^{-1}). The effect that incremental increases in pig density (P) had on the level of ground disturbance slowed at progressively high pig densities, because as the absolute level of disturbance increases with the product mP, the proportion of susceptible ground that is not currently disturbed declines. This has the effect of increasing the proportion of disturbance that occurs on ground that is already disturbed. Hence, the rate at which undisturbed ground becomes disturbed is curvilinearly related to prevailing pig density (Fig. 4).

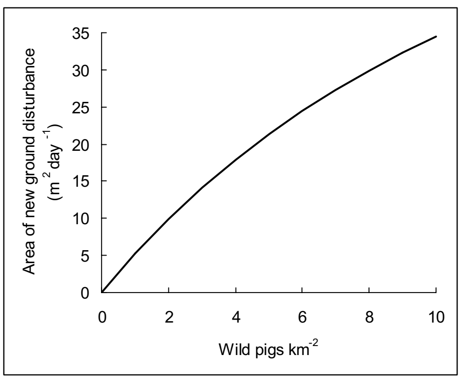

Fig. 4. The rate of new ground disturbance after 10 years as a function of wild pig density, predicted from a compartmental model described by Eqs 1. The simulations used to produce the figure were initiated with 10% of the susceptible area disturbed, and pasture biomass held at 0.

SIMULATING GROUND DISTURBANCE

Ground disturbance was simulated by using Eqs 1 to predict continuous change in the percentage of susceptible ground that was currently disturbed, as wild pig and pasture abundance varied through time according to an interactive model described in Choquenot and Ruscoe (2003). Fig. 5 shows variation in the density of wild pigs and associated changes in the percentage of susceptible ground disturbed, for a run of the simulation model in which the total area considered was 100 km^2, and contained 33% susceptible ground. Because all wild pigs inhabiting an area will concentrate their rooting on areas of susceptible ground, the ratio of the total size of an area to the area of susceptible ground will affect the level of ground disturbance that occurs in the susceptible area. For example, if pasture biomass on the 100 km^2 simulated in Fig 5 is less than 92 kg ha^{-1} and wild pig density is 1 km^{-2}, the 100 pigs occupying the area will be obtaining most of the food requirement by rooting in the 33 km^2 of susceptible country that the site contains. If the area of susceptible country in the area is reduced to 10%, the net level of impact remains the same, however it is now concentrated in just 10 km^2.

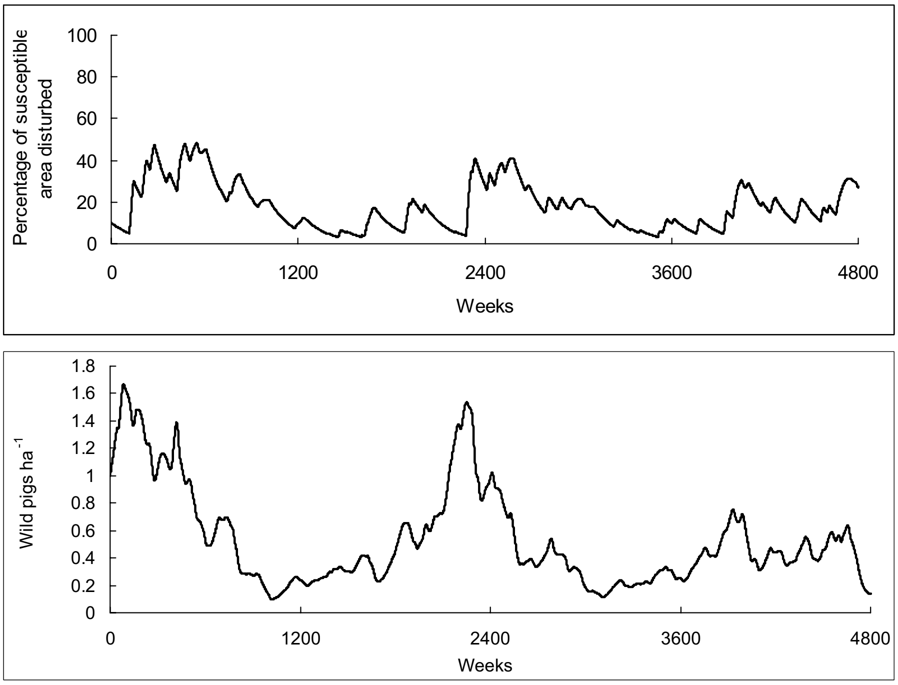

Fig. 5. Variation in wild pig density (bottom panel), and associated variation in the percentage of susceptible ground that is disturbed by wild pig rooting (upper panel). The results shown are predicted from a simulation model of interaction between wild pigs and pasture, to which was added the compartmental model of ground disturbance described by Eqs 1. The total area simulated was 100 km^2, of which 33% was susceptible to disturbance. The mean average percentage of susceptible ground disturbed, estimated from 100 iterations of the model, was 18.8%, with bootstrapped lower- and upper-confidence limits of 10.7% and 25.9%, respectively.

DISCUSSION

Applying the model in specific settings

There a two sets of inputs to the model that determine how ground disturbance will vary with pig abundance in specific settings; (1) factors that determine the rate at which pigs disturb the ground, and (2) factors that determine where pigs can disturb the ground. In the general form of the model described here, the first set of factors reduces to the influence that the availability of above-ground food resources has on the propensity of pigs to access below ground food resources, and the second set of factors is subsumed into a single variable controlling the proportion of an area susceptible to ground disturbance.

In reality, the rate at which pigs disturb the ground to access food resources would be controlled by a more complex set of factors that balance the costs and benefits of accessing below-ground food resources, relative to those that accrue in accessing above-ground food resources. While the costs associated with procuring above- and below-ground food resources will vary with their respective availabilities, a general expectation is that procurement of below-ground food resources will incur greater costs than above-ground food resources because they (1) may be more patchily distributed and hence difficult to locate, and (2) require digging for access. If this is true, pigs could be expected to only exploit below-ground food resources when that strategy yields a net nutritional value (nutritional benefit – costs) equal to or greater than the alternative of accessing only above-ground food resources. However, additional complications are added when both types of food resource are patchily distributed (the same trade-off would occur within the foraging patch of a pig, with the cost of moving between patches dictating the level of resource exploitation that occurs), and specific nutritional requirements associated with reproduction (successful production of viable, weaned piglets requires access to food with high levels of protein which may only be available from below-ground sources, regardless of the costs of accessing them). Incorporating these factors into the ground-disturbance model described here would at least require Eq. 2 to be replaced by a functional response that accounted for differential availability of above- and below-ground food resources on the rate of ground disturbance. If the spatial distribution of resources was considered an important factor controlling the trade-off between above- and below ground food resources, the functional response would have to be modified to reflect constrained patch foraging decisions.

Factors that determine where pigs can disturb the ground will vary considerably between environments. In the rangelands, most ground disturbance occurs in and around floodplains and drainage lines, but appears constrained by prevailing levels of soil moisture that determine hardness of the soil surface (Choquenot *et al.* 1996). In more temperate environments, consistently moister conditions mean that soils are generally more friable, and potential access to below-ground food resources is probably less temporally constrained.

Parametrising the model

While following the strongly "mechanistic" approach described above is theoretically appealing, it would present certain empirical challenges. For example, deriving a functional response model that accounts trade-offs associated with procurement of above- and below-ground food resources would require below ground food resources to be estimated and (perhaps) mapped. Similarly, differentiating the ability of pigs to find or access below-ground food resources would be difficult, even if the presence of those resources could be ascertained. These difficulties probably explain why studies of ground disturbance by pigs have focused on models that explain patterns of occurrence, rather than the underlying mechanisms that produce those patterns (Alexiou 1983, Hone 1988).

An alternative approach to direct parameterization is to develop a range of competing ground disturbance models based on elaborations of Eqs 1, and contrast their ability to predict spatial and temporal patterns of disturbance measured in the field.

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RELATIONSHIP BETWEEN YIELD LOSS OF SORGHUM CAUSED BY THE HOUSE MOUSE, *MUS DOMESTICUS*, AND NUMBER OF MICE

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ABSTRACT: The house mouse, *Mus domesticus*, has been reported to cause substantial pre-harvest yield losses of grain crops (e.g.; Mwanjabe *et al.* 2002; Singleton 2003; Stenseth *et al.* 2003; Brown 2004). The relationships between yield losses and number of mice have not been studied systematically (Brown 2001; Hone 2004). By quantifying and modeling the relationship between different densities of mice and yield losses, appropriate ecologically and economically-based management strategies can be established. This has been examined by using 16 rodent proof enclosures (pens) each one 225 m^2 in size on Gatton campus, UQ, QLD, Australia from December 2002 to May 2004. The pens allow us to determine and quantify the relationship between different numbers of adult mice which have been introduced in 4 different densities to each 4 pens and yield losses caused by mice to particular crops types for the period of 7 weeks from milky stage to ripening stage. Crop type examined was sorghum.

Yield losses caused by different density of mice have been assessed by comparing average dry grain weight for 4 excluded plots and 8 at-risk plots with 4 replicate for each level of mice densities to determine differences amongst enclosures. Also we caught all mice out, using live traps (Elliott) to monitoring population growth, population impact and possibly contribute to the differences in the yield loss. Using mix model to find out the effect of high abundances of mouse(15, 32, 63 and 125 mice/pen) on mean yield loss expressed as g/head showed a significant effect of mice on yield loss ($\mathbf{F}_{3,\,12} = 5.07$: $\boldsymbol{p} = 0.0439$: mix model). Also the results of the comparisons of least squares mean showed that yield loss in the pens with 32, 63 and 125 were remarkably similar. The result of trapping for find out the final population confirm that mice population within the pens with 63 haven not increased and even the population within the pens with 125 mice has decreased significantly, it maybe caused by stress because there is no limitation of food (carry capacity) and natural predator pressure.

The data from 2004 trial were analyzed by following ANOVA and GLM procedure to find out the effect of low abundances of mice (4, 8, 12 and 16 mice/ pen) on mean yield loss expressed as g/head. The results showed even low number of mice has a significant effect on yield loss ($\mathbf{F}_{3,\,12} = 5.57$; $\boldsymbol{p} = 0.013$: ANOVA).

There is a very strong positive linear relationship for low densities and non-linear relationship for high densities of mice and percentage of yield loss/head.

$$(y = 1.1885x + 3.0118;\ \boldsymbol{p} = 0.037), \quad ((y = \text{Max}\,(1-e^{-kx}));\ \boldsymbol{p} = 0.00045).$$

According to modeled relationships between pest damage and pest abundance by Hone (2004), the functional relationship appears to be type **II** (Concave-up relationship). These data will be used to develop a predictive model of cost and effect of mice on cereal crop, economically-based management strategies and to improve on farm monitoring methods.

UNEXPECTED CONSEQUENCES OF VERTEBRATE PEST CONTOL

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ABSTRACT: Although indirect effects are important structuring forces in ecological communities they are seldom considered in the design of pest control operations. However, such effects may cause unpredicted and deleterious changes in other populations that could reduce or even negate the benefit to endangered species for which control is undertaken. Furthermore, the complexity and nonlinearities inherent in interacting ecological communities may cause thresholds in the strength of pest control employed to occur, on either side of which indirect effects could vary greatly in their magnitude and desirability.

We constructed a 4-species simulation model for a common pest community in New Zealand beech (*Nothofagus* spp.) forests – house mice, ship rats, stoats, and brushtail possums. When the model was perturbed to simulate common control techniques, marked increases in the abundance of non-target pest species were observed at the next forest mast: higher mouse numbers following both toxin (1080) application and rat kill-trapping, and higher rat numbers following stoat kill-trapping, due to a release from predation in all cases. In comparison, a marked decrease in stoat abundance at the next forest mast was observed following simultaneous control of rats and mice, due to the knock-on effects of decreased prey abundance on the stoat population.

For rat control, the size of the indirect effect on mouse numbers increased monotonically with control strength. Since the curvature of the relationship is slight the relationship between the direct benefits of control and the indirect costs incurred would remain relatively unchanged regardless of the strength of control employed. For simultaneous mouse and rat control, however, high levels of control (as initially simulated) were predicted to cause decreased peak stoat abundance at the next mast event, while intermediate and low levels of control were predicted to cause increased stoat abundance.

We conducted additional simulations of the community model constructed to explore a separate matter – whether vertebrate control operations differ in their efficacy depending on the time of year in which they are employed. In contrast to conventional practice for rat control, where control is employed to coincide with the breeding seasons of vulnerable bird populations to gain a short-term direct benefit, our simulations indicate that the long-term impact on rat population levels is maximized by controlling in winter.

These results demonstrate three points of concern for pest managers. First, indirect effects of control operations do have the potential to reduce the planned-for benefit. Second, thresholds in the strength of control employed can potentially occur, across which indirect effects switch from being of conservation benefit to being of conservation concern. Finally, if we wish to shift to a long-term perspective on vertebrate pest control, different strategies to those currently employed to maximize short-term benefit may be required.

POSTER PAPERS

DEVELOPMENT OF A TRAP MONITORING SYSTEM FOR WILD DOG TRAPS

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ABSTRACT: Wild dogs threaten agricultural enterprises such as sheep production throughout the North-East and Gippsland regions of Victoria. The Department of Primary Industries undertakes a trapping program as part of an integrated approach to managing the impacts of wild dogs. Trappers currently operate and inspect 30-40 large rubber-padded leghold traps each across a number of sites on the periphery of private and crown land. These areas are characterised by mountainous and heavily vegetated landscapes that are often subject to snowfall. Considerable time is spent accessing and inspecting trap sets over rugged terrain using 4WD vehicles or horseback. Opportunities to improve the efficiency of the current trapping program could be realised if a reliable automated alerting system was utilised.

Current operational guidelines dictate that wild dog traps are to be inspected within three days of setting and then at least twice every seven days. Trap numbers utilised are restricted to the maximum that the trapper can effectively monitor given the stipulated inspection frequencies. A successful system would improve the response time to inspect triggered traps, which would lead to an improvement in the welfare of trapped animals. Additionally, there is potential to utilise greater number of traps given that traps sets can be 'inspected' remotely. Trappers will be able to respond to 'mis-fired' traps and thus maximise their trapping effort by ensuring that all traps in the field are actually set. Specifications for an effective system were prepared in association with appropriate regional staff. Key system requirements were identified:

- Compact rugged design that is both dust and weatherproof (including transmitter and antenna).
- Notifies trapper within 1 hour of trap being triggered.
- Daily message from trap indicating 'standby' status
- Field operation for minimum of 3 weeks.
- Remote from trap to reduce damage from dog or theft.
- System monitoring to be undertaken remotely from an office location.
- Straight forward and reliable operation.
- Minimal extra hardware required.

A review on trap monitoring systems found that no off-the shelf equipment was currently available that was suitable for the task of remotely monitoring wild dog traps in Victoria.

Discussions with communications engineers have led to the development of four prototype trap alert systems. Wild dog trappers are currently evaluating these prototypes that utilise different communication platforms and activation mechanisms. This range of platforms was selected to assess the most appropriate system for use in this application. The prototype systems utilise VHF, UHF, CDMA and 'SMR spread-spectrum trunked radio' platforms.

Trappers will assess factors including the ease of use, transmission coverage and field practicality of each system during their normal operations. Recommendations for the production and rollout of a particular system will follow at the conclusion of the field evaluation.

THE BARE BONES OF THE HSNO ACT

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ABSTRACT: In 1996 the Hazardous Substances and New Organisms (HSNO) Act became part of the research, science and technology landscape of New Zealand. Its role is to protect the environment, and the health and safety of people and communities, by preventing or managing the adverse effects of hazardous substances and new organisms. This broad role also includes putting biological control agents, including those for vertebrates, through a rigorous risk assessment. However, too often both scientists and technologists fail to view the lie of the land and only "discover" their HSNO Act requirements at the end when research is completed and the funds are all spent. It can be a rude awakening to discover that the research failed to address the key requirements of the HSNO Act. All those working with biocontrol agents need to be cognisant of the HSNO Act and to build its key requirements into their research proposals and programmes. The key requirements are to investigate whether there is any significant displacement of native species within natural habitats, deterioration of natural habitats, adverse effects on human health and safety, adverse effects to New Zealand's inherent genetic diversity, or if the organism could be a parasitic or a vector of human, animal or plant diseases (unless that is the purpose), and that Māori consultation has taken place. It is also desirable that real costs and benefits have been assessed. The incorporation of the HSNO Act into science planning will not only facilitate the smooth passage through the assessment procedures but may help to identify, at an early stage, biocontrol agents' whose risks would be considered too great to release and thus allowing the redirection of resources to other biocontrol agents.

POPULATION DYNAMICS OF WILD RABBITS AFTER THE OCCURRENCE OF RABBIT HAEMORRHAGIC DISEASE IN VICTORIA

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ABSTRACT: After the occurrence of rabbit haemorrhagic disease (RHD) in Australia, rabbit populations declined but RHD was least effective in cool, moist, temperate areas. In southern Victoria, a single site capture-mark-recapture study monitored the impact of: antibody status to RHD and benign calicivirus (CV) (Cooke *et al.* 2000), myxomatosis, and also season, gender, weight, condition and reproductive status on rabbit survival. From 1998 to 2003, 1550 rabbits were sampled on 23 occasions at 6-8 week intervals. Generalised linear models with Cormack-Jolly-Seber probability structure were used to estimate rabbit survival. Models were selected using χ^2 change in deviance tests. Analysis used the statistical package, MARK (http://www.cnr.colostate.edu/~gwhite/mark/mark.htm). Analysis indicates that weight at first capture, time accrued since first capture, condition, gender and antibody status to calicivirus, as measured by cELISA, are related to rabbit survival. Reproductive status and antibody status to myxomatosis and calicivirus as measured by IgG, IgM and IgA are not related to rabbit survival. These results imply RHD is associated with rabbit death, but at this site benign CV and myxomatosis have little influence on predicted rabbit survival. Further, it appears that rabbit death associated with RHD largely occurs with kittens that were born in the last quarter of the breeding season. The limited contribution of myxomatosis and calicivirus to survival at this site is likely to be related to high prevalence of antibodies (Table 1).

Table 1 Mean prevalence of antibodies for different age groups over a 5 year period.

	Adult (>1200 g)	Juvenile (800-1200 g)	Kitten (<800g)
Calicivirus (virulent & benign)	97%	75%	80%
Myxomatosis	89%	65%	75%
Calicivirus or Myxomatosis	99%	91%	94%
Calicivirus and Myxomatosis	86%	50%	64%

Contributors to the breeding population are (1) Adult rabbits with high annual survival probabilities (18%) that are not sensitive to the time of year, gender, condition or antibody status. (2) Kittens born in the first ¾ of the breeding season with moderate survival (2-6%) depending on gender and condition but not depending on cELISA. 3) Kittens born in the last quarter of the breeding season with low survival (1-4%) depending on cELISA, which increases survival probability, and also gender and condition. Within a breeding population, 79% are year 1 rabbits, 17% are year 2, 4% are year 3 and 1% are year 4 or older. There were seasonal periods of high survival during the breeding season followed by low survival, but there is no indication that survival rates differ for individual periods within a season. This suggests the population is not regulated by epizootics or deficit/surplus nutrition, and thus it is likely that reducing populations will not result in rapid recovery. Rabbit control should be implemented just prior to breeding and after most natural mortality has occurred to reduce the immune breeding rabbits which sustain the population. Controlled releases of RHD virus will have little impact since RHD is endemic and residual populations are immune. This study

shows that professionally designed and analysed mark-recapture studies that include antibody measurements can determine disease function and distinguish vulnerable groups of animals in vertebrate pest research.

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ADAPTIVE MANAGEMENT OF KANGAROOS ON RESERVES IN SOUTH AUSTRALIA

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ABSTRACT: On land set aside for nature conservation, excessive levels of herbivore grazing pressure can have negative impacts on biodiversity, and active management of total grazing pressure can be required to facilitate ecological restoration. Experience from the Flinders Ranges National Park in South Australia shows that complete removal of domestic stock, and effective management of feral herbivores (e.g. rabbits, goats), will not necessarily result in improvements to land condition (Alexander 1997). In these situations, reduction of kangaroo populations can also be required to meet restoration objectives.

Two species of large kangaroo (Western Grey Kangaroo, *Macropus fuliginosus* and Euro, *M. robustus*) are currently being culled as a component of ecological restoration programs on three conservation reserves in South Australia: Flinders Ranges National Park, Coffin Bay National Park and Para Wirra Recreation Park. All three reserves have integrated control programs for feral herbivores, and vegetation monitoring programs that suggest kangaroo grazing pressure is negatively impacting on native vegetation. Animal welfare requirements are met by ensuring that all kangaroos are culled in accordance with the *Code of Practice for the Humane Shooting of Kangaroos* (Environment Australia 1990).

Uncertainty is an inherent component of ecological systems, and in these systems, we are uncertain about the relationship between kangaroo density and the desired ecological response. We favour a trigger-point model to explain this relationship, under which the ecological response to culling is minimal until kangaroo populations are reduced to a specified target (or trigger-point) density. Due to the uncertainty involved in this model, programs are managed via an adaptive management cycle. This approach allows us to learn about the system as we manage, and refine future management based on information that is learnt.

We evaluate the success of each program over the last five years, and make recommendations for future management. As recovery of native vegetation in response to reductions in herbivore grazing can take up to 10 years (Alexander 1997), we define success as the extent to which culling has reduced kangaroo populations towards target densities, using results from annual kangaroo surveys conducted on foot using line transect methodology (Buckland *et al.* 2001).

Across the three reserves, kangaroo populations have shown a variable response to culling. On the reserve that is located on a peninsula (Coffin Bay), where rates of immigration into the reserve are low, culling has successfully reduced the population to the target density. On the reserves surrounded by pastoral leases (Flinders Ranges) or patches of native vegetation (Para Wirra), culling has been less successful at reducing kangaroo density. In these situations, amendments to the culling strategy may be required to maximise success. Targeting a culling strategy towards females may increase success through a greater impact on the population's rate of increase. Similarly, engaging in partnerships with neighbouring landholders may also increase success, by reducing levels of immigration onto reserves.

Preliminary information on ecological response suggests higher recruitment of indicator species such as native grasses in areas that kangaroos are culled, when compared to areas that are not culled. Ecological response will continue to be monitored, with necessary amendments to target densities and culling strategies made in response to information that is learnt.

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IS EFFECTIVE LONG-TERM MANAGEMENT OF RABBITS IN SEMI-ARID REGION RESERVES POSSIBLE? TEN YEARS ON

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ABSTRACT: Rabbit control is an enormous task requiring long-term commitment. It is also a critical element in managing total grazing pressure within the Flinders Ranges National Park (FRNP) of South Australia. Prior to 1995 rabbit densities in the FRNP were in excess of 1,400 per 100 km transect. In 1995 the release of rabbit haemorrhagic disease (RHD) decreased rabbit numbers to approximately 12% of the earlier recorded levels. This provided an opportunity to initiate a long-term rabbit management program, which significantly assisted in decreasing the total grazing pressure on the park and resulted in improved conditions for natural regeneration of flora. The intensity of infestation in the FRNP was so significant, both in area and rabbit numbers, that the number of warrens remaining post-RHD provided significant refuge for the residual populations. Consequently, focusing on the destruction of existing warrens to prevent their re-use, coupled with ongoing management strategies to ensure minimal reinfestation, was essential.

The methodology included accurately mapping individual warren position and density within a defined area using a GPS and on-ground counting of holes. This was followed by warren destruction, before initiating an ongoing rotational program for all treated areas that also identified optimal harbour requiring more frequent and intense monitoring and maintenance. This outcome not only achieved set target densities by destroying refuge but, equally importantly, provided an analytical approach to determining rabbit 'hot-spots', were conditions were optimal for rabbit numbers to increase rapidly and expand into surrounding areas. Given the aim was to effectively manage a large geographical area (250 square kilometres) over a long time period, this approach meant management decisions could be made in regard to which areas could be managed via a routine rotational program versus those areas that required a higher level of monitoring and maintenance. This rabbit control program in the Flinders Ranges National Parks has successfully demonstrated the effectiveness of thorough, systematic management effort where ecological benefits are now visible.

ECOTOXICITY OF SODIUM FLUOROACETATE (1080) TO PLANTS

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ABSTRACT: Sodium fluoracetate (1080) is a highly effective vertebrate pesticide used in large-scale possum control operations throughout New Zealand. Non-target effects of 1080 remain controversial, and the gaps in ecotoxicity data make it difficult to adequately assess the hazard of this pesticide in our environment. To investigate the implications of 1080-contaminated soil for growth of vegetation, Landcare Research conducted laboratory tests to obtain ecotoxic thresholds for plants in a natural soil. Percentage germination, time to emergence, and root and shoot growth were monitored in a monocotyledon (oat, *Avena sativa*) and a dicotyledon (lettuce, *Lactuca sativa*), following standardised international methodologies. Five replicates with six seeds per replicate of both plant species were exposed to 0, 0.32, 1.0, 3.2, 10.0, 32.0, and 100 mg 1080/kg soil (dry weight) under controlled laboratory conditions. The seeds were checked daily and their time to emergence recorded. After 14 days, seedlings were harvested and the root and shoot weights measured. Lettuce was clearly more sensitive than oats with a median effective concentration (EC50) for inhibition of germination at 47 mg 1080/kg soil. Time to emergence for lettuce seedlings increased with increasing 1080 concentration, with a lowest observable effect concentration (LOEC) of 10 mg 1080/kg soil. Growth of lettuce seedlings was also significantly inhibited at this concentration. Based on the EC50 results, 1080 would be classified under the Hazardous Substances and New Organisms Act (1996) into 'Category 9.2C: Substances that are harmful to the soil environment . A higher classification might be assigned if the LOEC values for time to emergence and growth inhibition are considered. The support of the Animal Health Board for this work is acknowledged.

INTERRUPTING ERUPTING MICE – TURNING REACTION INTO PROACTION

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ABSTRACT: In the past, management of mice in crops has been characterised as "late reactive", with intervention using large quantities of bait initiated only after an overwhelming plague had developed. This reactive management has been institutionalised yet a large amount of crop damage occurs when mouse numbers are modest or emerging, particularly if the rise in mouse numbers coincides with a vulnerable stage in the crop cycle. Moreover, early intervention once mouse numbers start to threaten a crop will prevent the development of a plague and avoid much of the crop damage at an early stage.

It is now generally accepted that pro-active mouse management requires on-farm vigilance, private and public sector advisors with accurate local knowledge, an adequate and timely supply of control products by manufacturers and merchants and an aproach based on early reconition of both the mice themselves and the potential risk to the crop. Even though the components of an effective response are recognised, the amount of time between significant mouse problems arising and the decision to treat is often short. Thus, responses must be planned and implemented promtly.

Regional early warning systems involving modelling and monitoring do give some indication of emerging problems but do not provide sufficiently advanced or reliable prediction for forward planning of bait requirements. Moreover, data from some monitoring is site specific, yet mice can erupt at sites or in paddocks where monitoring is not conducted. Equally, populations can rapidly collapse in some situations without the need for intervention and there is no reliable predictor of the declining phases of mouse plague eruptions.

To overcome these problems we believe that farmers should regularly monitor their own crops in order to make proper decisions as to the requirements for baiting. This approach required a transfer of knowledge and responsibility to a local level to provide a much broader knowledge base to underpin local actions.

In order to promote on-farm monitoring as a pro-active management technique, the Grains Research and Development Corporation (GRDC) supported a three-stage extension project to increase farmer and agronomist awareness of mouse damage and of the methods to reduce threats to crops. The extension package also aimed to improve knowledge of, and dispelled myths about, the use of zinc phosphide to control mice within crops. The development and distribution of the extension materials was enhanced by the active participation of most stakeholder agencies involved in mouse management and we acknowledge the inputs of a skilled advisory group of 22 experts who constructively reviewed all materials during preparation.

Stage one was to develop a 32-page booklet on best-practice mouse management. The booklet explained the history of major mouse infestations, mouse biology and factors that contibute to mouse plague erruptions. Options for prevention and, if necessary control of mice were explained. Importantly, the booklet explain the benefits of reducing factors that contribute to mouse infestations (e.g. grain spills and weed seeds) and encouraged landholders to move away from the traditional reactive "panic" management after crop damage has already occurred, and to adopt an approach based on prevention and monitoring,

with early intervention to minimise crop losses. The materials encourage a risk-benefit approach in which mouse numbers and potential crop vulnerability were linked as a basis for decisions on whether to apply bait.

Stage two was the development of a professional training video/DVD as a resource to assist government semi-government and private sector advisors conduct local mouse awareness workshops. This resource improved the capacity of local staff to runs seminars and information evenings to disseminate knowledge on mouse activity within an affected district, especially where a prompt reaction to emerging mouse problems is required. This resource was particularly directed towards encouraging a more pro-active approach by the more than 1000 merchant and private consultant agronomists who service the grains industry in Australia.

Stage three was the presentation of a series of "train-the-trainer" workshops were conducted in key grain-growing areas to directly explain the other information aids on pro-active mouse management and best practice use of zinc phosphide for in-crop mouse control. These training workshops were conducted by Applied Biotechnolgies in collaboration with local state pest management agencies.

Despite the highly focussed and practical approach to saving crops and the strategic nature of the information, the attendance at workshops was greatest when mice were a current problem and lowest in areas where there had been no recent history of mouse damage to crops. Surveys of participants were conducted before and after the workshops to assess the effectiveness of the information transfer and the extension materials and to reinforce the message transfer.

Train-the-trainer workshops were conducted in Qld, NSW, Vic & Tas and in SA. The workshops were held at locations that had traditionally experienced problems with mice in crops, as well as areas predicted to experience at least some mouse problems in the future (ie. Tasmania for intensive crops). The locations of the workshops were Dalby, Jambin, Capella & Theodore (Qld), Launceston & Hobart (Tas), Bellata, Narrandera & Trangie (NSW) and Horsham & Walpeup (Vic). Overall to date, 259 trainers have attended the 11 workshops (ave approximately 24 people per workshop, range 5 to 88). Three workshops are scheduled for SA in April 2005. On advice from AgWA no workshops were run in WA. In WA a different approach was taken in which information (the 32 page booklet) was mailed with GRDC newsletters to all major cereal growers.

Participants included representatives of nine groups including Aerial Contractors (16% of attendees overall), Government Agencies (40%), Private Consultants (4%), Rural Merchants (9%), leading farmers (29%), Grains Industry (2%), Students, Media and Pest Control Contractors (1%).

It is recognised that staff of the key government advisory agencies (such as departments of agriculture or primary industry or rural lands agencies) have already received considerable information about mouse management and most have been trained on approriate use of zinc phosphide bait as control option. Accordingly, our main focus was on rural merchant advisors, agronomists, private consultants and contractors, since these groups provide crop agronomy advice and deal directly and individually with mouse-affected landholders on a regular basis. Aerial contractors also provide the delivery capability to combat, on a large scale, mouse emergencies in developed crops and were therefore a second key focus group for the workshops. It was noteworthy that most key aerial contractors attended the workshops and actively sought the up-to-date and comprehensive information provided. However, despite their potential to increase the resources avilable to improve on-farm knowledge on mouse prevention and management, agronomists from the merchant sector made up a disappointing 13% of workshop attendees. This is surprising since this group provides the technology to farmers and has a pivotal role in advising farmers. All relevent merchnats stores were contacted prior to the workshops and both written and email invitations sent and in some cases the workshops were notified in the local press. Follow-up enquiries indicated that some merchant agronomists considered that they already had sufficient knowledge about mice and zinc phosphide bait and it is fair to say that the bait has been used commercially, albeit reactively, in most cereal growing areas since first released under emergency permit in 1997.

For the first 11 workshops a pre- and post-workshop questionnaire was conducted to assess both initial knowledge of participants and the success of the information transfer. The survey process also forced a reconsideration of the issues discussd and was thus directed at reinforcement of the key messages. Of the 259 workshop attendees, 157 completed a survey prior to the workshop and 50 attendees completed the post workshop survey.

- The majority of respondents were agronomists or farm advisors and it is presumed that the government attendees already had good knowledge of mouse problems and their prevention and treatment.
- The majority of respondents thought every farmer should take the primary responsibility for monitoring mice on his/her property.
- The majority of respondents thought looking for mice in crops or using canola soaked cards to detect mouse activity were the main methods they advised farmers to use to detect increases in mouse numbers.
- The majority of respondents thought that mouse activity in crops should be monitored weekly if there are indications of mice present on a property or identified in the district but reduce the monitoring frequency to monthly if the threat was low.
- The majority of respondents had never used or advised on methods to prevent mouse build up *before* an infestation has occurred.
- The majority of respondents ticked baiting as the method they advised to prevent mouse build up or treat mouse infestations.
- The majority of respondents thought mice can swim yet most thought heavy rains drown *adult* mice. Following the workshop the majority of respondents had learned that modest rains does not overcome a mouse plague but probably delays recruitment by reducing survival of young mice in nests if the rainfall is sufficient to flood nests.
- The majority of respondents did not belive that first kills mice.
- The majority of respondents had advised the use of MOUSEOFF® Zinc Phosphide Rodent Bait and were aware that the product took less than 2 days to reduce mouse numbers.
- The majority of respondents thought MOUSEOFF® bait was applied by aerial broadcast prior to the workshop, however following the workshop the majority of respondents were aware that it was applied by either ground or aerial application. This change reflects a change in availability between the permit phase (areial only in some States) and following registration in 2000, when both options were adopted nationally.
- The majority of respondents knew that MOUSEOFF® Zinc Phosphide Rodent Bait was applied in developing crops but knowledge of the approriate use of bait pre-sowing and pre-harvest was less evident.

- Most were aware that zinc phosphide bait killed by releasing phosphine gas internally after reaction with stomach acids with only one or two grains of bait required to kill a mouse.
- The majority of respondents considered that reapplication is sometimes required especially to rid local "hot spots" of very high mouse numbers or if the treated area is small and surrounded by harborage from which crops can be reinvaded.
- Many respondents pre-workshop thought rubber gloves were the most important safety procedure required when handling zinc phosphide bait but post workshop they were more aware of the dangers posed by phosphine gas in confined spaces. However, all were aware of the need to open MOUSEOFF® bait containers outdoors.
- Surprisingly the majority of respondents thought bait should be applied before mouse damage occurs yet experince in recent years has been that the decision to bait is generally left very late and often after significant damage has occurred. The divergenge here may indicate that the seminars were attended by those leaders in the industry who are already largely adopting the pro-active approach and raises the need for further information transfer to all growers.
- Prior to the workshops, many respondents looked to rural newspapers as a primary source of information about emerging mouse problems in their area and for information about mouse management for their clients. This possibly reflects the impact of advertising and editorial information that is commonly released by government agencies who correctly provide early warning of the need to check crops. Following the workshop the majority of respondents were clearly aware of the additional and comprehensive information available on DVD/video and in information booklets and fact sheets.

Overall, the messages that were highlighted during the seminars and accompanying handouts were reflected well in the survey responses following the workshop, indicating that the information transfer to those that attended the workshops was successful. As discussed earlier however, attendance by key advisors from the merchant sector was lower than anticipated. It must be noted that many of these staff have also recived information directly from the manufacturers of MOUSEOFF®, Animal Control Technologies) and many have already been involved with distribution and use of zinc phosphide bait over the last eight years since development. It is possible that distribution of information via government agencies and by direct interaction with the merhcant system has been more effective than first anticipated. Nevertheless, in order to continue with information transfer to those involved with mouse management at the farm level, our focus has now shifted to focussing directly on the landholders themselves via grain industry newsletters and other media and by making the information aids freely available to farmers both directly where feasible and also via the exstablished advisory chennels in the government and private sectors.

It is hoped that, with better knowledge of prevention and treatment at all levels and the transition to early intervention based on objective monitoring and risk assessment on a local crop basis, significant damage will be prevented and there will be less reliance on late reactions to classical mouse plagues. This improved crop protection can be achieved without any overall increase in mouse management costs on affected farms.

SOUTHLAND CONSERVANCY ISLAND BIOSECURITY PLAN

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ABSTRACT: Southland Conservancy of the Department of Conservation (DOC) has been an innovator when it comes to island biosecurity procedures. With responsibility for over 1000 islands which support numerous rare and endemic species, it is not surprising that Southland staff have afforded this aspect of conservation a high priority. Southland s Island Biosecurity Plan and a Best Practice Manual have formed the basis for standard operating procedures (SOPs) which now guide DOC s island biosecurity nationally.

Andy Roberts prepared a draft island biosecurity plan for Southland during 2003. Andy also produced a best practice manual. National templates were based on this work. The draft Southland plan was updated by David Agnew to align with the national template. It was approved by the Conservator in November 2004, and continues to be updated as necessary. The Island Biosecurity Plan has increased the awareness, effectiveness and efficiency of biosecurity and quarantine in Southland Conservancy.

The most obvious biosecurity risks are from animal pests and weeds. These can be managed by cleaning equipment, checking packs, etc. Less obvious risks are from diseases that may be transferred through contaminated clothing, food supplies, dogs, building equipment, etc. The plan contains procedures aimed at minimising these risks.

The Southland Island Biosecurity Plan will continually be updated as knowledge, technology, and best practice improves.

THE RED FOX IN TASMANIA; AN INCURSION WAITING TO HAPPEN

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ABSTRACT: Tasmania's high risk of continued red fox incursions and consequent establishment comes from a number of factors, some common to the issue of introductions, some specific to Tasmania.

Foxes themselves; their physical, ecological and behavioural flexibilities are important. They are extremely adaptable animals the pups of which can be mistaken for dogs and which some dogs will foster making smuggling easier. High fox densities in Victoria makes foxes easily available for malicious introduction and may give strong incentive for dispersal and active foraging which can contribute to 'accidents' such as foxes entering containers. The proximity of Victoria makes the survival of foxes in transit highly likely and increases the options for both accidents and malicious introduction.

The potential for foxes to survive in Tasmania is high. Much of Tasmania's landscape, fauna, stock, farming techniques and other land management is ideal for foxes. Tasmania has the potential to hold 300,000 foxes. Although there is obvious potential for Tasmanian devils to be a buffer against fox establishment through competition for food and dens and predation on unattended fox pups devils have been actively suppressed in many areas of small-medium stock farming. This lessening of the buffering potential has become much worse in recent years in most areas of fox evidence by Devil Facial Tumour Disease which reduces devil numbers independently of food; most of the carrion traditionally "left for devils" is now left to rot or is available to other species.

Social attitudes in general make incursions likely. Increasing urbanisation means many people are insulated against the effects of pests. There are mixed hunter ethics and values in both Tasmania and Victoria with a 'them vs us' attitude to government in general, and wildlife authorities in particular, common (this suspicion is of course generated both ways). Some Tasmanians go to Victoria to hunt and vice versa so access to foxes is not an issue. Tasmanians have widely varying attitudes toward foxes in Tasmania and many are sceptical of their presence meaning levels of evidence to trigger future actions may have to be dangerously high. Some Tasmanians believe cats (long established across Tasmania) to be far worse a problem and advocate switching fox eradication resources to cats, reacting to foxes only when they are doing obvious damage. Hoaxes have been a problem as well, wasting time and increasing public scepticism.

Several attitudes might lead to the suppression of information about foxes. Some elements of society are vehemently against the use of toxins in general and 1080 in particular. The 'cuteness' of foxes, especially pups, makes it increasingly difficult to counter animal rights demands to protect all animals.

The increasing rate of traffic (vehicles, containers, aircraft, boats etc) and emphasis on a smooth flow of cheap trade and tourism means incoming traffic is minimally inspected.

The failure to prosecute anyone so far for introducing foxes (the nearest was in 1890 when, at the moment of impoundment, an army officer released the two foxes he illegally imported) giving the impression one might ‘get away with it’. Although problems with a short statute of limitations and relatively small fines have been fixed, deliberately importing or possessing a live fox in Tasmania still does not carry a jail term; it is not seen as a criminal offence.

Historic and recent fox incursions into Tasmania (5 historic incursions and 5 recent pieces of hard evidence), continued increases in traffic across Bass Strait not always commensurate with increased inspection and continued public scepticism about foxes in Tasmania strongly suggest further incursions are inevitable. Perhaps ‘accidents’ will or have overtaken deliberate introductions in importance; both need to be actively guarded against.

THE WEST COAST INTEGRATED PEST MANAGEMENT PROGRAM: A COORDINATED COMMUNITY APPROACH TO PEST MANAGEMENT ON THE EYRE PENINSULA, SOUTH AUSTRALIA

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ABSTRACT: Over 400 landholders on central and western Eyre Peninsula, South Australia, are involved in the West Coast Integrated Pest Management Program, a Natural Heritage Trust-funded program which is managed by a partnership of four state and regional agencies. Central to the philosophy and success of the program is a coordinated, landscape scale approach to pest management activities on both public and private lands, with landholders organised into neighbourhood groups. This aims to benefit biodiversity through threat abatement, as well as improving agricultural productivity. The Program commenced in 1999 to support reintroduction programs for brush-tailed bettongs (*Bettongia penicillata*) and greater bilbies (*Macrotis lagotis*) within a predator-proof fence at Venus Bay Conservation Park. Due to community motivation and direction, the program has expanded beyond its original scope, in terms of both geographical area and issues addressed. Threat abatement activities include two coordinated fox baiting programs per year, planning and implementation of rabbit control programs, and promotion of feral cat control. The landholder network of groups and group leaders has become a medium through which capacity building for a variety of natural resource management activities can be achieved. The Program includes a comprehensive monitoring and evaluation component, which is showing promising results to date. The program has also attracted interest from research institutions that has resulted in collaboration on a range of projects. A summary of the program's development and current situation, together with selected results are presented.

BACKGROUND

Predation by foxes (*Vulpes vulpes*) and cats (*Felis catus*) has been one of the major factors both in the decline of medium-sized mammals in Australia and in the failure of recovery efforts for such mammals. With many habitat areas highly fragmented, the viability of remaining species and populations is under question, and introduced predators remain a serious threat (Kinnear *et al*., 1998; Priddel and Wheeler, 1997).

Weyland Peninsula at Venus Bay Conservation Park was the site of the first South Australian mainland reintroduction of the brush-tailed bettong (*Bettongia penicillata*) in 1994. The population progressed well, thanks to extensive fox and cat control in the release area and collaboration by surrounding landholders. Greater stick-nest rats (*Leporillus conditor*) were reintroduced in 1995 and persist in unknown numbers. In 1996, a 2-km long predator-proof fence was built across the neck of the peninsula, effectively enclosing an area of 1800 hectares. Greater bilbies (*Macrotis lagotis*) were successfully reintroduced into the area in 2001 (Copley *et al*. 1999).

Due to strong community interest, and a recognition of the extent and importance of remnant vegetation on north-western Eyre Peninsula, a decision was made in 1999 to expand the pest management program beyond the immediate vicinity of the park. The initial goal was fox and rabbit control in a 50 km buffer zone, with the long-term aim of releasing native fauna outside the fence. Involvement in a pilot workshop for *Pestplan* (Braysher and Saunders, 2003) helped to clarify priorities and costs. In a highly productive agricultural district, the multiple benefits of coordinated pest management were quickly recognised and over 4 years the program expanded from 30 to 400 participating landholders and from 2 to 4 partner agencies.

A vital asset to the program has been the employment of a project officer for on-ground works on parks and private land and liaison with landholders. Most importantly, the project officer is an ex-farmer and owned part of Venus Bay Conservation Park before it was acquired to add to the park. This has provided a wealth of local knowledge and has been significant for breaking down barriers between farmers and government agencies.

Although earlier studies of fox predation on lambs and the benefits of fox control, including field trials conducted on the Eyre Peninsula, indicated predation was minimal (e.g. Moore *et al.* 1966), more recent investigations suggest that fox predation is an important cause of lamb losses and has highlighted the need for further investigation of the effects of fox control on production (e.g. Greentree *et al.* 2000). Community perception, at least in the Eyre Peninsula region, is that fox predation has an impact on lambing performance, and that fox baiting reduces this impact.

CURRENT APPROACH

1. Location

Venus Bay Conservation Park, the site of reintroduced native fauna populations and the original focus of the West Coast Integrated Pest Management Program, is located approximately 80 km south-east of the township of Streaky Bay, on the west coast of Eyre Peninsula, South Australia. The Program now encompasses the district council areas of Elliston, Le Hunte, Streaky Bay and Ceduna, plus out of council areas in the far west coast of South Australia (Figure 1). The region is predominantly grain cropping and sheep grazing land, with large tracts of remnant open mallee woodland, and includes over 400 km of coastline. Average annual rainfall varies from 250 to 450 mm.

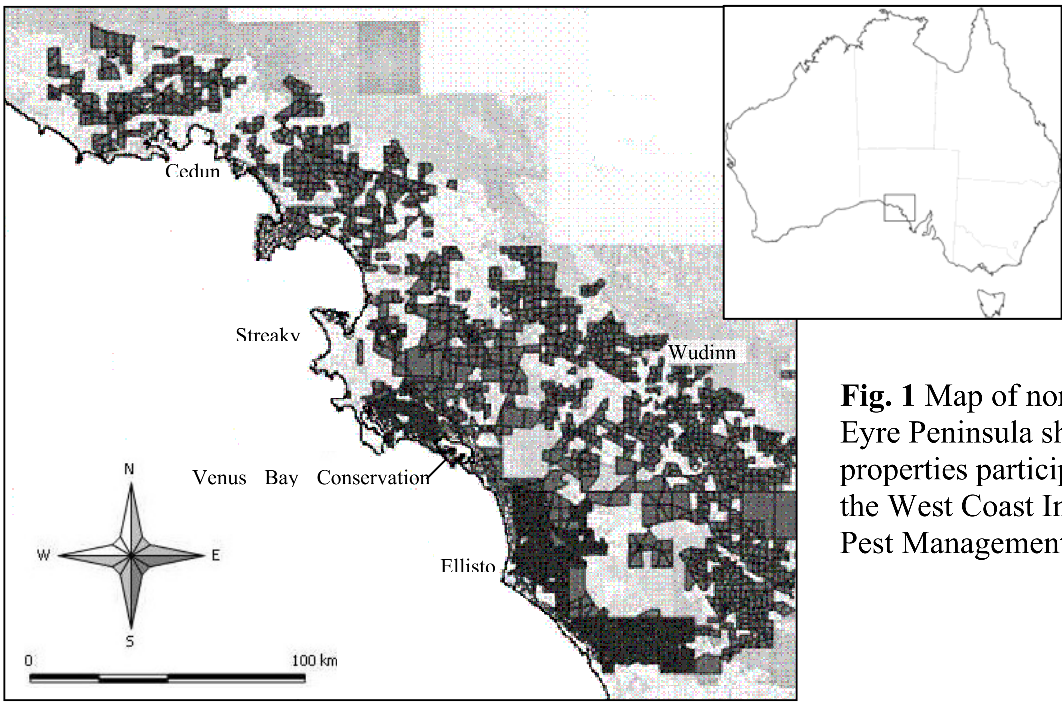

Fig. 1 Map of north-western Eyre Peninsula showing properties participating in the West Coast Integrated Pest Management Program.

2. Pest Management Activities
Pest control materials such as 1080 baits are supplied to landholders who coordinate their pest management in neighbourhood groups of 5-15 landholders. Group leaders are pivotal community members who organise meetings with their group and local Animal & Plant Control Board Officer to plan their control programs and collect equipment and baits. These 'Satellite Field Days' ensure that control efforts are coordinated on a landscape scale and that participating landholders regularly obtain updates on safe use of fox and rabbit baits, legislative requirements, progress of the program and the latest advances in pest management

The focus to date has been on a late Summer (March to mid-May) and an early Spring (mid-August to September) baiting period, taking into account both fox biology and local agricultural schedules. Rabbit control, including baiting and warren destruction, is promoted for late Summer, with assessment and planning encouraged in Spring when damage is evident. Pest management on conservation parks is coordinated with that on private lands, with additional control carried out in priority areas throughout the year.

3. Monitoring
The monitoring program is designed to indicate progress towards objectives, for the purposes of planning, evaluation, reporting and extension. Measures include relative abundance of pest species, recovery or relative abundance of native species, grazing pressure on native flora, and community participation and awareness levels. Results from different sources, including anecdotal evidence, are compared wherever possible for verification and to evaluate the Program's progress from the point of view of all stakeholders. In several cases, monitoring is achieved through collaboration with research institutions or with existing monitoring efforts in the region.

Spotlight surveys are currently conducted every second month at seven different locations within the program area, totalling 650 km of transect. Commonly observed species include fox (*Vulpes vulpes*), cat (*Felis catus*), rabbit (*Oryctolagus cuniculus*), kangaroo (*Macropus spp.*), and southern hairy-nosed wombat (*Lasiorhinus latifrons*). Records are kept of the number of baits obtained by each landholder. This provides data on participation rates and patterns for each baiting season, and has been used to map baiting activity in the region as well as evaluating the expansion of the program over time. A landholder survey is mailed to participants annually, including questions about pest management activities, lamb marking percentages and open questions about the program and current pest abundance.

Extensive ground vertebrate studies have been carried out as part of a study into the effects of fire regimes and fox baiting on flora and fauna. Baseline data for this study was collected in 2004-2005. Three malleefowl (*Leipoa ocellate)* survey sites of 2 x 2 kilometres have been established in areas of known malleefowl activity within the program area, including one on private land. These grids are to be ground-searched for mounds every 3 years and known mounds to be checked for activity annually.

4. Capacity Building
Education and capacity building activities are integral to the program. Apart from regular field days, participants receive a quarterly newsletter and group leaders attend an annual meeting to provide input and direction to the program. Media releases, school visits and presence at local events such as agricultural shows are employed to help raise awareness in the wider community about pest management and biodiversity.

Participants and other members of the community are invited to participate in various monitoring and research elements, and results from all aspects of the program are fed back to the community in a timely fashion.

RESULTS

Results of spotlight transects are presented in Figure 2. Seasonal variations due to pest abundance, behaviour and visibility are evident. There is also a trend towards lower fox abundance from year to year. Rabbit abundance is more variable; however sightings support reports of calici virus outbreaks in the area at certain times of year, together with the timing of control efforts. An analysis of the data from 2003-2004 has been conducted with the aim of improving the efficiency of the sampling effort, results of which are presented elsewhere (Field *et al*., 2005).

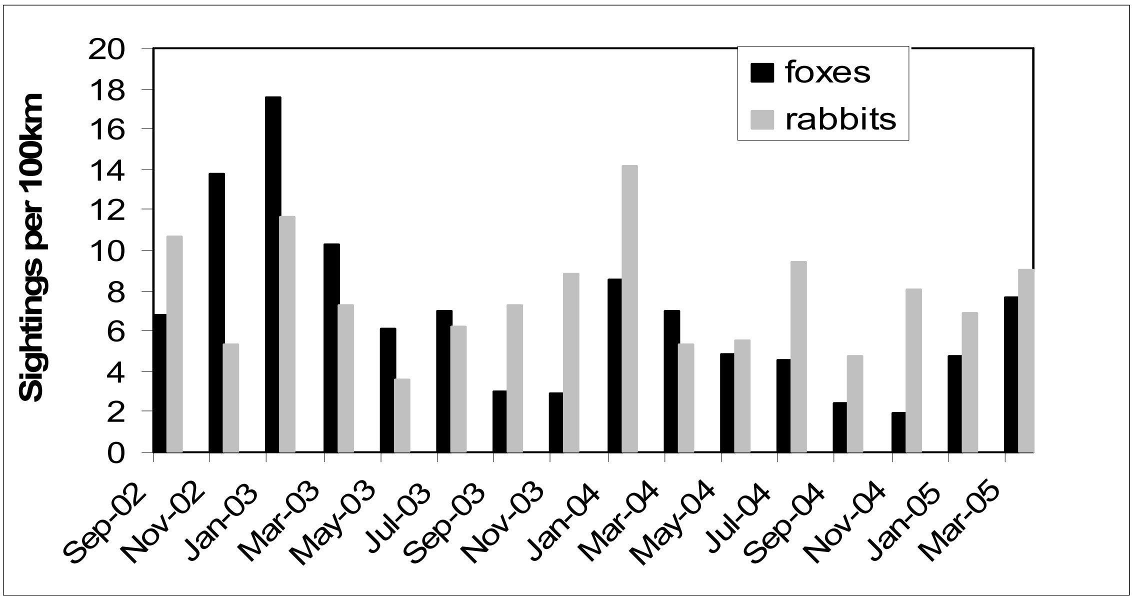

Fig. 2 Average rabbit and fox sightings per 100 kilometres of spotlight transect

Annual landholder surveys show continuing support for the program and high participation rates in summer fox baiting. In 2004, participation in a spring fox-control program dropped compared with 2003, probably due to lower fox numbers. However, participation in rabbit control works, particularly baiting and ripping, has increased. The majority of participants have farming enterprises that include both sheep and cropping. From 2000 to 2004, the average change in lambing percentage across all 112 respondents was a 6% increase. For the 56 landholders who reported having an increase *and* felt fox baiting had contributed, the average increase was approximately 12%. A range of anecdotal evidence from landholders supports the above trends. Monitoring of native fauna is in its early stages and results are not presented here.

DISCUSSION

The West Coast Integrated Pest Management Program is a successful working model of a community-based, landscape scale threat abatement program. Agency partnerships facilitating on-ground works on public and private land, together with ongoing community consultation and involvement, have improved relationships between the community and government agencies. A strong existing community ethic and a focus on education and capacity-building, have resulted in high participation rates for a number of years, with every indication that this will continue.

A primary objective of the Program is to reduce damage caused by pest animals. However, responses of lambing percentages or recovery of native species due to pest management are difficult to isolate from factors such as changes in farm management or seasonal variations. Due to the ad-hoc manner in which the program has expanded, there is a lack of baseline data which limits our ability to assess the long-term progress of the program and to set absolute management targets. To increase knowledge in this area, partnerships with research institutions are utilised wherever possible and monitoring methods are reviewed regularly. Although subjective, survey results and anecdotal feedback are seen as important ways of cross-checking other monitoring methods and maintaining interaction and responsiveness to community concerns. Involvement of landholders in monitoring and research gives them ownership of the information, ensures it is relevant to them and helps keep them interested in the program. The ability to provide results to stakeholders in a timely fashion has been the primary reason to monitor, over and above the requirement of reporting to funding bodies.

Current challenges for the program include the transitional situation for natural resource management delivery in South Australia, potential changes to 1080 regulations, and assessing effects of the program on native fauna and the potential for translocations.

ACKNOWLEDGEMENTS

The farming communities of Eyre Peninsula, who continue to drive the program and contribute many hours in organisation, pest management activities and data collection. The partner organisations for ongoing support and direction: Western and Elliston-Le Hunte Animal & Plant Control Boards; South Australian Department for Environment & Heritage; Eyre Peninsula Natural Resource Management Group. The Australian Government's Natural Heritage Trust for funding.

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CAN TRAP DATA FROM PREDATOR CONTROL OPERATIONS BE USED TO RELATE STOAT AND SHIP RAT CAPTURE SUCCESS TO MICRO-HABITAT FEATURES?

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ABSTRACT: Stoats (*Mustela erminea*) and ship rats (*Rattus rattus)* are major pests threatening New Zealand's native fauna. Control of these pests is being undertaken at sites throughout New Zealand to improve the breeding success and survival of threatened wildlife (Elliot 1996; Moorhouse *et al*. 2003; Gillies *et al*. 2003). Knowledge of the habitat factors that influence capture success is essential for improving pest control strategies. We were interested to see if trapping data, which is collected on a large scale and at relatively low cost, could be used in exploratory data analysis to look for micro-habitat features which may improve the probability of stoat and rat capture success.

Generalised linear models were used to explore the relationship between a suite of micro-habitat features and whether a predator was killed in a trap. We used data collected from large scale predator control operations at Okarito and Moehau kiwi (*Apteryx* spp) sanctuaries (Fig. 1). Direct comparison of models between the sanctuaries was not possible because micro-habitat features were recorded independently and in a different way at each sanctuary

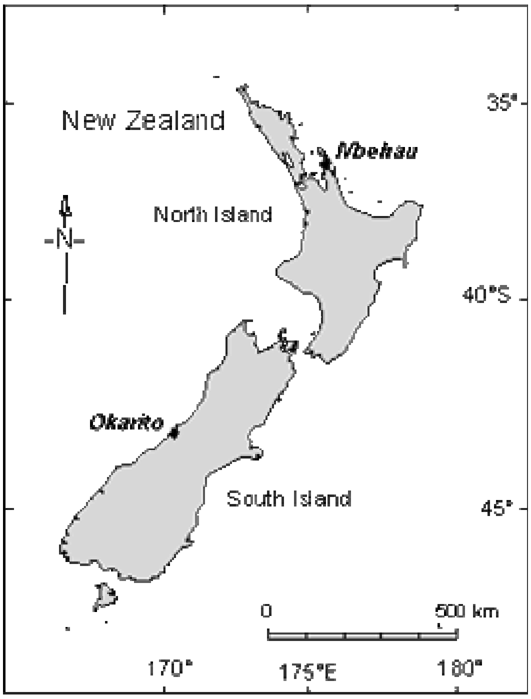

Fig. 1. Location of study areas.

A number of micro-habitat features significantly influenced the probability of catching both stoats and rats (Table 1). Many of the model results are consistent with findings from other research. For example, rat capture success increased in mature hardwood podocarp forest types at both sanctuaries and in sub-alpine scrub and scrub grassland mosaics at Moehau only. Habitat margins, such as road and lake margins, either had no effect or decreased the probability of catching a rat. Similar results for ship rats have been documented both in New Zealand and overseas (e.g., Dowding and Murphy, 1994; King *et al*., 1996; White *et al*., 1997; Cox *et al*., 2000)

Table 1. The best fit multiple logistic regression models of the probability of stoat or rat capture at Okarito and Moehau Kiwi Sanctuaries as predicted by micro-habitat features. Micro-habitat features are recorded for the area immediately surrounding the trap site unless a radius is specified (Note: n.i. = not included in final model; + n.s. = positive effect, not significant; - n.s. = negative effect, not significant; + = positive effect, significant at the 5 % level; ++ = positive effect, significant at the 1 % level; +++ = positive effect, significant at the 0.1 % level; - = negative effect, significant at the 5 % level; -- = negative effect, significant at the 1 % level; --- = negative effect, significant at the 0.1 % level). Examples of model interpretation are: the probability of stoat capture success increased [1] with the presence of a road edge and [2] as the soil around the trap became less moist at Okarito.

Location	Micro-habitat feature	Stoat model	Rat model
Okarito	Presence of rat 'plague'	ni	+++
	Trapping edge (buffer/core)	ni	---
	Altitude (metres a.s.l.)	- ns	---
	[1] Presence of road edge	+++	+++
	Presence of track edge	+++	ni
	Presence of farm edge	++	+
	Presence of undulating topography within 50 m	ni	---
	Presence of flat topography within 50 m	+++	---
	Presence of ridge within 50 m	+++	ni
	Presence of tall podocarp forest within 100 m	ni	+++
	Presence of short sub canopy forest within 100 m	ni	+ ns
	Presence of forest with thick & abundant kiekie within 100 m	ni	+++
	Presence of pakihi/swamp within 100 m	+	ni
	[2] Soil drainage	--	---
	Understorey density within 15m	- ns	ni
Moehau	Altitude (metres a.s.l.)	ni	---
	Presence of major stream	-	ni
	Presence of major ridge	+	--
	Presence of old hardwood/broadleaf forest	++	++
	Presence of sub alpine scrub	+	+ ns
	Presence of a grassland/manuka habitat mosaic	++	++
	Presence of manuka/kanuka scrub	+	+
	Presence of a rough dirt vehicle track	+ ns	---
	Presence of a car road	ni	- ns

Model results were confounded by the trap layout. Trap location was determined by ease of access and other logistical constraints. For example, the probability of catching a stoat increased at Okarito when a road, track or farm margin was present and at Moehau with the presence of a rough dirt vehicle track. However, not all bush margins had the same positive effect, some had no effect and others such as the presence of a major stream margin at Moehau significantly decreased the probability of stoat capture. Traps along road margins were checked more frequently, and therefore were available to catch more animals. Moreover, road and farm edges denote the trapping boundaries at both sanctuaries. These traps would catch more stoats precisely because it is the trapping boundary and there are more stoats to catch, not because of any particular habitat features.

Further investigation into the relationship between micro-habitat features and capture success is required, but needs to utilise random / systematic study design. This will aid in easier model interpretation and ensure stronger inference can be made from the model findings; disentangling the effects of trapping edge and biased topographical layout from trap capture success; and allow investigation into model interaction effects. Trap data from predator control operations should not be used for habitat analyses unless the sampling design is robust. Findings from our model will be used to select the types of micro-habitat features recorded in future research. These micro-habitat features should be standardised nationally, reflect biological mechanisms, be recorded as a continuous measure where possible and nest small scale spatial variables within large scale spatial variables.

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POSSUM ENTEROVIRUSES – POTENTIAL VECTORS FOR BIOCONTROL OF POSSUMS: ANTIBODY RESPONSES AND VIRAL EXCRETION IN POSSUMS EXPOSED TO POSSUM ENTEROVIRUSES BY THE ORAL ROUTE

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ABSTRACT: Two strains of enteroviruses, W1 and W6, were isolated from the colon contents of apparent healthy wild possums captured in Tokomaru, North Island, New Zealand. In order to understand the pathogenesis of these enteroviruses for possums, we infected naïve possums by the oral route. Twelve female possums were trapped from the Tokomaru area, and housed in individual cages. The possums had no detectable antibodies against the enteroviruses, as shown by virus neutralisation test (VNT). Five possums (#1 to #5) were fed with a piece of bread each containing approximately 10^7 median tissue culture infectious doses ($TCID_{50}$) of W1 isolate. Possums #6 to #10 were dosed similarly with the W6 isolate. Possums #11 and #12 were mock-infected with a piece of bread containing only cell culture medium. Possum body weights, rectal temperatures, faecal samples and blood samples were recorded at Day -1. Possums were observed daily during the trial. Possum body weight and rectal temperature were recorded at weekly intervals. A blood sample was collected for antibody detection on days 2, 7, 14, 21, and on day 35 when animals were euthanized. Faecal samples were collected on days 2, 4, 7, 9, 14, 16, 21, 28, and 35 for virus detection. No significant changes in body weight and rectal temperature were observed in possums during the trial. Diarrhoea was not detected. Virus neutralising antibodies were detected by VNT in possums #1, 5, 6, 8, 9 and 10. The antibodies became detectable from day 7 post inoculation, and titres ranged from 1:4 to 1:96. Possum enteroviruses were detected by tissue culture and/or RT-PCR from faecal samples of possums #1, 4, 6, 7, 8, and 9 collected from day 4 to up to day 35 when animals were killed. No visible lesions were noted at post-mortem. These results suggest that oral infection of possums with 10^7 $TCID_{50}$ of W1 or W6 isolate leads to active infection in a proportion of animals. The infected possums shed the inoculated virus for a long period of time after challenge, and developed a vigorous antibody response against the virus. Despite an active infectious process, the enteroviruses appeared to be avirulent to the inoculated possums. It is suggested that these possum enteroviruses are promising vectors for the delivery of bioactive molecules in possums.

HAIR TUBES: AN EFFECTIVE MEANS OF DETECTING STOATS

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INTRODUCTION

Stoats are major pests in New Zealand. They are the most numerous carnivores in forests, and their predation impacts on native fauna are severe (McLennan, 2000). Many methods are used to detect them and control their numbers, the most common being the use of tracking tunnels. Fenn™ trapping is the currently accepted control method (King and Edger 1977; Innes *et al*. 1995; Brown *et al.* 1996).

Problems are associated with using tracking tunnels as estimators of relative abundance of stoats: they are difficult to analyse when stoats are at low numbers; there is no reliable way to identify individual stoats from foot prints; and neophobia is reported as a possibility until tunnels become 'seasoned' (Robins; Potter; Martin; pers. comm. 1998). The use of Fenn traps is a different approach to detecting and estimating changes in stoat numbers. These traps are a kill trap in constant use year round.

Landcare Research has developed a method of detecting and tagging stoats using 'hair tubes' (Byrom *et al.* 2004; Gleeson *et al.* 2004). When a stoat enters a hair tube, a small patch of hair is removed. This sample can then be used to record presence or absence a particular area, and can also provide a means of tagging individuals by their DNA, which is contained in the follicle. The hair tube is a mark recapture devise that removes the need to trap and handle animals. Early indications are that hair tubes work exceptionally well at collecting hair without the associated issues of shyness inherent in other devices.

This detection method can provide two types of information:

- Detection of stoats through the presence of hair in tunnels
- Identification of individual stoats through DNA genotype information

METHODS

Study sites

The effectiveness of collecting stoat hairs via hair tubes has been tested at two locations in the South Island, New Zealand:

- In 2002 the first field trial was conducted at the head of the Matakitaki valley, in Red Beech (*Nothofagus fusca* Hook) forest, which comprised a 9-km² grid marked out for 100 tubes at 250-m spacings, with 500 m between lines. Stoats and rodents were not controlled in this area.
- The second location comprised three blocks near Okarito, SouthWestland: one in the kiwi sanctuary, which is a lowland broadleaf/podocarp mixed forest; one south of this block on farmland in the Waiho River area; and the third in logged-over native forest north of the Okarito kiwi sanctuary. Three blocks of 100 tubes each were established along access lines, with tubes placed at 250-m spacings. Stoats and rats in the kiwi sanctuary block

were intensively trapped as part of the Department of Conservation’s species recovery programme.

Hair collection methods

The hair tubes consist of 200-mm lengths of plastic drainpipe (45-mm in diameter), and were baited with rabbit meat. When a stoat enters the tube, samples of hair plus follicles are removed using adhesive gel on an elastic rubber band. Samples were sorted according to species, and stoat samples were sent to the Landcare Research genetics laboratory in Auckland for DNA analysis in order to identify individual stoats entering the tubes (Gleeson *et al.* 2005). Rodent samples were not analysed in either study.

In both studies, hair tubes were presented to resident stoats as ‘novel’ devices. Tubes were placed and set ready to collect hair on day 1 with no environmental conditioning, and sampling sessions were run for 7 nights. Initially, tubes were checked daily, and those with hair were processed in the field (hair was removed) but left unbaited to simulate longer intervals between checks.

RESULTS

It was found in both studies that hair tubes were visited almost exclusively by stoats; while a few rodent hair samples were collected, there was no rodent-stoat mix. In the Matakitaki study, 99% of the 350 individual samples collected were identified as stoat. However, there was a high percentage of mixed samples where the tube was visited by more than one stoat in the 24 hours between checks (about 50% in the first week), making successful identification of individual animals difficult.

In the Okarito study, 90% of the 53 samples collected were stoat hair, the remainder being rodent hair. There were also fewer stoat/stoat-mixed samples (about 10% of samples). In both trials, new animals were still being ‘captured’ after 7 nights (Fig. 1).

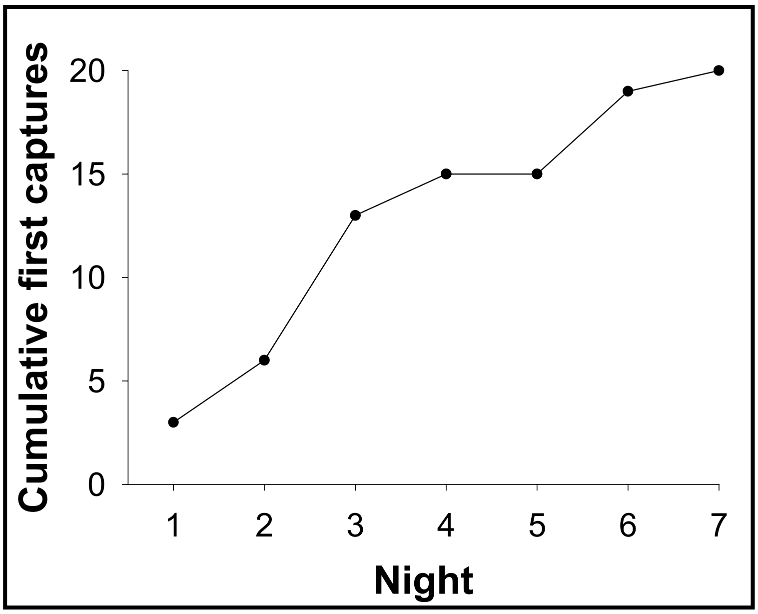

Fig. 1. Cumulative number of new stoats ‘captured’ by hair tubes in a 7-night trial in the Matakitaki valley (Northern South Island Beech forest).

DISCUSSION

The hair-tube system of detecting stoats has several advantages over existing methods. The small size and lightweight construction of tubes mean field staff can carry a large number without undue strain. Each tube was sealed at each end with a cap so it could be carried pre-set to a sampling station where it was opened and baited ready for placement.

Our initial sampling at Matakitaki highlighted the 'attractiveness' of these tubes to stoats. The number of stoats 'tagged' in the first week would be equivalent to catching 10 stoats a day for 7 days with new traps – exceptionally high use of a device by stoats compared with other methods. Further, the device continued to detect new animals even after 7 nights of sampling.

We need to improve methods so we can be sure hairs obtained on the rubber band represent one individual only. A new version of hair tube has been developed that closes after each visit, reducing multiple captures of stoat hair. The new design uses rectangular tubing, which allows a door to be fitted. This door opens when the tube is turned upside down, and closes when the bait is taken off the latching mechanism.

ACKNOWLEDGEMENTS

The Department of Conservation Stoat Technical Advisory Group (STAG) funded this project. We thank Gavin and Kathy Mercer of Matakitaki Station for allowing access across their land; DOC Franz Josef for permission to use their tracks at Okarito; and Steve Kincade and Robin Quaife, landowners in the Waiho River area, who kindly allowed us access to their land.

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RISK ASSESSMENT: HELPING TO PREVENT PETS FROM BECOMING PESTS

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Many species of introduced vertebrates have become established in Australia as a result of deliberate or accidental releases, costing the economy millions of dollars. Invasive species are internationally recognised as one of the most significant threatening processes to biodiversity (Lowe *et al*. 2000) and increasingly, they are causing considerable social problems. In Australia, the widespread holding and movement of *some* introduced species will pose high levels of risk of them being accidentally or deliberately released, with some having the potential to become established as feral populations and possibly become pests. The Vertebrate Pests Committee's 'Guidelines for the Import, Movement and Keeping of Exotic Vertebrates in Australia' outlines a national strategic approach to minimise the risks posed by introduced animals. A key part of this strategy is a uniform system of threat assessment for introduced vertebrates relating to primary production, the environment and public safety.

The Western Australian Department of Agriculture received funding from the Natural Heritage Trust, through the Bureau of Rural Sciences, to conduct threat assessments using the Bomford model (Bomford 2003). This model is designed to estimate the threat posed by exotic vertebrates to Australia. The model was applied in a standardised way to 47 bird species; extensive literature reviews were used to collect required information and the software CLIMATE (Pheloung 1996) was also used.

The model separated similar species, but with differing biological characteristics, into different threat categories. The model also allowed for species for which there is little information available, to be dealt with conservatively. Species for which there were no reports of damage to agriculture, the environment or the public and that had limited climate similarity to Australia were placed in the Low (lowest) threat category (e.g. Brown Kiwi). Iconic pest species were placed in the Extreme (highest) threat category (e.g. European Starling).

Many birds widely kept in private (and generally low security) premises and/or reported in the wild, were placed in the Extreme (guidelines recommend exclusion from Australia or very high security) or Serious (high security recommended) threat categories, presenting a risk management headache for regulators. Such species include the Indian Ringneck, the Monk Parakeet, the Eurasian Goldfinch and the Collared Dove.

In Western Australia, threat assessment results are beginning to underpin management strategies for dealing with these high-risk species and include:

- effective legislation to prohibit, regulate, extirpate and prosecute as required;
- cross-agency decision-making using assessments and prevention of entry to the State of high risk species;
- high risk captive animals kept under higher security conditions (double-doored aviaries, limits on numbers at each location);
- increased public awareness of high risk species (using assessment information) to encourage secure keeping and early reporting of species in the wild; and
- rapid response teams to eliminate species found in the wild.

We also had a person with little scientific training or experience use the model, in order to mimic the actions of a member of the public seeking to import a new species. This activity further confirmed our position that high quality, accurate, unbiased assessments should be prepared by assessors who meet relevant bias, scientific skill and experience criteria agreed by the reviewing agencies. This test also supported our finding that general internet searches (the tool most available to the general public) do not locate many reliable damage reports and that to conduct high quality assessments, information is required from a number of sources, including reference databases and standard text books.

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DEVELOPING 'BEST PRACTICE' STRATEGIES FOR MANAGING MICE IN QUEENSLAND'S GRAIN PRODUCING REGIONS

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ABSTRACT: Queensland grain producers have highlighted a need for 'Best Practice' strategies for reducing mice damage in their developing grain crops. Traditionally, the reaction to mouse plagues has been to ignore all the signs of an impending outbreak, and then apply vast quantities of rodenticides after the plague has erupted (Brown *et al*. 2004). This approach is neither cost effective nor environmentally aware. We aim to show how cost-effective, sustainable farm management practices affect residual mice populations and the frequency of plagues on farms. Where growers take a proactive rather than reactive approach to the problem of mice, in-crop damage and associated yield losses are expected to be significantly reduced without the expenses associated with poorly timed baiting campaigns. Eight sites on the Darling Downs are being used to compare the effects of proactive and reactive farm management practices and then develop a set of 'Best Practice' strategies that grain growers can use to reduce the impact of mice on their cropping enterprises. Preliminary results indicate that there is a difference in mice numbers between the treated and untreated properties, but it is too early in the project to confirm these results. Very low mouse numbers due to prolonged drought conditions also make the preliminary results inconclusive.

INTRODUCTION

Mice cause annual losses of around $30 million to the Australian grain industry (McLeod 2004). In Queensland, plagues appear to be more frequent than in other parts of Australia, possibly because of a progressive move to conservation tillage practices and often continuous cropping cycles.

Queensland has seen rapid adoption of conservation farming practices over the past 20 years, particularly on the Darling Downs where the bulk of the State's grain is produced. A large percentage of the arable land is farmed using minimum or zero till methods in strip cropping systems. Given adequate rainfall patterns, most growers operate on a 3 year cropping cycle, however, widespread drought conditions in recent seasons has led to more opportunistic cropping practices with more fallow land than usual. There is a lot of anecdotal evidence reported from growers that the rapid change from conventional to conservation farming practices has led to higher residual mice populations and more frequent plagues in grain producing regions.

These minimum- and zero-till farming practices provide ideal environmental conditions for irregular outbreaks of mice at local and regional levels, through a lack of soil disturbance, stubble retention and intensive cropping. Without the regular soil disturbances caused by ploughing, mouse burrow systems remain undisturbed from season to season and can become very extensive, sustaining populations for years on some properties. Stubble retention, which is an integral part of conservation farming, provides cover from predators, while unharvested and spilt grain left on the soil surface provide sufficient food resources to sustain mice until the next crop in an adjacent strip has become well established.

In mid-2004, a panel of grain growers and scientists from CSIRO, University of Queensland and the departments of Natural Resources & Mines and Primary Industries formulated a list of 'Best Practice' farm management strategies aimed at reducing in-crop damage and associated yield losses from mice in Queensland.

These strategies included introducing regular crop monitoring for mice activity, strategic full paddock and perimeter zinc phosphide baiting, habitat manipulation of fencelines and unmown verges by slashing, mowing or herbicide applications, and close monitoring of harvesting operations to minimise grain spillages in the crop. Fencelines and verges adjacent to crops provide alternative habitat for mice in between the most palatable stages of summer and winter crops. At the conclusion of the project, we aim to produce cost-effective, sustainable farm management guidelines that will enable Queensland grain producers to reduce crop and associated yield losses caused by mice.

METHODS

Field sites

The study began in July 2004, and is being conducted on eight grain producing properties on the Darling Downs in south-east Queensland. All properties are within 80km of Dalby and operated solely as grain production enterprises. Minimum or zero till conservation farming methods are practiced on each property.
Trapping and monitoring is being undertaken approximately monthly in sorghum (summer) and wheat or barley (winter) crops and their surrounding habitats.

Experimental design

Eight properties were selected and divided into four paired sites, each pair containing a treated and untreated property. Each property pair is geographically close to minimise any differences in crop development caused by rainfall distribution or vastly different soil types. Management of the untreated properties remains entirely in the hands of the owners, with minimal input from the research team. Managers of the treatment properties carry out mice reduction strategies by habitat manipulation and baiting at the request of the research team. The timing and extent of these strategies is based on the results of ongoing trapping and monitoring on each property.

Around thirty grain growers were surveyed and none were prepared to return to ploughing as a means of managing or reducing mice populations on their properties, thus, this option wasn't included in the list of possible strategies. Burning stubble to reduce cover met with similar negative reactions, the reason being that it leaves soils susceptible to erosion during heavy rainfall, and was also excluded as a possible management option.

Trapping

Trapping is conducted approximately monthly for two or three consecutive nights throughout the year using 80 snap-back traps per property. The traps are laid at 10m intervals in four lines of 20. Two lines are placed within the crop and two lines in surrounding habitats, such as fencelines, road verges or fallow paddocks. Traps are baited each night with fresh ham.

The traps are picked up early on the morning after setting. All mice caught are weighed, measured, sexed, and general health and condition recorded. All females >70mm head/body length are autopsied for breeding condition (lactation, pregnancy, number and size of embryos, scars from previous pregnancies). All field data is recorded on site. In the six months that data has been recorded, 8767 traps have been set over 15 trap nights.

Yield and damage assessments
Yield potential and mice damage for each crop is assessed in the last couple of weeks before harvest. Information on actual crop yields is gathered from each grower after harvest.

RESULTS

Preliminary statistical analysis indicates that while the continued drought conditions have reduced mice populations to very low levels, there are still many more mice trapped on the untreated properties than on the treated ones as seen in Fig.1. While this result may be attributed in part to habitat manipulation and strategic baiting carried out on the control properties, the research team does not yet have enough data to confirm this. For at least half of the trapping events used to generate the graph in Fig. 1, trap success rates averaged 0% across most of the sites. To show how drought has affected the trap success rates on this project, trapping records from the Central Downs transect indicate trap results ranging between 7% and 38% for the three month period January through March, between 1999 and 2003.

The Central Downs transect is trapped regularly and results used to update a plague prediction model developed for the Darling Downs. Improved seasonal conditions and several more years of regular trapping will give a more accurate outline of the effectiveness of the 'Best Practice' strategies being employed to reduce mice damage.

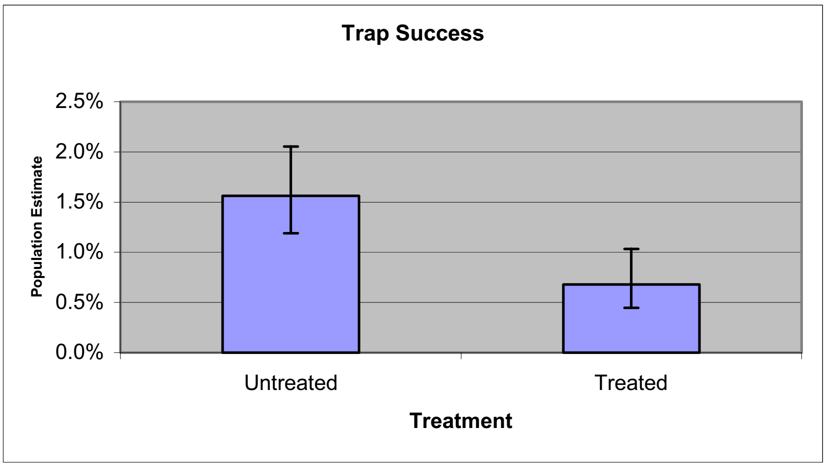

Fig. 1. Trap success rates in 4 treated and 4 untreated sites.

Trapping sites have been divided into 9 broad habitat types, namely young (no head/grain development) summer crop, young winter crop, mature (head/grain development) summer crop, mature winter crop, summer crop stubble, winter crop stubble, fallow, unmown/grassy verge and mown verges. Trap success rates have been so low that there has been no distinction made yet between treated and untreated properties (Fig.2).

The spike in populations trapped in mature winter crops (2004) is explained by high mice numbers in barley on one untreated property and very high numbers on its paired treated property. The treated property was baited with zinc phosphide after trap success rates reached 19% and populations rapidly fell. Mice populations remained high for a couple of months on the untreated site.

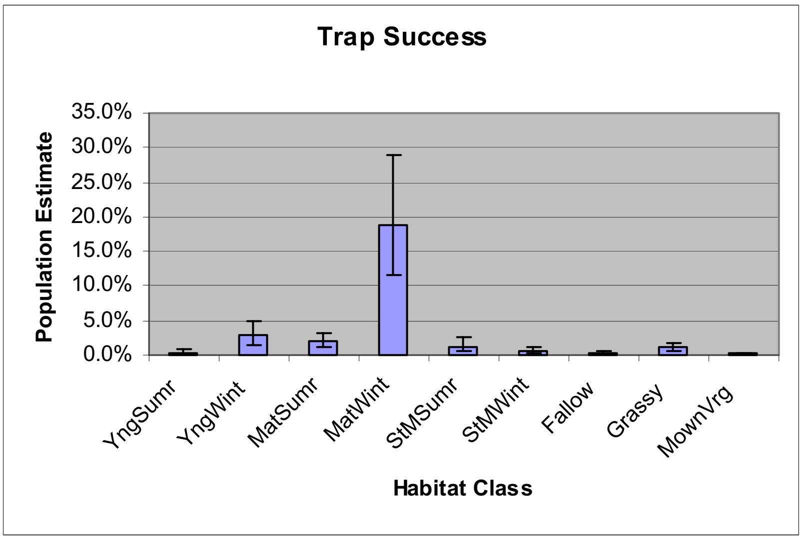

Fig. 2. Trap success rates by habitat class.

Breeding season began later than expected in 2004. The first pregnant females were trapped in November, while in a normal season, we'd expect to be catching breeding females by September or October. As very few pregnant or lactating females have been caught, no attempt has been made to correlate breeding activity with habitat or treatments.

DISCUSSION

Drought conditions have prevailed over much of Queensland for the past couple of seasons. A minor plague occurred on the Darling Downs during the spring/summer of 2004. Mice populations subsequently crashed and have remained low since then, with trap success rates ranging from 0 to 27%. In most months since this project began, trap results on most properties have ranged from 0% to 5%, with occasional short-term spikes in population levels. These results make comparisons between treated and untreated properties so early into the project very difficult.

Caughley *et al*. (1998) found that more mice tend to be found in undisturbed grassy verges and along fencelines. So far this study has shown that mature winter crops are preferred over undisturbed or alternative habitats (Fig. 2), however this result may be misleading due to the short duration of the project to date. It is expected that trap success rates in other habitats will change once several years of trapping data is accumulated.

The influence of habitat, treatments and environmental conditions on breeding patterns will be closely examined as more data is gathered during the project.

The consensus among Queensland's grain growers is that mice are a fact of life and are here to stay. This may well be the case but this project expects to show that there are a variety of cost-effective and environmentally sustainable methods for reducing their impact on crops at both local and regional levels. Improved proactive, rather than reactive management of the problem may go a long way toward reducing the frequency and severity of mice plagues in future years.

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ERADICATING FERAL GOATS FROM BANKS PENINSULA

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INTRODUCTION

Most of Banks Peninsula is the remnant of three extinct, Tertiary volcanos now joined to the mainland of the South Island by the outwash plains from the Southern Alps in Canterbury, New Zealand. It covers 107,600 ha and has a mosaic of land uses such as pastoral farming, exotic forestry, horticulture and viticulture, life-style blocks, and remnant patches of pre-human vegetation among larger areas of regenerating native vegetation. Only 4% of the area is in formal conservation reserves but the whole area has high biodiversity values with ecosystems that extend from the littoral to the subalpine, with a high degree of local endemism (2.2% of arthropods are endemic to the peninsula), and many plants reach their southern or northern limits (13 and one species, respectively).

These values are compromised by a suite of introduced pests and weeds, among which feral goats (*Capra hircus*) represent a significant, recent but tractable problem. Although domestic goats and a few feral goats have been present on the peninsula since the late 1800s, it was not until after 1980 that significant feral populations established after landowners imported animals to control woody weeds such as gorse. In 1988, public concern was raised about the problem of feral goats and action was begun against the herds on the peninsula, mostly those in the southern bays around the private reserve at Hinewai and Otanerito (Fig. 1), and largely funded under a national feral goat control plan developed by the Department of Conservation (DOC 1998). In 2003, a consortium of government agencies with management responsibilities on the peninsula (DOC, Canterbury Regional Council, and Christchurch City Council), as well as private groups, landowners and individuals facilitated by the Banks Peninsula Conservation Trust began a concerted campaign to eradicate feral goats from the whole peninsula (Parkes 2005). This poster reports on the plan to achieve eradication and on the results to date.

RESULTS

Distribution of feral and domestic goats

Feral populations established in seven partially discrete areas of the peninsula (Fig. 1) and currently 9 domestic herds are known to be present, although only one exceeds 50 animals.

Eradication

The feral goat populations in the eastern bays (Fig. 1) have been eradicated. Between 1987 and 1993, over 1200 feral goats were shot over c. 2000 ha during 1682 hours of hunting effort by ground hunters at a cost of about $50/ha.

Control by shooting from helicopters and ground hunting began in the southern bays (8000 ha) in 1990 and to date has accounted for more than 1000 feral goats. It is likely that none remain in most of this block, but a few are still present on one farm (Fig. 1). Control has begun in the other areas in the eastern peninsula and success is predicted.

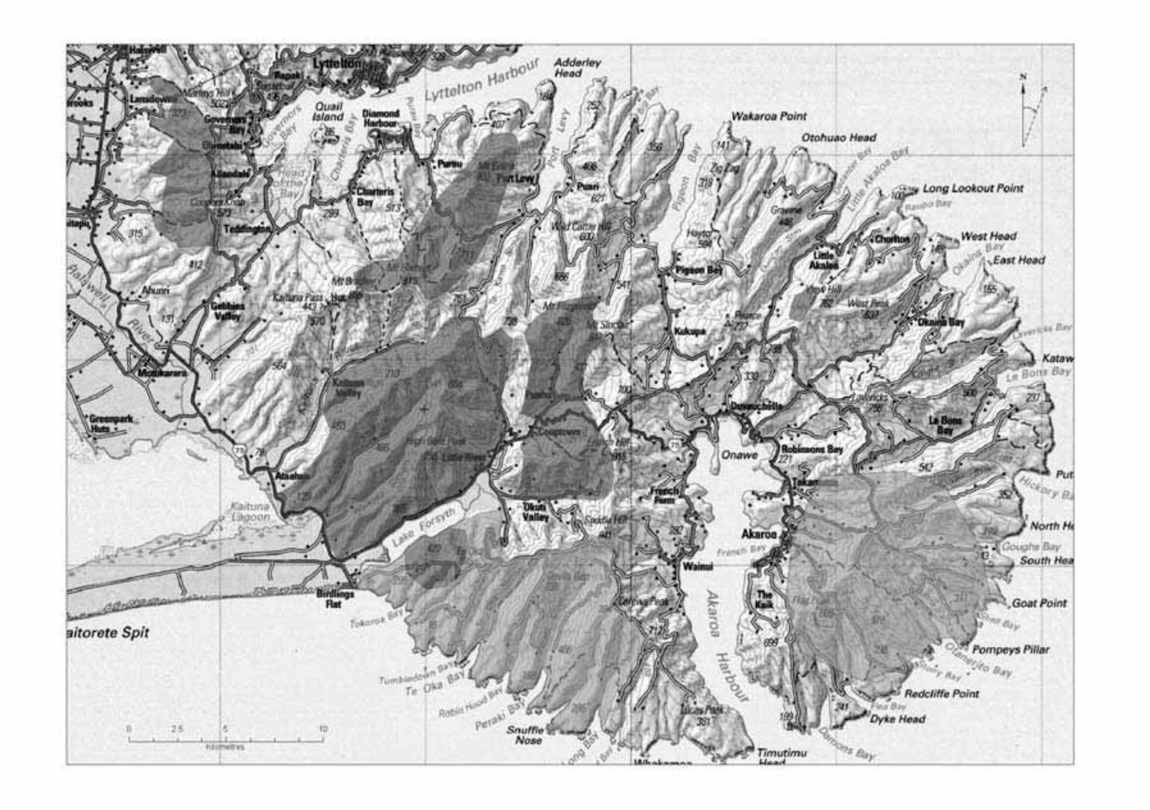

Fig. 1. Distribution of feral goats and management blocks on Banks Peninsula

The goats in the Port Hills area are held for weed control and so are seen by some landowners as assets rather than pests. Unless this attitude changes, this will clearly constrain the Trust's aim to eradicate goats from the whole peninsula. Similarly, the presence of domestic herds within the areas where eradication of feral herds is possible presents a risk of re-establishment of feral herds. The Banks Peninsula feral goat control plan (Parkes 2005) recommends a combination of proactive management (good fencing and enforcement of legal obligations of owners of domestic goats) and reactive management (surveillance and prompt action against escaping goats) to manage these risks.

Issues

Detecting survivors is always a problem in eradication campaigns that, by the nature of the control methods used, cannot kill 100% of the pests in a single operation (Parkes in press). An issue for our project has been how to allocate the annual budget between finding and dealing with survivors in the treated areas and starting control in new areas. The approach has been to use a combination of a telephone hot-line for landowners and others to report sightings of goats and more formal surveillance in 'suspect' areas to detect survivors (both relatively cheap options) followed by prompt attempts to find and kill any reported animals (which has variable costs depending on success and the number of goats present). Judas goats have not been used, but could be if reported survivors were not subsequently found and killed.

CONCLUSION

Pest control is a good way to bring together multiple stakeholders who otherwise often have different and sometimes contradictory aims in land management. Working together on a shared problem eases the way for better solutions for issues when people disagree.

The Banks Peninsula Conservation Trust, government agencies, private groups, landowners, and rununga of Ngai Tahu are currently discussing ways to better integrate all the pest and weed control done and required on Banks Peninsula.

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RODENT INCURSIONS ON NEW ZEALAND ISLANDS

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INTRODUCTION

New Zealand has been colonised by the four most wide-spread and invasive rodent species in the world (Atkinson 1985). In chronological order; the kiore (*Rattus exulans*, c.1200AD), the Norway rat (*R. norvegicus*, c.1790), the mouse (*Mus musculus*, 1824) and the ship rat (*R. rattus*, c.1860) all arrived and rapidly spread across the country, often displacing the former rodent species (Taylor 1978). From the mainland they have dispersed by transport (mostly accidental) and swimming to many of New Zealand's 300 offshore islands >5ha (Russell and Clout 2004).

Since 1964 New Zealand conservation practitioners have gradually increased the size of islands from which it has been possible to eliminate rodent species (Towns and Broome 2003). This increase has been particularly marked since the 1980s, with the advent of new technologies at that time (Clout and Russell in press). The trends in eradication of introduced mammals, in particular rodents, from New Zealand offshore islands have been documented elsewhere (Veitch and Bell 1990; Clout and Russell in press). Clout and Russell (in press) also draw attention to the increasing number of rodent reinvasions, once islands have had their incumbent rodent species removed. Less well documented are the instances where a single or small number of rodents have been detected arriving at an island, but have not subsequently gone on to colonise the entire island. These 'incursions' highlight the constant threats and pathways of reinvasion by which rodent free islands, including those from which rodents have been eradicated, are at risk.

DEFINITIONS AND DATA PRESENTATION

For the purposes of this paper we define an incursion as an instance where a rodent species is believed to have arrived on an island, but where a self-sustaining island-wide population (necessitating island-wide eradication) has not established. By comparison an invasion is what follows an incursion, where a rodent species colonises across an entire island. We collated all available information on incursions from a range of sources, including publications, file reports and personal accounts. All data on incursions are summarised in Table 1. The format is based on the original database of incursions, compiled by Fitzgerald and Veitch (1992), which was in turn generated from Roberts (1991). The table is organized by islands and gives the name of the island concerned, its rodent status at the time of the potential invasion, the suspected invader, the date and circumstances of the incursion, and key references.

RESULTS

Rodent incursions

Incursions by rodents are listed for 27 New Zealand offshore and outlying islands. On six islands more than one incursion has been recorded. In total 42 rodent incursions have been recorded. Fourteen of these are of mice, sixteen are of Norway rats and three of ship rats. The remaining nine are of an unknown rat species, although almost certainly one of the previous two. Kiore have relatively poor swimming abilities (Atkinson 1986). Three of the mouse incursions were locally established populations restricted to the area of landing, not having established across the entire island. This has also been recorded on Barrow Island (Burbidge and Morris 2002) and Ile Surprise overseas, (Courchamp 2004), and is attributable to incumbent rat populations (Taylor 1978).

Recent incursions have occurred through a combination of natural swimming, and accidental transport by fishing vessels, private boats and scientific expeditions. Roberts (1991, Table 2) also provides a list of nine islands from which there is parasitological evidence of rodent incursion.

Swimming distance

In many cases it can only be speculated as to whether incursions were from swimming or accidental transport of rodents. Recent advances in population genetic methods may allow the sources of invading rodents to be reliably identified (Abdelkrim *et al.* in press), but this requires a thorough genetic cataloging of local rodent populations.

However some statements about the swimming distances of the various rodent species can be made. It appears that mice do not swim as a method of dispersing to islands. All recorded mouse incursions have been via transport of stores and equipment (Taylor 1978).

No incursions of kiore are recorded here, and only one kiore invasion has ever been documented (McCallum 1986). The distribution of kiore in New Zealand is now much reduced, limiting their opportunities to invade new islands compared to the other rat species. Even when the opportunity exists their swimming abilities seem limited (Whitaker 1974; Atkinson 1986). All ship rat incursions appear to be from accidental transport and then by swimming only when very close to shore, given the distance offshore of the islands where incursions of this species have been recorded. However, the recent reinvasions of ship rats onto Motutapere (Chappell 2004) and Tawhitinui (Ward 2005) both involved crossings of approximately 500m in calm waters. Both invasions were presumably by swimming, and they extend the distance that this species has been suspected of swimming.

By far the majority of known rat incursions are by Norway rats. The Norway rat is evidently the most likely rodent invader of offshore islands given its inclination towards swimming (Russell *et al*. unpubl.), although ship rats may pose a greater overall threat to native biodiversity (Towns *et al.* in press). From the distribution and recorded reinvasions of Norway rats it appears that they can cross up to 1km of water comfortably, and up to 2km of open water more rarely when conditions are suitable (mudflats, intermediate rocky islets, tidal flow, etc). The Noises Islands, 2.2km offshore, have possibly been reinvaded up to six times from neighbouring Rakino, after apparently successful eradications (Moors 1985; Clout and Russell in press).

DISCUSSION

The number of recorded incursions of rats and mice onto New Zealand's offshore islands demonstrates that constant vigilance is needed to prevent rodents establishing on rodent free islands, including those recently cleared of these invasive mammals. Even despite this reinvasion can still occur such as on Moturemu and Motutapere where full-sale reinvasion took place, and on Moturoa and Rotoroa where established grids catch multiple rats annually, well above normal incursions rates, suggesting re-established populations that are instead maintained at low densities. Quarantine measures must be invoked at all of the potential points of departure, during transport, and on the islands themselves Incursions have been detected during all three of these stages (though only the latter are documented here). On islands biosecurity procedures (e.g. Jansen 1989) should include the unpacking of stores in secure areas, and permanently maintained rodent detection systems, with the availability of invasion response kits should an incursion be detected or suspected (Roberts 2003). Complacency in application of any of these measures can lead to new rodent invasions.

ACKNOWLEDGEMENTS

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Table 1 Records of rodents reaching New Zealand islands but not establishing populations. Rodent status is at the time of the potential invasion. The authors would be grateful to be made aware of any omissions or errors in this compilation.

Island	Distance Offshore	Rodent Status	Potential Invader	Date	Circumstances	Reference
Big South Cape (Stewart)	1.5km	Rodent free	*R. rattus*	1955	One female with active corpora lutea trapped near beach, no further sign till 1963	Bell 1978
Campbell (Subantarctic)	600km	*R. norvegicus*	*Mus*	<1931	Present at homestead and government depots	Waite 1909; Taylor 1978
		R. norvegicus	*Mus*	1978	Observed on south-east harbour beach but could not be caught	Dilks and Dunn 1978
Codfish (Stewart)	3.1km	*R. exulans*	*R. norvegicus*	1984	One male caught in possum trap	McSweeney 1984; Bell 1989
		R. exulans	*R. rattus*	1994	Dead male found on high-tide line, probably drowned swimming from moored fishing boat	A. Roberts pers. comm.
Kapiti (Wellington)	5.2km	*R. exulans* and *R. norvegicus*	*Mus*	?	Landed on occasions, failed to establish	Taylor 1978
			Mus	1970	Mummified specimen found in whare	L. Rodda pers. comm.
		Rodent free	*Rattus* spp.	1998	Missing bait from station, trapping undertaken, no further sign	C. Giddy pers. comm.
		Rodent free	*R. norvegicus*	1998	Corpse found by black-back gull colony	C. Giddy pers. comm.
Koi (Hauraki Gulf)	250m	Rodent free	*R. norvegicus*	1997	Green faeces found, ate old Talon and presumably died	Lee 1999
Korapuki (Coromandel)	5.8km	Rodent free	*R. rattus*	1988	Virgin female 'Virginia' trapped after 1986 kiore eradication follow-up	Dilks and Towns 2002; Towns and Broome2003
Little Barrier (Hauraki Gulf)	21.5km	*R. exulans*	*Mus*	1950s	One brought ashore in stores and killed	Watson 1961
Mana (Wellington)	2.5km	*Mus*	*R. norvegicus*	1974/75	One brought ashore in bales of hay and killed	M. Meads pers. comm.
		Mus	*Rattus* spp.	1976-	Jumped overboard, reached shore and killed	Veitch & Bell 1990
		Mus	*R. norvegicus*	1978	Partly eaten carcass on shore	Efford et al. 1988
		Mus	*Rattus* spp.	1981	Dead rat found in high tide drift line, about 300m south of jetty	M. Meads pers. comm.
		Rodent free	*Mus*	1992	One female from packed stores killed on boat before reaching island	T. Hook pers. comm.
Mangere (Chathams)	850km	Rodent free	*Mus*	1970s	Adult female and nest of young in equipment brought ashore by dinghy	Bell 1978, 1989
Maud (Marlborough)	850m	Rodent free	*Mus*	2000	Green faeces found in equipment in lodge, trapping undertaken, no further sign	Ward 2000
Matakohe (Whangarei)	550m	*Mus*	*Rattus* spp.	1999-2000	Four rats detected and killed on grid	Ritchie 2000

Mokoia (Rotorua)	2.1km	*R. norvegicus*	*Mus*	<1966	Extremely low numbers and confined to the vicinity of the huts	Beveridge and Daniel 1966;
		Mus	*R. norvegicus*	1995	Observed around hut, poison laid, body of very large virgin female found in hole on beach	I. Castro pers. comm.
		Rodent free	*R. norvegicus*	2003	Corpse found, possibly flown over by harrier	I. Castro pers. comm.
Motuhoropapa (Hauraki Gulf)	2.2km	Rodent free	*R. norvegicus*	1987	Carcass of young female found in old trap, sign on two islets	Moors 1987
Moturemu (Kaipara)	2.5km	Rodent free	*R. norvegicus*	1999	Sign reported by T. Wilson. Poison and traps laid, no further sign till 2002	Russell and Abdelkrim unpubl.
Moturoa (Bay of Islands)	375m	Rodent free	*Rattus* spp.	1996	Reinvade from mainland annually, grid present	Asquith 2004
Ohinau (Coromandel)	4.5km	*R. exulans*	*Mus*	2000-5	Low numbers present around north-west bay campsite	R. Chappell pers.comm.
Otata (Hauraki Gulf)	2.3km	Rodent free	*R. norvegicus*	2005	Escaped from controlled release on neighbouring Motuhoropapa, sign reported by owners, rat caught	Russell et al. unpubl.
Pitt (Chathams)	850km	*Mus*	*Rattus* spp.	1996/7	Swam from moored fishing vessel	Dilks and Towns 2002
Poutama (Stewart)	275m	Rodent free	*Rattus* spp.	1984	Rat sign reported by muttonbirders and seen by A. Cox, poison laid, no further sign	Bell 1989; Veitch and Bell 1990
Rangatira (Chathams)	850km	Rodent free	*Mus*	1998	Possible mouse sighting	Dilks and Towns 2002
Raoul (Kermadecs)	900km	*R. exulans* and *R. norvegicus*	*Mus*	1972	One pregnant female carried ashore in stores and killed	Taylor 1978; Veitch & Bell 1990
Snares (Subantarctic)	105km	Rodent free	*Rattus* spp.	1950s	Rat jumped from boat onto island during landing of scientific party	Roorda 1981
Stewart	27km	All 3 rat spp.	*Mus*	?	Landed in stores on several occasions	Taylor 1975
Takangaroa (Hauraki Gulf)	1.8km	Rodent free	*R. norvegicus*	1987	Sign reported by owners and seen by G. Taylor, poison laid, no further sign	Taylor 1989; Veitch and Bell 1990
Tawhitinui (Marlborough)	475m	Rodent free	*Rattus* spp.	1986-2000	Old sign found in 'rat hotel', trapping undertaken, no further sign	Dilks and Towns 2002; Ward 2005

Tiritiri Matangi (Hauraki Gulf)	3.4km	*R. exulans*	*Mus*	1986	Brought ashore in stores and killed	Roberts 1991
Ulva (Stewart)	800m	Rodent free	*R. norvegicus*	1997	One rat killed by trapping	Dilks and Towns 2002
		Rodent free	*R. norvegicus*	1999	One rat swam ashore from a moored yacht, killed by trapping	Dilks and Towns 2002
		Rodent free	*R. norvegicus*	2001	Mummified rat found in trap	B. Beaven pers. comm.
		Rodent free	*R. norvegicus*	2003	Found drowned on Boulder Beach	B. Beaven pers. comm.

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AN EFFICIENT AND ACCURATE WAY TO DOSE 1080 PREDATOR BAITS

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ABSTRACT: The Hamilton PB-600-1 Repeating Dispenser with gastight syringe is used in the injection process of predator baits with 1080 poison for the control of foxes and wild dogs in Victoria. The dispenser is a more effective and precise measure of 1080 fluid application and can achieve a very accurate dose rate in baits. Historically 1080 stock solution was injected into baits using a diabetic syringe and needle. The amount of 1080 stock solution required to be injected into each bait is 0.05 ml. Diabetic syringes hold 1.0 ml and therefore persons preparing baits had to inject one twentieth of the total volume held in the syringe by hand. This was a very difficult and inaccurate method of fluid application. Other 1080 stock solution injection methods were compared across the nation, such as the Phillips 2 ml Auto Injector used by the South Australian Plant and Animal Control Commission, with the outcome being the Hamilton device as the preferred option.

The Hamilton Repeating Dispenser is able to deliver a 0.05 ml dose to each bait within a 2% variation of accuracy. Also with each refill of the device up to fifty × 0.05-ml injections can be made. Another issue when preparing baits has been for a meat, fat or gristle particle to become lodged in the needle of the syringe when inserting the needle into the bait. This resulted in a blockage. This blockage sometimes proved difficult to remove, or led to a higher dose being applied. The gastight syringe system is such that the pressure applied when each injection is carried out automatically removes any blockage. The Hamilton Repeating Dispenser has a simple mode of operation, as you simply push a button on the side of the device to deliver each injection. To draw up more 1080 stock solution the plunger of the gastight syringe is pulled back together with the delivery mechanism arm, the same as drawing up fluid with an ordinary syringe. The device is robust, though care needs to be taken with the glass syringe. To date the device has been used at several bait preparation centres for three years and minimal maintenance is required and the system has performed without a flaw, and provides a mechanism for improved quality in the bait preparation process.