Review of Research into Alternatives to the use of 1080 for Management of Browsing Damage by Mammals in Tasmania

J.D. Coleman, R.P. Pech, B. Warburton
Landcare Research
PO Box 40, Lincoln 7640
New Zealand

D.M. Forsyth
Arthur Rylah Institute for Environmental Research
Department of Sustainability and Environment
123 Brown Street, Heidelberg
Victoria 3084
Australia

Landcare Research Contract Report: LC0506/144

PREPARED FOR:
Department of Primary Industries and Water
GPO Box 44, Hobart, Tasmania

DATE: July 2006

ISO 14001

Reviewed by:	Approved for release by:
Stakeholders in Tasmania	Phil Cowan Science Leader Pest Control Technologies

Contents

Abbreviations used in the text

AACT	Against Animal Cruelty, Tasmania
APVMA	Australian Pesticides and Veterinary Medicines Authority
CRC	Cooperative Research Centre
DEH	Department of the Environment and Heritage
DPIW	Department of Primary Industries and Water
DPIWE	Department of Primary Industries, Water and Environment
FEA	Forest Enterprises Australia
FIAT	Forest Industries Association of Tasmania
FFIC	Forests and Forest Industry Council of Tasmania
FT	Forestry Tasmania
NRM	Natural Resource Management
PFT	Private Forests Tasmania
RSPCA	Royal Society for the Prevention of Cruelty to Animals
TCA	Timber Communities Australia
TCFA	Tasmanian Community Forest Agreement
TCT	Tasmanian Conservation Trust
TFGA	Tasmanian Farmers & Graziers Association
WLPA	World League for Protection of Animals

Summary

Project and Client

Research into alternatives to compound 1080 for the management of browsing damage by mammals to Tasmanian forestry and agriculture was reviewed by Landcare Research and the Arthur Rylah Institute for Environmental Research, for the Department of Primary Industries and Water (DPIW), Tasmania, between April and July 2006.

Objectives

- Undertake a critical review of past and current research into and research uptake of alternative (i.e. non-1080 baiting) approaches relevant to managing mammal browse damage to Tasmanian forestry and agricultural production – with particular reference to the Tasmanian pademelon (*Thylogale billardierii*), Bennett's wallaby (*Macropus rufogriseus*), and brushtail possum (*Trichosurus vulpecula*).
- Assess the full range of research and demonstration activities into alternative browse-damage-management approaches based on economic feasibility, environmental sustainability, and social acceptability.
- Consult with researchers and stakeholders to identify gaps in, and propose modifications to, existing lines of research, and propose new research and demonstration directions.
- Present findings in the form of a comprehensive draft report by mid-June 2006, including presentation of this report to a stakeholder group, with a final report being presented in July 2006.

Methods

Techniques and strategies used for the management of browsing mammals affecting forestry and agriculture in Tasmania were reviewed. In mid-April 2006, two members of the review team attended a workshop held by DPIW in Launceston, where key stakeholder groups presented their perspectives and discussed priorities for research. This information was expanded using Internet search engines, the authors' databases, and by interviewing in Tasmania in early May key stakeholders. Gaps in current research and management were identified and ranked taking into account economic feasibility, environmental sustainability, and social acceptability. Key findings were then presented to a further stakeholder workshop in late June and relevant feedback included in this final report submitted in late July.

Main Findings

This review is the latest in a series on managing browsing damage in Tasmania. Previous reviews have focused on damage to forestry and less on damage to agricultural crops and pasture. This review seeks to redress that imbalance, while focusing on alternative techniques to compound 1080 to manage the mammals involved.

(1) The review identifies a set of recommended research topics for each potential alternative to 1080. *Neither the alternative techniques nor the research topics are listed in priority order.*

Chemical repellents:

- Quantify the benefits of existing registered products, or products in the process of being registered in Australia, at a management scale.
- Quantify the effects of pest density, alternative food availability, mosaics of preferred habitat and their size, and season on repellent effectiveness.
- Evaluate repellents in combination with techniques such as initial culling or maintenance of protective vegetation cover in plantations.

- Identify public acceptance of chemical repellents.
- Determine the cost-effectiveness of chemical repellents.

Acoustic repellents or deterrents:

- Identify appropriate stimuli such as distress or alarm signals or sounds of predators as potential repellents.

Physical barriers (fences and tree guards):

- Develop and demonstrate ‘best-practice’ guidelines for fencing of at-risk forestry and farmland.
- Assess public acceptance of fencing and tree guards for the control of browsing mammals.
- Identify acceptable levels of ingress by browsing mammals across physical barriers.
- Evaluate the development of a cost-benefit-based Decision Support System for determining where and when to undertake fencing of at-risk forestry and farmland.
- Determine the cost-effectiveness of physical barriers.

Fertility control:

- Assess the effectiveness of immunocontraception developed for possums for its effectiveness at inducing infertility in pademelons and wallabies.
- Assess the effectiveness of chemosterilants for use on pademelons and wallabies.
- Develop target-specific delivery systems: solid bait and gel for foliage application.
- Determine, using computer modelling, optimal integration of lethal and fertility control.
- Assess public acceptance of fertility control.

Farm and forestry crop and site practices:

- Determine the pest densities that various provenances can withstand, in order to optimally integrate silvicultural practices with browser management.
- Develop improved models for determining the impact of size and shape of coupes, and the role habitat availability (e.g. riparian strips) has, on browse risk.
- Determine if endophytes have any potential for limiting browse on seedlings.
- Assess the costs and benefits of using cover crops and natural regeneration to reduce browser impacts, and how both can best be integrated with alternative options.
- Determine the relative palatability to native browsing mammals as distinct from livestock for provenances of pasture grasses and legumes, in relation to browser density.
- Determine the cost-effectiveness of nursery and plantation practices.

Alternative toxins:

- Clarify public acceptance of alternative toxins.
- Determine the effectiveness of Feratox® for controlling pademelons and wallabies.
- Develop effective delivery systems for Feratox® that minimise risks to non-target species.
- Develop target-specific toxins for use against all three browsing species.
- Determine the effectiveness of foliage baiting for targeting critical individuals.
- Determine the cost-effectiveness of alternative toxins.

Trapping and snaring:

- Determine the cost-effectiveness of cage trapping.
- Identify optimal ways of integrating cage trapping with other techniques.
- Assess the acceptability and effectiveness of kill traps as humane and cost-effective alternatives for controlling possums.
- Determine the effectiveness of tunnel nets for capturing wallabies and pademelons.
- Determine the potential risk of predation to animals captured in ‘soft material’ traps (i.e. ‘Ivo’ and tunnel nets).
- Clarify public acceptance of kill traps.

Shooting:

- Quantify the relative cost-effectiveness of recreational, contract, and commercial shooters for mitigating browse damage in forestry and agriculture.
- Determine the costs of using contract shooters to reduce densities of critical browsers to target levels.
- Determine the increased effectiveness of using infrared spotlighting and/or baiting sites over shooting without these aids.
- Determine the relative cost-effectiveness of a regionally managed contract system versus an enterprise-based system.
- Determine the social acceptability of shooting of browsing mammals.

Commercial harvesting and the use of bounties:

- Quantify the relationship between commodity price and economic harvesting density.
- Identify constraints (e.g. costs, knowledge, policy and legislation) that limit harvesting success and its economic viability.
- Determine the spatial and temporal situations where harvesting can be best integrated with other control technologies.
- Determine the social acceptability of commercial harvesting of browsing mammals.
- Determine the cost-effectiveness of commercial harvesting.

(2) Gaps in research, demonstration, and extension in the *strategies* used to manage browsing mammals were similarly identified.

Defining the problem:

- Use time-series data from 1975 to the present to examine changes in abundance of browsing mammals.
- Assess shooters' log books as indicators of changes in browser abundance at the local scale.
- Design protocols to record, analyse, and assess industry-wide impacts of browsing mammals.
- Conduct surveys to measure public awareness of the need to prevent damage by actively managing browsing mammals, and to measure public attitudes to alternative control techniques.
- Assess the compatibility of conservation policies and management with those of reducing browsing damage.
- Evaluate animal welfare issues associated with proposed control techniques/strategies.

Objectives and performance criteria:

- With input from stakeholders, establish clear objectives for management of possums, pademelons and wallabies in forest and farmland.
- Determine the relationship between pest density and damage for forestry and agriculture.

Management strategies and techniques:

- Evaluate and rank alternative control strategies to manage browse damage.
- Develop operational monitoring protocols and thresholds to identify the need for control.
- Develop models to predict browse patterns by all three browsing mammals.
- Ensure all aspects of the ecology of all targeted mammals relevant to their browsing and control are covered.

Implementation:

- Use adaptive experimental management to promote the effective use of alternative techniques to 1080.
- Analyse the costs and benefits of managing browse at the enterprise level.
- Evaluate social constraints on effective management at the enterprise level.
- Develop options for improving information flow to all relevant stakeholders.

- Publish guidelines for managing possums, pademelons, and wallabies.

Monitoring and evaluation:

- Design protocols for data collection to monitor animal numbers and damage.

(3) Strategic research and research gaps for each of the key alternative techniques used to control browsing mammals were ranked according to a set of alternative strategic options. These rankings were also stratified by alternative technique categories, which are based on potential differences in public acceptability.

Recommendations

That the Implementation Committee:

- selects the appropriate management strategy (or strategies) from the options listed in Tables 12–17,
- selects the most socially acceptable category of techniques from the options listed in Tables 12–17, then
- uses the appropriate recommended rankings as shown in this review as a basis for allocating research funds.

That the Implementation Committee takes account of the following factors when allocating research funds:

- the balance between research effort for forestry and agriculture.
- whether the research is new or partly covered by existing research.
- long-term verses short-term outputs.
- the optimal mix of ‘research’ versus ‘demonstration’ versus ‘extension’.
- strategic issues as well as tactics.
- opportunities for testing alternative options using adaptive experimental management.

That the Implementation Committee recognizes the solution to managing the browsing and grazing of overabundant native vertebrates will require serious consideration of the political, environmental, economic, and social issues related to the problem.

1. Introduction

Research into alternatives to compound 1080 for the management of browsing damage by vertebrates to Tasmanian forestry and agriculture was reviewed by Landcare Research and the Arthur Rylah Institute for Environmental Research, for the Department of Primary Industries and Water (DPIW), Tasmania, between April and July 2006.

2. Background

The economy of Tasmania relies heavily on its primary production. The soils, temperate climate, and reliable rainfall provide ideal conditions for a productive agriculture sector that generates annual gross revenue 'at the farm gate' in excess of $750 million (Australian Bureau of Statistics 2006). Further, production forestry including both native and plantation forests has an annual turnover of about $1,200 million (Australian Bureau of Statistics 2006).

Tasmania also has a diverse assemblage of native marsupials, including three species (brushtail possum *Trichosurus vulpecula*, Bennett's wallaby *Macropus rufogriseus rufogriseus*, Tasmanian pademelon *Thylogale billardierii*) (hereafter termed possum, wallaby, and pademelon) that significantly damage forest and agricultural crops, and compete with livestock for available pasture (Coman 1994). These species primarily inhabit forest, scrubland and adjacent grazing or cropping land. Many of their populations have apparently benefited from recent agricultural and forestry activities that have increased the mosaic of land-use types and consequently the forest perimeters that abut grasslands, agricultural crops, or forestry coupes.

Since it was first tested in 1952, sodium monofluoroacetate (1080) has been the only toxin used in Tasmania to mitigate the browsing impacts of possums, wallabies and pademelons (Statham 2005). Compound 1080 is also considered critical in fox abatement planning (P. Mitchell pers. comm., see below). In 1999/2000, 15.2 kg of 1080 was used in Tasmania, but by 2004/05, its use had declined to 8.1 kg. For the period 2004/05, most 1080 was used to protect planted seedlings (54.9%), with the remaining amount used to protect pasture (41.9%), fodder crops (1.9%), and vegetables and poppies (0.7%), or to control 'vermin' (0.6%) (DPIW unpubl. data).

The use of 1080 to control native browsing animals in Tasmania has been strongly opposed for many years by animal welfare and conservation groups. In 2004, the Tasmanian Premier (Hon. Paul Lennon) announced a total ban on 1080 use on public lands from December 2005. This ban does not affect the use of 1080 on private lands. In May 2005, the Federal and Tasmanian Governments jointly announced the Tasmanian Community Forest Agreement (TCFA), which set out to enhance protection of Tasmania's forest environment, and growth in the Tasmanian forest industry and forestry jobs. Section 39 of the TCFA relates to the use of 1080 and requires that:

> The Parties agree to work collaboratively on a joint program to accelerate research into, and implementation of, alternative strategies for browsing animal control on private forest and agricultural lands. The Commonwealth will invest $4 million in a research, field testing and demonstration program to provide alternative options for private landholders, and work with the State in the light of these results to continue to reduce the usage of 1080 on private lands.

To maximise the outcome of the $4 million allocated for research, field testing, and demonstration programmes, the DPIW called for tenders to review past and current research into the management of browsing damage, to identify research gaps and recommend priorities for future research.

Published reports related to browsing damage in Tasmanian forests appeared as early as 1983. External reviews were first requested in 1987 (Coleman 1987), and further reviews followed (Coman 1994; Sutherland & Coleman 1994; Coleman 1995; Anon. 2001: Browsing animal control unpubl. workshop papers). Reviews of similar browsing damage problems in APM eucalypt plantations in Victoria were undertaken concurrently (Clunie & Becker 1991; Parkes et al. 1993; Arulchelvam & Parkes 1994). These reviews, though pertaining largely to production forests and excluding farmland, identified a range of research gaps and priorities, some of which have been subsequently investigated and others are 'work in progress'. Even so, browsing problems have persisted in both states and now threaten to become more pronounced in Tasmania with the decisions to stop using 1080 on state forest lands and to progressively reduce the use of 1080 on private lands.

Although this review focuses on research undertaken into the strategies and tactics necessary to mitigate browsing problems, it accepts the solution to managing the browsing and grazing of overabundant native vertebrates will require serious consideration of the political, environmental, economic, and social issues related to the problem. To ignore these components will reduce the value of this review, and increase the likelihood of the problem persisting into the future. In particular, the general lack of rigorous, defendable data on the costs of browsing damage and its management, to both forestry and farming, seriously undermines the case for better management techniques and tactics.

There is also a need to clarify the problem of managing browsing damage and the objectives of the research. Currently, section 39 of the TCFA seeks to reduce progressively the amount of 1080 used. This could be achieved by replacing 1080 with alternative pesticides such as Feratox® or zinc phosphide, but it is possible that such alternatives will meet similar opposition to 1080. Consequently, the tools and strategies required to resolve the problem must be acceptable to key stakeholders and clearly defined and agreed to. For example, is the problem one of the use of 1080 per se, or of lethal control, or of lethal control of native fauna? One requirement of the review is to consider the socially acceptability of alternatives to 1080.

This review makes no assumptions on what is likely to be socially acceptable; the stakeholders and wider community need to agree on what is acceptable to them because there is a risk that some potential effective alternatives will continue to be opposed.

The Tasmanian browsing problem has two major components: the first relates to the browsing impact of wallabies, pademelons, and possums on the establishment of production forests, and the second to the grazing impact of these species on agricultural crops and pasture. Because the impacts on production forest establishment are mostly of short duration (with *Pinus radiata* plantations a clear exception) and localised, management of the key problem species to protect this resource does not need to be sustained. In contrast, management of the same suite of browsing mammals for the protection of agricultural values is likely to require sustained control.

This review is structured around the major potential tactical alternatives (chemical repellents, acoustic repellents or deterrents, physical barriers, fertility control, farm and forestry crop and site practices, alternative toxins, trapping and snaring, shooting, and commercial harvesting and the use of bounties). Each section outlines the historical use of the technique, and past and current research. The strategies for managing browsing mammals, as well as the issues of problem definition and monitoring, are also discussed. This material follows rather than precedes the section dealing with potential tactical alternatives, in line with the order of the work set out in the 'terms of reference' in the contract. The authors use these findings to identify and rank gaps in research, as well as areas of information transfer and field demonstration currently either poorly understood or insufficiently researched, to ensure that more publicly acceptable and effective solutions to browse damage are pursued in the future by farm and forest managers.

This is a review of the *scientific* issues relevant to alternatives to the use of 1080 for managing browse damage to forestry and agriculture. The review does not preempt the choice of management strategies or attempt to second-guess what types of management techniques are acceptable for use in Tasmania. However, the review provides the Implementation Committee with recommendations on areas for research once Tasmanians have determined from the alternatives listed in this review which combination of strategies and category of techniques meets their requirements.

3. Objectives

- Undertake a critical review of past and current research into and research uptake of alternative (i.e. non-1080 baiting) approaches relevant to managing vertebrate browse damage to Tasmanian forestry and agricultural production – with particular reference to the Tasmanian pademelon (*Thylogale billardierii*), Bennett's wallaby (*Macropus rufogriseus*), and brushtail possum (*Trichosurus vulpecula*).
- Assess the full range of research and demonstration activities into alternative browse-damage-management approaches based on economic feasibility, environmental sustainability, and social acceptability.
- Consult with researchers and stakeholders to identify gaps in, and propose modifications to, existing lines of research, and propose new research and demonstration directions.
- Present findings in the form of a comprehensive draft report by mid-June 2006, including presentation of this report to a stakeholder group, with a final report being presented in July 2006.

4. Methods

In mid-April 2006, two members of the review team attended a workshop held by DPIW in Launceston, where key stakeholder groups presented their perspectives into the management of browsing damage and discussed priorities for research. The outcomes of that workshop provided key directions for the current review. The review team returned to Tasmania in May 2006 and interviewed individuals from key stakeholder groups identified by John Dawson (DPIW), including the Tasmanian Farmers & Graziers Association (Don Jones and members of his executive), Private Forests Tasmania (Arthur Lyons, David Bower), Forestry Tasmania (Andrew Walsh, Tim Wardlaw, Bob Knox, Nigel Foss), Forest Industries Association of Tasmania (Terry Edwards, Katy Hobbs), Forests and Forest Industry Council of Tasmania (Trevor Bird, Sean Riley), Gunns (Ian Blandon, Chris Barnes), Forest Enterprises Australia (Greg Linsley-Noakes), Norske Skog Australasia (Chris Berry), Browsing Damage Management Group (David de Little), Timber Communities Australia (Alan Ashbury, Keith Bill), regional natural resource management committees (Guy Robertson, Alistair McKinnon), Tasmanian Institute of Agricultural Research (Mick Statham), Department of Primary Industries and Water (Greg Hocking, Gary Davies, John Dawson, Georgia Webb, David Leguis), Rural Development Services (Amabel Fulton), Against Animal Cruelty, Tasmania (Yvette Watt), World League for Protection of Animals (Brenda Hickson), Royal Society for the Prevention of Cruelty to Animals (Julie Williamson), Sporting Shooters Association of Australia, Tasmania (D. Riddell), and private hunters (Rod Hill).

Students from the School of Plant Science, University of Tasmania, undertaking research relevant to this review (Natasha Wiggens and Prue Loney) were also interviewed. The list of those interviewed included many representatives from the forestry industry, and fewer from the farming industry, and reflected the breadth of research undertaken and its documentation for the two industries on the control of browsing mammals.

Further information on techniques and strategies for the management of browsing damage by mammals to Tasmanian forestry and agriculture was obtained by conducting a keyword literature search via the Internet using the search engines Scopus, CAB Abstracts, and Web of Science, and from the authors' own databases.

A draft report containing the key findings of the review was presented to a further stakeholder workshop in late June, and relevant comment received from the attendees included in the final report submitted in late July.

Phone and/or email advice was received from Alan Ashbarry (Timber Communities Australia), Dylan Craw (University of Tasmania), Ivo Edwards, Terry Edwards (Forest Industries Association of Tasmania), Bill Foley (Australian National University), Chris Hardy (CSIRO), Quentin Hart (Bureau of Rural Sciences), Terry Hill and Don Riddell (Sporting Shooters Association of Australia), Lyn Hinds (CSIRO and Invasive Animals Cooperative Research Centre), Greg Hocking (DPIW), Peter Jarman (University of New England), Michael Johnston (Arthur Rylah Institute for Environmental Research), John Kelly (Lenah Game Meats), Richard Jones (World League for the Protection of Animals), Steven Lapidge (Invasive Animals Cooperative Research Centre), Geoff Law and Gemma Tillack (The Wilderness Society Inc.), Greg Linsley-Noakes (Forest Enterprises Australia), Arthur Lyons (Private Forests Tasmania), Ian Martin (Tasmanian Farmers and Graziers Association), Alison Miller (University of Tasmania), Jonathan Miller (Department of Environment and Heritage), Perdi Mitchell (Department of Environment and Health), Tom Montague (Roe Koh & Associates), Julianne O'Reilly-Wapstra (Forestry Cooperative Research Centre), Daniel Ramp (University of New South Wales), Sean Riley (Forests and Forest Industry Council), Guy Robertson (National Resource Management), Glen Saunders (New South Wales Department of Primary Industries), Mark Smith (Tasmanian Agricultural Productivity Group), Robin Thompson (DPIW), Frank Vanclay (Tasmanian Institute of Agricultural Research), Andrew Walsh and Tim Wardlaw (Forestry Tasmania), Yvette Watt (Against Animal Cruelty, Tasmania), Craig Woodfield (Tasmanian Conservation Trust), Eve Woolmore (National Resource Management facilitator, King Island), and Kent Williams in Australia, and Ray Henderson (Pest-tech), and Graham Guildford (Environment Canterbury) in New Zealand. The following people at Landcare Research provided technical advice: Janine Duckworth, Penny Fisher, Dave Morgan, and Geoff Wright.

For each potential alternative technique, details are provided where appropriate on current use, practicality, cost-effectiveness, non-target problems, social acceptance, integration of techniques, legislation, stakeholder support, and research gaps. The research gaps are not ranked initially, but are then collated and prioritised according to various strategic options in the Recommendations.

5. Alternative Tools and Techniques

The following tools and techniques are grouped into non-lethal techniques and lethal techniques, and are not listed in order of importance or priority for research.

5.1 Chemical repellents

Current use

At present, chemical repellents are not used operationally to reduce damage by browsing mammals to forestry (FIAT pers. comm.) or agriculture (TFGA pers. comm.) in Tasmania. Repellents are available for localised nuisance management, for example in urban areas. A website of the Victorian Department of Sustainability and Environment (http://www.dse.vic.gov.au/dse/nrenpa.nsf/FID/-BA8F66E2207E9E1ACA256D9000082EC0?OpenDocument) lists, but does not endorse, 16 off-the-shelf products reputed to deter possums from eating plants. The website refers to trials conducted at Deakin University that showed some potentially useful repellent action by household bleach (White King®), camphor and naphthalene (household insecticidal fumigants), and the proprietary repellent products Keep off® and Scat®. The Australian Pesticides and Veterinary Medicines Authority (APVMA) lists the following animal repellents as registered products: D-Ter®, Sen-Tree® and Multicrop® Scat®.

Options for chemical repellents

Numerous chemical formulations have been tested for their ability to repel foraging by herbivores (Shafer & Bowles 2004) and new products are still being developed (e.g. Kimball & Nolte 2006). Their mode of action depends on the active ingredients present (Mason 1998; Nolte & Wagner 2000). They include:

- systemic repellents incorporated in the tissues of plants, mimicking the effect of natural chemical plant defences
- repellents designed to prevent herbivores entering the treated area, e.g. by using natural or synthetic predator odours that might indicate high risk of predation
- contact repellents applied to the surface of browse-susceptible plants.

The last of these types acts by inducing pain (e.g. irritants) (e.g. Andelt et al. 1994; Wagner & Nolte 2000), by its adverse taste (e.g. Moran 1996), or by inducing malaise (e.g. aversion due to induced nausea).

The repellent action of natural and synthetic chemicals has been tested against a variety of herbivorous mammal species in both contained and field trials and under a range of environmental conditions (e.g. Andelt et al. 1991; Eason & Hickling 1992; Coman 1994; Morgan & Woolhouse 1997; Nolte & Wagner 2000). Few, if any, repellents are species-specific, although some that are effective for mammals do not work for other taxa such as birds.

A review by Coman (1994) expressed little confidence in the potential of repellents to reduce browsing damage in Tasmania. For example, at that time a product named AD-3 being tested at the Keith Turnbull Research Institute, Victoria, was recommended for further investigation. Later results indicated the product prevented bark-stripping by rabbits (*Oryctolagus cuniculus*) for 25 days but increased damage by swamp wallabies (*Wallabia bicolor*) and showed severe phytotoxic effects on seedlings of *Eucalyptus regnans* and on some orchard species (Marks et al. 1995; Johnston et al. 1998). The lack of proven, cost-effective repellents for forestry or agriculture was also noted by Parkes et al. (1993) and Coleman et al. (1996). Using pen trials, Statham (1999) found that of 28 compounds tested, repellents based on spicy, bitter or malodourous compounds had little or no effect, but one with lion urine and one with Tasmanian devil (*Sarcophilus harrisii*) urine were effective against wallabies and pademelons.

In general, it appears that repellents most likely to be effective against mammalian herbivores are those that mimic predator odours and hence deter browsers from using the treated area (Mason et al. 1999). In a recent review listing 143 predator–prey combinations that gave positive results, there were two examples with the possum, one with the swamp wallaby, and two with the European rabbit (Apfelbach et al. 2005). There were four cases of native Australian species responding positively to predator odour. Of 52 predator–prey combinations with no effect or negative results, one involved the swamp wallaby and eight involved other Australian native mammal species. The effectiveness of repellents intended to generate anti-predator responses is likely to be different for social species compared with species that are solitary, and for relatively large-sized prey such as wallabies compared with smaller prey such as pademelons (While & McArthur 2005). For example, in pen trials synthetic predator odour repelled parma wallabies (*Macropus parma*) but attracted red-necked pademelons (*Thylogale thetis*) (Ramp et al. 2005). Although some trials have been conducted over extended periods (e.g. Sullivan et al. 2004), most have been unrealistically short, a few days to several weeks, with results that vary according to factors such as the browsing species, their level of hunger, and the prevailing weather conditions (Montague & Warburton 2000). Longer field trials may have generated results more useful for assessing the potential value of repellents to meet industry requirements (e.g. to protect seedlings until they are tall enough to escape significant browse damage).

In pen trials in New Zealand, 6 of 7 synthetic predator odour compounds were more effective than 'Treepel' (a commercial egg-based product available in New Zealand) in preventing possums browsing on *Pinus radiata* seedlings for up to 10 days (Morgan & Woolhouse 1997). An 81-day field trial comparing the ability of two compounds to prevent rabbit browse gave results inconsistent with the pen trials and highlighted the need for substantially more product development to achieve protection of seedlings for operationally useful periods (e.g. up to 12 months) while avoiding phytotoxic effects on seedlings. The most promising compound, called 'TOM', was an early formulation later developed, with an improved system of application, as Plant Plus (Roe Koh and Associates Pty.).

Unpublished trials using Bitrex (a bittering agent) systemic tablets and selenium as systemic repellents were unsuccessful (T. Montague pers. comm.), and no other potentially useful systemic repellents have been identified by us. Other than systemic repellents, all other products are likely to be affected by climatic conditions, especially rainfall that can wash the active agents off treated plants and hence reduce the period of effectiveness (e.g. Andelt et al. 1991; Woolhouse & Morgan 1995). The alternative is to develop a weather-resistant delivery system that releases the repellent over a sustained period (Morgan 2006).

Plant Plus (also known as Plant-gard) includes a synthetic predator odour. In an experimental plantation of *Eucalyptus globulus*, over a 16-week period, Miller et al. (2006a) found Plant Plus provided some protection to seedlings in addition to the protection provided by a tall dense crop of an unpalatable weed. A trial conducted by the Tasmanian Conservation Trust (TCT) (Law 2005) in a plantation of *E. nitens* claimed some potential benefits from Plant Plus and WR-1, the latter product using an abrasive powder to deter browsing (see below). Neither trial reached the stage of demonstrating clear benefits under operational conditions. Walsh & Wardlaw (2005) estimated that seedlings treated with Plant Plus were protected for 2–3 weeks. In pen trials with Plant Plus, Ramp et al. (2005) found that, in contrast to parma wallabies, red-necked pademelons tended to spend more, not less, time near repellent-treated seedlings while foraging. Presumably this behaviour improves the red-necked pademelons' ability to detect predators. Therefore Plant Plus might act as an attractant rather than a repellent for Tasmanian pademelons, which are not solitary foragers like the parma wallaby but have group foraging behaviour similar to red-necked pademelons (Johnson 1983; Johnson & Rose 1983).

Plant Plus is not yet registered for commercial use in Australia. The repellent costs c. 10c/seedling (Montague 2000, 2001), with additional costs for spraying. It is recommended that seedlings are treated in the nursery (T. Montague pers. comm.).

Sen-Tree®, initially trialled as WR-1, successfully deterred damage to eucalypt and pine seedlings by swamp wallabies (Marks et al. 1995; Johnston et al. 1998). Witt (2002) used feeding trials with captive animals to show that WR-1 effectively deterred browse on *E. globulus* seedlings by pademelons. In plantations, WR-1 deterred browsing damage to *E. nitens* and *E. globulus* seedlings where pademelons were probably the main browsing species, although possums, wallabies, hares (*Lepus capensis*) or rabbits were also present (Witt 2002). In one of these trials, seedlings treated with

WR-1 grew faster than untreated seedlings, provided apical buds were not removed by browsing animals.

Sen-tree® combines three components; whole egg solids and an abrasive (silicon carbide grit) are applied with an acrylic polymer adhesive to the foliage of seedlings. Seedlings can be treated in bulk in nurseries, although the costs of a full-scale commercial operation are not yet available. Future research would be needed to add the possum to the browsing species listed on the product label. The Victorian Department of Primary Industries, which developed the product, is in the process of licensing commercial production of Sen-Tree® (M. Johnston pers. comm.). This will facilitate economic evaluations of the product, either as a single treatment or as part of integrated browse management for forestry operations.

D-Ter® is claimed by its manufacturer to 'protect herbs, vegetables, trees and shrubs from possums, kangaroos, rabbits, hares, bandicoots [Family Paramelidae], deer, foxes [*Vulpes vulpes*] and other wildlife'. It comprises aluminium ammonium sulphate, sucrose octa-acetate and other chemicals, and is claimed to provide protection for up to 12 weeks, depending on weather conditions. It is used widely in Europe, including the UK, to deter birds. It is available commercially at a cost that suggests its use is primarily for localised applications to protect relatively high-value plants (Spurr & Coleman 2005).

Multicrop® Scat® also has as its active ingredient aluminium ammonium sulphate. The product comes as a water-soluble powder and is designed to repel 'a wide range of birds and animals' for 'approximately six to eight weeks' (Material safety data sheet, 4.3.2003). The Deakin University tests reported on the Department of Sustainability and Environment website (see above) found that Multicrop® Scat® showed 'some degree of repellency' against possums.

Naturally occurring chemical repellents (i.e. antifeedant chemicals or secondary metabolites) exist in the foliage of many trees, and influence browsing by mammals. Such plant defences are thought to influence the feeding, distribution, and abundance of some herbivores, including possums (Scrivener et al. 2004). However, many herbivores have a wide range of physiological mechanisms for detoxifying some of these metabolites and thus may feed in their presence (Dearing et al. 2005). The manipulation of plant chemistry to restrict the browsing of seedlings by mammals in Tasmania through provenance selection and nursery selection is providing opportunities for better forest management (see Section 5.5).

Delivery systems

Application of repellents is most efficient in forestry nurseries where there is potential to treat large numbers of seedlings with spray equipment. Follow-up applications may be required to refresh weathered repellents and to protect new growth once the seedlings have become established in plantations. Patterns of browse damage measured in Victoria (Arulchelvam & Parkes 1994) and Tasmania (Walsh & Wardlaw 2005) indicate that for many plantations, follow-up treatments are unlikely to be necessary for all seedlings.

Systems have yet to be developed and tested for broad-acre application of repellents, for example to crops. Plant Plus is not recommended for use on food crops because it has not been registered for such use (T. Montague pers. comm.). Obviously, the use of non-specific repellents on pasture or fodder crops would be useful only when areas are not being grazed by livestock, e.g. at the crop seedling stage. A field trial is currently in progress to measure the ability of Plant Plus to reduce the abundance of red-necked wallabies (*Macropus rufogriseus banksianus*) on roadside verges in mainland Australia (Gibson et al. 2004).

Target-specificity

None of the currently available, or prospective, chemical repellents or deterrents are specific to the three native species of interest in Tasmania. Some products may provide additional benefit by deterring browse by rabbits, hares and other species.

Cost-effectiveness

For forestry, the full operational cost of using repellents includes application to seedlings in nurseries, follow-up treatments in plantations, replacement of badly damaged seedlings and, if necessary, the use of supplementary techniques to reduce the number of browsing animals. There is potential to reduce costs if repellents are applied selectively to seedlings in areas of plantations most at risk from browsing animals. Complete cost estimates, which are not available for existing repellents in Australia, need to be part of either a cost-effectiveness analysis or a benefit–cost analysis. The former analysis requires specification of an operational target (e.g. level of acceptable browse damage), whereas the latter would require comparison with gains in the value of products harvested from treated plantations. No precise estimates of either kind are available for the use of existing repellents in broad-acre agricultural situations in Australia.

Trials with repellents in Tasmania have been conducted at very few forestry sites, with little or no replication at the site level, and at no agricultural crop sites. Some results have been compromised by attempting to include too many factors in the experimental design, as for example in the study reported by Law (2005). The results are likely to be influenced substantially by factors that have not yet been tested adequately either in field experiments or operationally. These factors include site, dominant browsing species, level of browsing pressure, availability of alternative food, and use of additional pest management techniques.

Repellents are most likely to be effective when browsing pressure is low to moderate (Miller et al. 2006a), when suppression of browsing is required for short periods of time, when used in combination with other techniques, and where the costs of permanent structures such as fencing are prohibitive (Nolte & Wagner 2000). Conversely, they are unlikely to be effective when alternative foods are sparse or unavailable.

Non-target problems

Chemical repellents are not species-specific, although some affect mammals but not birds (Mason 1998).

Social acceptance

The public acceptance of chemical repellents needs to be determined in Tasmania. Discussions with stakeholders in May 2006 (see Appendix 1) suggested that repellents would be generally acceptable provided they are effective, but a proper assessment of society's attitudes to repellents needs to take into account requirements for integration with other techniques, such as shooting, that are likely to have different levels of acceptability.

Integration of techniques

The effectiveness of repellents can be influenced by a range of factors that need to be managed as part of an integrated control programme. These factors include the abundance of the pest animals, the potential refuges for them, the size and shape of the area to be protected (which affects the opportunity of pest animals to access the entire crop and to move to alternative food), the availability of palatable alternative food in nearby areas (Nolte & Wagner 2000; Walsh & Wardlaw 2005), the use of 'hardened' seedlings, and the presence of protective, unpalatable vegetation around tree seedlings (Bulinski & McArthur 2003; Pietrzykowski et al. 2003; Miller et al. 2006b). Knowledge of likely patterns of pest animal behaviour in response to these factors has potential to improve the effectiveness of repellents when used in combination with other techniques (Walsh & Wardlaw 2005). A recent assessment by Walsh & Kincade (2005) of data from three hardwood plantations in Tasmania, combined with simulations using Forestry Tasmania's (FT) plantation production model, suggested that repellents (either Sen-tree® (WR-1) or Plant Plus) could be integrated effectively with the use of diversionary food, shooting, and browse monitoring, to successfully reduce browse damage to acceptable limits.

Legislation

Currently three products, D-Ter®, Sen-Tree® and Multicrop® Scat®, are registered with the APVMA as animal repellents. Registration of Plant Plus is in progress (T. Montague pers. comm.). Appropriate registration would be required for use on crops or in other situations where chemicals could contaminate food for human consumption.

Implementation

Forestry: Application of repellents can be done most efficiently to seedlings in nurseries. Use of repellents containing irritants would require care to avoid human exposure. Trials in Tasmania indicate that follow-up applications will be required to achieve protection until seedlings exceed browse height (A. Walsh pers. comm.: 'Trial of alternatives to 1080 at Russel 006g', 'TA003L repellent trial observations'). This will depend on the ability of the product to withstand weathering and may be required to protect new plant growth within browse height. Integration with other browse-management techniques is likely to be necessary to achieve acceptable reductions in browse damage.

Agriculture: The use of repellents on pasture or crops would be subject to regulatory requirements to prevent contamination of food products. There may be opportunities to use existing on-farm spray equipment for cost-effective application of repellents over large areas, but use of repellents containing irritants would require care to avoid human exposure. The value of protecting pasture prior to damage, for example during establishment or when areas are not required for livestock, and the stock withholding period need to be established.

Stakeholder support

The development of repellents to protect seedlings in plantations received support during discussions in April 2006 with representatives from FT and DPIW. Representatives of FIAT gave qualified support and suggested there would be potential for using systemic repellents in areas subject to relatively low levels of browsing damage. The use of repellents was considered acceptably humane by the representatives of Against Animal Cruelty, Tasmania (AACT), the RSPCA, and the World League for Protection of Animals (WLPA). Some members of the TFGA suggested the technique would be of no value for broad-acre applications because it would just shift the problem elsewhere.

Summary and research gaps (see Table 1)

Chemical repellents have provided mixed results for forestry and agriculture in Tasmania. However, at least two products, Plant Plus and Sen-Tree® (WR-1), have shown some (but not universal) promise in plantation forestry. The programme of the Cooperative Research Centre (CRC) for Forestry includes plans for research on three candidate repellents: Possum-shot® (a New Zealand product), Plant Plus, and Sen-Tree® (T. Wardlaw pers. comm.).

Table 1 Gaps in research into chemical repellents (not ranked).

Topic ID	Research topic	Justification
1a	Quantify the benefits of existing registered products, or products in the process of being registered in Australia, at a management scale.	There are a number of potentially effective repellents that need to be rigorously tested.
1b	Quantify the effects of pest density, alternative food availability, mosaics of preferred habitat and their size, and season on repellent effectiveness.	Repellents are unlikely to be effective where browsing animals are pressed for food. The optimal use of repellents needs to be assessed.

Topic ID	Research topic	Justification
1c	Evaluate repellents in combination with techniques such as initial culling or maintenance of protective vegetation cover in plantations.	Repellents are unlikely to be effective in all situations especially where browsing animal numbers are high, so their integration into strategies that reduce their densities need to be assessed.
1d	Identify public acceptance of chemical repellents.	Public opinion on chemical repellents is unclear and should be surveyed before any widespread use of these products.
1e	Determine the cost-effectiveness of chemical repellents.	Before chemical repellents can be promoted, their costs relevant to other control technologies should be clarified.

5.2 Acoustic repellents or deterrents

Acoustic devices for repelling or deterring mammals can be divided into two categories: bio-acoustic (biosonic) devices that mimic biologically meaningful sounds such as distress calls, alarm calls or sounds produced by predators, and devices such as gas guns that generate artificial sounds to scare animals or background noise (including infrasound and ultrasound) to ‘block’ animals’ ability to detect threats, e.g. from predators. The latter category includes two ultrasonic devices designed to repel or deter macropods and one to deter possums. Experimental tests demonstrated a very limited, short-duration response by wallabies and pademelons to sounds emitted by Roo-guard® (Statham 1991) and that neither Roo-guard® nor Shu Roo® were effective in altering significantly the behaviour of eastern grey kangaroos (*Macropus giganteus*), red kangaroos (*M. rufus*) or tammar wallabies (*Macropus eugenii*) (Muirhead et al. 2006; Bender 2001 cited by D. Ramp pers. comm.; Bender 2003). Po-guard was not effective in preventing possums from moving out of forest to forage on adjacent pasture (Coleman & Tyson 1994). These results are consistent with tests of ultrasonic devices on other mammal species overseas (e.g. Bomford & O’Brien 1990; Gilsdorf et al. 2004; VerCauteren et al. 2005; and references cited in these papers). Conversely, there is potential for perverse outcomes with acoustic devices: possums displayed a positive response to a novel auditory cue tested as an attractant to increase trap success in New Zealand (Carey et al. 1997).

At present no device relying on bio-acoustic signals is available commercially in Australia to prevent browse damage by wallabies, pademelons or possums, although recent studies have suggested this is a potentially useful approach. Foot thumps are used as an alarm signal by many species of macropods and other mammals (Coulson 1997; Bender 2006; and references cited in these papers). Pen trials with tammar wallabies sourced from Kangaroo Island demonstrated an increase in vigilance in response to playback of recorded foot thumps (Blumstein et al. 2000). This behaviour appears to be an innate response to sightings of predators but not predator vocalisations. Eastern grey kangaroos responded to playback of foot thumps with increased frequency of alert postures and a shorter mean time to take flight compared with responses to background noise (Bender 2005). Recent trials (Ramp et al. 2006) have found that red-necked pademelons displayed increased vigilance in response to playback of recorded distress calls but not sounds of gunshots or calls of dingoes (*Canis lupus dingo*) or wedge-tailed eagles (*Aquila audax*). Playback of recorded foot thumps resulted in red-necked pademelons spending more time close to shelter. Results from similar trials with red-necked wallabies are not yet available (D. Ramp pers. comm.).

Summary and research gaps (see Table 2)

Scaring or ‘blocking’ devices that generate ultrasonic frequencies have been developed for macropods and possums and found to be ineffective. These results, and results from similar research with other mammal species overseas, indicate that further research into deterrents of this type is not warranted.

Based on recent studies of animal behaviour, deterrents using bio-acoustic signals might be effective for wallabies, pademelons and/or possums. Current research appears promising but further research is required into the selection and testing of appropriate stimuli.

Table 2 Gaps in research into acoustic repellents.

Topic ID	Research topic	Justification
2a	Identify appropriate stimuli such as distress or alarm signals or sounds of predators as potential repellents.	Bio-acoustic signals appear to show the greatest promise as non-chemical repellents.

5.3 Physical barriers (fences and tree guards)

Two types of physical barriers are used to exclude browsing mammals from forestry plantations and farm crops: fences to protect tree and farm crops and tree guards to protect individual forest seedlings. Much research has been conducted on the ability of both fences and guards to reduce browsing damage on seedlings in Tasmania and Victoria, but there has been little research carried out on fences to limit damage to farm pasture and crops.

Fences

Conventional fences provide a physical barrier between the resource to be protected and the browsing mammal, whereas an electric fence has a deterrent effect by causing pain to any animal that touches it. Long and Robley (2004) recently reviewed fences designed to exclude feral animals from areas of high conservation value in Australia, and reached four conclusions relevant to this review:

- The primary determinant of the effectiveness of any fence is its ability to act as a physical barrier: electrified wires on their own ‘rarely’ provide a good barrier, with the spacing between the electric wires and earthed components critical to a shock being delivered to the transgressing animal.
- The base and corners of fences, along with gates and gully or waterway crossings, are most likely to be breached by animals.
- Some non-target native animals are killed by electric or non-electric fences, although the number is considered unlikely to affect local populations.
- Fences need to be regularly inspected and maintained, and both actions can be expensive.

Trials of fences in Tasmania

Fencing is only used routinely for the protection of stands of *Acacia melanoxylon* in north-western Tasmania (Jennings 2003), and by FT in eucalypt plantations where the site conditions are favourable to fencing (such as ex-pasture sites) and economic modelling shows that fences are affordable (A. Walsh pers. comm.). Many farmers also use fences to protect pasture and crops (G. Robertson pers. comm.). *A. melanoxylon* seedlings are the most attractive of the commercial tree species planted in Tasmania to browsing mammals, and without protection they are nearly always killed, particularly by pademelons (Jennings & Dawson 1998). Jennings and Dawson (1998) believed that it was economically viable to fence coupes on flat land with a high proportion of *A. melanoxylon* seedlings when there were ≥15 ha fenced for each kilometre of fencing. Assuming an average establishment cost of $4,420/km for standard fencing (though this is likely to vary considerably with the price of materials and overheads), this equates to about $280/ha. This edge-to-area ratio of 1:15.8 is also used to determine costs/ha given for other fences below. At least 520 ha of *A. melanoxylon*-rich regeneration was fenced in Tasmania between 1985 and 1998; these stands now have an average stocking rate of 2500 stems/ha compared with c. 70 stems/ha in adjacent unfenced areas (Jennings & Dawson 1998).

Fencing has been evaluated in several major trials for its effect on the growth and survival rates of seedlings of several timber species and of some farm crops in various parts of Tasmania.

The ability of captive wallabies and pademelons to overcome a variety of fence designs was examined by Statham (1991). The first design tested was a standard seven-wire stock fence, which was subsequently modified due to its failure to exclude both species. On the basis of that work, two electric-fence designs and a standard stock fence ('control') were field tested. Based on numbers of faecal pellets inside the three enclosures, the two electric fences worked equally well, and better than the stock fence, although possum, pademelon and wallaby faecal pellets were occasionally found in all enclosures. Statham (1991) considered wire spacing was a critical factor in determining the success of electric fences against wallabies. Both electric fences cost c. $4,000/km or c. $270/ha (establishment only).

The survival rates of *E. nitens* and *E. regnans* seedlings in fenced compartments ranging in area from 15 to 123 ha were compared in north-eastern Tasmania by Neilsen and Wilkinson (1995). Although the treatments were apparently not randomly assigned, highest seedling survival was recorded in the compartment fenced with two electrified wires (88% after 3 years). The establishment cost of the fencing was c. $300/ha. Using a different approach, Neyland and Jennings (2002) reported the results of a fencing trial using monofilament nylon gillnet at several sites in Tasmania in 1992. Although both the seedling stocking and growth rates were significantly higher inside than outside the fenced areas after 2 years, there was no difference after 4 years.

Browsing damage to *A. melanoxylon* in coupes 4–11 years old inside wire netting fences was compared with that in nearby unfenced stands matched for similar soil types, vegetation, and altitude (Jennings & Dawson 1998). Mean *A. melanoxylon* stocking rates were <100 in unfenced coupes and between c. 600 and 4700 in fenced coupes. However, there was no difference between eucalypt stocking rates in the fenced and unfenced coupes. The establishment cost of this fencing was $4,220/km or c. $280/ha. Modelling these costs, the known stocking rates, local growth and survival rates, and current sawlog values indicated that excluding pademelons from *A. melanoxylon* using fences is cost-beneficial. Sensitivity analyses indicated that the area-to-perimeter ratio of fencing is a critical determinant of the profitability of fencing (Jennings & Dawson 1998).

For *A. melanoxylon* establishment to be successful, Jennings (2003) suggested that fences needed to be at least 90 cm high, either buried or pegged down, and must remain intact for about 3 years. She compared the cost and effectiveness of five plastic-mesh fences with wire-netting, and ranked them for ease of use, durability, performance, and cost per metre. The heavy-duty wire netting outperformed all of the plastic meshes.

Bulinski and McArthur (1999) evaluated the effects of excluding vertebrate browsers with fences at seven sites throughout Tasmania, with each site comprising 10 randomly located control plots, each consisting of *E. nitens* seedlings fenced and roofed with 1.8-m-high wire poultry-netting. Ten non-treatment plots (unfenced) were established nearby. Although there was no difference in the mean height of fenced and unfenced seedlings at the time of planting, at 12 months the seedlings were generally taller in the fenced plots relative to the unfenced plots, although survival of seedlings was similar.

The efficacy of wallaby wire and 'Visual Barrier' fencing for excluding browsing mammals from stands of *E. globulus* in the Huon district was investigated by A. Walsh (pers. comm.). Two types of fences were constructed: a 'Visual Barrier' fence consisting of a non-woven synthetic fabric with two strands of electrified wire at the top, and a fence of commercially available Hurricane Wallaby Wire, again with two electric wires at the top. Two months after planting, 26 incursions were recorded beneath the wallaby wire fence, but no incursions were detected below the visual barrier. Video monitoring indicated that a wombat (*Vombatus ursinus*) was responsible for one breach. One wallaby was found in both the Visual Barrier and Wallaby Wire enclosures, and possum scats were present inside both enclosures. Browsing of seedlings was common in both enclosures.

Of the designs tested in Tasmania by Gregory (1989), the most effective electric fence reduced wallaby faecal rates by 80% in pasture but by only 50% in a highly palatable oat crop.

Trials of fences in Victoria

Several types of fences have been used in Victoria to protect at-risk crops from browsing. Heavy-grade, commercial, plastic bird-netting 90 cm high was trialled at two sites in Victoria (Fagg 2002). At Bendoc, it was apparently successful, although snakes sometimes became entangled in the netting and died. In contrast, at Mt. Cole, swamp wallabies jumped over the fence. Bird-netting is relatively cheap and biodegradable: thus it does not need to be recovered, and posts can potentially be reused after seedlings have grown beyond browsing height.

'Ringlock' wire mesh (30 × 13 cm) fencing 90 cm high (with an additional three plain wires on the top) was also tested at Mt Cole, but did not exclude small swamp wallabies. The full cost of initial construction and maintenance (for 1 year) of ringlock fencing was estimated to be $4,500/km (2002$) or $300/ha (Fagg 2002).

Rigid 'Cyclone' deer-fencing 1.5 m high was also trialled at Mt Cole. The full cost of initial construction and maintenance (for 1 year) of this fence was c. $7,000/km (2002$) or c. $470/ha (Fagg 2002). It was however expected that this type of fence would be recycled after the trees had grown above wallaby browse height (2–3 years).

The ability of two types of fencing to protect *E. regnans* seedlings from swamp wallabies was evaluated in day and night pen trials in Victoria (Montague et al. 1990). Both 'Rotonet' plastic mesh 1.23 m high and three-strand electric fencing prevented browsing of trees within small fenced areas for up to 7 days. Field trials of the Rotonet fencing with *E. regnans* and *P. radiata* over a period of 6 months showed that 75% fewer trees were browsed in fenced plots relative to unfenced plots. However, damage to Rotonet fencing by wombats was sometimes considerable, and led to suggestions of installing wombat 'gates' in areas where their numbers are high (A. Lyons pers. comm.).

Seven- and eight-strand electric fences were built to exclude swamp wallabies at Mt Cole and in East Gippsland from 1985 (Fagg 2002), but the wallabies eventually learned to breach the fences. These fences were also plagued by the periodic need to replace batteries and check the perimeter for electrical shorts. The full cost of construction, electricity supply, and maintenance for 1 year was estimated to be c. $5,500/km (2002$) or c. $370/ha. By 1996, other types of fencing had replaced electric fences in Victoria.

Six electric fence designs were tested by Clunie and Becker (1991) to deter macropods in Victoria. The five-wire design of Howard (1978) apparently kept all but one of 12 wallabies out of a 0.2-ha cereal crop. The Statham (1991) design discussed above was reported to have 'stopped up to 90% of macropods except during periods of acute food shortages' (Clunie & Becker 1991). Coulson (unpublished) tested this design in a short-term trial, but Statham (1991) considered his results 'inconclusive' because the trial did not include a non-treatment area. Clunie and Becker (1991) reported the results of a trial of their own fence design to protect *P. radiata* from swamp wallaby browsing at two sites in the Yarram Region, Victoria. The fence was 1.75 m tall and consisted of seven wires, with the third wire from the top and an outrigger electrified. No browsing damage was observed either inside or outside the fence. Swamp wallaby faecal pellets were found both inside and outside the fences, indicating that animals had breached them. Numerous problems were identified with electric fences during this study; holes developed under the fence due to animals and landslips; grass and other vegetation shorted the fence; regular maintenance was required to keep batteries charged and debris off the fence; the cost of fencing steep terrain was substantial; equipment was stolen, and any enclosed animals had to be removed from fenced areas. It was estimated that the fencing cost $1,060/km or c. $70/ha.

Trials of guards in Tasmania

Several trials of tree guards used to protect forest seedlings have been undertaken in Tasmania and Victoria over the last two decades. At Meunna and Smiths Plains, north-west Tasmania, a rigid guard and three flexible mesh protectors (standard, heavy and wide) made of biodegradable extruded polypropylene were evaluated using seedling *P. radiata, E. globulus, E. regnans, E. obliqua*, and *A. melanoxylon* in a randomised block design (Allen 1992; Neyland & Jennings 2002). Although there were strong interspecific differences in seedling survival rates, there was no significant effect of the guards (or of their length) on the survival or growth rate of protected seedlings compared with unprotected seedlings. *A. melanoxylon* seedlings in the heavy and wide guards had higher growth rates relative to those in the other two guard designs (Allen 1992; Neyland & Jennings 2002). Follow-up trials evaluated no guard (a control), polypropylene nets, chicken-wire guards, and fencing using *E. nitens* seedlings established on recently burnt coupes (Allen 1992; Neyland & Jennings 2002). At both 2 and 4 years after planting, there was no height or survival difference between the netted and control seedlings, while fenced seedlings had greater survival and were significantly taller than the netted seedlings, which were significantly taller than the control seedlings. However, where the browsing was intense, netting offered little protection (Allen 1992; Neyland & Jennings 2002).

Forestry Tasmania is currently evaluating the efficacy of guards for excluding browsing mammals from *E. globulus* seedlings in the Huon district (A. Walsh pers. comm.). Four different diameters of tree guard are being used, but no results are available as yet. Also, Private Forests Tasmania (PFT) has demonstrated significantly improved seedling growth rates in 1.2-m ‘coreflute’ reusable guards (A. Lyons pers. comm.), while Forest Enterprises Australia (FEA) is using onion net guards with limited success and low cost (11c/seedling) in areas of moderate browsing risk and where 1080 is not acceptable (G. Linsley-Noakes pers. comm.).

Trials of guards in Victoria

A wider variety of guards have been trialled in Victoria than in Tasmania (Fagg 2002). At Bendoc in 1990, light plastic-mesh guards were circumvented by swamp wallabies that managed to browse some seedlings, while some seedlings grew through the guard and became malformed.

Three different types of guards for protecting *E. globulus* seedlings from browsing by swamp wallabies were trialled by Basset et al. (2002) in north-east Victoria: Blu-Gro guards 30 and 45 cm high, and green plastic guards. Wallabies damaged 80% of seedlings in Blu-Gro guards, and killed 85% of seedlings in the green plastic guards. Part or all of the seedlings in Blu-Gro guards were accessed by wallabies pushing over, lifting, or splitting the tube, while the high loss rate of seedlings in green guards was due to the wider guard opening enabling easy access by wallabies. The taller of the two Blu-Gro guards was most effective, enabling seedlings to attain greater height. Better anchoring of the guards to supporting stakes was thought likely to reduce the number of guards ‘lifted’ by wallabies and the seedlings subsequently nipped off (Bassett et al. 2002).

Similar trials by Montague et al. (1990) evaluated the ability of two types of guards to protect *E. regnans* seedlings from swamp wallabies in short-term (i.e. 24-hour) pen trials: ‘Vexar’ cylindrical mesh tubing and stocking mesh guards were removed by swamp wallabies from most seedlings and the seedlings eaten within 2 hours of starting the trials. Further work included four additional tree guards: wire mesh (4 cm chicken-wire), plastic mesh, plastic film and rigid tubing (Montague 1993). Only 1-m-tall rigid tubing provided complete protection for the duration of the trial (7 days), and 95% of the unprotected seedlings were eaten within 16 hours of exposure. However, the commercial potential of 1-m rigid-tube tree guards was thought to be ‘limited’ by their cost (Montague 1993). Wire-mesh guards provided the next best protection (only 10% of seedlings browsed at 7 days), but were difficult and time-consuming to transport, assemble and install. Montague (1993) recommended that all tree guards for swamp wallabies be at least 1 m tall.

The ability of ‘Boral’ nylon-mesh guards, ‘Vexar’ polypropylene-mesh guards, and ‘Rosemay bud’ polyester guards were evaluated for their potential to protect *E. regnans* and *P. radiata* seedlings in the Yarram Region, Victoria (Clunie & Becker 1991). Six months after installation, survival was highest in seedlings protected by the guards, the height of browsed seedlings was significantly less (c. 21–67%) than that of unbrowsed seedlings (at 3 of 4 sites measured), and mean browsing scores on all protected seedlings were significantly reduced. Against these benefits, 31% of trees protected by guards at one site sustained unacceptable rates of bending of the stem (above 24^{o}) compared to none of the trees in the control group. Retention rates of the tree guards varied from 47 to 97% after 12 months, with poorer retention attributed to greater browser activity. The 1990 costs of fitting these guards ranged from $500 to $600/ha.

Strengths and weaknesses of the research conducted on physical barriers

A major problem with nearly all trials of barriers undertaken so far has been their short duration: most have lasted <1 year whereas seedlings are vulnerable to mammalian browsers for 2–3 years. Field trials should evaluate damage to seedlings over the entire at-risk period.

Although most field trials have documented the costs of constructing barriers, few have attempted to model the long-term benefits of the barriers in terms of timber production. The modelling by Jennings and Dawson (1998) for fencing *A. melanoxylon* is an example of the strengths of this approach, and we suggest that this type of modelling be an integral part of future research into physical barriers. We recommend that detailed modelling of costs and benefits of the various management actions is a central part of any future research on barriers.

Cost-effectiveness

Most of the physical barriers reviewed here protect forest seedlings and agricultural crops from browsing mammals for short periods, but few protect resources in a cost-effective manner for the entire time they are at risk. Fencing is not, therefore, generally considered a cost-effective management action for use against browsing mammals in Tasmania by most land managers (i.e FIAT and TFGA pers. comm.), although Natural Resource Management (NRM) representatives argue, without robust supporting data, that fencing is ‘likely’ to be cost-effective in areas of high-production farmland (as distinct from extensive grazing lands, G. Robertson pers. comm.). Electric fences may be effective at protecting high-value agricultural crops (A. Walsh pers. comm.), but are too maintenance-intensive to effectively exclude browsing mammals in most forest situations. Conventional fencing appears to be an effective barrier for the high-value and highly vulnerable seedlings of *A. melanoxylon*, but some landscapes are too rugged for fencing to be a cost-effective option (Fagg 2002). In contrast, fencing appears to have very little value in protecting stands of *P. radiata*, as these trees are attacked by browsing mammals throughout the stand rotation (Butcher 2000). At best, fencing is a cost-effective option for protecting some resources in some parts of the landscape.

Although fences *may* exclude wallabies and pademelons, most of these designs do not exclude rabbits or possums. Unfortunately, any fence can be breached and significant damage can follow very quickly (Neyland & Jennings 2002). In particular, wombats can force their way through or under most fence types, and wallabies and other browsers quickly exploit the breach. Presumably barbed wire could be used to reduce fence breakages by wombats, with its apparent absence from documented fencing trials presumably reflecting animal welfare concerns. Neyland and Jennings (2002) suggested that a ‘floppy-top’ fence design could be effective against possums, at least in the short term, but it is more expensive to construct than normal fences and requires a higher level of maintenance.

Fence establishment costs using wire netting may be as low as c. $280/ha (Jennings & Dawson 1998). However, both the establishment and maintenance costs of fencing are generally considered unacceptably expensive (A. Walsh, A. Lyons pers. comm.). In forestry, fences have only proven economic for *A. melanoxylon* (Jennings & Dawson 1998). Electric fences seem far less useful than conventional fences in forestry, suffering from electrical shorts and subject to theft, particularly when close to settlements, where solar panels and batteries are often taken (Neyland & Jennings 2002). Electric fences may, however, be useful for protecting small-scale high-value agricultural crops and short-term research trials.

The cost of placing guards on seedlings is generally considered too expensive for the benefits likely to follow (FIAT, Gunns pers. comm.). Most types of guard must eventually be removed to avoid affecting final tree form and tree growth rate, as many stems develop unacceptably high levels of bending while inside guards. Even guards constructed with photo-degradable materials may need to be removed. Alternatively, such guards may be dislodged before the seedling has escaped the browse tier. The loss rate of guards, which leaves seedlings exposed to browsing, may also be unacceptably high (Coleman 1991), in particular, guards are often blown away on windy sites or dislodged by browsing animals. Finally, browsing immediately above the guard can be a problem in older seedlings.

Despite their potential benefits, there are no robust cost-benefit analyses of the use of either fences or guards to use in determining their overall effectiveness (G. Hocking pers. comm.).

Non-target problems

Physical barriers occasionally put at risk both target and non-target animals. Electric fencing in particular, but even standard fencing can cause some deaths of non-target species – especially the echidna (*Tachyglossus aculeatus*; Fagg 2002), but such losses are thought to be rare events. These stakeholders reluctantly accept that the exclusion of browsing mammals from at-risk crops will result in reduced food resources for the animals and may result in the natural decline in local animal populations.

We are unaware of any such concern with tree guards.

Social acceptance

Fences and guards are the preferred option by animal welfare groups for the control of browsing mammals (Y. Watt, B. Hickson, J. Williamson pers. comm.). The acceptance of these devices by the wider public is unknown, and while it is likely to be similar, it should be investigated.

Integration of techniques

The integration of exclusion devices with lethal techniques such as shooting or toxic baiting is likely to provide better management, if only because the latter tools reduce the animal pressure on fences and guards and lower the risk of them being breached. However, conventional fences are the only exclusion device used as a routine management option for protecting tree seedlings from browsing mammals in Tasmania (Jennings & Dawson 1998; Jennings 2003), and are often used in isolation from other management techniques, as the costs of combining control techniques is often uneconomic (A. Walsh pers. comm.).

Legislation

The legislation pertaining to the erection and maintenance of boundary fences is covered by the Boundary Fences Act 1908. However, this does not apply to properties bounding unoccupied Crown land, reserves, or land owned by FT, making any costs accrued in building a fence there and maintaining it the responsibility of the private landowner alone. The legislative requirements affecting the placement of electric and non-electric fences and of tree guards about at-risk crops on privately or publicly owned land are unknown to us.

Stakeholder support

Stakeholder support from landowners for exclusion devices is minimal, and contrasts with that of animal welfare groups (i.e. AACT, TCT). At meetings with farmer- and forestry-based interest groups, most attendees argued that both fences and guards were too expensive, particularly for farmers with boundaries in rugged country or with large numbers of wombats present, and generally performed poorly and offered little support for their industries. However, this position may change for farmers in areas of higher productivity (and thus experiencing different costs and benefits of browse loss and fencing). Additional concerns included the lack of contribution by the Crown to fences between Crown and farm land, the lethal effect of fences on species such as the echidna, damage to the native environment when high numbers of browsing animals are fenced ‘into’ areas of ‘bush’, and the likelihood of animals being funnelled onto adjacent unfenced properties (G. Hocking pers. comm.). In contrast, there was a clear case stated for the use of fences about patches of regenerating *A. melanoxylon* (A. Walsh, N. Foss pers. comm.), while the animal welfare groups (Y. Watt, B. Hickson, J. Williamson pers. comm.) see fencing and guards as non-lethal techniques available to control browsing mammals and hence preferred options for reducing browsing damage.

Summary and research gaps (see Table 3)

Physical barriers have been used with mixed results. For agriculture, fences are probably the only non-lethal option.

Table 3 Gaps in research into physical barriers (not ranked).

Topic ID	Research topic	Justification
3a	Develop and demonstrate ‘best-practice’ guidelines for fencing of at-risk forestry and farmland.	‘Best-practice’ use of fences should be established to demonstrate their cost-effectiveness.
3b	Assess public acceptance of fencing and tree guards for the control of browsing mammals.	Fencing impacts directly and indirectly on native mammal populations and public acceptability of this management tool should be assessed.
3c	Identify acceptable levels of ingress by browsing mammals across physical barriers.	Given most fences will ‘leak’, managers need to know how leaky a fence can be and still provide useful protection.
3d	Evaluate the development of a cost-benefit-based Decision Support System for determining where and when to undertake fencing of at-risk forestry and farmland.	When and where to use fencing and/or other control options will be enhanced if expert systems are developed to assist landowners make informed choices.
3e	Determine the cost-effectiveness of physical barriers.	Before physical barriers can be promoted, their costs relevant to other control techniques should be clarified.

5.4 Fertility control

Current use

Fertility control is not currently used for large-scale vertebrate pest management in Australia. Sterilisation has been attempted as a population management tool for an iconic native species, the koala (*Phascolarctos cinereus*; Masters et al. 2004), and fertility inhibition has been proposed for the management of macropods (e.g. Kitchener et al. 2002; Nave et al. 2002; Herbert et al. 2005), particularly for intensively managed populations in areas where culling is deemed socially unacceptable.

Options for fertility control

The options for reducing the fecundity of free-ranging wildlife populations include chemicals that directly induce infertility or sterility (i.e. permanent infertility) and immunogens that stimulate an immune response to reduce fertility (Rodger 2003). The ideal products are species-specific, avoid requirements for tightly controlled administration of single or multiple doses, and do not lead to undesirable consequences for the welfare of individual animals. However, fertility control might not be suitable for all problem species; e.g. particular types of hierarchical social organisation (Caughley et al. 1993) or compensatory survival (Davis & Pech 2002) could lead to increased rather than decreased abundance of populations with intermediate levels of infertility.

Over the last decade, research into contraceptive vaccines has focused mainly on egg and sperm antigens (Mate & Hinds 2003; Duckworth et al. 2006). This research has been conducted by many groups around the world, and in Australia it has received impetus through the CRC programme (Rodger 2003). Although immunocontraception has been demonstrated to work in the laboratory (e.g. with possums (Duckworth et al. 2006) and house mice (*Mus domesticus*) (Jackson et al. 1998; Lloyd et al. 2003)), progress towards operational products for vertebrate pest species in Australia has been mixed. The Invasive Animals CRC has ceased this line of research for foxes and rabbits due to the slow rate of progress towards effective products, and the future of a viral-vectored immunocontraceptive agent (a recombinant murine cytomegalovirus) for house mice is uncertain (C. Hardy pers. comm.). However, in New Zealand, significant progress towards a bait-delivered contraceptive vaccine for possums is expected within 3–4 years (J. Duckworth pers. comm.). In terms of time, the development history of immunocontraceptive vaccines is probably similar to that for other pest control products such as toxins or repellents.

Hormone agonists have been used to inhibit fecundity in a range of mammals, including tammar wallabies (Herbert et al. 2005), but for these products, delivery systems suitable for reducing populations of possums, pademelons or Bennett's wallabies in Tasmania are not yet available. The current research programme of the Invasive Animals CRC has shifted focus from immunocontraceptive vaccines to two alternative anti-fertility agents: one is a chemosterilant and the other a protein that would block fertility without requiring an immune response (L. Hinds pers. comm.). Both agents would be delivered orally via bait. There are three major components to the research: (a) testing of the two potential chemical agents, including dose requirements, (b) formulation of a carrier to get the chemical past the high pH levels in the stomach to ensure optimal uptake across the small intestine, and (c) adaptation of existing bait formulations (e.g. pellets or gels) or development of new bait types suitable for the target species. The laboratory-based research will use the tammar wallaby as a model species but, as neither prospective fertility control agent is species-specific, a successful product should work for Bennett's wallabies (which are a seasonal breeder like the tammar wallaby) and pademelons (which are more or less continuous breeders). If infertility is less than permanent, then additional research such as population modelling would be useful for estimating the best time of year for delivery in the field. The most optimistic time frame for testing of the two candidate chemical agents by the Invasive Animals CRC is 3 years (L. Hinds pers. comm.). More realistically, it will take 3–6 years for product development, assuming research on carriers and bait types is run in parallel, with an additional period to meet registration requirements.

Delivery systems and target specificity

Although fertility control is technically feasible for individual animals, an effective delivery system is one of the major challenges for using this technique with free-ranging wildlife. For high-density populations over large areas, it is not feasible for animals to be live-trapped, treated (e.g. via injection or implant) and released, nor is this type of management feasible for wallabies unless particular care is taken to avoid post-capture myopathy and death (Lentle et al. 1997). Where live-trapping is a feasible management option, e.g. for localised prevention of low-to-medium browsing damage (see Section 5.7), killing or relocation, not fertility control, of trapped animals would be necessary if an immediate reduction in animal numbers is required.

The option of an engineered self-disseminating micro- or macro-parasite (Tyndale-Biscoe 1994) is not suitable for species where control needs to be restricted to non-isolated areas within a species' distribution (Williams 1997). Options for using these types of delivery systems are under consideration for possums in New Zealand (Cowan 2000) but use of self-disseminating immunocontraceptive (or lethal) agents should not be considered for use against possums, pademelons or wallabies in Tasmania because they could not be recalled once released.

Bait-delivered, non-disseminating, anti-fertility products have an advantage over self-disseminating systems in that their use can be restricted to specific locations and for pre-determined periods of time. None of the chemical fertility-control agents currently under development by the Invasive Animals CRC (L. Hinds pers. comm.) or for possums in New Zealand (J. Duckworth pers. comm.) are species-specific, although some are likely to be restricted in their effects to marsupials (Duckworth et al. 2006). The aim is to enhance species-specificity by designing appropriate delivery systems, e.g. the application of gel baits to leaves only within reach of browsing animals (Warburton 1990). In New Zealand, research is in progress on the use of transgenic plants to deliver contraceptive antigens to possums (Duckworth et al. 2006) but this type of product is not expected to be available in the near future (J. Duckworth pers. comm.).

Cost-effectiveness

Fertility control technology has not yet reached the stage where estimates of its cost-effectiveness are feasible for the management of wildlife populations on the scale required for forestry and agriculture in Tasmania. However, population models have been used for several species to estimate the potential effectiveness of fertility control using delivery systems based on baits (e.g. Hobbs et al. 2000; Shi et al. 2002), live capture (Merrill et al. 2006), or engineered viruses (e.g. Barlow 1994, 1997; Hood et al. 2000; Arthur et al. 2005). The models can be used to compare the effectiveness of current control techniques with fertility control (e.g. Barlow et al. 1997; Hobbs et al. 2000; Shi et al. 2002), with the added option of examining the potential for using fertility control in combination with lethal techniques.

Models for using fertility control for possums were reviewed by Cowan et al. (2003). These models indicate fertility control could, theoretically, achieve the substantial population reductions required for conservation and disease control in New Zealand. Robust models depend on good demographic data, primarily rates of survival and fecundity, and should include the influence of stochastic factors (e.g. climate; Pech et al. 1997) and compensatory factors (e.g. dispersal behaviour; Ramsey 2005). Currently demographic data are not available to model adequately the effectiveness of fertility control for either wallabies or pademelons. For possums, research in New Zealand has suggested that, apart from dispersal, the effects of compensatory factors may not be significant (Ramsey 2005). However, the potential impact of compensation was demonstrated in two experimental field studies in Australia where density-dependent survival of juvenile rabbits and enhanced survival of sterile female rabbits reduced the effectiveness of fertility control (Twigg & Williams 1999; Twigg et al. 2000).

In general, population models indicate fertility control can be effective where population reduction does not have to be as rapid as lethal control or where the objective is maintenance of a population at low levels established previously with exclusion or lethal techniques (e.g. Barlow 1994; Barlow et al. 1997). Where long-term population suppression is required adjacent to areas with untreated populations, fertility control would have to be applied regularly because neither wallabies nor pademelons have territorial behaviour that would prevent immigration of fertile animals from outside the treated area. Several studies in New Zealand have shown that possums recolonise areas relatively slowly, with limited immigration for the first 1–3 years of the post-control period (Cowan & Clout 2000). However, in an experimental study using relatively small, 12-ha sites, Ramsey (2005) found that immigration rapidly compensated for any effects of sterilising 50% or 80% of female possums.

Future assessments of the value of fertility control for managing browsing animals in Tasmania need to be based on clearly defined criteria. In particular, targets for damage mitigation and the abundance of browsing animals need to be defined. Fertility control needs to be compared with alternative existing or new control options, e.g. via a ‘pay-off’ function such as that proposed by Hood et al. (2000) to measure the additional benefits of using a particular control technique.

Social acceptance

Generally, in Australia and elsewhere there is support for the use of fertility control techniques, compared to lethal control, for the management of ‘overabundant’ wildlife (Singer 1997; Grandy & Rutberg 2002). In a survey conducted in Victoria, Johnston & Marks (1997) recorded high levels of public support for fertility control of pest animal populations. Fifty-eight percent of respondents supported the use of permanent fertility control for kangaroos and 7% supported temporary fertility control, compared with 16% support for a humane and target-specific toxin and 6% for biological control, presumably with a micro- or macro-parasite (7% of respondents were undecided). Fertility control, either temporary or permanent, was considered more suitable for managing kangaroo populations than for feral dogs (*Canis lupus familiaris*), feral cats (*Felis catus*), foxes or wild rabbits. This appears broadly consistent with public attitudes to the use of lethal and non-lethal means to control possums in New Zealand (Fitzgerald et al. 2000). However, it is unclear whether the respondents in these surveys took into account the potential need to integrate fertility control with initial or periodic reduction of animal populations using lethal techniques. A further survey of public opinion on this issue is warranted.

Integration of techniques

Fertility control alone is unlikely to achieve sufficiently rapid population reduction to meet operational requirements (e.g. Barlow 1997; Bayliss & Choquenot 1999), although for rabbits, elimination of the annual pulse of recruits was considered a successful outcome in terms of conserving pasture (Twigg et al. 2000). When operational specifications are available for candidate fertility control agents, population models can be used to predict the potential benefits of their integration with other techniques in Tasmania.

Legislation

Australia has stringent standards for the research, development and use of genetically modified products, including those intended for the biological control of pest species (Williams 2002). Chemical agents for fertility control would be subject to the same regulatory standards as toxins registered for use in agriculture (e.g. section 4.1 on the APVMA website http://www.apvma.gov.au/MORAG_vet/vol_2/category_2.html#gen12).

Stakeholder support

At meetings in Tasmania in May 2006, representatives of several stakeholder groups expressed support for research into fertility control techniques for wallabies, pademelons and possums, despite the relatively long time frame still required for development of this technology (a minimum of 3–6 years; see above). These groups included AACT, Forests and Forest Industry Council of Tasmania (FFIC), RSPCA, Timber Communities Australia (TCA), TFGA and WLPA.

Summary and research gaps (see Table 4)

There are several research groups working on fertility control technology for wildlife management in Australia and New Zealand, and the first products from this research might become available in 3–6 years. A critical component of this research is the development of suitable systems to deliver the control agent to the target animals. These systems should be designed for use in programmes aimed at the long-term prevention of browse damage on farmland through the maintenance of animal populations at low densities after initial reduction using other techniques. Fertility control is not likely to be useful for short-term, localised management of browsing damage, e.g. during the establishment phase of plantations.

Table 4 Gaps in research into fertility control (not ranked).

Topic ID	Research topic	Justification
4a	Assess the effectiveness of immunocontraception developed for possums for its effectiveness at inducing infertility in pademelons and wallabies.	Research on ZP-based immunocontraception is well advanced for possums and this progress could be capitalised on for the other species.
4b	Assess the effectiveness of chemosterilants for use on pademelons and wallabies.	Chemosterilants appear likely to provide suitable, publicly acceptable control for the permanent but reversible suppression of populations about farm margins.
4c	Develop target-specific delivery systems: solid bait and gel for foliage application.	Development of fertility control agents need parallel development of delivery systems.

Topic ID	Research topic	Justification
4d	Determine the optimal integration of lethal and fertility control using computer modelling.	Fertility control is unlikely to be an effective control tool by itself and therefore its integration with other control should be first assessed using computer models.
4e	Assess public acceptance of fertility control.	Fertility control is likely to be integrated with lethal control, and public acceptance of such use should be assessed.

5.5 Farm and forestry crop and site practices

The management of forest nursery tree stock in Australia to reduce or avert damage from browsing native mammals following planting out has been systematically investigated in both Tasmania (most recently by C. McArthur, colleagues and students at the University of Tasmania) and in Victoria (summarised by Parkes et al. 1993), with two key research areas being tree breeding and seedling fertiliser levels. This section summarises the research underpinning management of browsing mammals in Australia using crop and sites practices, and takes into account international literature only in so far as it is reviewed in Australian scientific papers and relevant to this work.

The ability of Tasmanian tree farmers to reduce the palatability to browsing mammals of seedlings grown for plantation forests is based on an understanding of the dietary preferences and foraging patterns of the three key native browsing species, and variability in the natural plant defences against browsing mammals. Recent studies have shown that possums and pademelons have distinctly different preferences for the foliage of some seedlings (McArthur & Turner 1997), with possums preferring *E. nitens* and *E. globulus* (especially nursery-grown stock; C. McArthur: presentation at the browsing animal workshop, Tasmania, 2001), while pademelons prefer *A. melanoxylon* over *P. radiata*, *E. globulus,* and *E. nitens* (C. McArthur pers. comm.). Intraspecific palatability also exists, at least for the foliage of some mature trees, with both possums and pademelons showing preferences for the foliage of some populations of *E. globulus* over other conspecific provenances (O'Reilly-Wapstra et al. 2002).

Such documented preferences have encouraged the search for seedlings from less palatable provenances of timber species for use as nursery stock, and for the manipulation of nursery conditions likely to produce seedlings less palatable to browsing mammals following planting. Clearly, the phenotypes of some seedlings, e.g. *E. globulus*, are less palatable than other phenotypes of the same species (C. McArthur, presentation at the browsing animal workshop, Tasmania, 2001), and possess sufficient levels of antifeedant chemicals to trigger aversive behaviour in mammals browsing their foliage. Similar results have been shown by PFT at its Cressy plantings, with strong differences in the palatability to possums of seedling eucalypt hybrids demonstrated (A. Lyons pers. comm.). This variation in seedling chemistry reflects that apparently present in the juvenile foliage in coppiced trees (O'Reilly-Wapstra et al. 2002). Unfortunately, the levels of antifeedants in seedlings, and hence their risk of being browsed, vary in a normally distributed manner in all open-pollinated tree stock (W. Foley pers. comm.), making the foliage of some seedlings grown from seed collected under identical conditions more palatable than others. While there are some provenances of timber species that all browsing mammals avoid, the relative acceptance of most provenances of key timber species by most browsing species is largely undetermined (W. Foley pers. comm.). The selection of seedling clones with high levels of defensive chemicals may come at some cost, but is worthy of further investigation. It is likely to involve trade-offs against other sought-after seedling characteristics, such as growth rates or tree form, although the evidence for such interactions is not yet available (W. Foley pers. comm.).

Genetic modification of tree seedlings is still limited to a few forest species and genotypes, and while genetically transformed lines have been created for *Pinus* and *Eucalyptus* spp., the traits selected for modification do not include resistance to browsing mammals (FAO 2006) and are thereafter not discussed further.

The level of fertiliser used on nursery seedling stock has been investigated for its ability to overcome browse damage, with additional fertiliser used to 'load seedlings with nutrients' in order to improve establishment and growth rates following planting and shorten the time taken by seedlings to escape browse height (Arulchelvum & Parkes 1994; Close et al. 2002). However, such enhanced growth may also come at a cost – heavily fertilised *E. nitens* seedlings are considerably more susceptible to, and more severely affected by, browsing mammals following planting out than those fertilised at normal rates (J. O'Reilly-Wapstra pers. comm.). Equally importantly, additional fertiliser may so increase plant palatability that the protection derived from selected resistance to browsing, present in some cultivars, is negated (O'Reilly-Wapstra et al. 2005).

In contrast, reducing fertiliser levels to harden up seedlings before planting has long been thought to limit browsing damage (Coleman et al. 1996), although the belief is apparently not supported by robust data. Current studies of the manipulation of seedling stock are showing some promise, however, including the frequent bending of seedlings to increase lignin levels and so reduce palatability. Tactics such as provenance selection or additional fertiliser applications to seedlings are argued to provide adequate protection for plantings at sites where the risk of damage is low (A. Walsh pers. comm.), but past and recent field trials on these topics provide ambiguous directions for management (e.g. Parkes et al. 1993).

Similar nursery silvicultural investigations were undertaken in the 1990s to lower browsing damage in Victorian forests (Parkes et al. 1993). They included trials into the breeding of less palatable provenances, altering fertiliser regimes (and hence the palatability of seedlings), selecting seedlings of less preferred age and size cohorts, and altering the time of planting. Results of this review indicated that despite the influence of confounding factors in many of the trials tree breeding poses some problems for tree growth rates and pulping characteristics, that trials using additional fertiliser for seedlings produced contradictory results, that seedlings planted out at an older age were generally less palatable, and that seedlings planted in autumn were at considerably more risk to browsing mammals than those planted in mid- to late winter. Clearly, the use of such strategies should be influenced by levels of anticipated browse risk at specific planting sites, with management tactics selected accordingly (A. Walsh unpubl. report). Research into the costs and benefits of selecting seedlings with specific growth characteristics and palatability for sites with predicted levels of medium-to-low animal browsing should be given high priority.

Endophytic fungi produce toxic metabolites that deter browsing by mammals on the foliage of host plants. The role of endophytic fungi causing aversive feeding behaviour is an area of new research being investigated for Australian tree species (W. Foley pers. comm.). Similar areas of research are providing exciting advances in the protection of grasses from chewing insects and grazing birds (Pennell & Rolston 2003) and providing answers to the patchiness of browse by possums in native New Zealand *Metrosideros* tree species and their limited browse in *Leptospermum* tree species (Johnston & Fletcher 1998). Both *Metrosideros* and *Leptospermum* are members of the Myrtaceae, along with *Eucalpytus* spp., indicating the aversion seen in possums towards some individuals of these two New Zealand tree genera may also occur in some Tasmanian tree species. The role of endophytes in limiting the browsing of mammals in plantation forestry requires long-term fundamental research into the fungal species involved, the range of their host trees used in the timber industry, and the effect of local soil types on the presence of fungi.

Farmers growing highly palatable pasture species and high-value agricultural crops face problems similar to the silvicultural problems of tree growers. The selection of crops and crop sites may involve serious opportunity costs, with individual farmers choosing to plant crops of lower value at high risk sites and thus more likely to survive through to harvesting. We are unaware of any research undertaken that evaluates the palatability to native browsing mammals (as distinct from that of livestock) of provenances of pasture grasses and legumes grown in Tasmania, or that ranks the browsing risk of locally grown fodder crops, vegetable seed crops, cereal crops, or flower crops.

Management and selection of planting sites

The relationship between the management of seedlings in plantation or natural forest regeneration sites, physical site characteristics, and browsing damage by native mammals in both eucalypt and *P. radiata* forests has been the subject of considerable research in Australia. Early research focused on the positive relationship between significant levels of browsing damage and the intensity of burning in native forest regeneration sites in Tasmania (e.g. Gilbert 1961; Cremer & Mount 1965; Cremer 1969), and in Victoria (summarised in Parkes et al. 1993). Later studies in both states focused more on plantation forests (e.g. Bulinski & McArthur 2000, 2003) and have examined characteristics such as slope, aspect, and local rainfall that affect seedling growth rates and hence the rate at which seedlings grow beyond the browse tier (Arulchelvum & Parkes 1994).

Native forest regeneration requires different management processes to that followed in plantation forests (Muirhead 2004). In the former, management to reduce the risk of unacceptable browsing damage is based around increasing aerial seeding rates near natural cover, the reduction of 'slash', development of favourable (suitably tilled) seedbeds, establishing perimeter fire breaks and internal roading to allow access for staff applying the various lethal control options, and regular monitoring to allow for damage control before it reaches unacceptable levels (A. Walsh unpubl. notes).

For plantation forests and especially where landscape features favour high populations of browsing mammals and significant browsing is predicted, control programmes to reduce numbers of browsing mammals are normally undertaken before the crop is planted (FIAT pers. comm.). Such actions are usually done routinely and are not based on modelling studies of site characteristics, despite one such study which accounted for 47% of subsequent browse damage (Bulinski & McArthur 2003). Alternatively, altering crop planting times to avoid periods of intense browsing or increasing stocking rates to overcome anticipated seedling losses are options, but are likely to come at an additional cost (A. Walsh unpubl. notes).

Crops grown as ground cover between windrows (e.g. bitter lupins *Lupinus albus*; Pietrzykowski et al. 2002) and natural regeneration on planted sites (e.g. bracken *Pteridium esculentum*, J. O'Reilly-Wapstra, unpubl. CRC notes; or other unpalatable weeds, Miller et al. 2006a,b) provide some protection from browsing for seedlings. Seedlings growing amongst these species are less obvious to browsing mammals. In addition, bitter lupins and bracken provide an apparently unpalatable patch for animals to feed in and are therefore avoided (Bulinski & McArthur 2003). Both wallabies and pademelons select open habitats within their home range (e.g. young plantations and grassland) to use as nocturnal feeding sites while avoiding closed habitats (native forest and mid-aged plantations; Le Mar & McArthur 2005). The relative quality, density and height of vegetation surrounding seedlings may be manipulated to reduce browsing damage, through its affect on the visibility and availability of seedlings to browsers, although the cost – including that of competition between seedlings and surrounding vegetation – and benefits of such site manipulation are largely unknown (A. Miller pers. comm.). A clearer understanding of the significance of cover crops and natural regeneration on seedling survival, and the integration of cover vegetation with other techniques of reducing browse damage, is warranted.

One extension of this form of management is the growing of highly palatable diversionary or decoy crops at the edge of high-value crops (Burton 2004). A range of such crops has been suggested as suitable for planting in annuli about at-risk crops including brassicas, cereals and grasses. However, seed and planting costs are high and while the strategy has been developed for both natural regeneration and plantation forests, it has yet to be evaluated. Alternatively, recent trials have evaluated the use of diversionary dumps of artificial feed about the periphery of planted coupes, as a means of diverting browsing mammals away from seedlings and towards sites where they are more easily shot (A. Walsh pers. comm.). However, even when local browsing mammals were extensively fed with mixed meal, at a cost of $89/ha, they continued to browse nearby seedlings at unacceptably high levels.

The effect of the size and shape of forest coupes on browsing damage has been reviewed (J. O'Reilly-Wapstra unpubl. CRC notes; Le Mar & McArthur 2002). Overall, forest coupes with large area-to-perimeter ratios suffer lower overall browsing damage compared with coupes with smaller area-to-perimeter ratios. Further, large coupes with only a small portion of their entire edge adjacent to existing forest incur lower damage than similar-sized coupes largely surrounded by intact forest (Bulinski & McArthur 2003). Such edge-effects primarily, but not solely, reflect the nearness of the entire crop to adjacent forest, with browse damage levels in Tasmanian forests positively correlated with distance to forest edge in some but not all coupes. Similar studies in Victoria indicated seedlings >150 m from forest edges were unlikely to be browsed to a serious extent (Arulchelvum & Parkes 1994). These data provide some evidence that herbivores browse seedlings close to the forest margin in preference to those deep within coupes, and that control on coupe margins will be effective in many but not all situations (Bulinski & McArthur 2000).

Windrows of slash from past tree crops or the presence of riparian strips within coupes provide good shelter for browsing mammals. Where such cover occurs, browse on seedlings is more widespread within the coupes, and the effect of shooting on browser populations is reduced (Bulinski & McArthur 2003; While & McArthur 2005). Both windrows and riparian strips should be avoided wherever possible when planning planting operations, while recognising the need to leave patches of native vegetation within coupes to provide a seed source and for biodiversity and aesthetic reasons.

Overall, browse patterns in forest coupes reflect the abundance of palatable on-site vegetation such as grasses and forbs that are preferred by browsing mammals (Sprent & McArthur 2002), with 56–91% of the biomass of these plants removed by them from one young plantation (Le Mar & McArthur 2002). Browse patterns also reflect species' foraging patterns and their scat distribution patterns from forest margins (While & McArthur 2005) (distances are least for possums – the least mobile of the three browsing species, intermediate for pademelons, and greatest for wallabies (Statham 1983; Coleman et al. 1996)). In addition, browse patterns reflect previous control operations against browsing mammals, with scat densities alongside areas of browse and grass cover after control revealing surviving numbers of possums but overestimating numbers of wallabies or pademelons (Bulinski 2000). A common perception is that most of the damage in plantations is by pademelons. However, studies indicate that possums are capable of consuming considerably more eucalypt foliage than pademelons and that possum damage may have been underrated in the past (J. O'Reilly-Wapstra pers. comm.). This work is to be complemented by a proposed student study planned within the Forestry CRC on the interactions between browsing mammals and eucalypts, on spatial feeding patterns across coupes and their prediction, and on the use of repellents to deter feeding animals. Overall, the complexity of these relationships reflected the often non-linear relationship between macropod abundance and damage to seedlings (Le Mar & McArthur 2002), and support the need expressed by J. O'Reilly-Wapstra for more risk modelling to predict site characteristics likely to influence future browse levels and crop losses.

Arulchelvum and Parkes (1994) reviewed the biological and physical characteristics of planting sites likely to affect the level of browsing damage by native mammals within forest coupes in Victoria, and subsequent silvicultural practices. The key factors screened as potential indicators of future browse included the presence of browser sign (faecal pellets), the treatment of slash on the site, the nature of the vegetation prior to planting, drainage, distance to forest edge, and slope. Of these, low risk of browsing was associated with little or no animal sign, low site slopes, limited vegetation cover on and adjacent to the coupe, and poor drainage. Site preparation, including the manipulation of natural cover and weed regrowth, was also investigated but no conclusive data were obtained on any of the techniques used – apparently because operational objectives invariably held sway over ecological research.

The deficit in robust research into what drives high levels of browsing damage is also a feature of Tasmanian forestry (Muirhead 2004). Without more site-based (e.g. coupe shape, aspect, and on- and off-site vegetation) ecological research into the factors driving unacceptable browsing levels, the industry will continue to rely on lethal control or exclusion techniques to get its crops through to harvesting.

The management of browsing damage on agricultural lands is driven by the nearness of farmland to native bush and forest, and by the diet and foraging patterns of browsing animals. Pademelons typically feed close to cover and, in so doing, create a distinctive grazing line on pasture or crops. In contrast, wallabies tend to wander while feeding and travel much further out into fields (Statham & Raynor 1998). To date, all attempts to control browsing mammals on established pasture have taken the form of lethal or physical exclusion techniques, and have largely ignored any approaches equivalent to the silvicultural techniques used in the forestry industry and outlined above. Thus, lethal or exclusion techniques appear likely to remain the mainstay of farming in areas with high numbers of browsing mammals. However, the emphasis placed on the management of such browsers needs to be based on robust estimates both of their numbers and on crop loss at the farm enterprise level. These data are largely unavailable, although pasture loss has been documented in unreplicated or poorly replicated unpublished field trials in Northern Tasmania (Donaghy & Tegg 2001, Statham 2000) and is currently being investigated as a Landcare-funded study on the Tasman Peninsula (D. Craw pers. comm.). The ability to manipulate the palatability of crops grown for forage for livestock away from that preferred by native browsers, or to manage the high opportunity costs of relocating fodder crops or cash crops to areas less susceptible to browsing mammals, is likely to be insurmountable in the short term. Studies on crop losses for all common agricultural crops and robust estimates of browsing animal numbers and trends are required before decisions can be made on how best to manage the problem.

Practicality

The nursery- and field-based silvicultural techniques and tactics offering greatest immediate benefit for controlling browsing damage to forest seedlings are those already in practice or being trialled in Tasmania or Victoria. They include the addition or restriction of fertiliser to seedlings, the planting of older and hence larger seedlings, planting later into the cooler months (as early planting extends the period of slow seedling growth and the at-risk browse interval), the use of ground cover or diversionary crops, the clearance of within-coupe slash and debris, and, within the very real limits that exist for available land for forest planting, the careful selection of planting sites with regard to browsing animal habitat and animal numbers. The success of these approaches, when used in the absence of lethal or exclusion techniques against browsers, relies on the successful prediction of the level of browsing risk at planting sites, and such approaches are generally thought to be of limited use at high-risk sites. Current studies of the selection of seedling clones with low palatability to browsing mammals or with increased lignin levels offer hope for improved seedling protection in the medium term, while the use of endophytic fungi to protect seedlings requires long-term investigation. None of these approaches exist for farmers, who appear likely to have to rely in the immediate or medium-term future on good prediction of animal numbers and trends, coupled with the use of exclusion or lethal control tools to protect their crops.

Cost-effectiveness

The true costs and benefits of using any of the above tactics to limit browsing damage are largely unknown, or at least do not appear to have been documented, and this should be rectified. Although the value of lost plantings is readily calculated from final stocking rates and wood quality (Griffith 1985), the reasons for seedling losses are often unclear. Equally importantly, the effectiveness of such silvicultural tactics needs to be related to browsing animal species, numbers, and trends, and such data are not available.

Non-target problems and social acceptance

All of the approaches outlined above seek to reduce if not eliminate browsing damage of seedling tree crops without the lethal control of browser populations, and thus serious non-target issues appear unlikely to arise. Limiting browsing mammals from feeding on nutritious crops should progressively see their numbers reduced in adjacent natural habitats.

Integration of techniques

The available crop management tactics are likely to work only where the numbers of browsing mammals are low. Elsewhere, their effectiveness is likely to be overwhelmed, unless integrated with exclusion or lethal control tools.

Legislation

No legislative requirements exist that limit any of the silvicultural tactics listed above being used or developed, provided they do not involve the importation of exotic species.

Stakeholder support

We are unaware of any resistance by any stakeholder interviewed to any of the techniques or tactics listed above. The animal welfare groupings (AACT, RSPCA and WLPA) have concerns over the fate of browsing native mammals excluded from artificial food sources, but agree there may be a need in the short term to reduce their populations to match the resources within adjacent natural habitats.

Summary and research gaps (see Table 5)

Provenance selection and silvicultural practices in the nursery and in newly established plantings have been researched for production forestry and continue to be so. However, benefits from this work have been variable. In contrast, agriculture has seen little equivalent research related to crop management and selection of browse-resistant crops. The conflict between growing crops for grazing stock and the use of them by native browsing mammals means there are fewer opportunities for research to provide solutions here.

Table 5 Gaps in research into farm and forestry crop and site practices (relating primarily to forestry; not ranked).

Topic ID	Research topic	Justification
5a	Determine the pest densities that various provenances can withstand in order to optimally integrate silvicultural practices with browser management.	Current research indicates that maximum benefits of planting 'browse resistant' provenances are obtained when integrated with alternative techniques.
5b	Develop improved models for determining the impact of size and shape of coupes, and the role habitat availability (e.g. riparian strips) has on browse risk.	Improved risk assessment based on an understanding of the effect that physical and habitat parameters have on browse pressure needs to be developed.
5c	Determine if endophytes have any potential for limiting browse on seedlings.	Endophytes provide a 'blue-sky' research opportunity that may reveal a totally new and 'clean' method of managing browsing impacts.
5d	Assess the costs and benefits of using cover crops and natural regeneration to reduce browser impacts, and how both can best be integrated with alternative options.	Cover crops and browse-resistant regeneration can be used in integrated programmes to better manage browsing species.
5e	Determine the relative palatability to native browsing mammals, as distinct from livestock, for provenances of pasture grasses and legumes, in relation to browser density.	Palatability rankings of livestock forage may provide farmers with the opportunity to manipulate grazing, and reduce damage by browsing mammals.
5f	Determine the cost-effectiveness of farm and forestry practices.	Before further farm and forestry practices are promoted, their costs relevant to other control techniques should be assessed.

5.6 Alternative toxins

Current use

Compound 1080 (sodium monofluoroacetate) is the only vertebrate pesticide currently registered for use against wallabies, pademelons and possums in Tasmania. It is also used locally against rabbits and, following their recent establishment, against foxes. Compound 1080 is one of the most toxic vertebrate pesticides known, and its direct effects on non-target species and risks of secondary poisoning are well documented (Eason et al. 1994). Although the use of 1080 in New Zealand to kill possums (Haydock & Eason 2001) and also wallabies (Warburton 1990) is well established, its use in Tasmania is currently minimal (7–8 kg/annum) by comparison and falling (G. Hocking, notes from Launceston workshop on alternatives to 1080). Such decline, combined with falling public acceptability when used against browsing native mammals, its recent ban from use on state land, and ongoing browsing damage in forests and farmland requires the development of replacement technologies.

Several other vertebrate pesticides are also used in Tasmania. They include pindone and phostoxin, both registered for use against rabbits, and alpha-chloralose, registered for use against birds (Parkes 2003).

The notes below summarise alternative toxins and toxin delivery systems worthy of consideration for use against browsing mammals in Tasmania. It should be noted, however, that none of the compounds listed below meet all the environmental and animal welfare attributes of an ideal mammalian pesticide, namely target specificity, low to zero environmental contamination, and a humane death.

Alternatives to 1080

Vertebrate pesticides have been used worldwide for several centuries. In the USA, toxicant pesticides (as distinct from chemicals used as fumigants, repellents or narcotics) now registered by the Environmental Protection Agency (EPA) for use against vertebrates, other than commensal rodents, include: zinc phosphide, cholecalciferol, strychnine, and warfarin for controlling field rodents; cyanide and 1080 for use against predators; and DRC-1339 for use against birds (Jacobs 2002). The characteristics and use of zinc phosphide, cholecalciferol, warfarin, and cyanide are discussed below.

The use of strychnine to prevent damage to forest seedlings by largely subterranean pocket gophers (*Spermophilus* spp.) in the USA is of relevance to this review. Strychnine has a long history as a rodenticide going back to the 16th century, but its long persistence in baits and poisoned carcasses, its toxic action manifested as violent seizures and muscular spasms in poisoned animals, and its risk to staff using it has led to its banning in many countries (Haydock & Eason 2001). Strychnine is used against house mice in mainland Australia, but despite such use, its mode of action in consumers and its fate in the environment make it very unlikely to be acceptable for use in Tasmania. It is not discussed further.

The use of alternative pesticides to 1080 in mainland Australia against mammals, other than rodents, has been quite limited, as 1080 has been recognised there as sufficiently efficient and cost-effective for the management of several major vertebrate pest species to largely rule out the use of alternative pesticides. Pindone has been adopted by most states for rabbit control and warfarin for feral pig (*Sus scrofa*) control (Coman 1994), although the quantities used of both remains very small (3.6 kg and 1.3 kg of pindone and warfarin respectively in 2002/03; Parkes 2003). In addition, 1.5 kg of alpha-chloralose was used for bird control. The characteristics of alpha-chloralose are also discussed below.

New Zealand, with a unique array of vertebrate pests, including possums and wallabies, has long sought to control them. To do so, it uses a variety of pesticides including 1080 (Eason & Henderson 1991; Eason & Jolly 1992). Pesticides currently registered for use against pest mammals other than rodents in a variety of baiting strategies include cyanide, cholecalciferol, brodifacoum, bromadiolone, diphacinone, pindone, warfarin, and phosphorus. *Most of these compounds are supported by a large* *international literature base and are complemented by both New Zealand-based research and international research linkages, particularly with the Central Science Laboratory in Britain and the National Wildlife Research Center in the USA.* Further new materials and methods of delivery are under development. Bromadiolone and diphacinone are used primarily against rodents, and only rarely against larger mammals, and, as internationally they are regarded primarily as rodenticides and have not been trialled against wallabies or possums, they are not considered further. A summary of the pesticides used in Australia and New Zealand, ranked according to their perceived suitability for use in Tasmania, the method of their application, humaneness (based largely on perceptions rather than scientific evaluations; see Mason & Litten 2003), environmental fate, effects on non-target species, and risks of secondary poisoning are presented below and summarised in Table 6. All of these pesticides pose some risk to non-target species wherever they are used, although a range of techniques have been developed for their delivery to encourage their consumption only by the animals targeted. However, if all vertebrate pesticides suitable for use against browsing mammals are unacceptable in Tasmania, i.e. are seen as effectively equivalent to 1080 products, then none of them will be acceptable as replacements to 1080 in the present situation.

Cyanide

Sodium and potassium cyanide are highly acute, broad-spectrum toxins suitable for the control of both birds and mammals. Cyanide kills within minutes through the suppression of cellular respiration, and has been judged to be a relatively humane pesticide (Mason & Litten 2003). As a paste comprising a 60:40 mix of cyanide and petrolatum, it has been used extensively and effectively in New Zealand since the 1950s by licensed operators for both controlling possum populations and for harvesting them. Baiting typically comprises placing on the ground exposed pea-sized baits lured with a mix of flour and fruit essence. Although the susceptibility of macropods to cyanide is largely unknown, it has been used successfully to control brushtail rock wallabies (*Petrogale penicillata penicillata*) on Motutapu Island near Auckland and unsuccessfully in one trial against Bennett's wallabies in the central south island of New Zealand (Morriss et al. 2000a). Its overall effectiveness in paste baits is limited by its rapid breakdown when wet and by the emission of hydrogen cyanide gas (HCN). Cyanide paste has low persistence in the environment and is very unlikely to lead to secondary poisoning. HCN emissions also result in bait shyness (primary aversion) in frequently targeted species and ultimately to reduced kills (Warburton & Drew 1994). HCN is also produced naturally by some eucalypt species and, as such, may affect the acceptance or rejection of foliage by browsing species in Australia (Haydock & Eason 2001).

A new cyanide formulation has recently been developed which eliminates emissions of HCN and the bait shyness that often follows. Feratox®[1] is an encapsulated cyanide bait product sold either separately, pre-packaged in a peanut butter block in a waxed paper bag at a cost of c. 37 cents per bag, or in a variety of alternative presentations (for further information, see http://connovation.co.nz). Feratox® is now widely used against possums by approved operators in New Zealand, and is both highly portable and highly effective. The baits are typically stapled to trees or fence posts near possum 'sign', c.1–2 m above ground level and above at-risk ground-based animals. Normal application rates are c. 30 baits/ha. Feratox® baits remain toxic for 2–3 months under all conditions, without posing any additional environmental concerns, and possess similar animal welfare and secondary poisoning characteristics as cyanide paste. However, where non-target animals are present and a concern, risks to them can be reduced by clearing bait from lines or stations immediately after each control operation. Feratox® baits have been trialled successfully against penned tammar wallabies, indicating this product has potential for use against some species of macropods (Morriss et al. 2000a). In a small pilot trial using larger than normal Feratox® pellets, wallabies were also killed (B. Warburton unpubl. data).

---

[1] Landcare Research participated in the development and field trialling of Feratox®, but no longer has any financial interest in the product or in the company that manufactures and markets it.

Cholecalciferol

Cholecalciferol (vitamin D3) is a sub-acute pesticide. It acts by metabolising calcium in the bloodstream and redepositing it in vessels near the heart, leading in possums (a susceptible animal; Eason & Henderson 1991) to cardiac failure 2–6 days after ingestion (Haydock & Eason 2001). Prior to death, consumers show a loss of appetite and some distress, indicating it is relatively inhumane (Mason & Litten 2003). Cholecalciferol is available in several bait formulations, including cereal baits and a long-life gel, and is sold under the trade names Campaign® and Feracol®, both of which are available for application by the general public in New Zealand. Both products are relatively high cost (bagged bait costs c. 82 cents each), and are used for follow-up operations after the use of other control tools. Feracol® has recently been tested against tammar wallabies in a pen trial and the results indicate a low acceptability by this species for this bait (Morriss & O'Connor 2001). Cholecalciferol is leached from baits into the soil, where it is not considered a significant hazard (Haydock & Eason 2001). It is also considered to pose a low risk of primary poisoning to species other than possums, and particularly to birds, and poses a very low risk of secondary poisoning to all species.

Pindone

Pindone is a first-generation indandione anticoagulant toxin. It acts by interfering with normal clotting factors in the liver, and consumers receiving a lethal dose suffer distress, haemorrhages, and/or pain over the several days it takes them to die (Mason & Litten 2003). Pindone is used in Australia and New Zealand primarily against rabbits (which are highly susceptible), and only rarely against other medium-to-large mammals, and users in New Zealand do not need to be licensed. It has been proven to be of limited effectiveness against possums and wallabies, but is perceived to be effective against tammar wallabies and is currently used to control them near Rotorua in New Zealand (Morriss et al. 2000a). However, if used in the presence of possums when only wallabies are targeted, it is likely to be very expensive as both species will feed on the bait material and all consumers require 1–2 kg of toxic pellets to die. Pindone is slowly degraded in soil and water (G. Wright pers. comm.), and may pose a threat of secondary poisoning to scavenging animals, especially raptors (Haydock & Eason 2001).

Warfarin

Like pindone, warfarin is a first-generation anticoagulant toxin developed for control of rodents. Also like pindone, it acts by interfering with normal blood-clotting factors, and depending on the dose consumed, may take animals many days to die (e.g. up to 31 days for pigs, Haydock & Eason 2001). Prior to death, animals haemorrhage, often become lame and show abdominal pain, and therefore warfarin is not considered a humane toxin (Mason & Litten 2003). Warfarin is used both in Australia and New Zealand for the control of feral pigs and rodents, but apparently not against any other mammals. While it has the potential to poison non-target species, it is rarely the cause of secondary poisoning. The rate of warfarin degradation from baits is undocumented but is likely to occur slowly by soil micro-organisms, and warfarin is an unlikely long-term soil contaminant (Haydock & Eason 2001).

Brodifacoum

In contrast to warfarin, brodifacoum is a potent second-generation anticoagulant. It is a slow-acting pesticide with death from a single dose taking several days from effects similar to those described for pindone above, and is therefore also considered to be relatively inhumane (Mason & Litten 2003). Brodifacoum, used in Australia for rodent control, is used widely by landowners and pest control operators for possum control in New Zealand, and do not need a licence to do so. In New Zealand, it is particularly effective against possums or rodents that have become shy to other toxins. It has also been trialled in cereal baits against penned wallabies in New Zealand, and the results indicated a promising cost-effective tool for New Zealand farmers (Coleman 1997). Brodifacoum is currently marketed as Talon® and Pestoff® in New Zealand and both products are highly toxic to most vertebrates as primary, secondary, or tertiary (i.e. second-order scavenging or predation) consumers. It is particularly long lasting in the environment – persisting in the liver in sub-lethally poisoned wildlife or livestock for greater than 24 months and often carried off-site by dispersing animals (Spurr et al.

2005). Brodifacoum should not therefore be used in delivery systems accessible to livestock or other non-target species or in areas from which wild game are harvested. An antidote is available, but it is very expensive. In response to concerns about the toxin's persistence, the Department of Conservation in New Zealand has recently developed a policy that aims to minimise the use of this poison on Crown land.

Phosphorus

Phosphorus is a very old pesticide first used in Australia and New Zealand for rabbit control in the 1920s. It is relatively slow acting, with consumers dying from progressive structural damage to their vital organs and gastric mucosa over 1–2 days. While historically phosphorus has been considered to be an inhumane pesticide, recent studies of the pathological response following ingestion indicate species-specific variation, and for possums the discomfort appears minimal (O'Connor et al. in press). Typically it is applied to exposed turf sods on the ground. In New Zealand, phosphorus paste is considered by pest managers to be very effective against tammar wallabies (D. Moore pers. comm., in Morriss et al. 2000a). Phosphorus is an unstable compound and, as such, appears unlikely to persist in the environment. It does, however, pose a significant risk to secondary consumers and, together with its apparent lack of humaneness, is not recommended for use in Tasmania as an alternative to 1080.

Zinc phosphide

Zinc phosphide is a pesticide used for rodent control throughout the world. It has recently been micro-encapsulated in New Zealand as a low-cost replacement for 1080, as it kills possums in 3–12 hours following a single oral dose in cereal bait (Wickstrom & Eason 1998), and is in the final stages of registration (R. Henderson, Pest-Tech, pers. comm.). Zinc phosphide does, however, cause severe pain for several hours before death (Mason & Litten 2003), and is thus considered to be inhumane, although current research is investigating ways of mitigating this effect (C. O'Connor pers. comm.). It appears likely that this product will also be effective in the control of tammar wallabies (Morriss et al. 2000a), although no such pen or field trials have yet been conducted. Zinc phosphide is used widely in the USA against many species of field rodents, where it is considered both safe and effective (Fagerstone 2002).

Table 6 Relative advantages and disadvantages of the vertebrate toxins discussed above for possum, pademelon, and wallaby control (adapted from Morriss et al. 2000a). Toxins are ranked in order of perceived suitability for use in Tasmania. Of these, only pindone is registered for use against browsing animals in Australia. Toxins 6 and 7 are not recommended for use in Tasmania. (? = no relevant data exist).

Toxin	Species	Relative susceptibility	Effectiveness	Humaneness	Non-target risks	Product available
1. Cyanide Feratox®	Possum	High	High	High	Low	Yes
	Pademelon	?	?	?	Low	Yes
	Wallaby	?	?	High	Low	Yes
2. Cholecaliferol	Possum	Very high	High	Low	Low	Yes
	Pademelon	?	?	?	Low	Yes
	Wallaby	?	?	Low	Low	Yes
3. Pindone	Possum	Low	Low	Low	Medium	Yes
	Pademelon	?	?	Low	Medium	Yes
	Wallaby	Medium	High	Low	Medium	Yes
4. Warfarin	Possum	?	?	Low	Low	Yes
	Pademelon	?	?	Low	Low	Yes
	Wallaby	?	?	Low	Low	Yes
5. Brodifacoum	Possum	High	High	Low	High	Yes
	Pademelon	?	?	?	?	Yes
	Wallaby	?	?	Low	High	Yes
6. Phosphorus	Possum	High	High	Low	High	Yes
	Pademelon	?	?	?	?	Yes
	Wallaby	High	?	Low	High	Yes

Toxin	Species	Relative susceptibility	Effectiveness	Humaneness	Non-target risks	Product available
7. Zinc phosphide	Possum	High	Yes	Low	?	No
	Pademelon	?	?	?	?	No
	Wallaby	?	?	Low	?	No

Delivery systems

Most commercial bait used around the World for ground-based control of vertebrates, other than for rodents or predators, is cereal-based. Such baits generally have a short field life, because, even when protected from direct rain, they are rapidly colonised by microbes, and their palatability declines sharply (Morgan & Hickling 2000). More recent developments in bait products in New Zealand include the encapsulation of pesticides to protect the active ingredient from moisture, and the inclusion of pesticides in long-life gels or waxed carriers, where they are at least as effective as pelleted formulations (Wickstrom et al. 1997). No new baits and bait products have been developed in the last decade for the control of browsing animals in Tasmania.

Bait stations (feeders) provide a means of targeting browsing mammals while providing protection to livestock, other at-risk native mammals, birds, and humans. For possums that climb readily, stations placed above the reach of ground-based animals and flightless birds provide more targeted control than ground-laid baits. Stations designed for elevated placement are available commercially in a variety of reusable forms, and provide weather-proof bait delivery systems for possums and some protection for non-target species. Many stations hold up to 1 kg of toxic bait, and provide for good control if sufficiently numerous, and refilled regularly. Examples of non-target native species or groups of species in Tasmania likely to climb to elevated bait stations include ringtail possums (*Pseudocheirus peregrinus*), Eastern quolls (*Dasyurus viverrinus*), sugar gliders (*Petaurus breviceps*), small dasyurids and Australian rodents.

Newer bait stations equipped with lids that exclude small mammals and birds but are accessible to brushtail possums are now available for use at ground level. Ground-based bait stations have been trialled against tammar wallabies in New Zealand and Bennett's wallabies in Tasmania, and while both species will readily feed from them, they are easily displaced by the more aggressive possums or pademelons, providing an obvious impediment to their targeted control in the presence of both these other species (Williams 2001; Le Mar & McArthur 2001).

Foliage baiting using 1080 in a petrolatum base has been used in New Zealand to control white-tailed deer (*Odocoileus virginianus*; Challies 1984), goats (*Capra hircus*; Parkes 1983), Bennett's wallaby and tammar wallaby (Warburton 1990), and population reductions of >85% have been achieved for each species. The technique involves anointing foliage targeted by the browsing mammal with the toxic mixture using a 'mastic' gun, *and only animals that eat the baited foliage are likely to die.* While the technique has not been trialled to protect seedlings in plantation forestry in New Zealand, its suitability for use on large-leaved eucalypt seedlings in production forests in Tasmania seems likely. For the technique to be considered for use on State land, where 1080 is now banned, an alternative pesticide needs to be identified.

Trans-dermal pesticides have been investigated for the control of possums (Eason & Munday 1995), but few compounds have suitable dermal toxicity for this species, and all compounds investigated were less humane and likely to be more dangerous than orally ingested pesticides to field operators. No trans-dermal pesticides appear to provide real advantages over traditionally used pesticides.

Target-selective toxins

Vertebrate pesticides that are species-specific provide a solution to the overriding concern of the general lack of specificity of existing pesticides and the risk they pose to other wildlife. While there are no such products presently registered for wallabies, pademelons or possums, B. Hopkins of Landcare Research is currently working on a new pesticide for the control of rodents that targets cell receptors found only in rats (*Rattus* spp.), leading to their rapid death. Registration of the toxin is planned for 2007 in USA, Australia and New Zealand, following field trials in California. Similar receptors that may be targeted by this product are being sought in possums and stoats (*Mustela erminea*). This work is similar to that in progress by collaborative research between the Arthur Rylah Institute for Environmental Research, the Western Australia Department of Conservation and Land Management, and the Commonwealth Department of the Environment and Heritage (DEH) to develop humane, species-specific toxins and delivery mechanisms that target physiological and behavioural 'Achilles heels' in feral cats. Further, the Invasive Animals CRC is investigating compounds for similarly managing populations of feral pigs, feral dogs and foxes. Such work could be extended further to include both macropods identified in this review, and would offer a completely new tool for the control of browsing mammals that may meet the requirements of target-specificity and humaneness. While the outcome of Hopkins' and related studies will be evident in 1–2 years, its extension to include usable toxins against the species of interest in Tasmania may be up to a decade away and require long-term funding.

Narcotics

Only one narcotic, alpha-chloralose, is currently registered for use against overabundant wildlife in Australia, and it is used only for the control of bird pests (Parkes 2003). Alpha-chloralose acts as a depressant on the central nervous system, and causes a slowing of the heart and respiration, hypothermia, and finally death from respiratory failure (summarised in Spurr & Eason 1999). Because its ingestion typically results in sub-lethal poisoning, it is unsuitable for use in control operations against wallabies, pademelons or possums (although susceptible to it; Eason & Jolly 1992).

Practicality

The pesticides offering greatest prospect for widespread use in managing browsing mammals in Tasmania appear to be those trialled in New Zealand on the same, or similar, species. Of these, encapsulated cyanide products show the most promise, pindone and warfarin show little promise, while cholecalciferol, brodifacoum and phosphorus baits possess characteristics that make them highly unlikely to be accepted. Current studies of target-specific toxins offer new opportunities for control, but are not yet available. Regardless of the toxic product contemplated for use, delivery systems are required to ensure the risks to non-target species and environmental contamination are kept to acceptably low levels. The risk of these toxins to wildlife managers and to the general public will require the use of similar field protocols to those in existence for the application of 1080.

Cost-effectiveness

The costs of toxic baits, their application, and eventual site clearance following control is likely to be considerably less than that accruing from the use of any other current non-lethal control tools. By comparison, trapping and shooting require numerous visits to each control site, and labour costs are high (A. Walsh pers. comm.). The costs and true benefits of using pesticides other than 1080 to control browsing mammals are unclear, but should be elucidated. This is because no robust data appear to exist in Tasmania that summarise the full cost of recent 1080 operations, including that of operational planning, achieving local consents, the inconvenience to the public of their exclusion from areas under control, and likely public antipathy, or of the population reductions achieved. Additionally no data are available on the benefits gained from using toxins.

All of the pesticides discussed above appear likely to provide effective and immediate short-term reductions in populations of wallabies, pademelons, and possums, and are thus suitable for the protection of newly planted forestry compartments or most high-value horticultural crops provided they are used following 'best practice' guidelines. However, the protection of pasture poses a different problem, often requiring long-term management (Statham 2000), and the costs and benefits of such persistent use of poisons has not been assessed. Additionally, persistent use of poisons can lead to behavioural problems such as bait shyness in sub-lethally poisoned animals (Morgan et al. 2002). A more likely option for reduction of damage on grazing land, as practiced regularly in New Zealand and parts of Australia, including Tasmania, is the integration of toxic control (to provide an instant population knockdown) with non-lethal exclusion techniques to provide long-term control. The latter options are discussed above (Sections 5.1–5.5).

Non-target problems

Problems of non-target poisoning exist wherever pesticides are used in field situations, and, depending on the toxin used, may involve primary, secondary, and occasionally tertiary effects. Tasmania, with its largely intact suite of native mammals, poses different problems when using pesticides to control wildlife compared with the problems encountered with introduced pest species in New Zealand and parts of mainland Australia. The key issue is one of target specificity, and this can only be overcome by either using pesticides in baits that are target-specific, or delivery systems that ensure only target animals are exposed to the bait used, or by demonstrating that non-target kills are of no population consequence or outweighed by the benefits of control. As no target-specific pesticides suitable for use in Tasmania are currently available, the testing and, if needed, further development of existing baits and bait delivery systems or the development of new delivery systems seem to provide the best way forward if toxic control is planned.

Social acceptance

The acceptance of alternative vertebrate pesticides by Tasmanian citizens is unclear, based on their recent response to the use of 1080. Telephone surveys of local public opinion on 1080 were conducted by Enterprise Marketing and Research Services in 2002 and 2004 and produced conflicting results. The first survey (Law 2005) asked respondents ‘whether 1080 should continue to be used to control wildlife’, and received 67% disapproval; the second asked respondents ‘what policy changes they wanted to see in forest management’, and 4% stated they wanted a ban on 1080. A rigorous survey of public opinion on the use of alternative pesticides is therefore warranted. This is because the management of browsing mammals through the use of pesticides has impacts on both the species involved and on the public. Where wallabies, pademelons, and possums are targeted and destroyed, their local populations are reduced, at least temporarily. However, as all three species are considered common in Tasmania, such outcomes appear to pose little if any long-term threat to the conservation of these species. For possums, any vacuum effect created by the reduction of the population is confined initially to small range adjustments by individuals with ranges overlapping the area of reduced density (Efford et al. 2000) and to subsequent infilling via dispersal of young animals (Cowan & Clout 2000). Similar movements are presumed to occur in both pademelons and wallabies (Le Mar & McArthur 2001).

Integration of techniques

Toxic baiting as used in Tasmania (where data are limited), elsewhere in Australia, and in New Zealand usually achieves a high and very rapid knockdown of target populations (e.g. Morgan & Hickling 2000; Le Mar & McArthur 2001), regardless of whether it is used alone or integrated with another control technique. The use of most of the above pesticides in well-planned operations in Tasmania is likely to be equally successful. Toxins can be integrated with other control tools such that the toxins are used initially to achieve a rapid reduction in population numbers, and then followed by potential alternative methods such as shooting (encouraged by DPIW), fertility control, repellents or trapping.

Legislation

No vertebrate pesticide other than 1080 (and phostoxin and pindone for rabbits) is currently registered for use against browsing mammals in Tasmania. Before any new pesticide is considered for field use other than in approved field trials, its registration will be required. The ease with which product registration is obtained is unclear.

Stakeholder support

On the basis of meetings held in Tasmania in May 2006, the use of alternative pesticides to 1080 currently receives mixed support from major stakeholder groups. Both farmer (TFGA) and forestry interests (FIAT) expressed support for the consideration of alternative toxins, but expressed reservations about the likelihood of community support for these products. Conversely, animal welfare groups (AACT, RSPCA and WLPA) and NRM representatives oppose the introduction of alternative pesticides, while DPIW appears to adopt a neutral position. Before any time or funds are allocated to seeking new toxins and/or registration, clear stakeholder support needs to be gained for such an option.

Monitoring

For all the pesticides outlined above, standard laboratory protocols exist for monitoring residues in bait material, soil, water and animal tissues.

Summary and research gaps (see Table 7)

Potential alternative toxins to 1080 are available but none meet all of the main attributes of an ideal mammalian pesticide, namely target specificity, low-to-zero environmental contamination, and a humane death. Nevertheless, some pesticides, especially those based on cyanide, seem close to satisfying these criteria, although there is a clear need to develop delivery systems for them that reduce the risk to non-target species.

Table 7 Gaps in research into alternative toxins (not ranked).

Topic ID	Research topic	Justification
7a	Evaluate public acceptance of alternative toxins.	Public opinion on alternative toxins is thought to be polarised and greater clarity is needed to underpin any development, testing, and use of alternative toxins.
7b	Determine the effectiveness of Feratox® for controlling pademelons and wallabies.	The effectiveness of Feratox® for controlling possums is well documented, but its effectiveness against pademelons and wallabies has not been established.
7c	Develop effective delivery systems for Feratox® that minimise risks to non-target species.	Feratox® satisfies the requirements for a humane and effective toxin, but its target specificity needs to be addressed.
7d	Develop target-specific toxins for use against all three browsing species.	Long-term research is needed to provide cost-effective and species-specific toxins, especially if non-lethal control options prove ineffective.
7e	Determine the effectiveness of foliage baiting for targeting critical individuals.	Targeting individuals doing the actual damage is likely to be more acceptable to the public than strategies that put local populations at risk. Such baiting now requires an alternative toxin to 1080. Such a delivery system could also have applications for fertility control.
7f	Determine the cost-effectiveness of alternative toxins.	Before alternative toxins can be promoted, their costs relevant to 1080 should be clarified.

5.7 Trapping and snaring

Current use

Live trapping with box or cage traps is commonly used in Tasmania to capture possums either for destruction or for harvesting (see Section 5.9), but is used infrequently to capture pademelons, and rarely if ever used to capture wallabies. Trapping possums is guided by the Tasmanian Animal Welfare Standard 2000 related to the capture, handling, transport, and slaughter of possums, which sets out minimum dimensions and construction material permissible for cage traps, as well as transport and slaughter requirements. Live-trapping pademelons is covered by a code of practice that is a legally enforceable condition of the permit under which trapping takes place.

The development and testing of the capture efficiency and animal welfare impacts of new and existing traps used for trapping wallabies, pademelons, and possums has been limited in Australia. Two existing large cage traps have been successfully modified for the capture of a range of small to medium-sized macropods, with modifications minimising injuries induced by capture and confinement (Kinnear et al. 1988; Pollock & Montague 1991). Two new 'box' traps have recently been developed and extensively trialled in Tasmania for the capture of both pademelons and possums, although there are no formal publications documenting the results of these trials. The 'Mersey' trap, which is constructed of wire mesh and flat iron, was recently approved for field use against pademelons and is now in production, while the 'Edwards' or 'Ivo' collapsible canvass trap with a metal frame is approved for trapping pademelons. The use of the 'Ivo' trap for capturing wallabies is being investigated.

The Tasmanian Animal Welfare Act 1993 prohibits the setting of leg-hold traps or snares without Ministerial exemption (given in recent years for the control of cats), but there are no apparent legislative restrictions on the use of kill traps provided they do not kill by strangulation. Currently there are no users of leg-hold traps in Tasmania. This is despite the fact that the technique, though often controversial, is commonly used to control pest vertebrates and harvest fur-bearing mammals in many countries. Snares offer few benefits over traps and require special skills to be used effectively. They are rarely used in the commercial harvesting or control of mammals in Tasmania or mainland Australia, or of possums in New Zealand.

Practicality

Restricting trap use to cage or box traps (and excluding leg-hold and kill traps) is likely to significantly limit the cost-effective contribution that trapping could play in the management of browsing mammals. The physical size and cost of cage traps pose practical limitations on the logistics of using these devices over large or remote areas, and even though such traps have a role to play at sites where vehicle access is easy, they will not by themselves generally provide a practical solution, especially for species such as wallabies that are reluctant to enter them (A. Walsh pers. comm.). Access for off-road vehicles used to ferry such cage traps into remote areas may need to be upgraded in some areas for more effective trapping.

The cage traps offering the greatest potential for widespread use in managing pademelons in Tasmania are the 'Mersey' and 'Ivo' models, because both traps are designed to meet all welfare issues likely to arise. Additionally, the 'Ivo' trap is collapsible and thus more portable than the non-collapsible 'Mersey' trap. However, the use in Tasmania of both models is likely to be compromised by both concerns of predation of live-trapped animals (Ivo trap only) and problems of trap theft.

In New Zealand tunnel nets are used by commercial trappers to capture wallabies for live export, and such net systems have the potential to provide cost-effective, humane alternatives to cage traps, especially for capturing wallabies (G. Guildford pers. comm.).

Cost-effectiveness

There have been no published studies in Australia and New Zealand that assess the relative cost-effectiveness of trapping for mitigating browsing problems, either in comparison with other techniques or in relation to the economic benefits of reducing populations of browsing animals.

One unpublished report (Walsh 2005) indicates that a significant reduction in seedling browse was achieved in a 15-ha coupe using 'Mersey' box traps. However, this trial was not replicated, and the presence and abundance of other browsing species was not recorded. Additionally, there were no costs provided nor any way of assessing whether the benefits from such a trapping effort were sufficiently sustained to protect seedlings through to when they are no longer at risk from browsing. However, the focus of this trial was to assess the welfare impacts of the trap, not the cost-effectiveness of its use.

The ‘Mersey’ box trap is large (c. 30 × 30 × 60 cm), weighs 8.5 kg, and is relatively expensive (c. $140), but appears to be well-designed and durable under field conditions. In contrast, the ‘Ivo’ trap comes in several sizes: all are less bulky than the ‘Mersey’ trap (can be folded up), with the ‘light weight’ model weighing c. 3 kg, and its cost likely to be c. $200. Both traps must be cleared daily, animals killed humanely and all possum carcasses burnt or buried (G. Hocking pers. comm.). The ‘Mersey’ box trap is argued to effectively reduce high-density pademelon populations to levels at which they no longer pose a browsing threat to newly established plantations (B. Knox pers. comm.) – the preferred strategy of use being c. 150 traps per 30-ha coupe, set for 4–5 consecutive nights, following a similar number of pre-feed nights. Such effectiveness is disputed by both farmer- and forestry-stakeholder groups (e.g. TFGA and FIAT), particularly when used in large, inaccessible areas, although both groups accept the merits of their use as the primary control tool in sites close to urban areas where shooting is not an option, or in areas of dense understorey. Finally, although no operational costings are available, the initial cost of such traps and the labour costs involved in setting them out in the field and checking them daily indicate higher costs per operation than that of other lethal control tools.

By comparison, leg-hold and kill traps are relatively light, cheap, and readily portable. For possums especially, kill traps offer a humane, cost-effective alternative to box traps.

Where nuisance animals are live-trapped, they can then either be killed humanely or translocated away from at-risk sites. However, the option of translocation of pest species such as wallabies, possums, and pademelons to established populations is generally not a sensible option, because the mortality rate of translocated animals due to predation or capture myopathy is likely to be high (Nielson 1988; Pietsch 1994; although this is based on data from mainland Australia, where predation of possums and small macropods by foxes was common). In addition, the cost of handling and translocating considerable numbers of animals is likely to be prohibitively high.

Social acceptance

The current use of cage traps and the approval of the ‘Mersey’ trap for use in Tasmania are based, in part, on meeting the Australian Animal Welfare Standard No. 12. The ‘Mersey’ trap achieves this by holding captured animals in conditions with low risk of injury until they are run into an external trapping ‘funnel’ and shot (or released, in the case of trapped non-target native animals).

Behaviours indicative of physiological stress and injuries resulting from capture were monitored in five pademelons captured in ‘Ivo’ traps (A. Walsh unpubl. report 2004). None of the five pademelons showed any evidence of physical injuries, and all showed a range of apparently no- or low-stress behaviours ranging from resting (25% of time), searching for a ‘way out’ (33% of time), grooming, or feeding. In addition, Walsh noted the potential risk from predation by Tasmanian devils that animals face when captured in ‘Ivo’ traps since they are held in a nylon bag that provides an ineffective physical barrier to predators (although never recorded by the trap designer (I. Edwards pers. comm.), and becoming increasingly unlikely with the advent of devil facial tumour disease). By comparison, the ‘Mersey’ trap provides good protection from predators. All acceptable traps for wallabies are now covered by a code of practice that must be followed as a condition of the permit to take protected wildlife (G. Hocking pers. comm.). Note, the welfare impact studies undertaken for the ‘Ivo’ trap would not satisfy the requirements of the National Animal Welfare Advisory Committee (New Zealand) guidelines for testing restraining traps, which require a minimum of 25 animals to be examined for assessing capture-related trauma.

In addition to physical injuries, captured animals can also suffer from physiological stress. This has been assessed for possums captured in cage and leg-hold traps (Warburton et al. 1999). Results showed that possums captured in leg-hold traps had significantly elevated levels of cortisol and after 8 hours of capture had elevated levels of serum enzymes such as creatine kinase that are indicative of muscle damage. In contrast, possums captured in cage traps had levels of these blood parameters not significantly different from non-captured control possums. Injuries caused by leg-hold traps to possums can be significantly reduced using padded traps such as the Victor Soft Catch (Warburton 1992).

The acceptability of kill traps in Tasmania is likely to depend on how target-specific these traps can be made. Modern kill traps for possums can kill very quickly (Warburton & O'Connor 2004) and therefore pose fewer welfare concerns for this species than do cage traps. However, their target-specificity would need to be determined and found to be acceptable before such traps could become widely accepted.

Various groups and associations in Tasmania have concerns about the humaneness of traps and snares. These groups include the AACT, RSPCA, TCT and WLPA. While the RSPCA accepts in principle the use of box traps but not leg-hold or kill traps (J. Williamson pers. comm.), it has some concerns that operators may clear traps unacceptably late the following day causing additional stress to captured animals. In contrast, representatives of AACT and WLPA argue that such trapping is unacceptable, wherever it is combined with the subsequent killing of captured animals (Y. Watt, B. Hickson pers. comm.). If kill traps are considered for use in Tasmania, a survey of their acceptability to the public should be undertaken.

Integration of techniques

There have been no studies of the integration of traps with other techniques for mitigating browse or grazing damage. However, because traps have specific characteristics that may offer potential benefits over other control options at certain times or sites, they should be considered for integration with either toxic or non-toxic methods. For example, in New Zealand, traps are often used in conjunction with poisons, either concurrently or sequentially, to maximise the probability of removing bait-shy possums and to avoid the development of trap or bait shyness that may arise from prolonged and repeated use of single control methods (Morgan et al. 2002).

Legislation

Section 12 of the Tasmanian Animal Welfare Act 1993 covers the use of leg-hold traps and snares, and prohibits the use of these devices unless Ministerial exemption is obtained. However, it does permit the use of box and cage traps. Although kill traps are not specifically mentioned in this Act, their use may be an offence under section 8(2)k and section 9. However, section 8 ('A person must not do any act, or omit to do any duty, which causes or is likely to cause unreasonable and unjustifiable pain or suffering to an animal') can be addressed with kill traps that are designed to kill rapidly and consistently. Several traps recently developed in New Zealand are designed to kill possums by carotid occlusion (leading to unconscious in c. 40 seconds) rather than strangulation (Warburton et al. 2000a).

The Tasmanian Nature Conservation Act 2002, section 29(2), allows the DPIW Secretary to issue a permit to take, including trap, possums, pademelons and wallabies on any specified land, including private land where the owner's permission has been obtained. Section 26 of this Act provides for regulations to be made, and the Tasmanian Wildlife Regulations 1999, Regulation 13, allows the Secretary to issue a permit to take, including trap, wildlife such as possums and wallabies to prevent the destruction of plants. Regulation 12 allows the Secretary to issue a permit to take wildlife where he/she is satisfied 'that it is necessary or desirable to do so'. Regulation 13 permits differ from Regulation 12 permits, in that they can also authorise the permit holder to have an agent do the taking on the permit holder's behalf (G. Hocking pers. comm.).

Live trapping of vertebrates using box or cage traps is permitted under the Nature Conservation Act 2002 and Wildlife Regulations 1999, provided it is undertaken using an approved trap and under an appropriate Crop Protection permit from DPIW.

Implementation

Traps are simple devices that require few skills in their use, apart from the selection of sites most likely to be visited by target animals. However, because species-specificity can be influenced by how the trap is set and baited, trappers must know how to maximise the capture of the target species and minimise the risk to non-target animals. In New Zealand, guidelines on how best to minimise any adverse effects on animal welfare and risks to non-targets species have been developed by the National Possum Control Agencies (NPCA 2006a,b,c), and similar information packages could be developed for trappers in Tasmania.

Traps, especially cage traps, but perhaps also padded leg-hold traps, possess two advantages over most other currently used tools for managing browsing mammals – they may be used in areas where other forms of lethal control are not possible, i.e. near human habitation, and non-target captures can be released unharmed.

Alternatives

Trap development and the testing of alternative traps have taken place in many countries outside Australia (e.g. North America; Proulx 1999). Leg-hold and kill traps are widely used to manage possums in New Zealand, cost c. $10–30/trap, and are very effective at achieving significant reductions in their numbers. The welfare performance of the traps used in New Zealand against several mammal pests has been assessed using testing protocols based on international standards (ISO 1999; Warburton 1995), and several kill traps and one leg-hold trap have been identified as acceptably humane. Further, a research programme at Landcare Research, New Zealand, has identified a range of new traps that have been developed to kill captured possums rapidly and consistently (Warburton et al. 2006). Such traps as the ‘Sentinel’, ‘Set-n-Forget’, ‘Holden Multikill’, ‘Possum Master’, and ‘Warrior’ all have potential for use in Tasmania.

The use of traps engineered to provide electric shocks to trapped possums has been investigated (Dix et al. 1994; Warburton & Coleman 1994), and a commercial trap (‘Zaptrap’) is now available (cost c. $490) that immobilises the animal, kills it quickly via cardiac arrest, ejects it, and resets itself. It is considered relatively humane (Mason & Litten 2003).

A net-based trap (‘Ecotrap’) recently developed in Australia (http://www.ecotrap.com/) might provide an alternative to rigid cage traps, but there are no reports available on its capture efficiency or welfare impacts. At a cost of c. $350, it is also expensive compared with all other commonly available traps for small mammals.

A low-cost alternative for trapping wallabies and, perhaps, pademelons that causes few or minimal injuries is the tunnel net (cost c. $10), which is used in the capture for export of wallabies from New Zealand. For the ‘Ecotrap’, ‘Ivo’ trap, and any other trap constructed from soft materials, the risk of predation by Tasmanian devils would need to be assessed.

Stakeholder support

In Tasmania, stakeholder support for trapping is varied. At meetings in May 2006, farmer and forestry-based interests and animal welfare groups offered lukewarm support for trapping, with representatives of TFGA, TCA and FIAT arguing current traps have little value in the management of browsing mammals, while the welfare lobby dismissed them as yet another lethal control tool (as any targeted animals captured are then shot). Exceptionally, Norske Skog use traps to control possums in *P. radiata* plantations (C. Berry pers. comm.), while FT uses them in their managed eucalypt forests (A. Walsh, B. Knox pers. comm.).

Summary and research gaps (see Table 8)

Live-capture traps are currently used to reduce pademelon numbers particularly, in and around plantation coupes and along farm edges, but there are few data available to determine whether such control is cost-effective or what ‘best-practice’ should be followed. The option of using kill traps to target possums does not appear to have been considered.

Table 8 Gaps in research into traps (not ranked).

Topic ID	Research topic	Justification
8a	Determine the cost-effectiveness of cage trapping.	Before traps can be promoted as an effective alternative to 1080, the practical constraints and costs of trapping to achieve specific target densities is required.
8b	Identify optimal ways of integrating cage trapping with other techniques.	Traps are unlikely to provide the complete solution, and their use needs to be integrated with other control methods.
8c	Assess the acceptability and effectiveness of kill traps as humane and cost-effective alternatives for controlling possums.	Recently developed possum kill traps are humane, and if non-target risks can be minimised, they offer an alternative method for controlling possums.
8d	Determine the effectiveness of tunnel nets for capturing wallabies and pademelons.	Tunnel nets offer a potential alternative to ‘Mersey’ and ‘Ivo’ traps, should they prove to be cost-inefficient for trapping wallabies.
8e	Determine the potential risk of predation to animals captured in ‘soft material’ traps (i.e. ‘Ivo’ and tunnel nets).	Fabric-covered traps provide little protection for captured animals from potential predators. Before these traps are used more extensively, this risk should be evaluated.
8f	Identify public acceptance of kill traps.	Public opinion on kill traps is unknown and should be surveyed before their use is promoted.

5.8 Shooting

Current use

Shooting is the most widely used method of controlling wallabies and pademelons in Tasmania, exceeding that of 1080 baiting (A. Lyons pers. comm.). It is used across the state, and involves c. 5000 hunters (G. Hocking pers. comm.). Shooting as a management option is excluded only from areas near human habitation or of high public use.

Shooting is carried out by recreational hunters for sport and to obtain game meat, by contract hunters who ‘shoot-to-waste’, and by commercial operators who harvest animals for their meat and skins. (Commercial harvesting is detailed in Section 5.9.)

Recreational shooters operate mainly along farm and forest margins during daylight, or during the evening if operating under a Crop Protection Permit. On properties with fallow deer (*Dama dama*), recreational hunters often have agreements with landowners to shoot wallabies and/or pademelons for several days per year as a prerequisite to hunting deer. Such practices are part of Property-based Game Management Plans and are encouraged by the Wildlife Management Branch, DPIW (G. Hocking pers. comm.). Documenting recreational hunter success via shooters’ log books has been encouraged for the last 3 years by the Sporting Shooters Association of Australia (Tasmania) (T. Hill pers. comm.), but these data have not been rigorously examined.

Contract hunting teams are often employed by forest managers on ‘rate per hour’ contracts under a tendering system (now a prerequisite to using 1080), although there are few teams available to the industry. In part, this is because of the high cost of public liability and workers' compensation insurance (D. Riddell, R. Hill pers. comm.).

Practicality

Because shooting is often done using a vehicle as a shooting platform, the method is often restricted to country accessible by vehicle. Hunting on foot is a less-used option. There is therefore a strong case for landowners improving the effectiveness of shooters by providing easy off-road vehicular access.

The future viability of shooting as a control tool is dependent upon the number of young hunters entering the sport or the industry. Anecdotal information given by recreational hunters (D. Riddell, R. Hill pers. comm.) and TFGA members indicate that the number of young hunters becoming involved in the shooting of browsing mammals is falling (from 7000 in the 1980s to <5000 since 2000; G. Hocking pers. comm.), and if this trend continues, it is likely to create real problems for the viability of this control option in the future.

While commercial shooting is normally a night-time activity, wallabies particularly are often difficult to 'hold' in a spotlight, and shooting during twilight hours when they first emerge may be a better option for hunters than night shooting. There appears to have been little experimentation with infrared spotlights in Tasmania (TFGA pers. comm.) or of rifle silencers, even though both are available commercially and thought likely to improve shooting effectiveness (T. Edwards pers. comm.). Alternatively, the use of packs of hounds during daylight hours to flush wallabies and pademelons out of dense cover is highly popular and, under Animal Welfare Standard No. 13, a legal add-on to normal recreational shooting, and one that greatly increases the effectiveness of the operator (D. Riddell, R. Hill pers. comm.).

Cost-effectiveness

The effectiveness of shooting in Tasmania is hard to judge, as data from shooters' log books or other sources are not freely available and have never been evaluated. Nor are there any published or unpublished reports on the cost-effectiveness of shooting as a control tool for mitigating browsing impacts, although there are several reports relating to the various practical aspects and constraints of shooting (Driessen 1992; Coleman et al. 1996). As one example of the effect of shooting following planting of tree seedlings, data from FT (Walsh & Kincade 2005) indicate that when shooting occurred on 5–12 occasions in three of four forest coupes, aided by the diversionary dumps of feed (see below), browsing levels fell away, but on the coupe not shot, browse levels continued to rise (Fig. 1).

The effectiveness of shooters at killing wallabies and pademelons is questioned by some landowners, who argue that shooting should be used alongside other control options only in an integrated programme of control in open, high-value sites (G. Hocking pers. comm.), to 'clean-up' animals surviving control operations using other techniques, or to remove problem individuals (Statham & Statham 1994; Coman 1994). In contrast, there is no evidence that shooting has controlled possum populations at the state-wide level and it is not recommended for use against them (Driessen & Hocking 1992) except at the local (enterprise) level where possums can be readily pursued into a tree on open farmland.

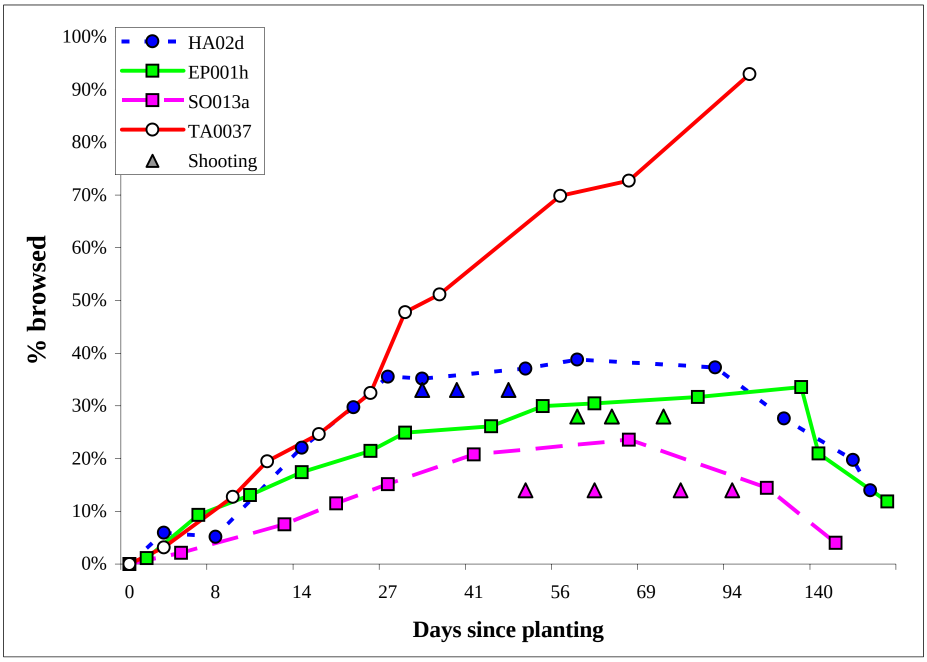

Fig. 1 Effect of shooting (timing of shooting indicated by a triangle below the relevant line) of pademelons and possums on browsing levels of *E. globulus* seedlings within four plantation coupes (from A. Walsh unpubl. data).

Where populations are high, sustained shooting is required to reduce all three target species to acceptable target levels (although these are normally unstated), and appears unlikely to provide effective protection in, or adjacent to, dense forest habitats, as individuals of all species become light-shy with repeated shooting activity (Statham & Statham 1994). Finally, shooting selectively removes the larger and older individuals, particularly males, and particularly wallabies at the expense of pademelons, resulting in increases in breeding performance by the surviving populations (Driessen 1992).

Hunting effectiveness is increased by such activities as pre-feeding sites with dumps of grain for several successive days before hunting (commonly used against possums in New Zealand; Montague & Warburton 2000), or by using hounds (see above). The coordination of hunters on adjacent farms or forest blocks would also seem likely to provide beneficial results (ensuring animals dispersed by one hunting team are ‘picked up’ by neighbouring hunting teams) but is thought to be impractical by some hunters (D. Riddell pers. comm.).

Overall, contract hunters appear likely to be more effective than recreational or commercial hunters when operating in remote or broken country, with each contractor negotiating a contract price based on the kill achieved over discrete areas of land. Independent and regular auditing of operations for their achievement of control targets prior to operator payment would further encourage effective control (Coleman et al. 1996). In contrast, shooting by recreational and commercial harvesters is the most common option on farmland where access is easiest, but the former group may be a less effective management option; recreational hunters are often driven by the need to achieve long-term access to deer hunting rights rather than a desire to reduce browsing mammals to low levels, and their control activities can thus be minimal. In contrast, commercial hunters are interested in long-term harvesting, i.e. sustained yield, and the animal population densities they require to begin or continue shooting are likely to be higher than those needed by land managers for crop or pasture protection. Commercial harvesting also requires access to animals free from any likelihood of 1080 poisoning, and so can be influenced by other forms of control occurring on hunted or neighbouring lands.

Choquenot and Warburton (2006) assessed the relative cost efficiencies of aerial and ground-laid 1080 and shooting for controlling wallabies in New Zealand. Although the poison option was most cost-effective, professional ground-based shooters (a team paid for from local government rates) still provided a viable option (in habitat similar to that of forest/farm margins in Tasmania) where the use of 1080 was unacceptable.

'Shooting-to-waste' as a method to control overabundant browsing mammals has to be paid for by the landowner, with costs greatest in large, at-risk forest coupes or farm fields adjacent to large areas of forest and scrub. If costs are, or can be, offset by recovery of meat or skins, then shooting costs to the landowner might be reduced. However, it is difficult to judge just how economical the method is without rigorous assessment. Both farmer and forestry groups appear unable to present total (direct and indirect) costings of the various shooting strategies. Equally, the real costs of browsing damage are unknown, but such analyses need to be fully developed by economists, if for no other reason than to underpin the argument for improved and continuing control of browsing mammals. As one example of the consequences of this dearth of data, farmers appear to be reluctant to pay recreational or contract hunters to control browsing mammals (K. Bill pers. comm.), apparently because they do not have sufficient information on the cost of browsing damage to their crops or pasture and thus the likely benefits from an effective shooting programme.

Non-target problems

Shooting is selective, with only the target animals normally placed at risk, and as such is seen by some as better than the less-selective action of 1080 or other toxins (A. Walsh pers. comm.). The shooting of non-target species should not arise, and it is not considered a significant issue by any stakeholder group addressed. However, targeting the species causing most damage is critical, as there appears to be some opportunity for the wrong local browsing species to be shot in the mistaken belief that it is primarily responsible for the observed damage, i.e. wallabies in place of possums (J. O'Reilly-Wapstra pers. comm.).

Social acceptance

Shooting either 'to waste' or for commercial harvest is unacceptable to some animal welfare groups (e.g. AACT, WLPA) and probably to many in the wider community (Coman 1994). For example, an opinion survey of Sydney and Melbourne residents found that only 31% thought it acceptable to use shooting to protect seedling trees (A. Walsh pers. comm.). As such, shooting may have a limited future in Tasmania as a widely used control tool, although the local hunting lobby argue that hunting is strongly supported by many Tasmanians (D. Riddell pers. comm.).

Animal welfare

Protocols exist for the shooting of wallabies and pademelons (Animal Welfare Standard No. 13) and possums that include a requirement to aim for the head, neck or chest, but recognise the likelihood of some animals being wounded. Shooting of these species now requires a follow up coup-de-grace of all shot but live animals. Shot females must also be inspected for the presence of pouch young, and where these are found, they must be dispatched humanely (a condition of the permit).

Legislation

Shooting of wallabies, pademelons, or possums is legal in Tasmania under licences or permits issued under the Nature Conservation Act 2002. Commercial operators require a commercial wallaby permit to hunt on Flinders or King Island, or a commercial wallaby licence on the Tasmanian mainland (both available from DPIW). Recreational shooters may shoot during the open season, but require a wallaby licence. In addition, both commercial and recreational hunters when hunting at night with a spotlight can only operate on farmland under a crop protection permit held by the landowner (see also Section 5.9 – 'Commercial harvesting and use of bounties').

Shooters can only use firearms for which they are licensed under the Firearms Act 1996, and these include (though not exclusively) .222 rifles or 12-gauge shotguns for wallabies, and .22 Hornet, .17 Remmington, or 12-gauge shotguns for pademelons or possums. Current legislation bans the use of silencers (except with permission of the Commissioner of Police) and shooting from public roads.

Implementation

Shooting is an integral part of the property-based game-management-plan system set up by DPIW, and the technique must be used prior to any use of 1080. As such, and as more such plans are established, shooting will become a more common means of controlling populations of browsing animals.

Alternatives

Recreational shooting has long been part of the management of small mammals in Australia and New Zealand, particularly that of rabbits (Boswell 1992), but it has never been seen as an adequate control tool in either country for most vertebrate pest species. Recreational hunting can, however, be used as an aid to professional control of both rabbits and larger animals, although its value has never been documented.

Commercial harvesting is used to control overabundant populations of mammals in many countries, although often without rigorous documentation. One well-documented example is the management of kangaroo populations in mainland Australia (e.g. Ramsay 1994). Tightly controlled and well-managed commercial hunting appears likely to grow as an alternative to toxins (P. Jarman pers. comm.), although is almost certain to face opposition from animal welfare groups who believe it is intrinsically counterproductive (AACT, TCT).

Stakeholder support

Shooting either by recreational or commercial hunters appears to be the technique of choice for many farmers (TFGA Game Management Committee, pers. comm.), receives indifferent support from forestry-based groups (except as a tool in environments incurring low levels of browsing), and no support from the animal welfare groups interviewed (i.e. AACT, WLPA, RSPCA, or TCT). Shooting by contract hunters is however favoured by forestry interests. In contrast to the position taken on shooting by the animal welfare groups interviewed, the Tasmanian Green Party leader (P. Putt) offered support for shooting provided it is the most appropriate method available (from ABC Radio Tasmania interview, 20 Nov. 2003). The development of formal protocols to cover hunting strategies and tactics and the collection of robust defendable data (particularly for the auditing of control effectiveness) may lead to a wider acceptance of shooting by all land-managing industries. For an example of shooting protocols and training planned for contracted pest control managers in Australia, see FAAST (2003).

Monitoring

Currently, recreational hunters record kill data, the number of animals seen but not shot, and hunting effort under property-based game management plans. This information is critical for the auditing of such harvests, although its reliability and hence its usefulness is thought to be variable (G. Hocking pers. comm.). The same information is required from contract and commercial hunters.

Summary and research gaps (Table 9)

Shooting of pademelons and wallabies is carried out by recreational hunters for sport and to obtain game meat, by commercial operators who harvest animals for their meat and fur, and by contract hunters who ‘shoot-to-waste’. The effectiveness of shooting has not been rigorously assessed, and although many farmers support the use of all types of shooting, recreational shooting receives indifferent support from forestry-based groups, and no support from animal welfare groups. The advantages of the technique are that it is target specific and, if carried out by well-trained shooters, should be relatively humane.

Table 9 Gaps in research into shooting (not ranked).

Topic ID	**Research topic**	**Justification**
9a	Quantify the relative cost-effectiveness of recreational, contract, and commercial shooters for mitigating browse damage in forestry and agriculture.	Shooting is a target-specific lethal control option but there is little information on its cost-effectiveness.
9b	Determine the costs of using contract shooters to reduce densities of critical browsers to target levels.	Before contract shooting can be promoted, the costs of achieving targeted densities need to be determined.
9c	Determine the increased effectiveness of shooting with and without infrared spotlighting and/or baiting sites.	The cost-effectiveness of shooting is likely to be improved by use of infrared spotlights for night shooting and baiting sites to expose more animals to the hunter.
9d	Determine the relative cost-effectiveness of a regionally-managed contract system versus an enterprise-based system.	Coordinated control managed at a regional level rather that at the enterprise level is likely to be more cost-effective.
9e	Determine the social acceptability of shooting of browsing mammals.	Before any effort or funding is expended in enhancing shooting, the method needs widespread public support.

5.9 Commercial harvesting and the use of bounties

Commercial harvesting of browsing mammals in Tasmania

Possums: Possums are protected in Tasmania under the Wildlife Regulations 1999 of the Nature Conservation Act 2002. Since 1974, the taking of possums has been allowed year-round on land used for primary production, i.e. grazing, farming, or forestry, and with the permission of the landholder, under a system of special commercial permits issued by the Parks and Wildlife Service, Department of Primary Industries, Water and Environment (DPIWE), now DPIW.

The harvesting method specified in these permits is shooting with the aid of a spotlight, although the use of cage traps may also be approved (DEH 2006a). A condition of these permits is that the numbers of possums killed and the numbers of skins or carcasses sold to licensed dealers is provided to DPIW. From 1976 to 1981, >250 000 possums were commercially harvested, and a harvest quota of 250 000 animals was introduced in 1983. However, since then the number of animals taken commercially declined to fewer than 7000 by 1995, apparently because of a declining average price paid per skin (DEH 2006a). A trade management plan for possums is in preparation that will include a mechanism for the quota to be adjusted annually in response to population trends (G. Hocking pers. comm.). There is presently relatively little domestic utilisation of possum skins. Note that for a native species, particularly one otherwise protected, a 'fixed' quota must be so low that it can have no serious impact on population density and, hence, is unlikely to have any value as a pest control technique. A quota designed to regulate a population must be adjusted to track its size, increasing when numbers are high and decreasing, if necessary to zero, when numbers are declining naturally or, for a pest species, when damage is not occurring.

Crop protection permits to kill possums are issued when the animals are or are likely to cause damage to crops or pasture (Callister 1991). However, products from possums killed under a Crop Protection Permit may only be sold by a person who holds a Commercial Possum Permit (G. Hocking pers. comm.).

In 1985, the Wildlife Regulations were amended so that possum meat could be sold for human or pet consumption, and by August 1996 two operators had been licensed to export possum meat. For possums harvested for their meat, their capture, handling, transport and slaughter must be carried out by operators accredited under the Meat Hygiene Act 1986. Under the Wildlife Protection (Regulation of Exports and Imports) Act 1982 (now the Environment Protection and Biodiversity Conservation Act 1999), commercial export is restricted to animals taken under an approved management programme administered by DEH. Hence, possum products can only be exported from Australia with a permit from DEH. A condition of the management programme is that live trapping and transport of possums must be conducted in accordance with the relevant code of practice (DPIWE 2000), which specifies the minimum size and construction of cage traps used to capture possums, the frequency of checking traps, method of transport, and the subsequent processing of captured animals.

Macropods: Wallabies and pademelons are 'partly protected wildlife' under the Wildlife Regulations 1999 of the Nature Conservation Act 2002. Both species may be harvested during a declared open season by persons having either a non-commercial or commercial wallaby hunter's licence. A commercial hunter's licence allows the hunter to take wallabies during daylight hours over the open season and sell the products. In addition, licensed hunters may operate under a crop protection permit and shoot wallabies at night with the aid of a spotlight (DPIWE 2000). However, although wallabies and pademelons may be harvested for export on Flinders Island, and wallabies may be harvested for export on King Island, both species are harvested only for domestic use on mainland Tasmania (DEH 2006b). As for possums, a person commercially harvesting wallabies for the domestic meat market must be accredited in accordance with the Meat Hygiene Act 1986 and the Australian Standard for the Hygienic Production of Game Meat for Human Consumption. Meat harvested for the overseas market relies on the approval of the Australian Quarantine and Inspection Service (AQIS).

Commercial hunters on the Tasmanian mainland shoot larger wallabies and, to a lesser extent, pademelons to service pet and human food markets. Commercial hunting is presently a small industry involving only a few companies, and unless legislation barriers limiting access to export markets are removed, the rate of harvesting is unlikely to expand (J. Kelly pers. comm.). Any export of harvested products relies on both DPIW and Federal Government approval. In contrast, export of products from the shooting of wallabies has recently been approved for King and Flinders islands.

Commercial harvesting of macropods in mainland Australia

Under the Environment Protection and Biodiversity Conservation Act, the DEH is required to approve management plans for kangaroos and wallabies, including plans that allow for the commercial harvest and export of kangaroo and wallaby products. The species of macropods and the states in which they are legally commercially harvested for export in 2005–2006 (DEH 2006c) include: red kangaroo (Queensland, New South Wales, South Australia, Western Australia); eastern grey kangaroo (Queensland, New South Wales); western grey kangaroo (*Macropus fuliginosus*; New South Wales, South Australia, Western Australia); euro (*M. robustus*; Queensland, New South Wales, South Australia); wallaby (Flinders and King islands, Tasmania); and pademelon (Flinders Island, Tasmania). The red, eastern grey and western grey kangaroos make up about 90% of the commercial harvest. Quotas are set on an annual basis and represent a maximum allowable take.

Research on commercial harvesting and bounties in Tasmania

There has been little research investigating the role of commercial harvesting in reducing the abundance of possums in Tasmania, and none for wallabies. With respect to the management of browsing mammals, a commercial harvest is likely to provide one of three outcomes (*sensu* Parkes 2006):

- The harvest may reduce the browser density to below some level at which the browsing impact becomes acceptable.
- The harvest may reduce both the browser density and the browsing impact, but the residual browsing impact remains unacceptable; this outcome may at least reduce some of the costs incurred by other agencies in further reducing the browsing impact.
- The harvest may provide no reduction in browsing impact.

However, there has been no research to evaluate which of these three outcomes has been delivered by past commercial harvesting of possums or macropods in Tasmania: there are no robust data that we are aware of on the extent to which commercial harvesting has reduced the abundance of possums or macropods, let alone their browsing impacts. There has also been no research on the potential for bounties in the control of wallabies in Tasmania.

Commercial harvesting of browsing mammals – general

In New Zealand, there is evidence that commercial hunting has reduced the abundance of possums in some areas (Brockie 1982; Clout & Barlow 1982). For example, Brockie (1982) found that a hunted block in the Orongorongo Valley near Wellington had a higher abundance of two highly palatable tree species than an adjacent unhunted block, and suggested that this was a result of lower possum density achieved by commercial harvesting.

One of the best examples of commercial harvesting reducing the impacts of browsing mammals is that of red deer (*Cervus elaphus scoticus*) in the alpine grasslands of New Zealand (Parkes 2006). Commercial harvesting of deer using helicopters began in New Zealand in the mid-1960s and, stimulated by extremely high prices for live animals in the early 1980s, virtually extirpated red deer from all open areas. This was followed by a substantial recovery in the quality of grasslands – the preferred food of red deer. Nugent & Choquenot (2004) subsequently modelled the cost-effectiveness of commercial, state-funded and recreational harvesting of wild deer in New Zealand. Commercial and state-funded hunters use helicopters to harvest deer, whereas recreational hunters are ground-based. Hence, in contrast to recreational hunters, both commercial and state-funded hunters can hunt all parts of the landscape, albeit with different effectiveness. For this case, the models indicated that it is usually more cost-effective to pay incentives to commercial harvesters than to conduct state-funded control. In comparison, recreational hunters are likely to achieve only moderate reductions in deer density, and then only in areas that are readily accessible and easy to hunt.

Commercial harvesting must deliver a profit to the harvester. Hence, the number of animals harvested is expected to be a function of the difference in the average price received per animal and the average amount expended obtaining it. Callister (1991) showed that the average price paid per possum skin in Tasmania was positively correlated with the number of skins sold, and hence the number of possums harvested. The same trend has also been observed for possum skins harvested in New Zealand (Warburton et al. 2000b). For possums, the average price paid per skin is set by a global market, which is a complex interaction of demand and supply of alternative fur types and currency values. Further, hunter efficiency is largely determined by the accessibility of possums; commercial harvesters in New Zealand have a greater impact on possum populations from well-roaded areas close to their homes than from remote areas (Warburton et al. 2000b).

Potential legal and policy instruments may be modified to increase the proportion of animals commercially harvested (Forsyth & Parkes 2004). An estimated one million feral goats are commercially harvested in mainland Australia annually for slaughter and export, with the functioning of the industry mirroring the commercial harvesting of possums in Tasmania. The price paid per feral goat and the costs of capture are the main factors determining how many goats are commercially harvested. Governments can not easily influence market prices, but can influence the profitability of commercially harvesting feral goats via taxes or subsidies that reduce the costs of capturing goats (Forsyth & Parkes 2004): these conclusions could apply to the commercial harvest of both possums and wallabies in Tasmania.

Bounties

A bounty can be defined as a ‘financial reward for killing an animal’. The economics of bounty systems are different from that of commercial harvesting only in that the price is usually set in advance, i.e. before the animal is killed, and is paid by the tax payer (Warburton et al. 2000a). Clearly, when the bounty value is high relative to the cost per animal killed, many people will hunt the species. They may also act to increase the supply of animals by ‘seeding’ new areas for later harvest.

Most bounty values have apparently been set too low relative to the costs of catching pests, so that populations have not been reduced significantly (Warburton et al. 2000a). For example, a bounty equivalent to NZ 25 cents was placed on possums in New Zealand in 1951, and c. 8 200 000 killed under this scheme over the following 10 years. However, the concurrent expansion of the geographic range of possums was not halted, and an analysis of the bounty returns indicated that a large proportion of kills came from non-critical areas (Warburton et al. 2000a).

A one-year trial of a fox bounty was undertaken in Victoria in 2002/03. A review of that trial identified three issues of general relevance to the use of bounties for reducing the abundance of mammals (Fairbridge & Marks 2005):

- The pattern of foxes killed during the trial was highly clustered, with <4% of the state estimated to have received sufficient control to reduce their abundance.
- There was anecdotal evidence that large numbers of foxes were killed outside of Victoria but presented for bounty within Victoria (Department of Primary Industries 2005).
- There was anecdotal evidence that shooters managed the resource to maximise their income, i.e. they left residual populations to ensure future harvesting opportunities.

Perhaps the most important problem for any bounty established for browsing mammals in Tasmania is the difficulty of determining whether or not the animal presented for payment came from the areas requiring pest control. Because the areas where browsing mammals cause significant damage to forest seedlings or grazing land is small relative to their total range, bounties are likely to be paid for animals killed unnecessarily. Apart from being an extremely expensive system of reducing crop damage, difficulties in restricting culling to damaged areas could generate legitimate environmental and animal welfare concerns.

Bounty systems, like commercial harvesting, will seldom provide enough incentive to reduce animal populations to very low densities, and there are many examples of harvesters attempting to maximise their income from these systems, e.g. by releasing pregnant females (e.g. Smith 1990). Two recent reviews of long-term dingo bounty schemes in New South Wales (Harden & Robertshaw 1987) and Queensland (Allen & Sparkes 2001) concluded that both schemes were ineffective at controlling this animal (see also Smith 1990).

Several modifications have been proposed to bounty schemes in order to increase their cost-effectiveness, i.e. so-called ‘smart bounties’. Examples of such modifications include limits on the people who participate in such schemes, altering the duration and eligible areas of schemes, and limiting the payment only to problem animals. However, in a review of ‘smart bounties’, Hassall and Associates P/L (1998) concluded that such modifications are unlikely to overcome the problems identified above. For browsing mammals in Tasmania, we can see no way to ensure that a bounty targeted at animals causing damage at key sites and at key times would be paid only for those animals.

Cost effectiveness

The extent to which the commercial harvesting of macropods improves pasture and biodiversity is uncertain because appropriate studies have not been conducted to evaluate the benefits of commercial harvesting. However, the effects of different densities of sheep (*Ovis aries*) plus kangaroos, and sheep only (but unfortunately not kangaroos only), on forage biomass have been compared for semi-arid rangelands in north-west New South Wales (Freudenberger 1995). The data indicated that both species had similar impacts on forage biomass, and that any harvesting of kangaroos without concurrent reductions in both sheep and feral herbivores (e.g. feral goats and rabbits) would be unlikely to have any effect on forage biomass in rangelands (Freudenberger 1995).

Apart from the control of red deer in New Zealand (Parkes 2006), there is no robust evidence of commercial harvesting effectively reducing browsing damage. Similarly, all available evidence suggests that bounties are not a cost-effective method of managing browsers.

Integration of techniques

Commercial harvesting alone is unlikely to reduce the densities of the targeted browsing mammals in Tasmania such that browsing damage is eliminated. However, commercial harvesting could reasonably be integrated with other techniques into an effective system for managing browsing mammals. One likely impediment to the use of commercial harvesters is access to sites: not all companies or land managers are apparently willing to provide access to their forests or farmlands. We see no role for bounties in a system for managing browsing mammals in Tasmania.

Stakeholder support

It is uncertain what the public attitude would be to the establishment of commercial harvesting of wallabies in mainland Tasmania, and this situation needs to be clarified. Certainly, the TCT is concerned about the commercial harvesting of wallabies and pademelons on Flinders Island and wallabies on King Island (Woodfield 2005). There is a very large kangaroo-harvesting industry on mainland Australia, but this also has its opponents.

Some hunting groups in Tasmania feel that they can play a useful role in reducing wallaby damage (Coman 1994). Such beliefs are difficult to substantiate, as no useful data exist to support hunters' claims.

Summary and research gaps (see Table 10)

Commercial harvesting either for meat and/or pelts may contribute to the off-take of overabundant browsing mammals. However, the level of any contribution will be determined by the relationship between per capita harvesting costs and product price.

Table 10 Gaps in research into commercial harvesting and bounties (not ranked).

Topic ID	**Research topic**	**Justification**
10a	Quantify the relationship between commodity price and economic harvesting density.	For commercial hunting to provide real benefits for control, the price of game products must be sufficiently high to enable harvesters to operate economically at browser densities commensurate with acceptable browse impacts.
10b	Identify constraints (e.g. costs, knowledge, policy and legislation) that limit harvesting success and its economic viability.	The economic viability of commercial harvesting is constrained by legislation and policy requirements that need to be minimised.
10c	Determine the spatial and temporal situations where harvesting can be best integrated with other control technologies.	Commercial harvesting might be best used to reduce high numbers of animals to more moderate densities then maintained by contract shooters or reduced further.
10d	Determine the social acceptability of commercial harvesting of browsing mammals.	Before any effort or funding is expended in enhancing commercial harvesting, the method needs widespread public support.
10e	Determine the cost-effectiveness of commercial harvesting.	Before commercial harvesting can be promoted, its costs relative to other control techniques should be assessed.

6. Strategies for Managing Damage by Browsing Mammals in Tasmania

Effective wildlife management must focus on both strategic issues and tactics, but recognise that some strategies and tactics may be both site- and species-specific. The essential components of a strategic approach to vertebrate pest management were set out by Braysher (1993). They were used subsequently as the framework for a series of guidelines for managing damage caused by rabbits (Williams et al. 1995), foxes (Saunders et al. 1995), feral pigs (Choquenot et al. 1996), feral horses (*Equus caballus*) (Dobbie et al. 1993), feral goats (Parkes et al. 1996), and other vertebrate pest species in Australia. The same structured approach is applicable to managing browse damage in Tasmania. It comprises the following elements (Braysher 1993; Olsen 1998):

- Definition and scope of the problem.
- Specification of objectives and performance criteria.
- Identification and evaluation of management strategies and techniques.
- Implementation of the plan.
- Monitoring of management programmes and evaluation against agreed objectives.

In the following sections we outline research issues relevant to each of these elements.

6.1 Defining the problem

At the meeting held at Launceston in mid-April 2006, and during discussions with stakeholders in May 2006, it was apparent that many foresters and farmers in Tasmania think that possums, wallabies and pademelons cause significant damage to production, and that the magnitude of the problem has increased in recent years. Probably the best quantitative support for this view is the data from annual spotlight surveys conducted across the eastern and northern two-thirds of the state by DPIW (and its predecessors). The data from 1975 to 1990 were reported by Driessen and Hocking (1992); these and subsequent data from 1990 to 2004 were presented at the Launceston meeting by G. Hocking (DPIW). On a state-wide scale, there has been a trend of increasing numbers of pademelons since 1975 that is broadly consistent across the four regions where most data were collected (Northwest, Northeast, Central and Southeast). Over the same period, there was no significant change in the state-wide number of wallabies, although there is some evidence of increased numbers in the Central region since 1990. The data for possums show a similar pattern to those for wallabies, with a period of relatively high numbers beginning around 1990, particularly in the Central region. Data presented by G. Hocking at the Launceston meeting also show a pattern of increasing use of 1080 against possums and wallabies from 1978/79 to 1987/88, followed by generally consistent levels of use until the downward trend over the last 4–5 years.

The type of fluctuations in possum, pademelon and wallaby abundance in Tasmania since 1975 are qualitatively no different to those recorded for macropod populations in mainland Australia, albeit mostly for more-arid environments (e.g. Pople et al. 2000). Large, superficially inexplicable changes in the size of these populations can be due simply to time lags in the response of vegetation and unmanaged herbivores to climatic variability (Caughley 1987). However, in the case of Tasmanian wildlife populations, an analysis of data from 1975 to 1990 by Driessen and Hocking (1992) showed time-lagged effects of rainfall, and that the state-wide changes in the combined abundance of wallabies and pademelons were negatively correlated to levels of commercial hunting but not to 1080 poisoning. They attributed the increases in numbers of possums and pademelons to a combination of increased availability of favourable habitat due to plantations and land clearing, and decreased hunting pressure. Clearly there is an opportunity now to repeat the analyses of Driessen and Hocking (1992), using the longer time series of data and to explore in more detail statistical associations between changes in animal abundance and potential explanatory variables, including climatic factors, changes in land use, levels of control and changes in trophic interactions (e.g. in numbers of predators). However, it should be noted that significant positive or negative correlations do not prove causal relationships; these need to be tested, preferably in well-designed experiments. For example, it has not yet been rigorously demonstrated that commercial hunting can regulate wallaby populations.

In addition to the spotlight surveys and levels of 1080 use, there are several sources of evidence that should be examined to determine if numbers of browsing mammals have changed in recent years. Shooters' log-books generally record the number of mammals shot, the number seen but not shot, and hunting effort. In principle, it should be possible to use this information to calculate an index of 'catch per unit effort' for monitoring changes in animal numbers in areas of farmland where shooting is conducted regularly. Forestry operators also record the results of control programmes, although these data might have less value where they are collected only for a relatively short period during the establishment phase of plantations.

During discussion with stakeholders in May 2006, it became apparent that there are no data available to quantify current or past levels of damage caused by possums, pademelons and wallabies to pasture or agricultural crops at local, regional or state-wide scales (Appendix 1). Several studies have demonstrated that damage to pasture can occur and be substantial (Statham & Raynor 1998; Statham 2000); these provide an indication of potential damage but not a measure of what is lost or to whom. Data collection is required to quantify how much damage is occurring, whether this is economically significant in comparison to other losses in production, and which areas and types of agricultural production are most at risk of damage. For forestry, damage can be recorded relatively easily at the establishment phase of plantations (e.g. the number of browsed seedlings replaced or conversely the proportion of seedlings that exceed browse height), but the final cost of lost timber production is more difficult to determine (see Section 6.2). Unless accurate, quantitative data are collected to define and measure the problem of browse damage, it will be difficult to determine whether the problem is getting better or worse over time, how much control of wildlife is required, and what techniques are justified socially or economically.

Current requirements to stop the use of 1080 on State land and to reduce its use on private land are partly a response to a perceived lack of public support for this method of control. In order to develop acceptable management strategies, it is essential to determine the views of the Tasmanian public on the importance of the browse-damage problem, what are acceptable targets for reduction in the numbers of possums, pademelons and wallabies, and what type of control techniques are acceptable. Discussions with stakeholders in May 2006 indicated general support for surveys to measure public and industry attitudes to the use of techniques other than 1080 poisoning for the management of browsing animals (Appendix 1). Public support for control tools and tactics should be evaluated together with that of landowner/land managers, i.e. the latter should be treated as a separate group in social surveys.

There are a range of environmental issues that are important in defining the scope of the browse-damage problem, and there is potential for conflict between management objectives based on industry perceptions of browse damage and public-interest objectives concerned with protecting wildlife (including non-target species that might be affected by control programmes) and their habitat. For example, at one stakeholder meeting in May 2006, an interest group suggested that changes in the boundaries of the conservation reserves had contributed to increased problems with browse damage to farmland, although the exact mechanism generating this outcome was not explained. Research is required to determine whether policies such as re-establishment of native vegetation on farmland or use of 'aggregated retention' in forestry coupes do, or do not, exacerbate problems of browse damage on adjacent land. In addition, research is required to determine whether the conservation status of public forest abutting farmland leads to conflicts of interest in managing populations of browsing wildlife, particularly with regard to reducing numbers of animals in buffer strips in forest adjacent to farmland.

6.2 Management objectives and performance criteria

For forestry, the objective for managing browsing animals seems well-defined: limit the amount of browse damage to within economically acceptable targets until seedlings escape browse height (for hardwood plantations and native forest regeneration) or until harvest (for softwood plantations). However this objective requires the specification of what level of browse damage is acceptable. This damage has been identified in terms of seedling survival for FT (although we are unaware of what the loss is), while a loss of c. 5% of seedlings is argued by FIAT to be a reasonable threshold for the commercial industry to carry. In addition, it is unclear whether the forestry industry will continue to deal with browse damage on a coupe-by-coupe basis or would prefer broad-scale solutions to the problem, for example by a general reduction in the abundance of browsing animals. Which objective is pursued has obvious consequences for the choice of browsing-mammal control strategies and techniques. However, when selecting acceptable alternatives to 1080, it would be useful to specify performance criteria that currently appear to be implicit, including targets relating to conservation impacts and public acceptance of mammal control programmes in forests.

The immediate objectives for the management of browsing mammals on farmland are not at all clear. This is not surprising given that the amount of damage by browsing animals has not been quantified, except perhaps where there are extremely high levels of damage near farm–forest interfaces. Performance criteria are required for establishing whether or not control programmes can be judged to be successful. Regular off-take of animals by recreational or commercial shooters does not constitute a criterion for gauging effective reductions in damage to pasture or crops; however, estimates of the number of browsing mammals on farmland can be used to set performance targets if the relationship between pest numbers and damage is known.

Relationship between damage and abundance of browsing mammals

In order to achieve the desired benefits from vertebrate pest control, it is essential that pest populations are reduced to levels at which their impacts are acceptable. The relationship between pest density and resource impacts in most situations will be non-linear (Hone 1994), and therefore a given reduction in pest density will not always provide a commensurate reduction in impact. If the damage–density relationship is highly non-linear, i.e. effectively having an impact threshold, then any reduction that results in pest density remaining above that threshold will provide few if any benefits to the land manager. If ineffective control is carried out, there are significant ethical issues to be considered in having killed animals for little or no benefit (O'Connor et al. 2005). This will be avoided in Tasmania only if there is adequate research to determine damage–density relationships for both forestry and agriculture. Ideally, such relationships should be measured across the full range of browsing pressure by possums, pademelons and wallabies but, for practical purposes, it might be sufficient to establish damage thresholds above which a reduction in the number of browsing mammals is required.

6.3 Management strategies and techniques

Strategies for managing vertebrate pests include eradication, one-off control, sustained control, sporadic control, commercial harvesting and hunting, and no control (Parkes 1991). For the purposes of this review, commercial harvesting and hunting have been treated as aspects of using shooting as a control technique. Also, given the strong perceptions of farmers and foresters of an increasingly serious browse management problem, the option of no control was considered to be unacceptable. Of the remaining four options, all except one could apply to the management of native browsing mammals in Tasmania, and all have requirements that will affect the choice of control technique. Even the exception, i.e. eradication, could have proponents at the local scale in farmland. An alternative toxin to 1080, provided it is publicly acceptable, is the only technique that currently would be compatible with all potential control strategies. Setting aside the option of local eradication, non-commercial shooting could be a generally effective technique provided sufficient reductions in animal numbers can be achieved to meet acceptable damage thresholds. Several other techniques could be developed to the stage where they are effective, either alone or as part of integrated control, for short-term control such as that required in the establishment phase of plantations. Sustained control, which appears to be the major requirement for farmland, could be achieved by lethal techniques (toxins or shooting, including contract hunting), commercial harvesting (depending on acceptable pest densities and markets for products), fencing, or fertility control if it becomes available in the future. A proper assessment and selection of management strategies should be done as an interactive process with stakeholders and is an essential step in setting priorities for developing alternatives to 1080 poison. The pros and cons of each strategic and technical option should form part of published guidelines for the management of native browsing mammals in Tasmania.

For forestry, one-off or short-term control appears to be current practice, except for *P. radiata* plantations, where sustained control is used to reduce browse damage by possums over a significant period of the stand rotation. In some cases professional shooters are used but not as part of commercial harvesting operations. Viable alternatives that could be considered include sporadic control and no control. For forestry operations, the former option would amount to using an ‘action threshold’ (Norton 1988), which, when reached, would trigger a control programme to prevent further damage. This option requires monitoring protocols and control techniques that are affordable and can operate within a time frame for preventing unacceptable levels of damage. The ‘no control’ option is contrary to the apparent forestry norm of pre-emptive control, but could be a viable option for some coupes if models can be developed to give reliable predictions of the risk of browse damage.

Sporadic control, hunting, and to a limited extent commercial harvesting appear to be the current management strategies for farmland. Sporadic control is best suited to techniques such as 1080 poisoning that can be imposed relatively quickly according to perceived or measured levels of damage, and with an immediate ‘knock-down’ of the mammal population. Continuation of this strategy will focus the choice of new control techniques on those that are functionally equivalent to 1080 poisoning (e.g. the use of alternative toxins). Hunting by landholders and recreational shooters is a common form of pest control in Tasmania. Whether or not it is effective in achieving adequate reduction in damage is yet to be established. However, the negative correlation between commercial hunting and numbers of pademelons and wallabies during the period 1975–1990 (Driessen & Hocking 1992) lends some support to the value of this form of pest control.

Ecologically based pest management

The premise of ecologically based pest management (Singleton et al. 1999) is that it is easier, cheaper and more effective to take advantage of natural processes like predation, competition and disease to reduce the abundance of pests than to rely on technological solutions that do not tackle the cause of the problem and invariably attempt to deal with only one, or occasionally two, species at a time. It makes little sense, ecologically, to provide high-quality forage adjacent to daytime forest refuges without expecting significant changes in the population dynamics of local native herbivore populations. In the long term, economically and environmentally sustainable solutions to the management of overabundant populations of native browsing mammals will have to be based on a sound understanding of their ecology. Landcare Research projects in New Zealand and Australia to assess the advantages of exploiting natural variations in heterogeneity of pest species’ distributions are examples of a new approach to ecologically based management. In addition, a failure to take an ecosystems approach to pest management can lead to perverse outcomes where control of one species can enable another species to increase in abundance and cause greater problems (Sinclair & Byrom 2006).

6.4 Implementation

There are several opportunities for integrating research and extension into future browsing-mammal control programmes. During discussions with farming interest groups in May 2006, it was suggested that on-farm projects be used to demonstrate the effectiveness of alternatives to 1080 poisoning, the value of using combinations of techniques, and the potential benefits of coordinating control programmes with neighbouring properties, particularly for the management of possums and wallabies (Appendix 1). Demonstration projects will have most value for improving control strategies if they are conducted using the adaptive experimental management (AEM) approach (one strongly favoured by AACT, TCT, and The Wilderness Society). AEM compares alternative management-scale treatments (i.e. techniques and/or strategies for pest control) within a formal experimental design (Holling 1978; Walters & Holling 1990). Much of the current and published research on browse damage to forestry has been conducted without adequate replication at the site level: AEM might be a viable approach to improve this aspect of future research projects. For managing browsing mammals in Tasmania, the aim is to use fully-operational control programmes, on farms or plantations, as replicated experimental treatments and to compare the outcomes of control with equivalent untreated properties (Parkes et al. 2006b).

Because the browsing problem in Tasmania has a large number of uncertainties, it is recommended that all stakeholders participate in an AEM approach to finding solutions to the problem, which is larger than just the science of the pest–resource system. That is, the values and objectives are part of the experiment. There is a range of conditions that need to be met for AEM to be effective (adapted from Parkes et al. 2006a):

- Managers, scientists and stakeholders have to agree on the questions to be addressed, commit to the process, and stick to the management protocols even if their management option appears to be suboptimal.
- There must be differences in the way managers can manage similar systems or they must be willing to adapt management over time according to the results of their monitoring (informed by a competing model approach).
- There must be some rationale to justify these differences in management (i.e. conceptual models of how the pest–resource system behaves).
- The predictions of these conceptual models must be matched by more formal models that predict specific outcomes from different actions.
- An experiment must be designed to compare the outcomes resulting from different management actions. The experiment must have a defined and measurable set of attributes, and ideally it should have replicated and randomly allocated treatment and non-treatment sites.
- Management actions and outcomes must be monitored in some standard way, ideally as part of normal management practice.

As well as testing and promoting the use of alternatives to 1080, demonstration projects would provide opportunities for detailed analyses of the costs and benefits of pest management at the enterprise level. One highly ranked example of such a project (see Tables 13–15) would be a demonstration of low-cost/low-maintenance fences to exclude browsing mammals. A full cost–benefit analysis would require well-designed techniques for measuring the loss of production due to damage by native herbivores. Such losses could be modelled using currently available pasture-production/animal-production models provided they can be modified to include data for wallabies (R. Thompson pers. comm.). Alternatively, cost-effectiveness analyses require that targets for control programmes are specified (e.g. acceptable abundance of native herbivores). These analyses can be used to maximise the benefits from a fixed budget or to minimise the costs required to achieve a predetermined level of control (Choquenot & Parkes 2000). Ideally, examination of the financial issues associated with pest management for individual enterprises should be accompanied by an assessment of social factors that influence the ability of managers to deal effectively with pest species (A. Fulton pers. comm.).

Despite the extensive experience of some pest control operators and publications generated by existing research programmes, e.g. the Forestry CRC, it appears that management of browse damage could be improved by better flow of information among members of the forestry and farming industries, and to the general public. In addition, there is a need for training programmes to maintain a pool of skilled pest-control operators (Appendix 1). Internet-based networks are used increasingly for transferring information within interest groups, and might be an option for improving browse management in Tasmania. ‘Best practice’ guidelines have been published for managing the major introduced vertebrate pest species in Australia; production of similar guidelines is warranted for managing possums, pademelons and wallabies in Tasmania. The manual produced by Coleman et al. (1996) would be a good starting point.

6.5 Monitoring and evaluation

Monitoring should be implemented and maintained for at least four reasons – and include:

- Performance monitoring to determine how well a management action has achieved the immediate goal (e.g. percentage kill).
- Outcome monitoring to determine whether the desired benefits have been achieved (e.g. reduction in number of browsed seedlings or biomass of pasture eaten).
- Monitoring of possum, pademelon and wallaby populations at the scale of management units so that the intensity and methods of control can be modified to match management objectives.
- Monitoring of target and interacting non-target native mammal populations at regional and state-wide scales to detect unexpected or undesirable outcomes that could require modifications to future control programmes.

The recent impact of devil facial tumour disease on the abundance of Tasmanian devils illustrates the importance of the last reason: it is a topical example of how changes in the distribution and abundance of a native mammal population can arise from an unforeseen factor. At present, state-wide and regional monitoring of native mammal populations is conducted annually at a fairly coarse spatial resolution. Research is required to evaluate other sources of monitoring data (such as shooters' log books) or to develop new operational monitoring protocols suitable for forestry and agriculture. In some cases, monitoring techniques might have to be adapted to meet special local requirements, e.g. to audit commercial harvesting on King and Flinders islands.

6.6 Recommendations for research (Table 11)

Table 11 Gaps in research in the underpinning strategies used to manage browsing damage (not ranked).

Topic ID (from sections 6.1 – 6.5)	**Research topic**	**Justification**
Defining the problem		
11a	Use time series data from 1975 to present to examine changes in abundance of browsing mammals.	State-wide trends in abundance of browser populations underpin need for ongoing control.
11b	Assess shooters' log books as indicators of changes in browser abundance at the local level.	Log books may provide indications of browser population trends at the enterprise level.
11c	Design protocols to record, analyse, and assess industry-wide impacts of browsing mammals.	Improved data on browse damage is necessary to underpin future pest management.
11d	Conduct surveys to measure public awareness of the need to prevent damage by actively managing browsing mammals, and to measure public attitudes to alternative control techniques.	Continued use of existing techniques or development of new ones is dependent on public acceptability.
11e	Assess the compatibility of conservation policies and management with those of reducing browsing damage.	Control policies must not impact adversely on conservation policies for browsing mammals or native habitats.
11f	Evaluate animal welfare issues associated with proposed control techniques/strategies.	Control methods must be suitably humane to be publicly acceptable.
Objectives and performance criteria		
11g	With input from stakeholders, establish clear objectives for management of possums, pademelons, and wallabies in forest and farmland.	Stakeholder acceptance of management objectives is necessary for ownership and resolution of problem.

Topic ID (from sections 6.1 – 6.5)	Research topic	Justification
11h	Determine the relationship between pest density and damage for forestry and agriculture.	Understanding this relationship will allow the setting of meaningful pest-control targets.
Management strategies and techniques		
11i	Evaluate and rank alternative control strategies to manage browse damage.	Control strategies determine the techniques to be used.
11j	Develop operational monitoring protocols and thresholds to identify the need for control.	Monitoring protocols will identify timing and intensity of control.
11k	Develop models to predict browse patterns by all three targeted browsing mammals.	Current risk models do not sufficiently predict browse damage.
11l	Ensure all aspects of the ecology of all targeted mammals relevant to their browsing and control are covered.	Effective control requires a sound understanding of the ecology of target species.
Implementation		
11m	Use adaptive experimental management to promote the effective use of alternative techniques to 1080.	Need to test techniques and strategies under operational conditions.
11n	Analyse the costs and benefits of managing browse at the enterprise level.	Control is undertaken at the enterprise level so any benefits must accrue there.
11o	Evaluate social constraints on effective management at the enterprise level.	All control programmes must work within existing social constraints.
11p	Develop options for improving information flow to all relevant stakeholders.	Some management solutions are common to both forestry and farming.
11q	Publish guidelines for managing possums, pademelons and wallabies.	Current control techniques and strategies vary in their application and effectiveness.
Monitoring and evaluation		
11r	Design protocols for data collection to monitor animal numbers and damage.	Robust data are needed for ongoing justification of browsing mammal control.

7. Recommendations

This review provides a set of recommended research topics that relate to each of the potential alternatives to 1080 and takes into account economic feasibility, environmental sustainability, and social acceptability. They have been ranked below, based on a range of possible strategic options (local eradication, one-off control, sustained control, and sporadic control) and constraints on the use of techniques (i.e. lethal control with some non-target risks, target-specific lethal control, non-lethal control). However, as well as basing priorities on such strategies and constraints, it is recommended that the Implementation Committee also takes into account the following factors in allocating resources to projects:

- The balance between research effort for forestry and agriculture. Past research has focused predominantly on forestry-related browsing impacts, in contrast to those of agriculture. Consequently, there is less information, experience, and knowledge available to draw on to identify alternatives to 1080 for agricultural protection.
- Whether the research is new or is covered, partly or fully, by existing research programmes (e.g. in the Forestry CRC or Invasive Animals CRC), or whether there might be added value in providing extra support to expedite existing research of particular relevance to Tasmania.
- Long-term versus short-term outputs. Some stakeholders stressed the need for short-term applied research (e.g. TCA); others considered some investment for research in long-term outcomes such

as fertility control is warranted. The Implementation Committee should accept that some short-term solutions are required (even if less than ideal in effectiveness and public acceptability) to enable both the forestry and agricultural industries to continue to operate, until more effective and publicly acceptable options are developed in the longer term.

- The optimal mix of 'research' versus 'demonstration' versus 'extension'. To maximise the benefits of any research, results need to be disseminated to as many end-users as possible. This can be done through using demonstration projects and a range of extension activities. Although some initial research trials might provide potential demonstration sites, these and extension work are more likely to follow on from some initial successes and therefore could be started later in this programme of research.

7.1 Research priorities

The setting of priorities is contingent on the strategy for control and the likelihood that some methods of lethal control will be acceptable to the Tasmanian public. The latter criterion is particularly important because public views appear to have been an important factor in reducing the use of 1080 in Tasmania. The possible constraints on techniques are categorised as follows:

- Category 1: all techniques, including lethal techniques with limited species-specificity, are acceptable. This implies that the full ranges of techniques discussed in this review are options, including toxins other than 1080.
- Category 2: it is acceptable to use non-lethal techniques and strictly species-specific lethal techniques (i.e. lethal techniques that directly affect only wallabies, pademelons and possums). Lethal techniques such as shooting are compatible with this constraint but toxins such as cyanide (Feratox®) are ruled out unless species-specific delivery systems can be developed.
- Category 3: use of non-lethal techniques only. Physical barriers, repellents and deterrents, and fertility control are appropriate techniques, provided they can be used effectively without the need for integration with culling programmes.

In the following tables (12–16), research priorities are ranked for each of the major strategies subject to constraints on the use of some techniques. The rankings are a consensus view of the authors and are based on a combination of criteria: relevance to the management strategy, compatibility with the constraints based on social acceptability, ability to achieve environmental sustainability, level and success of previous research, likelihood of a successful research output within the timeframe of this funding programme, and likelihood of achieving a useful management outcome. Topics that relate to defining the extent of the problem, determining objectives, implementation, monitoring and extension are relevant to all strategic options (Table 12).

Priorities listed in Table 12 reflect the current availability of information to evaluate and manage browse damage in Tasmania. Discussions with stakeholders in April and May 2006 indicated a need for research into quantifying the extent of browse damage at industry and state-wide levels. Exclusive use of non-lethal techniques would address many animal welfare concerns and, with the possible exception of fencing, is likely to have minimal impact on conservation values. It is essential to reach consensus on appropriate goals and strategies for both forestry and agriculture. Current monitoring protocols and knowledge of damage–density relationships are inadequate, particularly for agriculture, and progress towards sustainable strategies for browse management is dependent on continued ecological research. There is considerable scope for using demonstration projects, particularly where new techniques and the integration of existing techniques are employed. The financial and social costs and benefits of managing browse damage, particularly at the level of single-farm enterprises, appear to be poorly understood; research in this area should have high priority. Improved communication of management strategies and techniques is important, and particularly so if alternative toxins are used as direct replacements for 1080.

Table 12 Priorities for research, demonstration and extension on topics not specific to particular strategic options (Priority: E = essential, H = high, M = medium, L = low).

Topic (from Table 11)	Constraint		
	Category 1: Use of all techniques, including lethal techniques with limited species-specificity, are acceptable	**Category 2: Use of non-lethal techniques and strictly species-specific lethal techniques are acceptable**	**Category 3: Use of non-lethal techniques only**
Defining the problem			
11a. State-wide trends	H	H	H
11b. Local monitoring	E	E	E
11c. Industry-wide impact assessment	E	E	E
11d. Public awareness	H	H	H
11e. Compatible policies and outcomes for conservation, agriculture and forestry	H	H	L
11f. Animal welfare issues	H	H	L
Management objectives and performance criteria			
11g. Agreed objectives	E	E	E
11h. Damage-density relationship	H	H	H
Management strategies and techniques			
11i. Agreed strategies	E	E	E
11j. Monitoring protocols and thresholds	H	H	H
11k. Modelling browse risk	M	M	M
11l. Ecological research	H	H	H
Implementation			
11m. Adaptive experimental management	M	H	E
11n. Single-enterprise costs and benefits	E	E	E
11o. Single-enterprise social constraints	H	H	M
11p. Communications	H	H	H
11q. 'Best practice' guidelines	H	H	H
Monitoring and evaluation			
(see 11b and 11j)	E	E	E

7.2 Strategy of 'local eradication'

Given that the species to be controlled are native to Tasmania, a strategy of 'local eradication' could apply only to restricted areas of farmland and to plantations embedded in farmland, and for FT, only within fenced areas (T. Wardlaw pers. comm.). Eradication on any spatial scale is feasible only if a stringent set of conditions can be met (Bomford & O'Brien 1995). Therefore, it is critical that stakeholders are aware of these conditions and agree to this strategy. Also it will be essential to develop a clear specification of the problem, gain public support for the strategy, and establish monitoring programmes to determine if the strategy is successful. Regardless of which category of techniques is used (Table 13), the use of fencing will have high priority for reducing immigration to treated areas; the expense is likely to be justified because the aim is to establish areas permanently free of native browsing animals. Also, some research is needed to support other control strategies for areas where ‘local eradication’ is not appropriate (Tables 14, 15 and 16).

Rationale for priorities given to Category 1 techniques

Alternative toxins have the highest priority because they are most likely to provide a cheap means of achieving substantial, rapid reductions in animal abundance over areas large enough for immigration to be minimal and controllable. High priority should be given to integrating poisoning with other lethal techniques (e.g. contract shooters and kill-trapping) to remove bait-shy animals. Commercial harvesters and recreational hunters are of limited relevance within ‘local eradication’ areas because they are not likely to operate where there are very low numbers of animals, but they could help to prevent immigration from nearby high-density populations. Research into non-lethal techniques is not required for this strategy when effective lethal techniques are available.

Rationale for priorities given to Category 2 techniques

Research into new species-specific toxins and delivery systems has high priority because currently available poisoning techniques are not species-specific. This category would have a heavy reliance on shooting and live-trapping, and use of contract operators in local eradication areas, supported by commercial harvesters and recreational shooters in adjacent areas. Some research into non-lethal techniques, and the integration of some lethal and non-lethal techniques, is justified because the goal of ‘local eradication’ would be difficult to achieve with Category 2 techniques.

Rationale for priorities given to Category 3 techniques

In principle, fertility control could be used to achieve ‘local eradication’ but this would require an ability to impose extremely high levels of infertility (and this appears unlikely); hence research on development of efficient delivery systems would be essential.

Table 13 Research priorities for a strategy of ‘local eradication’. (Priority: E = essential, H = high, M = medium, L = low, N = not recommended, blank = not applicable). Topic numbering follows the numbering in earlier tables, but excludes topics from Table 6.

Topic (summarised from Tables 1–5, 7–10)	Constraint		
	Category 1: Use of all techniques, including lethal techniques with limited species-specificity, are acceptable	**Category 2: Use of non-lethal techniques and strictly species-specific lethal techniques are acceptable**	**Category 3: Use of non-lethal techniques only**
Chemical repellents			
1a. Benefits of products			
1b. Impact of site factors			
1c. Integration			
1d. Public acceptance			
1e. Cost-effectiveness			
Acoustic repellents or deterrents			
2a. Stimuli			
Physical barriers (fences and tree guards)			
3a. Best-practice guidelines	M	M	M
3b. Public acceptance	L	L	L
3c. Permeability of fences	H	H	E
3d. Decision support system	L	L	H
3e. Cost-effectiveness	E	E	E
Fertility control			
4a. Immunocontraception		L	H
4b. Chemosterilants		L	E
4c. Delivery systems		L	E

Topic (summarised from Tables 1–5, 7–10)	Constraint		
	Category 1: Use of all techniques, including lethal techniques with limited species-specificity, are acceptable	**Category 2: Use of non-lethal techniques and strictly species-specific lethal techniques are acceptable**	**Category 3: Use of non-lethal techniques only**
4d. Population modelling		L	H
4e. Public acceptance		N	N
Farm and forestry crop and site practices			
5a. Provenances (forestry)			
5b. Model risk of browse			
5c. Endophytes			
5d. Cover crops			
5e. Provenances (pasture)			
5f. Cost-effectiveness			
Alternative toxins			
7a. Public acceptance	E	E	
7b. Feratox® for pademelons and wallabies	H	N	
7c. Species-specific delivery	H	E	
7d. Target-specific toxins	L	E	
7e. Foliage baiting	L	H	
7f. Cost-effectiveness	E	E	
Trapping and snaring			
8a. Cost-effective trapping	L	H	
8b. Integration	H	H	
8c. Kill trapping	H		
8d. Tunnel nets	L	M	
8e. Predation risk	L	H	
8f. Public acceptance	H	H	
Shooting			
9a. Cost-effectiveness	M	E	
9b. Contract shooters	H	E	
9c. Spotlighting / baiting	M	H	
9d. Neighbourhood coordination	H	H	
9e. Public acceptance	E	E	
Commercial harvesting and the use of bounties			
10a. Economics	M	H	
10b. Constraints	M	H	
10c. Integration	L	H	
10d. Public acceptance	N	M	
10e. Cost-effectiveness	L	M	

7.3 Strategy of short-duration control

A strategy of short-duration (up to 1–2 years in one place), or one-off, control can be used to protect plantations during the establishment phase and could be appropriate for agricultural crops. Research recommendations for this strategy are listed in Table 14. Regardless of constraints on the use of techniques, an ability to predict which areas have high risk of browse damage would be valuable, but commercial harvesting and fertility control are not appropriate if only short-term protection from browse damage is required.

Rationale for priorities given to Category 1 techniques

Poisoning is an established technique for obtaining rapid, effective control of vertebrate pest populations. Therefore, research into alternative toxins has high priority. Other research recommendations for lethal techniques are similar to those for 'local eradication' with Category 1 techniques, with the exception of commercial harvesting, which is irrelevant to short-duration control. Research into 'passive' defence of plantations through techniques such as selection of browse-resistant seedlings and use of cover crops has low-to-medium priority because the strategy of short-duration control does not achieve the permanent solution of 'local eradication'. Research into fencing is not justified, given the assumed access to a wide range of effective lethal techniques.

Rationale for priorities given to Category 2 techniques

The research priorities are broadly similar to those for the use of Category 1 techniques, with two major exceptions. Research to improve the efficiency of lethal techniques switches to species-specific methods and there is increased emphasis on research into non-lethal techniques, including 'passive' defence of plantations and chemical repellents that can be used for rapid effect. Research into the use of low-cost, expendable fencing is appropriate.

Rationale for priorities given to Category 3 techniques

Short-term protection from browse damage will rely on pre-emptive protection (e.g. through the use of browse-resistant plants and cover crops), and the use of physical, chemical and acoustic barriers; hence research in these areas has very high priority.

Table 14 Research priorities for a strategy of one-off or short-duration (<1–2 years) control. (Priority: E = essential, H = high, M = medium, L = low, N = not recommended, blank = not applicable). Topic numbering follows the numbering in earlier tables, but excludes topics from Table 6.

Topic (summarised from Tables 1–5, 7–10)	**Constraint**		
	Category 1: Use of all techniques, including lethal techniques with limited species-specificity, are acceptable	**Category 2: Use of non-lethal techniques and strictly species-specific lethal techniques are acceptable**	**Category 3: Use of non-lethal techniques only**
Chemical repellents			
1a. Benefits of products	L	H	E
1b. Impact of site factors	L	H	H
1c. Integration	L	H	E
1d. Public acceptance	L	L	L
1e. Cost-effectiveness	L	M	H
Acoustic repellents or deterrents			
2a. Stimuli	L	M	H
Physical barriers (fences and tree guards)			
3a. Best-practice guidelines	N	M	H
3b. Public acceptance	N	L	L
3c. Permeability of fences	L	H	E
3d. Decision support system	N	M	H
3e. Cost-effectiveness	L	H	E
Fertility control			
4a. Immunocontraception			
4b. Chemosterilants			
4c. Delivery systems			
4d. Population modelling			
4e. Public acceptance			

Topic (summarised from Tables 1–5, 7–10)	Constraint		
	Category 1: Use of all techniques, including lethal techniques with limited species-specificity, are acceptable	**Category 2: Use of non-lethal techniques and strictly species-specific lethal techniques are acceptable**	**Category 3: Use of non-lethal techniques only**
Farm and forestry crop and site practices			
5a. Provenances (forestry)	M	H	E
5b. Model risk of browse	H	H	E
5c. Endophytes	M	M	H
5d. Cover crops	M	H	H
5e. Provenances (pasture)	L	M	H
5f. Cost-effectiveness	M	H	H
Alternative toxins			
7a. Public acceptance	E	E	
7b. Feratox® for pademelons and wallabies	E	N	
7c. Species-specific delivery	E	E	
7d. Target-specific toxins	M	E	
7e. Foliage baiting	M	M	
7f. Cost-effectiveness	E	E	
Trapping and snaring			
8a. Cost-effective trapping	E	E	
8b. Integration	H	H	
8c. Kill trapping	H		
8d. Tunnel nets	L	M	
8e. Predation risk	L	H	
8f. Public acceptance	H	E	
Shooting			
9a. Cost-effectiveness	E	E	
9b. Contract shooters	E	E	
9c. Spotlighting / baiting	M	M	
9d. Neighbourhood coordination	H	H	
9e. Public acceptance	E	E	
Commercial harvesting			
10a. Economics	N	N	
10b. Constraints	N	N	
10c. Integration	N	N	
10d. Public acceptance	N	N	
10e. Cost-effectiveness	N	N	

7.4 Strategy of sustained control

A strategy of sustained control (Table 15) is required for areas with chronic problems of browse damage. This strategy is appropriate for farmland and plantations of *P. radiata*. Research into the improved use of fencing is appropriate, but development of repellents or deterrents is not justified because of the need for frequent reapplication of chemicals or the high probability of animals becoming habituated to acoustic devices.

Rationale for priorities given to Category 1 techniques

The history of using 1080 poison in Australia and New Zealand has demonstrated that effective, sustained control with toxins is feasible. If alternative toxins can be used, high-priority research should be directed towards demonstrating their cost-effectiveness. Poisoning should be integrated with other potentially cost-efficient lethal techniques such as shooting – either contract, commercial or recreational – to remove bait-shy animals. Some research is appropriate to develop other techniques that could provide effective long-term protection from browse damage, such as fertility control and selection of browse-resistant plant varieties.

Rationale for priorities given to Category 2 techniques

Research priorities are similar to those for Category 1 techniques, except that high priority is given to improving species-specific methods of lethal control (e.g. new toxins and delivery techniques, live-trapping). A reduced range of lethal control options justifies increased emphasis on research into non-lethal techniques.

Rationale for priorities given to Category 3 techniques

Sustained protection from browse damage could be achieved, in principle, with combinations of physical barriers, pre-emptive 'passive' protection (e.g. browse-resistant plant varieties, cover crops in plantations) and fertility control. This requires that high priority be given to research in these areas.

Table 15 Research priorities for a strategy of sustained control. (Priority: E = essential, H = high, M = medium, L = low, N = not recommended, blank = not applicable). Topic numbering follows the numbering in earlier tables, but excludes topics from Table 6.

Topic (summarised from Tables 1–5, 7–10)	**Constraint**		
	Category 1: Use of all techniques, including lethal techniques with limited species-specificity, are acceptable	**Category 2: Use of non-lethal techniques and strictly species-specific lethal techniques are acceptable**	**Category 3: Use of non-lethal techniques only**
Chemical repellents			
1a. Benefits of products	N	N	N
1b. Impact of site factors	N	N	N
1c. Integration	N	N	N
1d. Public acceptance	N	N	N
1e. Cost-effectiveness	N	N	N
Acoustic repellents or deterrents			
2a. Stimuli	N	N	N
Physical barriers (fences and tree guards)			
3a. Best-practice guidelines	H	H	H
3b. Public acceptance	L	L	L
3c. Permeability of fences	H	H	E
3d. Decision support system	M	M	H
3e. Cost-effectiveness	E	E	E
Fertility control			
4a. Immunocontraception	L	M	H
4b. Chemosterilants	L	M	H
4c. Delivery systems	L	H	E
4d. Population modelling	L	M	H
4e. Public acceptance	N	N	N
Farm and forestry crop and site practices			
5a. Provenances (forestry)	M	H	E
5b. Model risk of browse	M	H	H
5c. Endophytes	M	M	H
5d. Cover crops	L	H	H
5e. Provenances (pasture)	L	M	H
5f. Cost-effectiveness	M	H	H
Alternative toxins			
7a. Public acceptance	E	E	
7b. Feratox® for pademelons	E		

Topic (summarised from Tables 1–5, 7–10)	Constraint		
	Category 1: Use of all techniques, including lethal techniques with limited species-specificity, are acceptable	**Category 2: Use of non-lethal techniques and strictly species-specific lethal techniques are acceptable**	**Category 3: Use of non-lethal techniques only**
and wallabies			
7c. Species-specific delivery	M	E	
7d. Target-specific toxins	L	E	
7e. Foliage baiting	M	E	
7f. Cost-effectiveness	E	E	
Trapping and snaring			
8a. Cost-effective trapping	L	H	
8b. Integration	M	M	
8c. Kill trapping	L		
8d. Tunnel nets	L	L	
8e. Predation risk	H	H	
8f. Public acceptance	H	H	
Shooting			
9a. Cost-effectiveness	E	E	
9b. Contract shooters	E	E	
9c. Spotlighting / baiting	M	M	
9d. Neighbourhood coordination	H	H	
9e. Public acceptance	E	E	
Commercial harvesting and the use of bounties			
10a. Economics	E	E	
10b. Constraints	H	H	
10c. Integration	H	H	
10d. Public acceptance	H	H	
10e. Cost-effectiveness	H	H	

7.5 Strategy using 'action-threshold' control

Effective monitoring of browse damage would justify the use of a management strategy where actions are initiated once a damage threshold is reached (Table 16). This strategy could be used for farmland and forestry but would require an ability to respond with techniques that act rapidly. Broad-scale, slow-acting techniques, such as fertility control, or techniques that cannot be applied easily in response to localised damage, are inappropriate.

Rationale for priorities given to Category 1 techniques

Research priorities are essentially the same as those for short-duration control, except that pre-emptive techniques (farm and forestry crop and site practices) are inappropriate. The value of coordination of control effort between neighbouring landowners would depend on the size of the area requiring immediate treatment.

Rationale for priorities given to Category 2 techniques

Compared to Category 1 techniques, restriction to the use of Category 2 techniques requires greater emphasis on research into species-specific lethal methods and rapidly acting non-lethal methods of control. Research into the cost-effectiveness of temporary physical barriers is warranted.

Rationale for priorities given to Category 3 techniques

A restriction to Category 3 techniques for a strategy based on an 'action-threshold' has similar challenges as a strategy based on short-duration control, without the option of using pre-emptive techniques. It will rely on chemical and acoustic barriers, and low-cost, expendable fencing and tree guards.

Table 16 Research priorities for a strategy of sporadic, 'action-threshold' control. (Priority: E = essential, H = high, M = medium, L = low, N = not recommended, blank = not applicable). Topic numbering follows the numbering in earlier tables, but excludes topics from Table 6.

Topic (summarised from Tables 1–5, 7–10)	**Constraint**		
	Category 1: Use of all techniques, including lethal techniques with limited species-specificity, are acceptable	**Category 2: Use of non-lethal techniques and strictly species-specific lethal techniques are acceptable**	**Category 3: Use of non-lethal techniques only**
Chemical repellents			
1a. Benefits of products	M	H	E
1b. Impact of site factors	M	H	H
1c. Integration	M	H	H
1d. Public acceptance	L	L	L
1e. Cost-effectiveness	M	H	H
Acoustic repellents or deterrents			
2a. Stimuli	L	M	H
Physical barriers (fences and tree guards)			
3a. Best-practice guidelines		L	M
3b. Public acceptance		N	L
3c. Permeability of fences		L	H
3d. Decision support system		L	L
3e. Cost-effectiveness		H	E
Fertility control			
4a. Immunocontraception			
4b. Chemosterilants			
4c. Delivery systems			
4d. Population modelling			
4e. Public acceptance			
Farm and forestry crop and site practices			
5a. Provenances (forestry)			
5b. Model risk of browse			
5c. Endophytes			
5d. Cover crops			
5e. Provenances (pasture)			
5f. Cost-effectiveness			
Alternative toxins			
7a. Public acceptance	E	E	
7b. Feratox® for pademelons and wallabies	E		
7c. Species-specific delivery	M	E	
7d. Target-specific toxins	L	E	
7e. Foliage baiting	H	H	
7f. Cost-effectiveness	E	E	
Trapping and snaring			
8a. Cost-effective trapping	E	E	
8b. Integration	H	E	
8c. Kill trapping	H		

Topic (summarised from Tables 1–5, 7–10)	Constraint		
	Category 1: Use of all techniques, including lethal techniques with limited species-specificity, are acceptable	**Category 2: Use of non-lethal techniques and strictly species-specific lethal techniques are acceptable**	**Category 3: Use of non-lethal techniques only**
8d. Tunnel nets	L	L	
8e. Predation risk	H	H	
8f. Public acceptance	E	E	
Shooting			
9a. Cost-effectiveness	E	E	
9b. Contract shooters	E	E	
9c. Spotlighting / baiting	M	M	
9d. Neighbourhood coordination	M	M	
9e. Public acceptance	E	E	
Commercial harvesting and the use of bounties			
10a. Economics	N	N	
10b. Constraints	N	N	
10c. Integration	N	N	
10d. Public acceptance	N	N	
10e. Cost-effectiveness	N	N	

7.6 Summary

An assessment that takes into consideration management strategies and potential constraints on the choice of techniques highlights some of the differences between techniques in allocating research priorities. Alternative toxins have the advantage of simply replacing a proven technique, i.e. 1080. There is scope for improvement, e.g. in developing species-specific delivery systems, and in integrating their use with techniques to remove bait-shy animals. However, given the decision to reduce the use of 1080 in Tasmania (see TCFA document), a strategy of relying on access to toxins would need to be tested for public acceptability. A range of species-specific lethal techniques are available: the value of shooting for controlling possum, pademelon and wallaby populations needs to be quantified and the use of traps appears relatively labour-intensive and limited to small-scale operations at this stage.

The operational value of repellents, deterrents and ‘passive’ defence techniques (e.g. use of browse-resistant plant varieties) is yet to be demonstrated. The priority for research in these areas depends on the likelihood of lethal techniques continuing to have public acceptability. Fencing would be essential for ‘local eradication’ but requires the use of low-cost or portable materials for strategies relying on short-duration, rapid response to browse damage. Research into fertility control has not yet delivered products suitable for testing on the scale required in Tasmania. This technology appears to have high public support and additional research is required to tailor products for use against wallabies and pademelons in Tasmania. However, it is important to note that the results of population modelling have suggested the optimal use of fertility control may require integration with lethal techniques.

7.7 Comparison of recommendations from this review with those of previous reviews

This review is the latest in a series of reviews over the last 10–15 years that have focused mostly on the problem of managing browse damage to forestry; substantially less attention has been given to the impacts of browsing or grazing by native animals on agricultural crops and pasture (Table 17). The purpose of this section is to compare the recommendations stemming from all reviews as an indication of the tractability of the problem and to gauge the extent to which priorities have changed in recent years.

Coleman (1987) and Clunie and Becker (1991) provided comment on the impacts of browsing mammals in forests and farmland and in forests only, respectively, and identified areas of research into techniques for minimising the damage. The review by Parkes et al. (1993) made a series of recommendations for research into aspects of animal browsing damage in plantation forestry in Victoria. Most of these recommendations are relevant to managing the impact of native browsing animals in Tasmanian softwood and hardwood plantations. The following year, Sutherland & Coleman (1994) recommended research projects across six major areas relating to both forestry and agriculture (including one on the ‘specificity of 1080’ that is not relevant to the current review). Their review was followed by another, more comprehensive, review several months later (Coleman 1995), which dealt only with browse damage and mammal control in plantation forests managed by North Forest Products (now Gunns) in northern Tasmania. Also between 1993 and 1998, reviews commissioned by the Browsing Animal Research Council provided recommendations for research into the management of browse damage in Tasmania (summarised in Anon. 1998).

All the previous reviews listed in Table 17 predate the decision to phase out the use of 1080 in Tasmania. Nevertheless, several of these early reviews recommended research into alternatives to 1080 (particularly chemical repellents for plantations, shooting, and to a lesser extent fencing and silvicultural techniques), or alternative presentations of toxic bait (i.e. foliage baiting), either in anticipation of the move against 1080 or recognising that integration of several techniques is required to achieve effective control of browsing mammal populations. Most of the reviews, including this one, have stressed the need for better assessments of the cost of browse damage to forestry and agriculture, and a requirement for monitoring trends in damage and numbers of native browsing mammals. Also, there has been near unanimous support for more ecological research, ranging from the foraging behaviour and movements of browsing animals to their population dynamics: the reasons for damage need to be understood in order to design effective management strategies and techniques. Sutherland & Coleman (1994) stressed the need for well-designed, statistically robust field trials, a view supported by the authors of the current review. Many of the research trials that have been undertaken lack scientific rigour either from an absence of replication, lack of randomisation, no control for confounding effects, or not being run over sufficiently long periods to reflect real operational conditions. To enable robust inferences to be made from research results and thus enable results to be useful to as wide a group of stakeholders as possible, it is essential that good experimental design be followed. It is also essential that the results of research are peer-reviewed for quality control, and published.

Recommendations for some areas of research have changed little since 1993, reflecting the difficult and diverse nature of the management problem. However, due to its terms of reference, the current review is more comprehensive than previous reviews, especially in dealing with issues relating to prevention of damage to agricultural crops and pasture. Several new options have emerged from recent research or offer more promise following recent technical improvements: examples include more targeted delivery systems for toxins, live-capture traps, use of cover crops in plantations, bio-acoustic repellents and fertility control. It is unlikely that additional reviews in the next few years would generate any new areas for research.

Stakeholder support

Most of the topics covered in this review were discussed with stakeholder groups in May 2006 (Table 17), although the focus of those meetings was more on alternatives to 1080 than strategic options for managing browse damage. Most stakeholders agreed there is insufficient quantitative information on trends in the abundance of browsing native mammals and the scope of browse damage to forestry and agriculture; however, all producer groups are convinced the damage is significant and increasing in many areas. There was strong interest by forest and farm managers in new toxins as direct substitutes for 1080, although there was recognition that some effort might be required to gain public support for this form of mammal control. In general, shooting either by contract shooters, commercial harvesters or recreational hunters was seen as a valuable management tool, but the cost-effectiveness of this technique has yet to be established, particularly if it becomes the primary option for lethal control. Apart from stakeholder groups concerned with animal welfare, there was generally less enthusiasm for non-lethal control methods, possibly because these have not had high priority for use, or development, while 1080 poisoning was an acceptable technique. There were mixed views on the balance between short-term and long-term research: some stakeholders insisted research should be directed to technical solutions that can be implemented almost immediately, while others accepted the need for limited investment in research, such as fertility control, that is likely to deliver improved management only in the long term.

Table 17 Comparison of the coverage of research recommendations in this review with those from previous reviews since 1987. Also shown are the recommendations relating to issues discussed with stakeholders in May 2006 (S), and whether the recommendations from the earlier reviews dealt with forestry or agriculture. Review A = Coleman 1987, B = Clunie & Becker 1991, C = Parkes et al. 1993, D = Sutherland & Coleman 1994, E = Coleman 1995, F = summaries of reviews contracted by the Browsing Animal Research Council (Anon. 1998).

Topic (summarised from Tables 1–5, 7–11)	Forestry plantations and regeneration	Agricultural crops and pasture
Chemical repellents		
1a. Benefits of products	S, C, D, F	S
1b. Impact of site factors	S	
1c. Integration	S	S
1d. Public acceptance	S	S
1e. Cost-effectiveness	S	
Acoustic repellents or deterrents		
2a. Stimuli	S	S
Physical barriers (fences and tree guards)		
3a. Best-practice guidelines		S
3b. Public acceptance	S	S
3c. Permeability of fences	S	S, D
3d. Decision support system		
3e. Cost-effectiveness	S, F	S, D
Fertility control		
4a. Immunocontraception	S	S
4b. Chemosterilants	S	S
4c. Delivery systems		
4d. Population modelling	S	S
4e. Public acceptance	S	S
Farm and forestry crop and site practices		
5a. Provenances (forestry)	S, C	
5b. Model risk of browse	S, B	
5c. Endophytes		
5d. Cover crops	S, B, C	
5e. Provenances (pasture)		
5f. Cost-effectiveness	S	
Alternative toxins		
7a. Public acceptance	S	S
7b. Feratox® for pademelons and wallabies	S, D, E	S, D
7c. Species-specific delivery	S, C, D, E, F	S, D, F
7d. Target-specific toxins	S, A	S
7e. Foliage baiting	A, B, D, E	
7f. Cost-effectiveness	S	S
Trapping and snaring		
8a. Cost-effective trapping	S	S
8b. Integration	S	

Topic (summarised from Tables 1–5, 7–11)	Forestry plantations and regeneration	Agricultural crops and pasture
8c. Kill trapping	S, D	D
8d. Tunnel nets	S	
8e. Predation risk	S	
8f. Public acceptance	S	S
Shooting		
9a. Cost-effectiveness	S, C, E	S
9b. Contract shooters	S	S
9c. Spotlighting / baiting	S	S
9d. Neighbourhood coordination	F	S
9e. Public acceptance	S, E	S
Commercial harvesting and the use of bounties		
10a. Economics	S, F	S
10b. Constraints	S	S
10c. Integration	S	S
10d. Public acceptance	S	S
10e. Cost-effectiveness		S
Defining the problem		
11a. State-wide trends	S, C, F	S, F
11b. Local monitoring	S, A, B, C, E	S
11c. Industry-wide impact assessment	S, C, E, F	S, F
11d. Public awareness	S, E, F	S, F
11e. Compatible policies and outcomes for conservation, agriculture and forestry	S	S
11f. Animal welfare issues	S	S
Management objectives and performance criteria		
11g. Agreed objectives		
11h. Damage-density relationship	S, C, D	S, D
Management strategies and techniques		
11i. Agreed strategies		
11j. Monitoring protocols and thresholds	S, C, E	S
11k. Modelling browse risk	S, C, D	S, D
11l. Options for implementing shooting	S	S
11m. Ecological research	S, A, C, D, E, F	S, D, F
Implementation		
11n. Adaptive experimental management		S
11o. Single-enterprise costs and benefits	S	S
11p. Single-enterprise social constraints		S
11q. Communications network	S, E	S
11r. Best-practice guidelines		
Monitoring and evaluation		
(see 11b and 11j)		

8. Acknowledgements

We thank John Dawson for his assistance in all spheres of this work. Representatives of all key stakeholder groups interviewed directly or contacted indirectly, along with M. Johnston of the Arthur Rylah Institute for Environmental Research, gave freely of their time and information, without which this work would not have prospered. Phil Cowan, Penny Fisher and Christine Bezar provided editorial comment; Tanja Webster undertook keyword literature searches; and Wendy Weller carried out the final word processing.

9. References

Allen D 1992. Blackwood plantations in Tasmania. Tasmanian NRCP Technical Report No. 8, Forestry Commission, Tasmania, and Department of the Arts, Sport, the Environment, Tourism and Territories, Canberra. 88 p.

Allen LR, Sparkes EC 2001. The effect of dingo control on sheep and beef cattle in Queensland. Journal of Applied Ecology 38: 76–87.

Andelt WF, Burnham KP, Manning J 1991. Relative effectiveness of repellents for reducing mule deer damage. Journal of Wildlife Management 55: 341–347.

Andelt WF, Burnham KP, Baker DL 1994. Effectiveness of capsaicin and Bitrex repellents for deterring browsing by captive mule deer. Journal of Wildlife Management 58: 330–334.

Anonymous 1998. Browsing Animal Research Council final report. Department of Primary Industry and Fisheries, Kings Meadows, Tasmania. 48 p.

Apfelbach R, Blanchard CD, Blanchard RJ, Hayes RD, McGregor IS 2005. The effects of predator odors in mammalian prey species: a review of field and laboratory studies. Neuroscience and Biobehavioural Reviews 29: 1123–1144.

Arthur AD, Pech RP, Singleton GR 2005. Predicting the effect of virally vectored recMCMV immunocontraception on house mice (*Mus musculus domesticus*) in mallee wheatlands. Wildlife Research 32: 631–637.

Arulchelvum M, Parkes JP 1994. Predicting browse damage to seedlings on stocking-rate plots from analysis of site factors. Landcare Research Contract Report LC9495/50 to Victorian Browsing Co-operative, Morwell, Victoria (unpubl.). 27 p.

Australian Bureau of Statistics 2006. hhttp://www.abs.gov.au/AUSSTATS/abs

Barlow ND 1994. Predicting the effect of a novel vertebrate biocontrol agent: a model for viral-vectored immunocontraception of New Zealand possums. Journal of Applied Ecology 31: 454–462.

Barlow ND 1997. Modelling immunocontraception in disseminating systems. Reproduction, Fertility and Development 9: 51–60.

Barlow ND, Kean JM, Briggs CJ 1997. Modelling the relative efficacy of culling and sterilisation for controlling populations. Wildlife Research 24: 129–141.

Bassett O, DeLeeuw B, McKenzie L 2002. An operational trial of guards for the protection of planted *E. globulus* seedlings from browsing on the Stanley Plateau, Victoria. In: Bassett OD ed. Proceedings of the South-Eastern Australia Native Forest Browsing Workshop, Ballarat, Victoria, 27–29 April 1999. East Melbourne, Department of Natural Resources and Environment. Pp. 55–57.

Bayliss P, Choquenot D 1999. Ecological modelling and possum biocontrol in New Zealand. In: Sutherland G ed. Advances in the biological control of possums. Royal Society of New Zealand Miscellaneous Series 56: 19–23.

Bender H 2003. Deterrence of kangaroos from agricultural areas using ultrasonic frequencies: efficacy of a commercial device. Wildlife Society Bulletin 31: 1036–1046.

Bender H 2005. Effectiveness of the eastern grey kangaroo foot thump for deterring conspecifics. Wildlife Research 32: 649–655.

Bender H 2006. Structure and function of the eastern grey kangaroo (*Macropus giganteus*) foot thump. Journal of Zoology 268: 415–422.

Blumstein DT, Daniel JC, Griffin AS, Evans CS 2000. Insular tammar wallabies (*Macropus eugenii*) respond to visual but not acoustic cues from predators. Behavioural Ecology 11: 528–535.

Bomford M, O’Brien PH 1990. Sonic deterrents in animal damage control: a review of device tests and effectiveness. Wildlife Society Bulletin 18: 411–422.

Bomford M, O’Brien P 1995. Eradication or control for vertebrate pests? Wildlife Society Bulletin 23: 249–255.

Boswell S 1992. Shooting and other control methods. In: Foran B ed. Rabbit managers’ fact pack. Lincoln, New Zealand, MAF. 2 p.

Braysher M 1993. Managing vertebrate pests: principles and strategies. Canberra, Bureau of Resource Sciences, Australian Government Publishing Service. 58 p.

Brockie RE 1982. Effect of commercial hunters on the number of possums, *Trichosurus vulpecula,* in Orongorongo Valley, Wellington. New Zealand Journal of Ecology 5: 29–35.

Bulinski J 2000. Relationships between herbivore abundance and browsing damage in Tasmanian eucalypt plantations. Australian Forestry 63: 181–187.

Bulinski J, McArthur C 1999. An experimental field study of the effects of mammalian herbivore damage on *Eucalyptus nitens* seedlings. Forest Ecology and Management 113: 241–249.

Bulinski J, McArthur C 2000. Spatial distribution of browsing damage and mammalian herbivores in Tasmanian eucalypt plantations. Australian Forestry 63: 27–33.

Bulinski J, McArthur C 2003. Identifying factors related to the severity of mammalian browsing damage in eucalypt plantations. Forest Ecology and Management 183: 239–247.

Burton D 2004. Executive summary of fodder crops in Tasmania. Mammal Browsing Research file note (unpubl.) No. 62363. 6 p.

Butcher S 2000. Impact of possums on primary production. In: Montague TL ed. The brushtail possum: biology, impact and management of an introduced marsupial. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 105–110.

Callister DJ 1991. A review of the Tasmanian brushtail possum industry. TRAFFIC Bulletin 12: 49–58.

Carey PW, O’Connor CE, McDonald RM, Matthews LR 1997. Comparison of the attractiveness of acoustic and visual stimuli for brushtail possums. New Zealand Journal of Zoology 24: 273–276.

Caughley G 1987. Ecological relationships. In: Caughley G, Shepherd N, Short J eds. Kangaroos: their ecology and management in the sheep rangelands of Australia. Cambridge, UK, Cambridge University Press. Pp. 159–187.

Caughley G, Pech R, Grice D 1993. Effect of fertility control on a population's productivity. Wildlife Research 19: 623–627.

Challies CN 1984. Deer control and vegetation response on Stewart Island. What’s New in Forest Research 126. 4 p.

Choquenot D, McIlroy J, Korn T 1996. Managing vertebrate pests: feral pigs. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra. 163 p.

Choquenot D, Parkes J 2000. Development of decision support systems for possum management. In: Montague TL ed. The brushtail possum: biology, impact and management of an introduced marsupial. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 271–277.

Choquonot D, Warburton B 2006. Modelling the cost-effectiveness of wallaby control in New Zealand. Wildlife Research 33: 77–83.

Close DC, McArthur C, Pietrzykowski, E, Fitzgerald H, Paterson S 2002. Field browsing resistance of shining gum and Tasmanian blue gum seedlings raised under different nutrient regimes in the nursery. CRC for sustainable Production Forestry Technical Report No. 96.

Clout MN, Barlow ND 1982. Exploitation of brushtail possum populations in theory and practice. New Zealand Journal of Ecology 5: 29–35.

Clunie P, Becker S 1991. The problem of browsing animals in eucalypt/pine forest establishment, and research into techniques for minimising damage. Lands and Forests, Victoria Department of Conservation and Environment, Technical report 6. Melbourne. 121 p.

Coleman JD 1987. Wild animals control in Tasmania – a synopsis of current research and management problems and techniques. Forestry Research Centre, Christchurch, file note to Tasmanian Department of Agriculture, Hobart (unpubl.). 4 p.

Coleman JD 1995. North Forest Products vertebrate pest control programme: strengths and weaknesses. Landcare Research Contract Report LC9495/63 to North Forest Products, Hobart (unpubl.). 21 p.

Coleman JD 1997. Acceptability and lethality of cereal bait containing brodifacoum to Bennett's wallaby – a pilot trial. Landcare Research Contract Report LC9697/084 for Animal Control Products, Wanganui (unpubl.). 11 p.

Coleman JD, Tyson P 1994. Re-evaluation of the Po-guard ultrasonic device as a deterrent for possums. Landcare Research Contract report LC9394/98 to Shu-Roo (Aust) Pty, Indooropilly (unpubl.). 9 p.

Coleman JD, Montague TL, Eason CT, Statham HL 1996. A manual for the management of problem browsing and grazing mammals in Tasmania. Landcare Research Contract Report LC9596/106 to the Browsing Animal Research Council, Hobart (unpubl.). 73 p.

Coleman M 1991. An overview of tree guards. Trees and Natural Resources 33: 29–30.

Coman BJ 1994. A review of methods for the mitigation of browsing damage in Tasmania. Vernox Pest Management report to the Browsing Animal Review Committee, Hobart (unpubl.). 44 p.

Coulson G 1997. Repertoires of social behaviour in captive and free-ranging grey kangaroos, *Macropus giganteus* and *Macropus fuliginosus* (Marsupialia: Macropodidae). Journal of Zoology, London 242: 119–130.

Cowan P 2000. Biological control of possums: prospects for the future. In: Montague TL ed. The brushtail possum: biology, impact and management of an introduced marsupial. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 262–270.

Cowan P, Clout M 2000. Possums on the move: activity patterns, home ranges, and dispersal. In: Montague TL ed. The brushtail possum – biology, impact and management of an introduced marsupial. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 24–34.

Cowan P, Pech R, Curtis P 2003. Field applications of fertility control for wildlife management. In: Holt WV, Pickard AR, Rodger JC, Wildt DE eds. Reproductive science and integrated conservation, Conservation Biology 8. Cambridge University Press, UK. Pp. 305–318.

Cremer KW 1969. Browsing of mountain ash regeneration by wallabies and possums in Tasmania. Australian Forestry 33: 201–210.

Cremer KW, Mount AB 1965. Early stages of plant succession following the complete felling and burning of *Eucalyptus regnans* forest in the Florentine Valley, Tasmania. Australian Journal of Botany 13: 303–322.

Davis SA, Pech RP 2002. Dependence of population response to fertility control on the survival of sterile animals and their role in regulation. Reproduction Supplement 60: 89–103.

Dearing MD, Foley WJ, McLean S 2005. The influence of plant secondary metabolites on the nutritional ecology of herbivorous terrestrial vertebrates. Annual Review of Ecology and Systematics 36: 169–189.

Department of Primary Industries, Water and Environment 2000. Code of practice for capture, handling, transport and slaughter of brush-tail possums (*Trichosurus vulpecula*). Animal Welfare Standard – Tasmania No 12. Animal Welfare Advisory Committee, Department of Primary Industries, Water and Environment, Tasmania. 11 p.

Department of Primary Industries 2005. Evaluation of the 2002/03 Victorian fox bounty trial. Frankston, Primary Industries Research Victoria, Department of Primary Industries. 34 p.

Department of the Environment and Heritage 2006a. Management program for the brushtail possum *Trichosurus vulpecula* (Kerr) in Tasmania – Review of background information. http://www.deh.gov.au/biodiversity/trade-use/wild-harvest/possum, Accessed 1 June 2006.

Department of the Environment and Heritage 2006b. Commercial and non-commercial wallaby harvest quotas for Tasmania (1 July 2005 – 30 June 2006) http://www.deh.gov.au/biodiversity/trade-use/wild-harvest/kangaroo/quota/2006-wallaby.html.

Department of the Environment and Heritage 2006c. Background information: commercial kangaroo and wallaby harvest quotas. http://www.deh.gov.au/biodiversity/trade-use/publications/kangaroo/pubs/2006-commercial-harvest-quotas.pdf, Accessed 8 June 2006.

Dix GI, Jolly SE, Bufton LS, Gardiner AL 1994. The potential of electric shock for the humane trapping of brushtail possum (*Trichosurus vulpecula*). Wildlife Research 21: 49–52.

Dobbie WR, Berman DMcK, Braysher ML 1993. Managing vertebrate pests: feral horses. Canberra, Bureau of Resource Sciences, Australian Government Publishing Service. 123 p.

Donaghy D, Tegg R 2001. Report on effects of wildlife on pasture growth at Elliott Research and Demonstration station, 2000-2001. Tasmanian Institute of Agricultural Research, Birnie. 8 p.

Driessen MM 1992. Effects of hunting and rainfall on Bennett's wallaby and Tasmanian pademelon populations. Hobart, Tasmania, Parkes and Wildlife Service. 175 p.

Driessen MM, Hocking GJ 1992. Review and analysis of spotlight surveys in Tasmania: 1975-1990. Report funded by the Australian National parks and Wildlife Service under the States Co-operative Assistance program. Tasmania, Department of Parks, Wildlife and Heritage. 65 p.

Duckworth JA, Byrom AE, Fisher P, Horn C 2006. Pest control: does the answer lie in new biotechnologies? In: Allen RB, Lee WG eds. Biological invasions in New Zealand. Berlin Heidelberg, Springer. Pp. 421–434.

Eason CT, Henderson RJ 1991. The identification and development of alternative toxins to 1080 for possums. Forest Research Institute Contract Report FRI 91/48 to the Animal Health Board (unpubl.). 5 p.

Eason CT, Hickling GJ 1992. Evaluation of a bio-dynamic technique for possum pest control. New Zealand Journal of Ecology 16: 141–144.

Eason CT, Jolly SE 1992. Alternative toxins to 1080 for possums (July 1991–July 1992). Forest Research Institute Contract Report FRI 92/32 to the Animal Health Board (unpubl.). 14 p.

Eason CT, Munday R 1995. Trans-dermal toxins for possums. Landcare Research Contract Report LC9495/122 to Hort-Research, Ruakura (unpubl.). 8 p.

Eason CT, Gooneratne R, Rammell CG 1994. A review of the toxicokinetics and toxicodynamics of sodium monofluoroacetate in animals. In: Seawright AA, Eason CT eds Proceedings of the science workshop on 1080. The Royal Society of New Zealand Miscellaneous series 28: 82–89.

Efford M, Warburton B, Spencer N 2000. Home-range changes by brushtail possums in response to control. Wildlife Research 27: 117–127.

FAAST 2003. Feral Animal Aerial Shooting Team. NSW National Parkes and Wildlife Service, Murrumbidgee College of Agriculture, Yanco, NSW.

Fagerstone KA 2002. Professional use of pesticides in wildlife management – an overview of professional wildlife damage management. Proceedings of the 20th Vertebrate Pest Conference, Reno, Nevada. Pp. 253–260.

Fagg PC 2002. Control of browsing in Victorian State forests: past and present. In: Bassett OD ed. Proceedings of the South-Eastern Australia Native Forest Browsing Workshop, Ballarat, Victoria 27–29 April 1999. Department of Natural Resources and Environment, East Melbourne. Pp. 7–14.

Fairbridge D, Marks C 2005: Evaluation of the 2002/03 Victorian fox bounty trial. Frankston, Vertebrate Pest Research Unit, Department of Primary Industries.

FAO 2006. Preliminary review of biotechnology in forestry, including genetic modification. Http://www.fao.org/docrep/008/ae574e/AE574E06.htm

Fitzgerald G, Wilkinson R, Saunders L 2000. Public perceptions and issues in possum control. In: Montague TL ed. The brushtail possum: biology, impact and management of an introduced marsupial. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 187–197.

Forsyth DM, Parkes JP 2004. Maximising the conservation benefits of the commercial goat industry in Australia. Arthur Rylah Institute for Environmental Research report to Department of the Environment and Heritage. 79 p.

Freudenberger D 1995. Separating the sheep from the roos: do we know the difference? In: Grigg GC, Hale D, Lunney D eds Conservation through sustainable use of wildlife Centre for Conservation Biology, University of Queensland.

Gibson CP, Wilson SP, Monamy V 2004. An assessment of animal repellents in the management of vehicle-macropod collisions. Conference of the Ecological Society of Australia, Adelaide.

Gilbert JM 1961. The effects of browsing by native animals on the establishment of seedlings of *Eucalyptus regnans* in the Florentine Valley, Tasmania. Australian Forestry 25: 116–121.

Gilsdorf JM, Hygnstrom SE, VerCauteren KC, Clements GM, Blankenship EE, Engeman RM 2004. Evaluation of a deer-activated bio-acoustic frightening device for reducing deer damage in cornfields. Wildlife Society Bulletin 32: 515–523.

Grandy JW, Rutberg AT 2002. An animal welfare view of wildlife contraception. Reproduction Supplement 60: 1–7.

Gregory GG 1989. The control of wallaby pest species. MSc thesis, University of Tasmania, Hobart. Pp. 208–214.

Griffith A 1985. Economics of wild animal control/management in production forests. Wild animal management – changing emphasis towards the 1990s. Forestry Training Centre report, Rotorua (unpubl.). Pp. 79–88.

Harden RH, Robertshaw JD 1987. Human predation on the dingo. Australian Zoologist 24: 65–72.

Hassall and Associates P/L 1998. Economic evaluation of the role of bounties in vertebrate pest management. Canberra, Bureau of Resource Sciences.

Haydock N, Eason CT 2001. Vertebrate pesticide toxicology manual (poisons). Department of Conservation Technical Series 23, Department of Conservation, Wellington, New Zealand. 122 p.

Herbert CA, Trigg TE, Renfree MB, Shaw G, Eckery DC, Cooper DW 2005. Long-term effects of deslorelin implants on reproduction in the female tammar wallaby (*Macropus eugenii*). Reproduction 129: 361–369.

Hobbs NT, Bowden DC, Baker DL 2000. Effects of fertility control on populations of ungulates: general, stage-structured models. Journal of Wildlife Management 64: 473–491.

Holling CS 1978. Adaptive environmental assessment and management. Wiley International series on Applied Systems Analysis 3. New York, Wiley. 377 p.

Hone J 1994. Analysis of vertebrate pest control. Cambridge, Cambridge University Press. 258 p.

Hood GM, Chesson P, Pech RP 2000. Biological control using sterilising viruses: Host suppression and competition between viruses in non-spatial models. Journal of Applied Ecology 37: 914–925.

Howard KF 1978. Electric fencing controls wallabies. Queensland Agricultural Journal 104: 237–238.

ISO 1999. Animal (mammal) traps – Part 5: Methods for testing restraining traps. Geneva, Switzerland, International Organisation of Standardization ISO 10990-5. 20 p.

Jackson RJ, Maguire DJ, Hinds LA, Ramshaw IA 1998. Infertility in mice induced by a recombinant ectromelia virus expressing mouse zona pellucida glycoprotein 3. Biology of Reproduction 58: 152–169.

Jacobs WW 2002. Current issues with vertebrate pesticides – from a regulators perspective. Proceedings of the 20th Vertebrate Pest Conference, Reno, Nevada. Pp. 261–266.

Jennings S 2003. Alternative fencing materials for blackwood swamp coupes. Tasforests 14: 31–40.

Jennings S, Dawson J 1998. Fencing eucalypt coupes for blackwood regeneration. Tasforests 10: 103–113.

Johnson KA 1983. Red-necked pademelon. In: Strahan R ed. Complete book of Australian mammals. Sydney, Angus & Robertson. P. 228.

Johnson KA, Rose R 1983. Tasmanian pademelon. In: Strahan R ed. Complete book of Australian mammals. Sydney, Angus & Robertson. P. 226.

Johnston MJ, Marks CA 1997. Attitudinal survey on vertebrate pest management in Victoria. Report Series Number 3, Department of Natural Resources and Environment, Victoria. 35 p.

Johnston MJ, Marks CA, Moore SJ, Fisher PM, Hague N 1998. WR-1 and AD-3 browsing repellents: a journey from problem to product. Proceedings of the 11th Australian Vertebrate Pest Conference, Bunbury, Western Australia. Pp. 305–311.

Johnston P, Fletcher M 1998. Do fungi influence leaf palatability to browsing possums? He Korero Paihama – Possum Research News 10: 8–9.

Kimball BA, Nolte DL 2006. Development of a new deer repellent for the protection of forest resources. Western Journal of Applied Forestry 21: 108–111.

Kinnear JE, Bromilow RN, Onus ML, Sokolowski RES 1988. The Bromilow trap: a new risk-free trap suitable for small to medium-sized macropodids. Australian Wildlife Research 15: 235–237.

Kitchener AL, Edds LM, Molinia FC, Kay DJ 2002. Porcine zonae pellucidae immunization of tammar wallabies (*Macropus eugenii*): fertility and immune responses. Reproduction, Fertility and Development 14: 215–223.

Law M 2005. Evaluation of non-1080 non-lethal techniques for commercial control of marsupial herbivores. Report to Tasmanian Conservation Trust, Hobart. 8 p.

Le Mar K, McArthur C 2001. Changes in marsupial herbivore densities in relation to a forestry 1080-poisoning operation. Australian Forestry 64: 175–180.

Le Mar K, McArthur C 2002. How do marsupial herbivores use the forestry environment in Tasmania & what does this mean for managing browsing damage? Cooperative Research Centre for Sustainable Production Forestry Technical Report 95. Hobart. 40 p.

Le Mar K, McArthur C 2005. Comparison of habitat selection by two sympatric macropods, *Thylogale billardierii* and *Macropus rufogriseus rufogriseus*, in a patchy eucalypt-forestry environment. Austral Ecology 30: 674–683.

Lentle RG, Potter MA, Springett BP, Stafford KJ 1997. A trapping and immobilisation technique for small macropods. Wildlife Research 24: 373–377.

Long K, Robley A 2004. Cost effective feral animal exclusion fencing for areas of high conservation value in Australia. Report to the Department of the Environment and Heritage, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg (unpubl.). 54 p.

Lloyd ML, Shellam GR, Papadimitriou JM, Lawson MA 2003: Immunocontraception is induced in BALB/c mice inoculated with murine cytomegalovirus expressing mouse zona pellucida 3. Biology of Reproduction 68: 2024–2032.

Marks CA, Fisher P, Moore S, Hague N 1995. Techniques for the mitigation of plantation seedling damage by the European rabbit (*Oryctolagus cuniculus*) and swamp wallaby (*Wallabia bicolor*). Proceedings of the 10th Australian Vertebrate Pest Control Conference, Hobart, Tasmania. Pp. 155–160.

Mason JR 1998. Mammal repellents: options and considerations for development. In: Baker RO, Crabb AC eds Proceedings of the 18th Vertebrate pest Conference. University of California, Davis. Pp. 325–29.

Mason JR, Hollick J, Kimball BA, Johnston JJ 1999. Repellency of Deer Away Big Game Repellent® to eastern cottontail rabbits. Journal of Wildlife Management 63: 309–314.

Mason G, Litten KE 2003. The humaneness of rodent pest control. Animal Welfare 12: 1–37.

Masters P, Duka T, Berris S, Moss G 2004. Koalas on Kangaroo Island: from introduction to pest status in less than a century. Wildlife Research 31: 267–272.

Mate KE, Hinds LA 2003. Contraceptive vaccine development. In: Holt WV, Pickard AR, Rodger JC, Wildt DE eds Reproductive science and integrated conservation, Conservation Biology 8. Cambridge University Press, UK. Pp. 291–304.

McArthur C, Turner S 1997. Feeding preferences of captive brushtail possums for eucalypt and acacia foliage. Tasforests 9: 155–162.

Merrill JA, Cooch EG, Curtis PD 2006. Managing an overabundant deer population by sterilization: effects of immigration, stochasticity and the capture process. Journal of Wildlife Management 70: 268–277.

Miller AM, McArthur C, Smethurst PJ 2006a. Characteristics of tree seedlings and neighbouring vegetation have an additive influence on browsing by generalist herbivores. Forest Ecology and Management 228: 197–205.

Miller AM, McArthur C, Smethurst PJ, Wang SF 2006b. Preferences of two mammalian herbivores for tree seedlings and potential cover crops in plantation forestry. Australian Forestry 69: 114–121.

Montague TL 1993. An assessment of the ability of tree guards to prevent browsing damage using captive swamp wallabies (*Wallabia bicolor*). Australian Forestry 56: 145–147.

Montague T 2000. Hairy pests and plantations. New Zealand Tree Grower, May. P. 21.

Montague T 2001. Plant protection and repellents. New Zealand Tree Grower, February. P. 25.

Montague T, Warburton B 2000. Non-toxic techniques for possum control. In: Montague TL ed. The brushtail possum – biology, impact and management of an introduced marsupial. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 164–174.

Montague TL, Pollock DC, Wright W 1990. An examination of the browsing animal problem in Australian eucalypt and pine plantations. Proceedings of the 14th Vertebrate Pest Conference, University of California, Davis. Pp. 203–208.

Moran S 1996. Efficacy of the repellent RO-PEL® in reducing damage by the rock hyrax (Procavia capensis) to fruit trees. International Journal of Pest Management 42: 273–276.

Morgan D 2006. An introduction to long-life odour release technology for vertebrate pest management. Landcare Research file note, Lincoln, New Zealand (unpubl.). 15 p.

Morgan D, Hickling G 2000. Techniques used for poisoning possums In: Montague TL ed. The brushtail possum – biology, impact and management of an introduced marsupial. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 143–153.

Morgan DR, Woolhouse AD 1997. Predator odors as repellents to brushtail possums and rabbits. In: Mason JR ed. Repellents in wildlife management: proceedings of a symposium. National Wildlife Research Centre, Fort Collins, Colorado, 1997. Pp. 241–252.

Morgan DR, Milne L, O’Connor C 2002. Learned bait-shyness by possums (*Trichosurus vulpecula*) towards baits containing cyanide, 1080, cholecalciferol, or brodifacoum. Proceedings of the 20th Vertebrate Pest Conference, Reno, Nevada. Pp. 282–289.

Morriss GA, O’Connor CE 2001. Palatability of Feracol® for dama wallaby (*Macropus eugenii*) control. Conservation Advisory Science notes 340. Department of Conservation, Wellington. 3 p.

Morriss GA, O’Connor CE, Warburton B, Eason CT 2000a. Alternative toxicants for dama wallaby (*Macropus eugenii*) control. Landcare Research Contract Report LC9900/81 to the Animal Health Board (unpubl.). 11 p.

Morriss GA, Warburton B, Ruscoe WA 2000b. Comparison of the capture efficiency of a kill-trap set for brushtail possums that excludes ground-birds, and ground set leg-hold traps. New Zealand Journal of Zoology 27: 201–206.

Muirhead A 2004. Mammal browsing in Tasmanian native forest regeneration. Forestry Tasmania discussion paper 27, Hobart. 26 p.

Muirhead S, Blache D, Wykes B, Bencini R 2006. Roo-Guard® sound emitters are not effective at deterring tammar wallabies (*Macropus eugenii*) from a source of food. Wildlife Research 33: 131–136.

National Possum Control Agencies 2006a. A guideline for using leghold traps to trap small mammals. Wellington. 17 p.

National Possum Control Agencies 2006b. A guideline for improving the welfare of trapped vertebrate pests in New Zealand. Wellington. 21 p.

National Possum Control Agencies 2006c. A guideline for using kill traps to trap small mammals. Wellington. 21 p.

Nave CD, Coulson G, Poiani A, Shaw G, Renfree MB 2002: Fertility control in the eastern grey kangaroo using levonorgestrel implants. Journal of Wildlife Management 66: 470–477.

Nielsen L 1988. Definitions, considerations, and guidelines for the translocation of wild animals. In: Nielsen L, Brown RD eds Translocation in wild animals. Wisconsin Humane Society, Milwaukee.

Neilsen WA, Wilkinson GR 1995. Browsing damage, site quality and species selection – a case study of their effects on the economic viability of eucalypt plantations in north-eastern Tasmania. Proceedings of the 10th Australian Vertebrate Pest Control Conference, Hobart. Pp. 161–170.

Neyland M, Jennings S 2002. Browsing management in native forest regeneration in Tasmania. In: Bassett OD ed. Proceedings of the South-Eastern Australia Native Forest Browsing Workshop, Ballarat, Victoria, 27–29 April 1999. East Melbourne, Department of Natural Resources and Environment. Pp. 161–170.

Nolte DL, Wagner KK 2000. Comparing the efficacy of delivery systems and active ingredients of deer repellents. In: Salmon TP, Crabb AC eds Proceedings of the 19th Vertebrate pest Conference. University of California, Davis. Pp. 93–100.

Norton GA 1988. Philosophy, concepts and techniques. In: Norton GA, Pech RP eds Vertebrate pest management in Australia. A decision analysis/systems analysis approach. Project Report No. 5. CSIRO Division of Wildlife and Ecology, Australia. Pp. 1–17.

Nugent G, Choquenot D 2004. Comparing cost-effectiveness of commercial harvesting, state-funded culling, and recreational deer hunting in New Zealand. Wildlife Society Bulletin 32: 481–492.

O'Connor C, Warburton B, Fisher M 2005. Ethics and the killing of wild sentient animals. Proceedings of the 13th Australasian vertebrate pest conference, Wellington, New Zealand. Pp. 203–207.

O'Connor CE, Litten KE, Milne LM, Airey AT, Webster R, Arthur DG, Eason CT in press. Behavioural, biochemical, and pathological responses of possums poisoned with phosphorus paste. New Zealand Veterinary Journal.

Olsen P 1998. Australia's pest animals: new solutions to old problems. Bureau of Resource Sciences. Sydney, Kangaroo Press. 160 p.

O'Reilly-Wapstra JM, McArthur C, Potts BM 2002. Genetic variation in resistance of *Eucalyptus globulus* in marsupial browsers. Oecologia 130: 289–296.

O'Reilly-Wapstra JM, Potts BM, McArthur C, Davies NW 2005. Effects of nutrient variability on the genetic based resistance of *Eucalyptus globulus* to a mammalian herbivore and on plant defensive chemistry. Oecologia 142: 597–605.

Parkes JP 1983. Control of feral goats by poisoning with compound 1080 on natural vegetation baits and by shooting. New Zealand Journal of Forestry Science 13: 266–274.

Parkes J 1991. Pest management for conservation in New Zealand. Forest Research Institute Contract Report FEW 91/10 to the Department of Conservation, Wellington (unpubl.). 28 p.

Parkes JP 2003. Report of the 30th meeting of the Vertebrate Pest Committee, Alice Springs, May 2003. Landcare Research Contract Report LC0203/131 to the Ministry of Agriculture and Forestry, New Zealand (unpubl.). 9 p.

Parkes JP 2006. Does commercial harvesting of introduced wild mammals contribute to their management as conservation pests? In: Allen RB, Lee WG eds Biological invasions in New Zealand. Ecological Studies Vol. 186. Berlin, Springer-Verlag. Pp. 407–418.

Parkes JP, Coker RJ, Warburton B 1993. A review of the animal browsing problem in Australian paper manufacturer's plantation forests in Victoria. Landcare Research Contract Report LC9293/33 to APM Forests Pty, Morwell, Australia (unpubl.). 58 p.

Parkes J, Henzell R, Pickles G 1996. Managing vertebrate pests: feral goats. Canberra, Bureau of Resource Sciences and Australian Nature Conservation Agency, Australian Government Publishing Service. 129 p.

Parkes JP, Choquenot D, McGlinchy A, Drew K, Forsyth DM, Kean A, Green B 2006a. Optimising the maintenance control of possums through adaptive management: V. Final reports of the establishment phase. Landcare Research Contract Report LC0506/090 to the Department of Conservation. 22 p.

Parkes JP, Robley A, Forsyth DM, Choquenot D 2006b. Adaptive management experiments in vertebrate control in New Zealand and Australia. Wildlife Society Bulletin 34: 229–236.

Pech RP, Hood GM, McIlroy JC, Saunders G 1997. Can foxes be controlled by reducing their fertility? Reproduction, Fertility and Development 9: 41–50.

Pennell CGL, Rolston MP 2003. The effect of grass-endophyte associations on feeding of Canada geese (*Branta canadensis*). Proceedings of the New Zealand Grasslands Association 65: 239–243.

Pietrzykowski E, McArthur C, Smethhurst P, Barnes C 2002. Effectiveness of lupins as a cover crop for reducing damage by browsing mammals. CRC Sustainable Production Forestry Tech Report 89.

Pietrzykowski E, McArthur C, Fitzgerald H, Goodwin AN 2003. Influence of patch characteristics on browsing of tree seedlings by mammalian herbivores. Journal of Applied Ecology 40: 458–469.

Pietsch RS 1994. The fate of urban common brushtail possums translocated to sclerophyll forest. In: Serena M ed. Reintroduction biology of Australian and New Zealand fauna. Sydney, Surrey Beatty. Pp. 236–246.

Pollock DC, Montague TL 1991. A new trap mechanism for the capture of swamp wallabies *Wallabia bicolour* (Marsupialia: Macropodidae) Wildlife Research 18: 459–461.

Pople AR., Grigg GC, Cairns SC, Beard LA, Alexander P 2000. Trends in the numbers of red kangaroos and emus on either side of the South Australian dingo fence: evidence for predator regulation? Wildlife Research 27: 269–276.

Proulx G 1999. Review of current mammal trap technology in North America. In: Proulx G ed. Mammal trapping. Sherwood Park, Canada, Alpha wildlife research & management. Pp. 1–46.

Ramp D, Russell BG, Croft DB 2005. Predator scent induces differing responses in two sympatric macropodids. Australian Journal of Zoology 53: 73–78.

Ramp D, Portelli D, Croft D 2006. Evaluation of acoustic repellents. Milestones 1 and 2: Behavioural responses of red-necked pademelons (*Thylogale thetis*) and red-necked wallabies (*Macropus rufogriseus banksianus*) to acoustic stimuli: an examination of the feasibility of developing an acoustic deterrent. D1. Summary report to Forestry Tasmania, Consultancy 05-288, Agreement L105/063.

Ramsay BJ 1994. Commercial use of wild animals. Bureau of Rural Sciences, Canberra. 185 p.

Ramsey D 2005. Population dynamics of brushtail possums subject to fertility control. Journal of Applied Ecology 42: 348–360.

Rodger JC 2003. Fertility control for wildlife. In: Holt WV, Pickard AR, Rodger JC, Wildt DE eds Reproductive science and integrated conservation, Conservation Biology 8. Cambridge University Press, UK. Pp. 281–290.

Rural Industries Research and Development Corporation 2006. Kangaroo Industry Strategic Plan 2005–2010. http://www.rirdc.gov.au/pub/kangaroo5yr.html#_Toc110226708, Accessed 9 June 2006.

Saunders G, Coman B, Kinnear J, Braysher M 1995. Managing vertebrate pests: foxes. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra. 141 p.

Scrivener NJ, Johnson CN, Wallis IR, Takasaki M, Foley WJ, Krokenberger AK 2004. Which trees do wild common brushtail possums (*Trichosurus vulpecula*) prefer? Problems and solutions in scaling laboratory findings to diet selection in the field. Evolutionary Ecology Research 6: 77–87.

Shafer EW, Bowles WA 2004. Toxicity, repellency or phytotoxicity of 979 chemicals to birds, mammals and plants. United States Department of Agriculture, Animal and Health Inspection Service, Wildlife Services, National Wildlife Research Center, Research Report No. 04-01, 123 p.

Shi D, Wan X, Davis SA, Pech RP, Zhang Z 2002. Simulation of lethal control and fertility control in a demographic model for Brandt's vole (*Microtus brandti*). Journal of Applied Ecology 39: 337–348.

Sinclair ARE, Byrom AE 2006. Understanding ecosystem dynamics for conservation of biota. Journal of Animal Ecology 75: 64–79.

Singer P 1997. Neither human nor natural: ethics and feral animals. Reproduction, Fertility and Development 9: 157–162.

Singleton GR, Leirs H, Hinds LA, Zhang Z 1999. Ecologically-based management of rodent pests – re-evaluating our approach to an old problem. In: Singleton GR, Hinds LA, Leirs H, Zhang Z eds Ecologically-based management of rodent pests. Canberra, Australian Centre for International Agricultural Research. Pp. 17–29.

Smith MJ 1990. The role of bounties in pest management with specific reference to State dingo control programs. Associate Diploma in Applied Science (Agricultural Protection) thesis, Charles Sturt University, Wagga Wagga, New South Wales. 95 p.

Sprent JA, McArthur C 2002. Diet and diet selection of two species in the macropodid browser-grazer continuum: do they eat what they ‘should’? Australian Journal of Zoology 50: 183–192.

Spurr EB, Coleman JD 2005. Cost-effectiveness of bird repellents for crop protection. Proceedings of the 13th Australasian Vertebrate Pest Conference, Wellington, New Zealand. Pp. 227–233.

Spurr EB, Eason CT 1999. Review of avicides. Landcare Research Contract Report LC9900/44 to the Victorian Institute of Animal Science (unpubl.). 48 p.

Spurr EB, Maitland MJ, Taylor GE, Wright GRG, Radford CD, Brown LE 2005. Residues of brodifacoum and other anticoagulant pesticides in target and non-target species, Nelson Lakes National Park. New Zealand Journal of Zoology 32: 237–249.

Statham HL 1983. Browsing damage in Tasmanian forest areas and effects of 1080 poison. Forestry Commission, Tasmania. Bulletin No. 7 (unpubl.).

Statham M 1991. Non-toxic control of wallabies. Proceedings of the 9th Australian Vertebrate Control Conference, Adelaide, South Australia, Pp. 328–331.

Statham M 1999. Some Tasmanian experiences with control of wallabies. Proceedings of the south-eastern Australian native forest browsing workshop, Ballarat, Department of Natural Resources and Environment. Pp. 45–48.

Statham M 2000. Demonstration of the economic benefits to grazing from effective wallaby control. In: Salmon TP, Crabb AC eds Report to the National feral animal control program, Bureau of Rural Sciences. 9 p.

Statham M 2005. The development of 1080 use for rabbit control in Tasmania. Papers and proceedings of the Royal Society of Tasmania 139: 1–6.

Statham M, Raynor PJ 1998. Loss of pasture and crop to native animals in Tasmania. Browsing Animal Research Council: Final report. Department of Primary Industry and Fisheries, Launceston. Pp. 14–18.

Statham M, Statham HL 1994. Control of browsing in plantations. Faces of farm forestry, Australian Forest Growers conference. Pp.199–202.

Sullivan TP, Sullivan DS, Reid DG, Leung MC 2004. Weasels, voles, and trees: influence of mustelid semiochemicals on vole populations and feeding damage. Ecological Applications 14: 999–1015.

Sutherland O, Coleman JD 1994. Animal browse problems in Tasmania: a review by Manaaki Whenua- Landcare Research, Christchurch: field notes. Report to the Browsing Animal Research Council, Tasmania. 19 p.

Twigg LE, Williams CK 1999. Fertility control of overabundant species; can it work for feral rabbits? Ecology Letters 2: 281–285.

Twigg LE, Lowe TJ, Martin GR, Wheeler AG, Gray GS, Griffin SL, O'Reilly CM, Robinson DJ, Hubach PH 2000. Effects of surgically imposed sterility on free-ranging rabbit populations. Journal of Applied Ecology 37: 16–39.

Tyndale-Biscoe CH 1994. Virus-vectored immunocontraception of feral animals. Reproduction, Fertility and Development 6: 9–16.

VerCauteren KC, Shivik JA, Lavelle MJ 2005. Efficacy of an animal-activated frightening device on urban elk and mule deer. Wildlife Society Bulletin 33: 1282–1287.

Wagner KK, Nolte DL 2000. Evaluation of Hot Sauce® as a repellent for forest mammals. Wildlife Society Bulletin 28: 76–83.

Walsh A 2005. Evaluation of the Mersey box trap for live capturing Tasmanian pademelons. A report to the Animal Welfare Advisory Committee (unpubl.). 1 p.

Walsh A, Kincade T 2005. Integrated mammal browsing management in plantation forestry. Draft Technical Report, Division of Forest Research and Development, Forestry Tasmania (unpubl.). 25 p.

Walsh AM, Wardlaw TJ 2005. An integrated pest management strategy to manage mammal browsing on state forest in Tasmania. 13th Australasian Vertebrate Pest Conference, Wellington, New Zealand. Pp. 48–55.

Walters CJ, Holling CS 1990. Large-scale management experiments and learning by doing. Ecology 71: 2060–2068.

Warburton B 1990. Control of Bennett's and Tammar wallabies in New Zealand using compound 1080 gel on foliage baits. Australian Wildlife Research 17: 541–546.

Warburton B 1992. Victor foot-hold traps for catching Australian brushtail possums in New Zealand: capture efficiency and injuries. Wildlife Society Bulletin 20: 67–73.

Warburton B 1995. Setting standards for trapping wildlife. Proceedings of the 10th Australian Vertebrate Pest Control Conference, Hobart. Pp 283–287.

Warburton B, Coleman MC 1994. Evaluation of the electrostrike possum trap. Landcare Research Contract Report LC9394/100 for Carlton Taylor Industries (unpubl.). 8 p.

Warburton B, Drew KW 1994. Extent and nature of cyanide-shyness in some populations of Australian brushtail possums in New Zealand. Wildlife Research 21: 599–605.

Warburton B, O'Connor C 2004. Research in vertebrate pesticides and traps: Do wild animals benefit? In: Balls M, Firmani D, Rowan AN eds The three Rs at the beginning of the 21st century. Proceedings of the 4th World congress on alternatives and animal use in the life sciences, New Orleans. Pp. 229–234.

Warburton B, Gregory N, Bunce M 1999. Stress response of Australian brushtail possums captured in foothold and cage traps. In: Proulx G ed. Mammal trapping. Sherwood Park, Canada, Alpha wildlife research & management. Pp. 53–66.

Warburton B, Gregory NG, Morriss G 2000a. Effect of jaw shape in kill-traps on time to loss of palpebral reflexes in brushtail possums. Journal of Wildlife Diseases 36: 92–96.

Warburton B, Tocher G, Allan N 2000b. Possums as a resource. In: Montague TL ed. The brushtail possum: biology, impact and management of an introduced marsupial. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 251–261.

Warburton B, Coleman JD, Fugelstad M, Dietrich J 2006. Maximising benefits of using existing possum control tools – developing a Decision Support System. Landcare Research Contract Report LC 0506/061 to the Animal Health Board (unpubl.). 24 p. http://possumdss.landcareresearch.co.nz

While GM, McArthur C 2005. Foraging in a risky environment: a comparison of Bennett's wallabies *Macropus rufogriseus rufogriseus* (Marsupialia: Macropodidae) and red-bellied pademelons *Thylogale billiardierii* (Marsupialia: Macropodidae) in open habitats. Austral Ecology 30: 756–764.

Wickstrom M, Eason CT 1998. The development of alternatives to 1080 for possum control. Landcare Research Contract Report LC9798/42 to the Animal Health Board (unpubl.). 21 p.

Wickstrom M, Henderson RJ, Eason CT 1997. Alternatives to 1080 to possums (July 1994–July 1996). Landcare Research Contract Report LC9697/97 to the Animal Health Board (unpubl.). 26 p.

Williams CK 1997. Development and use of virus-vectored immunocontraception. Reproduction, Fertility and Development 9: 169–178.

Williams CK 2002. Risk assessment for the release of genetically modified organisms: a virus to reduce the fertility of introduced wild mice, *Mus domesticus*. Reproduction Supplement 60: 81–88.

Williams D 2001. Aussie immigrants wreak havoc in New Zealand's Bay of Plenty. Proceedings of the 12th Australasian Vertebrate Pest Conference, Melbourne. Pp. 347–351.

Williams K, Parer I, Coman B, Burley J, Braysher M 1995. Managing vertebrate pests: rabbits. Bureau of Resource Sciences and CSIRO Division of Wildlife and Ecology, Australian Government Publishing Service, Canberra. 284 p.

Witt A 2002. The effect of repellents on eucalypt seedling growth and herbivory. Honours thesis, School of Zoology, University of Tasmania, Hobart.

Woodfield C 2005. One step forward… two steps back: the commercial harvest of native wildlife. Tasmanian Conservationist 301 (September): 3.

Woolhouse AD, Morgan DR 1995. An evaluation of repellents to suppress browsing by possums. Journal of Chemical Ecology 21: 1571–1583.

Appendix 1 Summary of research, demonstration and extension topics that were covered during discussions with stakeholders in May 2006

Topic	Objectives
Monitoring trends in numbers of browsing animals	
Research: Develop robust operational techniques to quantify changes in the abundance of each species of browsing animal in plantations, forest regeneration areas and farmland. Possible techniques include wax tags, chew cards, pellet counts, spotlight counts and catch-per-unit effort.	To quantify long-term population trends and the effectiveness of control programmes on a regional and land-use basis. To assist in setting targets for reductions in populations of browsing animals. To assist in quantifying the potential browsing damage to the forestry industry and to agriculture.
Research: Assess the value of data recorded in shooters' log books and in permit returns for monitoring changes in the abundance of browsing animals.	To maximise the value of data already collected on an operational basis.
Research: Using existing state-wide monitoring data collected by DPIW, update models to determine which factors (e.g. climate, control programmes, changes in land use) influence changes in the abundance of browsing animals.	To identify factors likely to be responsible for broad-scale trends in the abundance of native browsing animals.
Research: Develop models of the population dynamics of browsing animal species on King Island and Flinders Island.	To set culling rates using a sound understanding of the population ecology of pest species.
Monitoring trends in damage caused by browsing animals	
Research: Design data collation protocols to provide regular industry-wide assessments of the impacts and costs of browsing animals.	To better inform public debate on the management of browsing damage in the forestry and agricultural industries.
Research: Develop and test robust operational techniques for evaluating damage to crops and pasture by wallabies, pademelons and possums.	To improve farmers' ability to estimate the importance of damage to crops and pasture by wallabies, pademelons and possums.
Research: Continue development and testing of robust operational techniques for evaluating damage to plantations and native forest regeneration by wallabies, pademelons and possums.	To provide damage estimates based on standardised protocols. To improve the ability of foresters to fine-tune control programmes to the level of damage incurred.
Research: If robust techniques can be developed for the operational monitoring of browsing species, then determine if the relationships between animal abundance and browsing damage can be quantified, taking into account site-specific factors.	To quantify (and justify) the level of control required to meet acceptable levels of browsing damage to plantations, native forest regeneration, crops and pasture.
Research: Develop and test operational methods and thresholds (e.g. bait-take during pre-feeding) to determine whether or not a control programme is warranted.	To avoid unnecessary control programmes.
Research: Use data collected during trapping programmes to help evaluate the degree of risk of species-specific browsing damage to plantations.	To improve assessment of the risk of browsing damage to plantations.
Research: Investigate how environmental factors, e.g. adjacent habitats and farm design, influence the risk of browsing damage on farms.	To provide quantitative assessment of factors potentially affecting the risk of browsing damage to agricultural production.
Costs and benefits of managing browsing animals	
Research: Evaluate the costs and benefits of browsing damage management at the level of individual farming and forestry enterprises.	To facilitate clear, financially based decision making on the merits of browsing animal management at the individual-enterprise level. To facilitate market-based solutions to pest animal

Topic	Objectives
	control.
Demonstration: Demonstrate the cost-effectiveness of using site-specific techniques and combinations of techniques for managing browsing animals, especially on farms.	To increase the efficiency of browsing animal management by optimising the use of current techniques.
Social issues relating to the management of browsing animals	
Research: Evaluate the social impacts of browsing damage management at the level of individual-farm enterprises.	To improve decision making on the merits of browsing animal management at the farm-enterprise level.
Research: Conduct surveys to measure public, industry and other interest-group attitudes to the use of alternatives to 1080 for the management of browsing animals.	To determine the need for, and acceptability of, alternatives to the use of 1080. To monitor trends in public attitudes using surveys at regular time intervals.
Environmental issues relating to the management of browsing animals	
Research: Evaluate the potential biodiversity consequences of large changes in the numbers and distribution of browsing animals at local and regional levels (for example, King Island).	To provide quantitative information for decision making on conservation issues.
Research: Evaluate the potential non-target and biodiversity consequences of an increased use of wallaby-proof fencing and other alternatives to 1080 in agricultural areas.	To identify policies and management objectives consistent, or inconsistent, with the objective of reducing browsing damage to forestry and agriculture.
Management techniques: commercial harvesting	
Research: Conduct economic analyses of options for expanding the commercial use of browsing animal species.	To increase the cost-effectiveness of shooting as a management option.
Research: Assess the scope for commercial operators to conduct control programmes, taking into account auditing, licensing and quality assurance issues.	To increase the efficiency of control programmes. To facilitate market-based solutions to pest animal control.
Research: Measure home ranges and dispersal distances of browsing animals, particularly wallabies and possums, in forests and farmland.	To determine where coordinated control programmes would benefit neighbouring properties.
Extension: Document successful management techniques and strategies taking into account regional differences in species’ population densities.	To ensure the best available techniques and management strategies are used in each region.
Extension: Develop and promote training programmes in the management of browsing animals for forestry and farming operations (including training for young shooters).	To improve efficiency in the use of existing techniques. To ensure compliance with animal welfare requirements and other relevant standard operating procedures. To ensure a future supply of skilled pest control operators.
Management techniques: trapping	
Research: Compare the relative operational costs and benefits of the trap types developed so far in both hardwood and *P. radiata* plantations.	To maximise trapping efficiency.
Research: Determine how to use data collected during trapping programmes to refine control programmes and audit operators, e.g. by setting cost-efficient stopping rules for trapping or by adjusting trapping intensity required for high-, medium- and low-risk sites.	To improve the efficiency of trapping as a control technique for forestry operations.
Research: Develop effective and humane traps for wallabies.	To extend trapping techniques to situations where wallabies are causing significant browsing damage.

Topic	Objectives
Management techniques: shooting	
Research: Determine the operational value of feed stations (i.e. feed lures) to increase the efficiency of shooting to control browsing animal populations.	To improve the efficiency of the most commonly used lethal control technique in forestry applications.
Research: Evaluate options for technical improvements, e.g. use of silencers, night vision equipment and feed lures, for increasing the efficiency of shooting.	To increase the cost-effectiveness of shooting as a management option.
Research: Develop protocols and auditing systems for recreational and contract shooters.	To monitor the performance of shooters with respect to predetermined criteria.
Management techniques: fencing	
Demonstration: Promote the effective use of wallaby-proof fencing as part of integrated pest management.	To increase the efficiency of browsing animal management by optimising the use of current techniques.
Management techniques: tree guards	
Research: Develop and improve low-cost, effective tree guards to prevent browsing damage by wallabies.	To develop a non-lethal technique that can be included in integrated pest management in areas where brushtail possums are not a significant cause of browsing damage.
Research: If methods can be developed to predict where browsing damage is most likely to occur, then determine if the use of diversionary food can be used to improve the management of browsing animals, e.g. with tree guards.	To improve the efficiency of the integrated use of non-lethal techniques for preventing browsing damage.
Management techniques: alternative toxins	
Research: Test alternative toxins (particularly cyanide) and species-specific delivery systems at a management scale in properly designed experiments.	To provide an alternative control method that is a cost-effective, direct substitute for 1080.
Management techniques: repellents	
Research: Test registered repellents at a management scale in properly designed experiments.	To develop a non-lethal technique that can be included in integrated pest management at an operational scale.
Research: Develop and test a proposed acoustic repellent that exploits specific behavioural attributes (e.g. foot thumping) of wallabies and/or pademelons.	To improve the efficiency of non-lethal techniques for preventing browsing damage.
Research: Evaluate the use of diversionary food to improve the efficiency of other management options.	To improve the efficiency of the integrated use of non-lethal techniques for preventing browsing damage.
Management techniques: habitat manipulation	
Research: Evaluate the potential for changing land use, including the establishment of shelterbelts, plantations and other conservation planting in farmland, to increase or decrease problems with browsing animals.	To identify policies and management objectives consistent, or inconsistent, with the objective of reducing browsing damage to forestry and agriculture. To predict future trends in the regional and state-wide importance of browsing damage.
Research: Determine whether access to high-quality forage on farmland is a significant factor affecting the local abundance of browsing animals.	To establish the underlying causes of increased populations of browsing animals.

Management techniques: fertility control	
Research: Enhance current research into fertility control (including species-specific delivery techniques) for possums, wallabies and pademelons.	To develop a publicly acceptable non-lethal method for reducing populations of browsing animals.
General issues	
Extension: Establish an easily accessible communications network to facilitate the flow of expert knowledge on the management of browsing animals, between forestry companies, individual landholders, government agencies and researchers.	To make relevant knowledge easily accessible to all groups and individuals involved in browsing animal management. To ensure maximum benefit from completed research.
Extension: Develop and promote the use of educational material on the management of browsing animals.	To increase public awareness of the need to manage browsing animals in forestry and farming.
Demonstration: Use demonstration sites to evaluate the benefits of coordinating management of browsing animals on neighbouring properties.	To increase the efficiency of programmes to manage browsing animals.