Bureau of Resource Sciences

Managing Vertebrate Pests: Feral Pigs

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FOREWORD

Feral pigs cause problems for farmers because they eat crops, pasture and lambs. Conservation authorities are concerned that feral pigs, through selective feeding, trampling and rooting, could have negative impacts on a range of native plants and animals, including invertebrates. Quarantine authorities need to manage the risk that feral pigs could be involved in exotic disease outbreaks, such as foot-and-mouth disease or swine fever, should such diseases enter Australia. On the other hand, feral pigs are valued by those who hunt them commercially or recreationally and feral pig meat is exported to Europe as wild boar.

There is little reliable information about the extent and nature of many of the problems caused by feral pigs and how they can best be solved. This has led to diverse views about feral pig management. Although spending on pest control should be justified in terms of economic returns on such investments, this is clearly difficult when the impacts of feral pigs on both agricultural and conservation values, and the responses of pig populations to control operations, are often poorly quantified. Conservation organisations would like to see pig populations eradicated or reduced to low numbers in areas where they pose a particular threat to conservation values. Pastoralists would like to have cost-effective means for reducing pig predation on lambs. Quarantine authorities wish to ensure that feral pigs could be controlled if they were involved in an exotic disease outbreak. People interested in hunting feral pigs for commercial use, recreation or subsistence food want to retain them as a resource. Those concerned with animal welfare want to ensure that feral pig control or hunting is humane. The authors have attempted to take all these divergent views and objectives into account in compiling these guidelines.

The principles underlying the strategic management of vertebrate pests have been described in *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993). The emphasis is on the management of pest damage rather than on simply reducing pest density. The guidelines recommend that, wherever practical, management should concentrate on achieving clearly defined conservation or agricultural production benefits.

This publication, which is one in a series, provides land managers with ‘best practice’ national guidelines for managing the agricultural and environmental damage caused by feral pigs. Others in the series include guidelines for managing feral horses, rabbits, foxes, feral goats and rodents. The publication was developed and funded by the Vertebrate Pest Program in the Bureau of Resource Sciences.

To ensure that the guidelines are widely accepted as the basis for feral pig management, comment has been sought from State, Territory and Commonwealth Government agricultural, environmental, and resource management agencies. Comments were also sought from land managers and community organisations, including the Australian Conservation Foundation, the National Farmers’ Federation, the National Consultative Committee on Animal Welfare, the Australian Veterinary Association, the Northern Aboriginal Land Council and four research and development corporations. The Standing Committee on Agriculture and Resource Management has endorsed the approach to managing feral pig damage set out in these guidelines.

These guidelines will help land managers reduce damage to agriculture and the natural environment caused by feral pigs through the use of scientifically based management that is humane, cost-effective, and integrated with ecologically sustainable land management.

Peter O'Brien
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All dollar values have been converted to 1994–95 Australian dollars unless otherwise stated in the text.

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The draft manuscript was circulated to the following organisations for comment:

- Commonwealth Department of Primary Industries and Energy
- Standing Committee on Agriculture and Resource Management
- Vertebrate Pests Committee
- Australia and New Zealand Environment and Conservation Council
  - Standing Committee on Conservation
  - Standing Committee on the Environment
- Land and Water Research and Development Corporation
- Meat Research Corporation
- Rural Industries Research and Development Corporation
- International Wool Secretariat
- Australian Conservation Foundation
- National Consultative Committee on Animal Welfare
- Australian and New Zealand Federation of Animal Societies
- National Farmers' Federation
- Australian Veterinary Association
- Northern Land Council

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SUMMARY

The introduced feral pig or wild boar (*Sus scrofa*) is widely distributed throughout eastern and northern Australia, with smaller populations in the west. Their distribution in inland or seasonally dry areas of Australia is restricted to the vicinity of watercourses and their associated floodplains. In the more forest-covered parts of eastern Australia and south-west Western Australia, populations are still spreading, often through deliberate or accidental releases. Feral pigs prey on lambs and some native animals, trample and eat crops, could play a role in spreading exotic diseases such as foot-and-mouth disease (should they enter Australia), and cause an unknown amount of land degradation. Feral pigs are also an economic resource and are hunted commercially and recreationally.

These guidelines are a comprehensive review of the history of feral pigs in Australia, their biology, the damage they cause, and past and current management. The attitudes of landholders, conservationists, animal welfare groups, commercial and recreational hunters, Aboriginal peoples and other interest groups were sought during their production. Techniques and strategies for feral pig management are recommended and illustrated by case studies. Deficiencies in knowledge, management and legislation are identified.

Why develop national guidelines?

These guidelines for managing the impact of feral pigs were developed as part of the Vertebrate Pest Program administered by the Bureau of Resource Sciences. The VPP, in cooperation with the Vertebrate Pests Committee of the Standing Committee on Agriculture and Resource Management, has produced a series of pest management guidelines including ones for feral horses, rabbits, foxes, feral goats and rodents.

The purpose of these guidelines is to assist in developing the most cost-effective strategies to reduce feral pig damage to production and conservation. Ideally, such strategies are based on reliable quantitative information about the damage caused by pigs, the cost of control measures and the effect that implementing control has on reducing damage. In developing these guidelines the authors have used all such available information. In some instances, however, where reliable information is not yet available, land managers responsible for feral pig management will have to make assumptions about feral pig impact and the efficacy and cost-effectiveness of control techniques.

Who will use the guidelines?

The guidelines have been prepared primarily for state and territory land management agencies as a basis on which to consult with private land managers and other relevant interest groups and prepare state, regional and local strategies for reducing the damage feral pigs cause to agricultural production and the environment. The guidelines should be read in conjunction with *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993), which explains why national pest guidelines were developed, their aims, the planning process, their use and the principles on which pest management should be based.

The feral pig problem

Feral pigs are responsible for several types of agricultural damage. They prey on newborn lambs, eat and destroy grain crops, damage fences and water sources, reduce yields of sugarcane and some tropical fruit crops, and compete with stock for feed by eating or damaging pasture. There are no reliable estimates of the cost of feral pig damage to agricultural production, although it is likely that the damage is at least of the order of $100 million annually, and it may be much more.

Although feral pigs are often regarded as having deleterious effects on the environment, there is little objective information available on their impact. The most important environmental impacts are likely to be habitat modification through selective feeding, trampling damage and rooting for under-

ground parts of plants and invertebrates; as well as predation on, competition with, or disturbance of, a range of native animals. Most perceptions of environmental damage caused by pigs focus on their rooting up of soils, grasslands or forest litter, particularly along drainage lines, moist gullies and around swamps and lagoons, or after rain, when the ground is softer. Their impact on different plants is largely unknown, as is the extent of their role as seed eaters or dispersers, and in spreading rootrot fungus (*Phytophthora cinnamomi*), responsible for dieback disease in native vegetation. Feral pigs readily eat animal material, but are probably not significant predators of most fauna except local populations of earthworms.

Feral pigs are the main wild animal of concern in Australia in relation to the potential spread of exotic diseases, particularly foot-and-mouth disease (FMD), the main exotic disease of concern in Australia. Feral pigs can act as hosts or vectors of several endemic and exotic diseases and parasites that can affect other animals, including domestic livestock and people. The major endemic diseases and parasites of concern are leptospirosis, brucellosis, melioidosis, tuberculosis and sparganosis. The involvement of feral pigs in an exotic disease outbreak could delay disease detection; increase the rate and extent of disease spread; make disease eradication measures expensive, time-consuming or impossible; and have severe repercussions for Australia's livestock industries. Although Commonwealth, State and Territory authorities have prepared contingency plans for dealing with outbreaks of exotic diseases, and have also developed stringent quarantine regulations, recent research indicates that outbreaks of FMD could establish in feral pig populations in parts of Australia.

Resource value

The Australian feral pig is taxonomically, ecologically and physically comparable to the European wild boar and there is a significant export of wild pig meat from Australia to European markets. It is estimated about $5 million of the $10–20 million derived from the export market of wild pig meat is paid to shooters and chiller operators, and that recreational hunting of feral pigs also injects considerable funds into the general community each year through money spent by pig shooters.

History and biology

Most feral pigs in Australia are descendants of various breeds of the Eurasian wild boar or the domestic pig, which for various reasons, particularly lack of restraint and deliberate releases, reverted to living in the wild. Horizontal black stripes on the piglets of many feral pigs indicate the infusion of Eurasian wild boar genes. Initially, the distribution of pigs was close to major settlements throughout Australia, but as changes occurred in the management of rural properties, many pigs were left unattended, wandered away and established truly feral colonies.

Once established, colonies of feral pigs rapidly built up in many areas. Estimates of population size vary between 3.5 million and 23.5 million, inhabiting 38% of Australia, but their distribution and abundance can vary markedly from year to year according to environmental conditions.

The biology and ecology of feral pigs are two of the major reasons why they are such an important and successful vertebrate pest in Australia. Their large robust bodies, snouts specially developed for rooting up the ground, omnivorous diet and adaptive activity patterns allow them to live in a wide range of habitats. Feral pigs are habitat generalists and have colonised subalpine grasslands and forests, dry woodlands, tropical rainforests, semi-arid and monsoonal floodplains, swamps and other wetlands in many parts of the Northern Territory, Queensland, New South Wales, other states and the Australian Capital Territory. Their prime requirements are a reliable and adequate supply of water, food and cover. Temporal changes can occur in their use of habitats to satisfy these requirements, particularly to obtain shade and water and exploit seasonally abundant food sources.

The reproductive potential of feral pigs is more similar to that of rabbits than to that of other large mammals in Australia. Fecundity increases with age and body weight but can be strongly affected by seasonal conditions. Under favourable conditions, breeding can occur throughout the year and sows can produce two weaned litters every twelve to fifteen months, with an average of six piglets per litter. This gives feral pigs the capacity to recover quickly from the effects of management programs or other setbacks such as droughts.

Techniques to control feral pigs

Poisoning is a control technique that is widely accepted throughout rural communities. It is perceived as a method which, if properly used, can produce a quick knockdown of feral pig populations. The negative aspects of poisoning are associated with its non-specificity and welfare implications. The success of a 1080 poisoning program revolves around adequate free-feeding with non-toxic bait to attract pigs. CSSP, a yellow phosphorus-based poison, is effective in killing pigs but there are serious doubts about its humaneness. Warfarin, an anticoagulant, is a poison readily accepted by feral pigs. It is very effective if extended feeding is practiced. Despite this, no Australian states or territories have registered warfarin for feral pig control.

Shooting from helicopters is time-efficient and provides a quick knockdown to protect susceptible enterprises from short-term damage. Pig populations recover rapidly between shooting episodes. Shooting from the ground, with or without dogs, is generally considered to play an insignificant role in damage control except where it is intensively conducted on small accessible populations.

Trapping can be effective, but results are variable, being affected by season, trap type and site, pre-baiting techniques and trapping frequency. Trapping is a flexible technique that can be fitted into routine property activities.

There are currently no biological or fertility control agents suitable for use against feral pigs.

Integrated management using a range of control techniques produces the best results, but a lack of reliable information on ‘on-farm’ control costs is seen as a barrier to adoption of some techniques. This deficiency should be addressed if best practice management is to be widely adopted.

Development of a strategic management approach

Management of the feral pig problem has been traditionally ad hoc but there is now a trend towards more strategic and scientific management. Before the 1970s no research had been conducted on feral pig biology, ecology or management and land managers typically used shooting, bounties and poisoning with either strychnine, arsenic or phosphorus, as control tools.

Since the 1970s considerable work has been done to evaluate and improve trapping, poison efficacy and bait acceptance, fence design and shooting from helicopters as control tools. This work has coincided with the phasing out of bounties and the introduction of coordinated management using landholder groups. The success of the coordinated approach was validated by numerous programs conducted in New South Wales which produced positive outcomes in the way of decreased lamb predation and crop damage for participants. Both Queensland and New South Wales have a policy of encouraging the use of coordinated management.

Current management is increasingly sensitive to environmental and animal welfare issues. Increasing effort is expended to ensure that techniques and methods are sensitive to the community’s needs in this regard.

Future management of feral pig damage can be enhanced by improved training of control agency staff in extension and the facilitation of stakeholder groups. Lack of such skills can be a serious barrier to the rapid adoption of best practice management by landholders.

What is the strategic management approach?

The emphasis in these guidelines is on the strategic management of feral pigs to minimise the damage they cause to production and conservation values, not merely to kill pigs. Feral pigs need to be considered as one factor in a complex and changing system which includes a highly variable climate, fluctuating commodity prices, other animal and plant pests, the number and quality of farm stock, and the profitability of farming businesses.

Achieving a strategic approach to the management of feral pigs and other vertebrate pests involves four key components. These are:

Defining the problem — The problem first needs to be determined in terms of the impact of feral pigs on a valued resource, be it economic or environmental. The next step is to quantify the impact which may require experimental assessment of the damage.

Management plan — In developing a management plan, it is essential that clear objectives are established, wherever practicable in terms of the desired production and/or conservation outcome sought, relative to the costs of control. Options for feral pig management include local eradication, strategic management (targeted, sustained or one-off), crisis management, commercial harvesting or no management. In light of the objectives, and the choice of management options, a management strategy should be developed based upon the techniques available for pig control.

Economic frameworks need to be developed to assist land managers to assess the relative value of alternative control strategies. Such frameworks require: definition of the economic problem; data on relative costs and benefits of different feral pig management strategies; an understanding of why the actions of individual land managers may not lead to optimum levels of pig control; and how such problems can be addressed.

Implementation — The most effective approach is to coordinate management of feral pig damage on a local and regional level, involving cooperative action by land managers, both private and public, government agencies and industry.

Monitoring and evaluation — Monitoring has two aspects. Operational monitoring assesses the efficiency of the management strategy over time, particularly to determine whether it is being carried out in the most cost-effective manner. Performance monitoring gathers information by which the effectiveness of the strategy in meeting the desired long-term production or conservation objectives can be determined. Evaluation of data from both forms of monitoring can help determine if and how the management strategy should be modified.

The above approach has been adopted for developing these national guidelines, and the information in this publication is designed to facilitate the development of strategies for managing feral pigs at the local and regional level.

Community attitudes

The feral pig is considered by the community to be many things: agricultural pest, endemic and exotic disease hazard, environmental liability, export commodity and recreational resource. These attitudes have varied through time and location. Although the status of feral pigs as an agricultural pest was responsible for raising their profile initially, the feral pig is no longer simply regarded as an agricultural pest and environmental threat, but also as a contributor of significant income to rural communities through recreational and commercial hunting.

The multiple use of feral pigs leads to conflict within the rural community as well as within the general community. The significant benefits from the game meat export industry and recreational hunting are politically attractive. Despite arguments from some rural groups that commercial and recreational use of feral pigs is incompatible with their effective management, experience suggests otherwise. There is an increasing acceptance among communities that multiple-use management of feral pigs is both practical and appropriate.

The future

More information in some key areas is essential if the strategic approach to feral pig management is to be developed further. Although the biology and ecology of feral pigs in most major habitats in Australia is generally well understood, there is limited information about pigs for some parts of tropical Australia, especially in rainforests.

Two of the basic weaknesses in being able to determine priorities for where to control feral pigs in many areas of Australia are the lack of objective, quantitative data on the impact of pigs on the environment, and a means of comparing the cost of this environmental damage with economic losses caused by pigs to agriculture.

The major poisons used to control feral pigs in Australia are 1080 and CSSP. Extensive work has been conducted on the threat 1080 poses to non-target species but no studies are known to have been conducted or reported on CSSP, despite its longstanding and widespread use as a feral pig control agent.

There are no reliable data on how much it costs property managers to control feral pigs. Land managers need better information on the types and extent of damage caused by feral pigs and on control costs. This will enable a change in management philosophy from one focussed on killing more pigs to one focussed on cost-efficiently reducing the damage caused by pigs.

Adoption of the national guidelines will require a change in understanding and behaviour at various levels, ranging from land managers to policy makers and officers of state agencies. Currently, few extension staff are trained in the principles of education, sociology or psychology, all key elements associated with facilitating a change in behaviour in individuals or groups.

INTRODUCTION

These guidelines for managing feral pigs are one in a series prepared as part of the Vertebrate Pest Program of the Bureau of Resource Sciences in cooperation with the Vertebrate Pests Committee of the Standing Committee on Agriculture and Resource Management. Other guidelines include feral horses, rabbits, feral goats, foxes and rodents.

The need for a new approach to vertebrate pest management is described in *Managing Vertebrate Pests: Principles and Strategies* (Braysher 1993), which explains why national guidelines for managing pest animals were developed, the management process, and the principles on which pest management should be based. The need to focus on the damage caused by the pest and not the pest itself is stressed.

As acknowledged in *Managing Vertebrate Pests: Principles and Strategies*, a set of guidelines for all vertebrate pests, taking into account the links between them, and other aspects of land management, would have been more desirable than the single species approach adopted in these guidelines. This would have been consistent with the holistic approach to land management advocated under the Ecologically Sustainable Development (ESD) Strategy and the National Landcare Program (NLP). Although this was not practicable, all the guidelines, including this one for feral pigs, consider interactions between species and other aspects of land management.

The guidelines are principally for state and territory land management agencies to assist them more effectively manage feral pig damage through better coordination, planning and implementation of local and regional management programs. The Commonwealth Government also has a major interest in the effective management of feral pest damage both through its responsibilities as a land manager, and through various initiatives such as the NLP and the National Strategy for the Conservation of Australia's Biological Diversity. Applying the strategic approach to the management of pigs and other vertebrate pests involves four key components as shown in Figure 1. This approach forms the basis of these national guidelines.

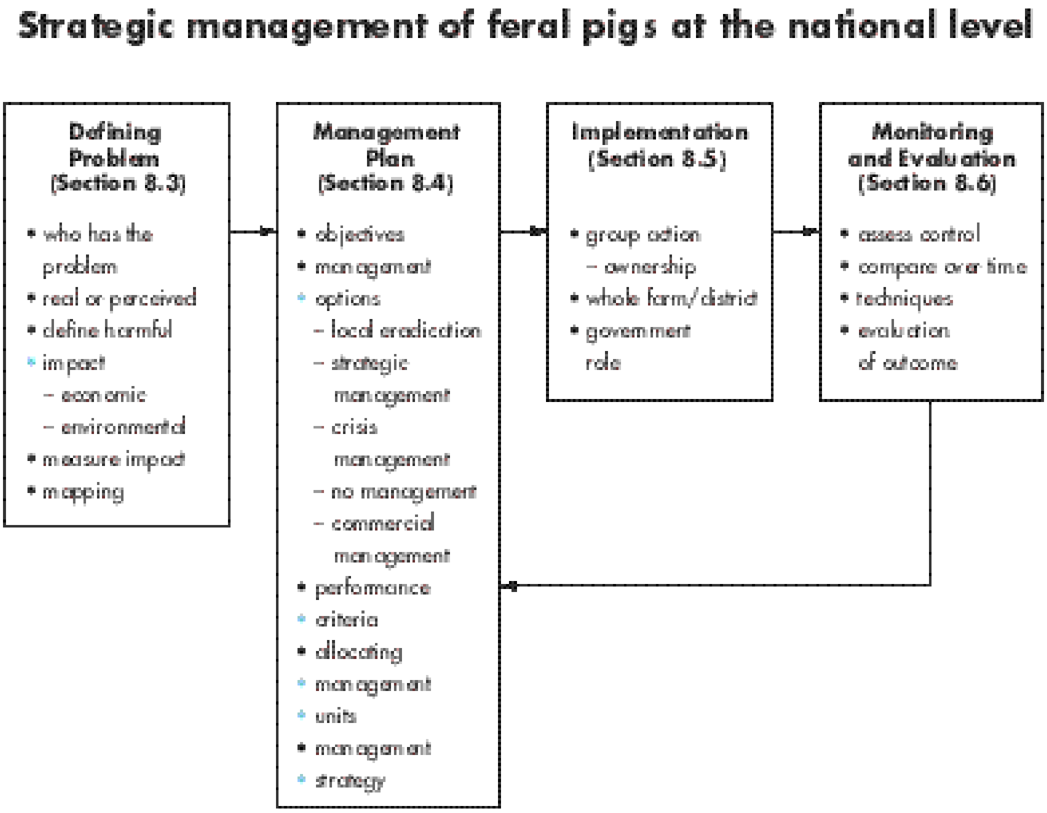
Defining the problem

Feral pigs are estimated to cause losses to agricultural production in Australia in the order of at least $100 million each year, although this might be a substantial underestimate. Although feral pigs are often regarded as having deleterious effects on the environment, there is little objective information. Determining the nature and extent of the economic or environmental threat due to feral pigs requires knowledge of their status and biology. Thus, Chapter 1 describes the history of their introduction and spread; Chapter 2 their distribution and abundance; and Chapter 3 their biology.

Chapter 4 reviews the evidence concerning the economic and environmental impact of feral pigs in Australia. It also reviews commercial use of feral pigs. Public attitudes can strongly influence the perceived nature of feral pigs as a resource or as a problem, and these issues are reviewed in Chapter 5. Past and current management of feral pigs and their legal status are discussed in Chapter 6. The impact of feral pigs can be assessed in several ways, and these are reviewed in Chapter 7, together with the efficacy of techniques to reduce these impacts. In many cases, feral pig impact on one property or area is influenced by their presence in neighbouring properties or areas. Thus many people or agencies, including governments and the community, jointly own feral pig problems and need to seek solutions cooperatively.

Management plan

The objective of the national guidelines is to stimulate a change in approach to feral pig management from ad hoc measures by individuals and agencies to a strategic management approach based on cooperative



Figur e 1: Strategic approach to managing feral pig damage (after Braysher 1993).

action. Adopting a whole property approach to management, preferably integrated into a regional or total catchment plan, is advocated since it can help manage the risks posed by feral pigs.

The guidelines will have succeeded in meeting this objective when the strategic approach they advocate is accepted and implemented by a significant number of agencies and individuals.

Several management options are identified and discussed in Chapter 8, including local eradication, strategic sustained management, commercial management, crisis management and no management. There are many ways of managing pig damage, including poisoning, exclusion, trapping, and shooting from the ground or helicopters. Ideally the management strategy should aim to achieve the desired production or conservation outcome by the most cost-effective means consistent with ecologically sustainable use of the management system. In many cases lack of knowledge may initially prevent identification of the best strategy. A flexible approach, however, where the land manager evaluates the benefits of management action and continually modifies it in the light of experience (that is, 'learning by doing') is often the best approach. Chapter 8 describes how such a management strategy can be developed.

Implementation

These guidelines for managing feral pig damage encourages the group approach at the local and regional level. This involves all land managers and others with a significant interest in feral pig management cooperating at an early stage in planning and implementation. Chapter 8 describes the features of such an approach for implementing management plans.

At the national level, such an approach requires that the various roles and responsibilities of government agencies, groups and individuals are taken into account and integrated. The Commonwealth Government is involved in pest management as a manager of Commonwealth land, through its responsibilities in exotic disease preparedness and overseas trade and through the threat that pests pose to such national initiatives as the National Landcare Program, the ESD strategy and the National Strategy for the Conservation of Australia's Biological Diversity. State and territory governments are responsible for providing the legislative and regulatory framework, administered through pest control agencies. At the local level, responsibility for pest management lies with the landholders and occupiers, whether government or private. The active participation of the Vertebrate Pests Committee in developing these guidelines is thus important in obtaining their acceptance and implementation. Chapter 9 reviews these issues and also addresses the role of extension services and group action for implementing effective feral pig management.

Monitoring and evaluation

Monitoring is an essential component of the strategic management approach to enable managers to determine whether their management strategy needs to be modified. Operational monitoring aims to assess the efficiency of the implementation of the management strategy so that areas where efficiency can be improved are identified. Chapter 7 reviews techniques for assessing the cost-effectiveness of control. Performance monitoring seeks to evaluate the outcome of the management plan; that is, whether the goals set initially in terms of production or conservation outcomes are being met. Methods of evaluating such outcomes are also described in Chapter 7.

Chapter 10 looks to the future and addresses research and management developments.

Strategic management at the local and regional level

This document sets out best practice feral pig management at the national level based on current knowledge. It brings together the best available information on effective feral pig management, as a basis for better management of the damage they cause.

The challenge for local and regional land managers and others with a major stake in the outcome of feral pig management is to use the information and processes described in this book to develop a strategic management plan to address the damage caused by feral pigs. Chapter 8 explains how this might be achieved, and provides hypothetical examples of its application.

Vertebrate Pest Program

In its Environment Statement of December 1992, the Commonwealth Government provided increased resources to complete the guidelines for managing Australia's major vertebrate pest species and to establish key demonstration projects to facilitate adoption of best practice pest management. Projects draw on the management strategies outlined in the relevant guidelines for each species. For most projects, including management of feral pigs, it is anticipated that best practice management will evolve based on experience gained from strategic management. Using the management system to refine pest management strategies is called adaptive management, or 'learning by doing'.

It is expected that community-based groups will become more involved in the strategic management of vertebrate pests. The guidelines are designed to facilitate the ownership of the pest problem by such local groups, and the management strategy which might be developed and implemented based on them. Accordingly, the Vertebrate Pest Program (VPP) gave preference to projects which involved collaboration between several appropriate government and/or non-government agencies and involved community-based groups in their design and implementation. The VPP supported projects which addressed the impact pests have on primary production. The complementary Feral Pests Program (FPP) administered by the Australian Nature Conservation Agency gave priority to strategic pest management in areas primarily used for conservation. Projects which addressed both agricultural and conservation damage by pests were jointly funded. It is intended that these guidelines and the results of the VPP and FPP projects will assist state and territory governments in their role of providing legislative, technical and policy support for feral pig management.

1. History

Summary

Most feral pigs in Australia are descendants of various breeds of the domestic pig Sus scrofa, *which for various reasons, particularly lack of restraint and deliberate releases, reverted to living independently of people. The main founder breeds were probably the European Berkshire and Tamworth, which had already been greatly modified by cross-breeding with other breeds from China, India, Italy and Portugal. Some* S. celebensis, *brought from Timor and Kisar to early settlements on the Coburg Peninsula last century, may also have established in the Northern Territory and* 'S. papuensis', *a hybrid between the two species from New Guinea may have been released in some areas of Queensland in the past. Initially, the distribution of pigs was closely correlated with major settlements throughout Australia, but as changes occurred in the management of rural properties, many pigs were left unattended, wandered away and established truly feral colonies.*

1.1 Origin of feral pigs in Australia

Feral pigs (*Sus scrofa*) belong to the small Old World Family Suidae of nine species classified into five genera: *Babyrousa* (babirusa); *Phacochoerus* (wart hogs); *Hylochoerus* (giant forest pigs); *Potamochoerus* (bush pigs); and *Sus* (wild boar, feral and domestic pigs). All have large, long heads with mobile snouts used for rooting up the ground, short necks and powerful, stocky bodies with coarse, bristly coats.

Feral pigs can be distinguished from three of the four other species of *Sus* (*S. barbatus, S. celebensis* and *S. verrucosus*) by their lack of facial warts, hair type and skull characters (Groves 1981), and from the fourth, the pygmy hog (*S. salvanius*), by their larger size, longer tail and six pairs of nipples instead of three (Cumming 1984). *Sus scrofa* and its subspecies gave rise to most domestic pigs, and hence to feral pigs in Australasia, the Americas and Oceania (Clarke and Dzieciolowski 1991). During the 18th and early 19th centuries, European domestic pigs (*S. scrofa scrofa*), such as the Berkshire, were extensively modified by cross-breeding with Chinese *S. scrofa moupinensis*, Indian *S. scrofa cristatus* and pigs from Naples and Portugal (Epstein and Bichard 1984). Such highly modified domestic breeds, many of which were partly or wholly Asian in origin, form the basis for the modern European pig industry. These and other improved European breeds (for example, the Tamworth) were the pigs mostly taken by explorers, mariners and settlers on 18th and early 19th century voyages to Australia and New Zealand (Clarke and Dzieciolowski 1991).

1.2 Introduction and spread in Australia

It is not known when pigs were first successfully introduced into Australia. Captain Cook presented some pigs to the Maori and released others during his second and third voyages to New Zealand during 1773–1777 (McIlroy 1990; Clarke and Dzieciolowski 1991). These included pigs from Capetown (presumably of European origin) and some Polynesian pigs of Indo-Malay origin (possibly *Sus scrofa vittatus*), obtained from Tongatapu (Tonga Islands) and Huahine (Society Islands). Cook's diaries, however, make no mention of the release of pigs in Australia except for a boar and a sow that were set free on Bruny Island in Tasmania in 1777, which he expected to be killed by the Aborigines (no signs of pigs were seen on the island by the Baudin expedition in 1802; Statham and Middleton 1987). The diaries also note that one piglet, from a sow and piglets being kept ashore while Cook careened the Endeavour near the present Cooktown in north Queensland, was scorched to death by a fire deliberately lit by the Aborigines (Pullar 1953). Pigs could have been introduced onto Cape York from Papua New Guinea before then, but this seems unlikely given the apparent lack of a word for 'pig' in the languages of the Aboriginal peoples (Pullar 1950; Pavlov et al. 1992). Pullar (1953), however, received reports indicating pigs may have been introduced into Cape York from Papua New Guinea late last century.

The New Guinea pig (the so-called *Sus papuensis*) is a hybrid between domesticated *S. celebensis* and imported, domesticated *S. scrofa vittatus* (Groves 1981). Some *S. celebensis* were brought to the Melville Island and Coburg Peninsula settlements in the Northern Territory from Timor and Kisar, between 1824 and 1843 (Letts 1962; Calaby and Keith 1974). Some of the pigs on Melville Island wandered at liberty, while pigs considered to be the offspring of a boar and several sows left at Raffles Bay in 1829, when the settlement was abandoned, were observed in the forests around Port Essington in 1843 (Letts 1962). Leichhardt reported that at Port Essington a good number of pigs strayed away into the bush (Calaby and Keith 1974). Although signs of pigs are not common in the area today (Calaby and Keith 1974), there is a chance that *S. celebensis, S. scrofa* and *'S. papuensis'* may all occur in some northern parts of Australia (Groves 1981).

The first official record of pigs in Australia is that of 49 hogs (one boar, nineteen sows, others not defined) after the arrival of the First Fleet in Sydney (Rolls 1969). From then on the introduction and spread of pigs is unclear, but various breeds or subspecies of *S. scrofa* were probably brought to Australia from different countries by trading ships and many pedigree pigs were imported from England in the 1820s (Anon. 1983).

Pigs became feral and subsequently spread by unrestrained domestic stock wandering away, accidental escape of domestic stock when farm buildings were insecure or when trucks were damaged or overturned, and deliberate releases of feral pigs to start new colonies or to improve the conformation of existing feral pigs (Pullar 1953). Such releases and spread continue today.

'The first official r ecord of pigs in Australia is that of 49 hogs in the First Fleet.'

Initially, the distribution of feral pigs was closely correlated with settlement, where until about the middle of the 19th century they were kept under semi-feral conditions. In some areas they quickly became nuisances, such as around the settlement of Sydney Cove by 1795 and in Lonsdale Street, Melbourne in the 1840s. After about 1865, when the fencing-in of properties became general practice and many original runs and stations were subdivided, a considerable number of pigs were left unattended and became truly feral. The main established colonies of pigs then, according to Pullar (1950, 1953), were in the greater part of Queensland and the Northern Territory, the Upper Darling and Lachlan–Murrumbidgee Junction, the Darling Ranges in Western Australia and on Flinders and Kangaroo Islands (in the latter two cases, aided by releases from sealers and other mariners). By the 1880s pigs had run wild in New South Wales and were such a nuisance that they were being shot (reportedly in thousands in the Riverina) and poisoning of them was about to begin (Rolls 1969).

2. Distribution and abundance

Summary

Feral pigs are generally sedentary animals, but may become semi-nomadic in environments where there are marked changes in the availability of food and water. The most critical factors affecting their distribution in Australia are their poor heat tolerance and the accompanying need for access to daily water and dense shelter. This largely restricts their distribution to the vicinity of watercourses and associated floodplains in inland or seasonally dry areas of Australia. These factors are less critical in the more forest-covered parts of eastern Australia and south-west Western Australia, where populations are still spreading.

Once established, colonies of feral pigs rapidly build up in many areas. Because estimates of pig numbers are subject to many sources of variation, total numbers of pigs in Australia could be anywhere between 3.5 million and 23.5 million. They inhabit 38% of the continent, but their distribution and abundance can vary markedly according to environmental conditions from year to year. Densities in different habitats vary from about one pig per square kilometre in drier eucalyptus woodland, forests and grazing land to ten to twenty pigs per square kilometre, and possibly higher, in wetlands and seasonally inundated floodplains.

2.1 Distribution in Australia

Feral pigs are now widely distributed in Queensland, the Northern Territory, New South Wales, and the Australian Capital Territory (Figure 2). Isolated populations occur in Victoria, Kangaroo Island in South Australia, in Western Australia and on Flinders Island in Bass Strait. In Tasmania, accidental releases lead to small, temporary populations.

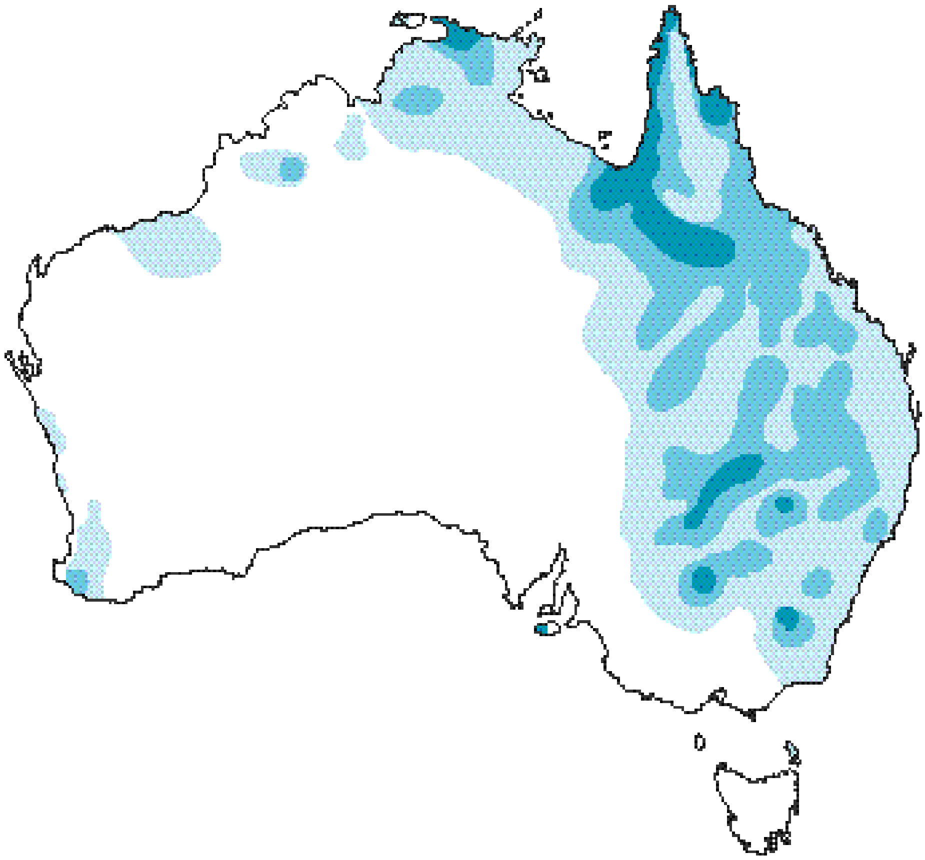
The distribution and spread of feral pigs in western Queensland and New South Wales is directly related to the location of inland watercourses and their associated flood plains. Feral pigs can tolerate high ambient temperatures only where both drinking water and dense vegetation for shelter are available (Wilson et al. 1992a). Natural spread along watercourses into these areas depends on good seasons and has largely occurred only during the last 40 to 80 years (Pullar 1953). McKnight (1976), for example, provides reports of feral pigs spreading widely throughout Queensland's Channel Country between 1913 and 1921, to the Cobar and Hillston districts of New South Wales and well back from the Darling River around Bourke (from the Walgett and Moree districts and marshes on the Macquarie and Lachlan Rivers) during a succession of good seasons in the early 1950s, and into the Cunnamulla area since 1950.

'The distribution and spread of feral pigs in inland Queensland and New South Wales is along watercourses and their flood plains.'

Numerous isolated populations of feral pigs have also appeared in eastern Queensland and New South Wales over the last 30 years, particularly in the tablelands and coastal areas (Hone and Waithman 1979; Wilson et al. 1992a). In many cases the founding animals for these populations were probably deliberately released by hunters, rather than being a product of natural dispersal.

In the Australian Capital Territory an unstated number of pigs were released in the Boboyan district in 1900 and others escaped or were released into the general area between 1959 and 1968 (Boreham 1981). Since then, the pigs have dispersed throughout most rural areas in the Australian Capital Territory and adjacent parts of New South Wales. Some unauthorised releases still occur.

Populations of feral pigs in Victoria are small, local, but widespread, and are indicative of deliberate liberations



Figur e 2: Distribution of feral pigs in Australia (after Wilson et al. 1992a).

(Townsend 1981). Accidental releases in Tasmania lead to small populations occupying areas of private and Crown land. Dispersal is contained by rangers and local hunters (G. Atkinson, NPWS, Tasmania, pers. comm. 1995). On Flinders Island in Bass Strait about 1000 pigs inhabit the north and east coast lagoon areas, Strzelecki National Park and Darling Range (Statham and Middleton 1987). In Western Australia feral pigs occur in four main areas: the river systems of the east and west Kimberley; the Pilbara; north-west lower Murchison and Geraldton areas; and the river systems, swamps and forest country in the south-west of the state (Long 1988).

In the Northern Territory feral pigs occur mainly in higher rainfall areas, particularly on the extensive floodplains and adjacent woodlands close to the coast (Bayliss and Yeomans 1989). They tend to concentrate near watercourses and billabongs, but during the wet season they range further throughout the open forest country. Their main distribution extends from the Moyle River and the northern catchment of the Victoria River to the eastern edge of the Arnhem Land escarpment, but occasionally they are observed further east of this, including along the Roper River (Letts 1964; Bayliss and Yeomans 1989). Like buffalo (*Bubalus bubalis*), they have colonised forest and woodland scattered throughout the sandstone plateau. Feral pigs also occur on Bathurst Island but none are now known to occur on Melville Island (Bayliss and Yeomans 1989).

'Feral pigs are still colonising parts of Australia.'

Feral pigs are normally sedentary animals, generally confining their movements to a defined home range. This reluctance to leave their home range may explain why they are still colonising parts of Australia. In the Northern Territory feral pigs were observed near the Liverpool River in east Arnhem Land for the first time during the mid-1980s (Caley 1993). If these pigs were descendants of the original pigs that escaped or were released at Port Essington 240 kilometres away in the mid-1800s, the dispersal rate would be about two kilometres per year.

2.2 Changes in abundance

The changes in abundance of feral pigs in Australia, both in time and location, are similar to the irruptive pattern observed in pig and other ungulate populations following their liberation in other countries (Caughley 1970). Once established, they increased rapidly. In some areas pig populations remained high for a period and then declined, through either depletion of their preferred foods or cover by land development, increased control efforts or the effect of droughts. In other areas management practices, particularly cropping and the provision of stock watering sources, have allowed pigs to remain at moderately high densities, while in some areas they are still increasing and spreading.

In many areas major concentrations of feral pigs built up during both World Wars (as also occurred in New Zealand, McIlroy 1990), because of a shortage of hunters, rifles, ammunition and petrol for transport (Pullar 1953). Since then, their numbers have fluctuated. Some colonies have died out, while others have started, particularly through releases, and there has been considerable variation in the extent of range they inhabit from year to year. Hone (1990a)

Feral pigs are widely distributed in Queensland, the Northern Territory, New South Wales and the Australian Capital Territory. *Source: P. O'Brien, BRS* estimated that feral pigs now inhabit about 38% of Australia and there could be 13.5 million (with 95% confidence intervals of 3.5 million to 23.5 million) of them in Australia. This estimate encompasses the three other most recent estimates of the numbers of pigs in Australia (Flynn 1980; Tisdell 1982; Cutler 1989). Hone (1990a), however, recommended that any current estimates of abundance of feral pigs in Australia should be interpreted with great caution because of the inadequate data that can be used as a basis for such estimates and the strong evidence that population size of feral pigs is not constant from year to year, but is determined by environmental influences.

Estimates of the abundance of feral pigs in different habitats at different locations throughout Australia are shown in Table 1.

Table 1: Estimates of abundance of feral pigs in various locations and habitats in Australia.

Location	Density (pigs per square kilometre)	Habitat	Source
South-west Western Australia	1–4	Forest	Masters (1979)
Warren, New South Wales	8.0–17.5	Wetlands	Giles (1980)
Yantabulla, New South Wales	0.2–0.8	Semi-arid rangelands	Giles (1980)
Flinders Island, Tasmania	0.5–3.0	Forest and swamp	Statham and Middleton (1987)
Goondiwindi, Queensland	0.1–3.9	Pasture, woodland, forests and wheat crops	Wilson et al. (1987)
Kosciusko National Park, New South Wales	1.1	Forest	Saunders (1988)
Macquarie Marshes, New South Wales	10.3	Wetlands	Saunders and Bryant (1988)
Namadgi National Park, Australian Capital Territory	1.8	Forest	McIlroy et al. (1989)
Aurukun, Queensland	1–>20	Floodplain, swamp and woodland	Dexter (1990)
Adelaide River, Northern Territory	2.6–10.9 2.2–10.2 0–1.2	Paperbark swamp Open floodplain Dry woodland	Hone (1990b)
Mary River, Northern Territory	6.1	Floodplain and woodland	Hone (1990c)
Sunny Corner, New South Wales	2	Pasture, forest and woodland	Saunders and Kay (1991)
Kapalga, Northern Territory	<1	Open forest and woodland	Ridpath (1991)
Douglas–Daly area, Northern Territory	0.8–3.5	Woodland and crops	Caley (1993)
Nocoleche Nature Reserve, New South Wales	0.2–1.5	Semi-arid rangelands	Choquenot (1994); Dexter (1995)
Paroo River, New South Wales	0.2–1.2	Floodplain and woodland	Dexter (1995)

3. Biology and ecology

Summary

The biology and ecology of feral pigs make them important and successful pests in Australia. Their large robust bodies, specially developed snouts for rooting up the ground, omnivorous diet and adaptive activity patterns allow them to live in a wide range of habitats. Some variation occurs in physical size, shape and coat colour between different regional populations. Overall, feral pigs are smaller, leaner and more muscular than domestic pigs, with well developed shoulders; longer, larger snouts and tusks; smaller, mostly pricked ears; coarser hair and straight rather than curly tails. Males tend to be longer and heavier than females and have larger heads and tusks.

Feral pigs are habitat generalists and have colonised subalpine grasslands and forests, dry woodlands, tropical rainforests, semi-arid and monsoonal floodplains, swamps and other wetlands in many parts of Australia. Their prime requirements are a reliable and adequate supply of food, water and cover. Their opportunistic feeding habits and omnivorous diet allow them to exploit various temporarily abundant food sources, such as fruits and seeds, foliage and stems, rhizomes, bulbs and tubers, fungi and animal material. Feral pigs have relatively high energy and protein requirements, particularly during pregnancy and for successful lactation and growth of young. These requirements cannot always be met by the seasonal availability of foods in any particular area. Consequently feral pigs often move to other parts of their home range that are better sources of the foods they require, including agricultural crops. This seasonal need for either more food, or high energy or protein-rich food, is both the reason for their impact on agriculture and the environment and a weakness in their ecology that can be exploited for management purposes. Individuals can move up to 55 kilometres, particularly from one watercourse to another, in their search for food, or in response to major prolonged disturbance by people. But most pigs retain a strong fidelity to their home ranges, even when subjected to minor disturbance, such as infrequent hunting by people and dogs.

Although adult boars are invariably solitary, and farrowing sows will temporarily separate themselves from other pigs, feral pigs are mostly social, gregarious animals. The basic group consists of one or more sows and their piglets, but other groups consist of young females, bachelor groups of young males and other combinations. Group sizes vary considerably, ranging from 1–12 up to 40–50 in different seasons and areas. Mobs of more than 100 can gather around remaining waterholes in dry seasons.

Home range sizes are determined primarily by resource abundance, and secondarily, by population density and body size. Boars have larger daily, seasonal and overall home ranges than sows. Activity patterns depend on the location, weather and the degree of disturbance from people. Feral pigs tend to be more nocturnal or crepuscular during hot weather or when they are subjected to disturbance, and more diurnal in cooler climates.

The reproductive potential of feral pigs is more similar to that of rabbits than to that of other large mammals in Australia. Under favourable conditions, breeding can occur throughout the year, but where food availability and quality is variable, breeding is usually seasonal. Adult females have a 21-day oestrus cycle, a gestation period of about 113 days, and as soon as they reach 25 kilograms in weight are able to give birth to an average of five or six piglets. Fecundity increases with age and body weight but can be strongly affected by seasonal conditions. Under favourable conditions sows can produce two weaned litters every 12–15 months, providing them with the capacity to recover quickly from control programs or other setbacks such as droughts or floods. Mortality of young piglets is generally high, especially from starvation and loss of

contact with their mothers, ranging from 10–15% when food supplies and weather are favourable, up to 100% when conditions are poor. Adult mortality can vary from 15–50% with few pigs living beyond five years of age. Dingoes and feral dogs can prey on substantial numbers of young pigs but it is not clear if they limit the size or distribution of pig populations.

Feral pigs are subject to many infectious diseases and parasites, including some economically important exotic diseases, such as foot-and-mouth disease, and endemic diseases and parasites, such as leptospirosis, brucellosis, and melioidosis, that can affect the health of domestic livestock or people. Several parasites are important in terms of domestic livestock or public health.

The population dynamics of feral pigs have been studied in various habitats in Australia, although in detail only in the semi-arid rangelands and the wet–dry tropics. In both of these habitats rate of change in population abundance is driven by food availability. In the wet–dry tropics, food availability varies in a reasonably consistent pattern with the annual cycle of wet and dry seasons. In the rangelands, food availability varies with rainfall and flooding. There is evidence that food and predation operate together to regulate the abundance of feral pig populations in the south-east tablelands and subalpine regions. Little is known about the dynamics of feral pig populations in the wet tropics.

3.1 General description

Feral pigs in Australia generally more closely resemble Eurasian wild boar than domestic pigs. Pigs belong to the Order Artiodactyla, or even-toed ungulates, the largest and most diverse group of large land-dwelling mammals living today. Like their closest relatives, peccaries (Family Tayassuidae) and hippopotamuses (Family Hippopotamidae), they are non-ruminant mammals that are primarily omnivorous, with low-crowned molars with simple cusps, large tusk-like canines, rounded body contours, and short legs with four toes (two of which have been modified to large dewclaws in pigs). In contrast, the ruminant artiodactyls (for example, camels, deer, giraffes, cattle, sheep and goats) are specialist herbivores, with ridged, often high-crowned molars, a multi-chambered stomach, and often longer legs and only two functional toes.

3.1.1 Morphology

Feral pigs in Australia are smaller, leaner and more muscular than domestic pigs, with well developed shoulders and necks and smaller, shorter hindquarters. They also have longer, larger snouts and tusks, smaller, mostly pricked ears (not pendant like those of many domestic pigs) and much narrower backs. Older boars usually develop keratinous plaques or shields up to three centimetres thick on their shoulders and anterior flanks, which provide some protection from serious injury during fights with other boars. Their hair is sparse and longer and coarser than that of domestic pigs. Some individuals develop a crest or mane of bristles extending from their neck down the middle of their back; up to ten centimetres long on the neck, diminishing to one centimetre nearer the tail, hence the nickname razorback. These bristles often stand erect when the pig becomes enraged (Giles 1980). The tails of feral pigs are usually straight with a bushy tip rather than curly as in domestic pigs.

'Feral pigs in Australia are smaller, leaner and more muscular than domestic pigs.'

Males tend to be longer and taller than females, have larger heads, and are up to 10–20 kilograms heavier when one year old (Australian Meat Research Committee 1978, Masters 1979, 1981; Pavlov 1980, 1983). Body weight depends on habitat conditions but adults generally range up to 115 kilograms for males and 75 kilograms for females. Feral pigs in the temperate forests of New Zealand may grow to over 200 kilograms (McIlroy 1990) and in Namadgi

National Park, near Canberra, a 175 kilogram boar was caught (J. McIlroy, unpublished). Lactating sows usually weigh less than non-lactating sows of the same age. Average body length of adults is 105–155 centimetres for males and 100–130 centimetres for females.

3.1.2 Colour

Regional populations of feral pigs vary in physical size, shape and coat colour, differences probably inherited from the breeds which initially escaped or were released. Pullar (1953) described two extremes of feral pigs as early and recent types but recognised that there was a large and varied range of intermediate forms. The smaller, mainly black or dark red early types, which were in decline in the 1950s, were perhaps the direct descendants of pigs which escaped or were liberated 90 to 140 years ago. The larger recent types, similar to poorly developed domestic pigs, are probably progeny of more recent additions (Pullar 1953). Colour patterns vary both within and between areas. Black is, and apparently always has been, the most common colour (Pullar 1953; Pavlov 1983). Other colours include rusty red and a high proportion of lighter or mixed colours, including white, light ginger, brown and white, brown with black spots and agouti patterned (brown or black hair with a lighter tip). The agouti pattern is more typical of pigs in north-west New South Wales, whereas black pigs predominate further east (Australian Meat Research Committee 1978). Some piglets are marked with dark longitudinal stripes, which disappear as they grow older (Wilson et al. 1992a). Such stripes are rarely seen in domestic pigs, but occur in wild *Sus scrofa*, *S. celebensis* and '*S. papuensis*'.

3.1.3 Facial characteristics

The young of some feral pigs are marked with longitudinal stripes which are rarely seen in domestic pigs.

Source: P. O'Brien, BRS

The nostrils of pigs face forward on the end of their blunt, rounded snouts, which are flattened and strengthened by a cartilaginous plate supported by prenasal bones (Groves and Giles 1989). Their eyes are small and their eyesight poor, but their senses of smell and hearing are well developed. Their dental formula is I 3/3 C 1/1 PM 4/4 M 3/3 = 44. The permanent teeth are in place by 20–22 months old. The continuously growing canine teeth (tusks) of adult males are larger than those of domestic pigs and project from the sides of the mouth. The lower tusks are triangular in cross section and curve upwards, outwards and backwards, forming an arc of a circle up to 60 centimetres in circumference (Pullar 1953; McIlroy 1990). Their total length is up to 30 centimetres, but up to 80% is embedded in the lower jaw (Pullar 1953; McIlroy 1990). The upper canines are considerably shorter; up to nine centimetres long (Pullar 1953; McIlroy 1990) and oblong in cross section. They curve outwards and back, functioning as whetstones or grinders to the lower tusks. If an upper tusk is broken or deformed, the corresponding lower one can continue to grow in a complete circle, ultimately re-entering the lower jaw.

3.2 Habitats

Feral pigs occupy a wide range of habitats in Australia, including the subalpine grasslands and forests of Kosciusko National Park, the semi-arid floodplains (often dominated by lignum — *Muehlenbeckia cunninghamii*) in western New South Wales, the *Typha* and *Phragmites* reed-beds of the Macquarie Marshes in central New South Wales, the rainforests in the wet tropics of northern Queensland, and the paperbark (*Melaleuca* spp.) swamps, open floodplains, monsoon forest patches, *Mimosa pigra* thickets and dry woodlands in the Northern Territory (Australian Meat Research Committee 1978; Giles 1980; Saunders 1988; Hone 1990b; Bowman and McDonough 1991; McIlroy 1993; Dexter 1995). They prefer moist areas that provide a reliable and adequate supply of food, water and cover for seclusion and protection from extremes of temperature (Pullar 1950; Australian Meat Research Committee 1978). Details on movements of pigs between habitats are given in Section 3.3.2.

3.3 Food and movements

3.3.1 Food

Pigs have a single stomach, with a poor capacity to digest cellulose, so they cannot feed solely on roughage as ruminants do. Instead, they are opportunistic omnivores, with strong preferences for succulent green vegetation, a wide variety of animal material, fruit and grain (Giles 1980). Other foods include underground starch-rich plant material, such as roots, bulbs and corms.

The items eaten by feral pigs in Australia vary from region to region, but include:

(a) Fruits and seeds:
Figs, palms, pandanus and other rainforest trees; cycads (*Macrozamia* spp.); bush peanuts (*Elaeocarpus* spp.); sweet briar (*Rubus rubiginosa*); *Acacia* spp.; *Persoonia* and *Coprosma*; bananas, mangoes and a wide range of orchard fruit; grasses; and crops such as pumpkins, watermelons, potatoes, peanuts, maize, wheat, oats, sorghum and other cereals.

(b) Foliage and stems:
Small palms, pandanus and other rainforest seedlings; young coconut and banana trees; sugarcane; succulents such as *Portulaca oleracea*; semi-aquatic ferns (for example, nardoo — *Marsilea drummondii*); and a range of forbs, grasses and legumes, including native medics, introduced clovers and lucerne, *Paspalum paspaloides*, *Poa* spp. and young wheat.

(c) Rhizomes, bulbs and tubers:
Lilies (for example, *Helmholtzia* spp. and vanilla lily — *Arthropodium milleflorum*); grasses, sedges and rushes such as *Eleocharis* spp., *Cyperus rotundus*, *Setaria sphacelata*, *Phragmites* spp., *Typha* spp., *Scirpus* spp. and *Juncus* spp.; bracken (*Pteridium esculentum*); dock (*Rumex* spp.) and thistles (Family Asteraceae); native

geranium (*Geranium solanderi*); *Oxalis* spp.; yams and other tropical rootstocks (*Ipomoea*, *Dioscorea* and *Ampelocissus* spp.); and *Macrozamia* spp.

(d) Fungi:
Underground fungi.

(e) Animal material:
Earthworms, snails, arthropods (especially beetles), crustaceans, shellfish, frogs, fish, reptiles (including turtle eggs), eggs of ground-nesting birds, birds, mice, young rabbits, lambs and other small mammals and carrion.

(Sources of information: Pullar 1950; Masters 1979, 1981; Giles 1980; Boreham 1981; Alexiou 1983; Hopkins and Graham 1985; Statham and Middleton 1987; Bowman and McDonough 1991; Pavlov 1991; Ridpath 1991; Pavlov et al. 1992; Mitchell 1993).

The nutrient levels in these different foods can vary considerably (Table 2). Fruits usually contain much higher concentrations of readily digestible carbohydrates (sugars and starch) than foliage, and some are especially high in lipids which provide readily available energy (Cork and Foley 1991). Fruits, however, usually contain far less protein than foliage, although the amount that pigs may obtain from fruit could vary according to whether it contains large seed capsules and if the pigs chew and digest these as well as the softer pericarp.

'Feral pigs have high protein requirements, particularly for successful lactation and growth of young.'

Feral pigs probably have relatively high protein requirements, similar to those of domestic pigs (Table 3), particularly for successful lactation and growth of young. If intake of crude protein falls below 15% of the diet, lactation can cease and piglets may die (Giles 1980). The dietary energy needs of feral pigs are also relatively high, particularly for sows in the last month of pregancy, which require about twice the digestible energy of non-breeding sows, and lactating sows which require up to three times the non-breeding energy requirments. If these requirements are not met by dietary intake, they must be met by mobilising tissue reserves (Giles 1980). Puberty in feral pigs may also be delayed by severe restriction in energy intake.

Table 2: Chemical constituents (ranges) of tropical and temperate fruits and other items likely to be eaten by feral pigs. Adapted from Bolton and Phillipson (1976), Barrett (1978), Lee (1985), Bell (1990) and Cork and Foley (1991). Dashes indicate no data available.

	Constituent (% dry matter)		
Food item	**Crude protein**	**Sugars and starch**	**Cellulose**
Tropical and temperate:			
Fruits	3–12	12–78	1–8
Seeds	3–15	2–16	–
Grasses	4–17	3–19	15–40
Forbs	4–35	2–18	6–33
Tropical trees and shrubs:			
Young leaves	7–55	0–33	6–25
Mature leaves	5–36	1–15	11–30
General:			
Bulbs	12–15	–	–
Legumes	24–25	–	–
Earthworms	54–80	–	–
Insects	60	7	–
Carrion (cow)	57	–	–

Table 3: Daily nutrient requirements of domestic pigs for different weight classes (Barrett 1978).

	Growing pigs			Breeding sows	Lactating sows	Boars
	5–10 kg	**10–20 kg**	**20–35 kg**	**110–160 kg**	**136–200 kg**	**110–180 kg**
Digestible energy:						
Kilocalories per kilogram forage	3500	3500	3300	3300	3300	3300
Kilocalories per day	2100	4370	5610	6600	16 500	8250
Total feed:						
Air dry weight (kilograms)	0.6	1.3	1.7	2.0	5.0	2.5
Crude protein:						
Percentage of diet	22	18	16	14	15	14
Grams per day	132	225	272	280	750	350

Both the availability and nutrient levels in the different foods and their consumption by pigs change seasonally. For example, in central and western New South Wales, feral pigs feed mainly on green herbaceous material when it becomes available after heavy rain or floods (Giles 1980). During dry periods they eat roots, carrion and little else. In the Girilambone area in central New South Wales, they mainly eat forbs such as *Solanum ellipticum* and insects in autumn, native medics (*Medicago* spp.) with their high protein content in winter, and wheat in spring and summer. Roots, however, are the most consistent food item in all seasons (Pavlov 1980). Consumption of animal matter, with its high protein content, varies greatly between seasons and rarely exceeds 5–18% of the diet (Giles 1980; Pavlov 1980).

3.3.2 Movements

Feral pig movements are largely driven by the location of food, and there is often a trade-off between the energy needed to obtain food and the protein and energy derived from it. Hence feral pigs readily switch foods and feeding places, and they may move correspondingly little or extensively, depending on variations in locally or seasonally abundant food sources.

Movements are also influenced by requirements for shelter, including wallowing areas, during different times of the year, and to a lesser extent by the local topography and disturbance. For example, McIlroy (1989) found that in New Zealand feral pigs were sedentary in a relatively undisturbed area containing improved pasture, bracken and forest with abundant food, water and shelter. However, some pigs moved to more open lambing paddocks in late winter when food became less abundant.

'Feral pigs readily switch foods and feeding places.'

Most observed movements of feral pigs in the wet tropics of northern Queensland similarly appear to be seasonal and related to food supplies (McIlroy 1993). In more settled areas pigs are reported to move from rainforests to sugarcane, banana and other crops, orchards and other areas during the dry season and back into the rainforest once the wet season begins. Common routes for movements are the drier, more open ridges leading down to cane fields. Examples of such movements are to cane fields in April onwards, when the cane has a high sugar content; to house gardens and small orchards in August–November, when ripe fruit is available; and to irrigated pastures, municipal parks and golf courses in September–October, when the ground in many other areas is too hard to root up for earthworms. Diong (1973) similarly found in Malaya that some feral pigs moved up to 16 kilometres to feed on sugarcane and other crops when their food in the native forest became limited. The pigs generally moved along well-marked customary trails to these feeding areas, and were usually in a better condition than pigs that remained feeding in the native vegetation. In less settled areas of northern Queensland pigs regularly forage for soil invertebrates in ephemeral swampy areas of the coastal plains during the early dry season, as well as scavenging food from orchards, household compost heaps, open garbage dumps and tourist areas, but move into higher rainforest areas once conditions become drier (Pav Ecol 1992). Seasonal changes in habitat use also occur in the South Coast area of New South Wales. Here feral pigs tend to retire to the thickly forested headwaters of creeks or swamps, where water is permanent during dry periods; but return to the coastal plain where food supplies are more abundant during rainy weather (Hart 1979). In the Northern Territory, feral pigs primarily exploit the seasonally flooded swamp communities during the dry season and the open floodplains and dryland forests during the wet season (Hone 1990b; Bowman and McDonough 1991).

'Feral pigs can shift home range if they are subjected to intensive or prolonged disturbance, such as hunting or other control activities.'

Temporal changes can also occur in the use of habitats by feral pigs. During hot weather, for example, feral pigs may rest during the day in shady places under thick lignum bushes, in riverine woodland communities, or in patches of monsoon forest and then move to more open grasslands, sedgelands and waterholes to drink and feed after dark (Giles 1980; Ridpath 1991; Dexter 1995).

Feral pigs generally do not move very far in response to minor disturbance, including infrequent hunting by people, and usually return to their home ranges shortly afterwards (Pullar 1950; Masters 1979; Saunders and Bryant 1988; McIlroy and Saillard 1989; Caley 1993). Feral pigs can, however, shift permanently to more remote areas, for example, up to five kilometres away in forest, if subjected to intensive or prolonged disturbance, such as large-scale hunting or other control activities (Pullar 1950; McIlroy 1989; McIlroy et al. 1989; Caley 1993). Maximum linear distances that feral pigs are known to have covered in Australia are 55 kilometres for a sow from one watercourse to another over open plains in western New South Wales after a major control operation (Saunders and Bryant 1988) and 23 kilometres, over a period of at least two years, for two boars in similar country, probably in response to flooding (Giles 1980).

3.4 Social organisation and behaviour

Although adult boars over 18 months old are invariably solitary, and farrowing sows will temporarily separate themselves from other pigs, feral pigs are gregarious animals. The basic group consists of one or more sows and their piglets, but groups may also consist of young females, bachelor males or other combinations. Interactions with individuals from other litters begin early in life and often persist into adulthood (Graves 1984). Weaned piglets remain with their mother until the next litter is due and then run together until the young sows mate. Bachelor groups of males remain together until they are about 18 months old (Masters 1979; Giles 1980; Pavlov 1980). After that they generally only rejoin groups for mating or to feed on localised food resources.

Group sizes can vary considerably in different areas and with seasons. In the forests of south-west Western Australia, group sizes rarely exceed 12 pigs, but in more open country mobs of 30–40 have been reported (Masters 1979). Caley (1993) recorded the largest group sizes, 12–45, during the mid-dry season in the Douglas–Daly area, Northern Territory, and the smallest, 5–30, during the late wet season and early dry season. In contrast, Hone (1990b) reported that the most frequently observed group size near the Mary and Adelaide rivers, further east, was 1–10 pigs (maximum 50) in both the dry and wet seasons. These are similar to those reported for parts of western New South Wales by Hone and Pedersen (1980) and for Kosciusko National Park by Saunders (1988). Ridpath (1991) likewise reported that in tropical northern Australia often only single pigs were observed and groups rarely exceed 20 individuals, but that in times of severe drought, groups of over 100 could gather around remaining waterholes.

'The size of a feral pig's home range is mainly determined by food abundance.'

Feral pigs make consistent use of trails to travel from one area of specific use to another, such as from refuge or bedding sites to feeding grounds or water (Saunders 1988). Signs of rubbing or tusking are often found on trees or logs along these trails. Wallowing in dust or muddy depressions is also common and serves as both a method to reduce ectoparasite infection (as does rubbing) and a means of thermoregulation.

Both boars and sows have carpal glands (Signoret et al. 1975) which, along with saliva, are used as scent markers. Despite this, there is no evidence of territorial behaviour (Barrett 1978; Giles 1980).

The size of home ranges is primarily determined by the abundance of food and is correlated with body weight and population density (Saunders 1988; Caley 1993). Boars have larger daily, seasonal and overall home ranges than sows, particularly recently farrowed sows which stay close to their young for the first two weeks or so after farrowing (Saunders 1988; McIlroy et al. 1989; Caley 1993). Daily home ranges are generally small (0.7–1.4 square kilometres) compared with seasonal and aggregate home ranges, indicating that pigs do not cover their entire range over short periods as territory-holding animals generally do. The home range of a recently farrowed sow may be as small as 0.16 square kilometres (Saunders 1988). Where food supply is poor, such as in Kosciusko National Park and during the early dry season in the Northern Territory, average home ranges can be quite large (Table 4).

Activity patterns of feral pigs depend on location, season, weather and degree of disturbance from people. Generally, pigs are nocturnal or restrict their activity to the

Table 4: Home ranges of feral pigs.

Area	Home range (square kilometres)		Source
	Male	Female	
Western New South Wales	43	6.2	Giles (1980)
Sunny Corner, New South Wales	10.7	4.9	Saunders (1988)
Kosciusko National Park, New South Wales	34.6	10.2	Saunders (1988)
Namadgi National Park, Australian Capital Territory	1.4–6.6	1.5–5.5	McIlroy and Saillard (1989); McIlroy et al. (1989)
Douglas–Daly area, Northern Territory	31.2	19.4	Caley (1993)
North-west New South Wales	8.9–11.6	4.9–8.1	Dexter (1995)

early morning, late afternoon, evenings and early night in hot weather, or when they are subjected to hunting or other disturbances (Pullar 1950; Giles 1980; Saunders and Kay 1991). They are more diurnal in cloudy or rainy conditions, or in cooler seasons or areas, although they are not usually active during the middle of the day (Saunders 1988; McIlroy et al. 1989; Saunders and Kay 1991). In the Northern Territory feral pigs are most active during the early dry season and least active during the late dry season (Caley 1993).

3.5 Reproduction

Feral pigs are polyoestrous: adult females have a 21-day oestrus cycle and a gestation period of 112–114 days. Under favourable conditions breeding can occur throughout the year but is usually seasonal where food availability and quality are variable. In the high country of Kosciusko National Park, for example, most births occur in summer and autumn, in response to the spring flush of growth (Saunders 1988). Reduced rates of conception occur in autumn and winter because of the decreasing availability of high-protein food. Feral pigs living on the semi-arid floodplain of western New South Wales generally breed continuously, but more conceptions tend to occur after flooding when more food is available (Giles 1980).

Breeding also occurs throughout the year in feral pigs in the monsoonal lowlands of the Northern Territory, with a peak in births during the early dry season (Caley 1993). This is because many sows come into oestrus and mate during the wet season when food is abundant. In comparison, during the late dry season many adult sows are in poor condition due to the nutritional demands of previous pregnancies and lactation and a shortage of high quality food, so fewer piglets are born during the wet season. Droughts and shortage of food can delay the onset of breeding by young sows and increase the length of post-partum anoestrus in older sows, as well as reducing the number of foetuses and piglets born, especially in younger sows (Section 3.3.1; Giles 1980).

The average number of viable embryos in feral pigs in Australia (4.6– 8.2) is far fewer than that for domestic pigs (14 –22 for a large white sow on a high nutrition diet) (Masters 1979; Giles 1980; Pavlov 1980). Fecundity increases with age and body weight. In domestic pigs sexual maturity occurs at 4–9 months old but in feral pigs body weight is more important; in Australia feral sows only breed when they have reached 25–30 kilograms, usually at about 7–12 months old (Masters 1979; Giles 1980; Pavlov 1980). Average litter sizes vary from 4.9 to 6.3 piglets, but up to 10 piglets can be born in good conditions.

'Breeding can occur throughout the year in good conditions but it is usually seasonal.'

Weaning age can vary from two to three months. The time for a feral sow to return to oestrus after parturition is also variable, being up to 94 days compared with a minimum of 18–22 days for domestic sows (Giles 1980; Pavlov 1983). Under favourable conditions, sows can produce two weaned litters every 12–15 months (Giles 1980; Pavlov 1983; Ridpath 1991) but, where breeding is seasonal, only 0.85 litters per year are produced (Saunders 1988). This potentially high reproductive rate, closer to that of rabbits than that of other feral ungulates in Australia, gives feral pig populations the capacity to recover quickly from natural setbacks or control programs and is a major factor to be considered in strategies for their management.

3.6 Diseases and parasites

Feral pigs are susceptible to many infectious exotic diseases and parasites, including those specific to pigs, such as swine fever, and others that are widespread among other animals such as foot-and-mouth disease (FMD) (Section 4.3.2). The exotic diseases and parasites that can occur in feral pigs that attract most attention in Australia include FMD, other vesicular diseases, classical swine fever (CSF), African swine fever, Aujeszky's disease, trichinosis and screw-worm fly. Several of these, such as FMD and swine fever, were accidentally introduced into Australia in the past, but were prevented from establishing (Robertson 1932; Pullar 1950).

Feral pigs in Australia also carry several endemic diseases and parasites of economic importance to the livestock industries and some of importance to human health (Section 4.3.1). These include leptospirosis, brucellosis, tuberculosis, melioidosis, sparganosis, porcine parvovirus, Murray Valley encephalitis and other arborviruses. Other parasites of feral pigs of less importance economically include helminths such as *Ascarops strongylina* and *Simmondsia paradoxa*, the stomach worm (*Physocephalus sexalatus*), red stomach worm (*Hyostrongylus rubidus*), kidney worm (*Stephranus dentatus*), lungworms *(Metastrongylus* spp.), thorny-headed worm (*Macracanthorhyncus hirudinaceus*), hydatid cysts (*Echinococcus granulosus*), cysts of bladder worm (*Taenia hydatigena*), liverfluke (*Fasciola hepatica*), pig lice (*Haematopinus suis*), mange mite (*Sarcoptes scabei*) and various ticks (Pullar 1950; Masters 1979; Giles 1980; Saunders 1988; Thompson et al. 1988; Pav Ecol 1992; Pavlov et al. 1992; D. Spratt, CSIRO, Australian Capital Territory, pers. comm. 1994).

3.7 Mortality

Mortality among young feral pigs during their first year of life, particularly from the foetal stage to weaning, is generally high, but can vary considerably from 10–15% when food supplies and weather are favourable, to 90% where conditions are poor, and even 100% during drought (Masters 1979; Giles 1980; Saunders 1988). In Kosciusko National Park, piglets born during the summer have a greater chance of survival than those born in the cold months (Saunders 1988). Mortality of feral pigs, particularly piglets less than two months old, is similarly low during the wet and early dry seasons in the tropical north of Australia, and high during the late dry season (Caley 1993). Adult mortality can vary from 15 to 50% between age cohorts, with few feral pigs in western New South Wales living beyond five years old (Giles 1980).

The main mortality factors are loss of foetuses, accidental suffocation of piglets by sows, loss of contact between piglets and sows and starvation at all ages, including old pigs when excessive tooth wear interferes with chewing. Sows whose crude protein intake drops below critical levels cease to lactate, resulting in high piglet mortality (Giles 1980; Pavlov 1980). Lack of adequate protein also affects the general health of pigs of all ages, increasing their susceptibility to parasites and diseases. Dingoes (*Canis familiaris*) and feral dogs prey on piglets and are probably responsible for the frequent high mortality of immature pigs and sometimes sows, but there is conflicting opinion about whether dogs limit the size or distribution of pig populations (Pavlov 1983, 1991; Woodall 1983; Saunders 1988; Corbett 1995).

3.8 Population dynamics

3.8.1 Overview of large mammal population dynamics

Animal populations are often described as being regulated by intrinsic and/or extrinsic factors. The rate of increase of an intrinsically regulated population slows through the effect of some sort of spacing behaviour as density increases. Such populations can be thought of as being self-regulated; rate of change in their abundance at any time being a consequence of prevailing density. The rate of increase of an extrinsically regulated population, on the other hand, is imposed by some limiting environmental resource (such as food or nesting sites), or the effect of some limiting environmental factor (such as a pathogen or predator). The abundance of these populations at any time is determined by the availability of the limiting resource or the effect of the limiting factor.

Animal populations may also be described as being density-dependent or density-independent. Density-dependence means that a population's rate of increase is affected by density. Conversely, density-independence means that no relationship exists between population density and prevailing rate of increase. Intrinsically regulated populations by definition display density-dependence, their rate of increase being a direct function of their density. However, extrinsically regulated populations can also (although not always) display density-dependence, when their previous density influences the current availability of a limiting resource or the effect of a limiting factor. To illustrate this latter case, Caughley (1987) described the example of a population of deer (Family Cervidae), extrinsically regulated by the availability of grass. At any given time, the population's rate of increase is determined by the biomass of grass, but that biomass is influenced by the previous history of grazing. Hence present rate of increase might well be predicted from either current or past population densities, using an appropriate population model, and in that sense the dynamics of the population are said to be density-dependent.

Populations of large mammals are generally believed to be regulated by extrinsic factors, most commonly food supply, predation, or both. Regulation of large mammal populations by extrinsic factors is considered to be manifested through direct effects of food shortage and/or predation on the population's demographic rates, which determine its prevailing rate of increase. Hypotheses relating large mammal abundance to food supply have been generalised to propose that density-dependent mortality regulates population abundance through food shortage (Sinclair et al. 1985). In this context, density-dependence refers not to a direct causal link between current population density and rate of increase (self-regulation), but to the negative effect on prevailing mortality rates of a correlation between previous population density and current food supply. Caughley's (1987) example of a deer population would conform to this definition of density-dependence.

3.8.2 Dynamics of feral pig populations

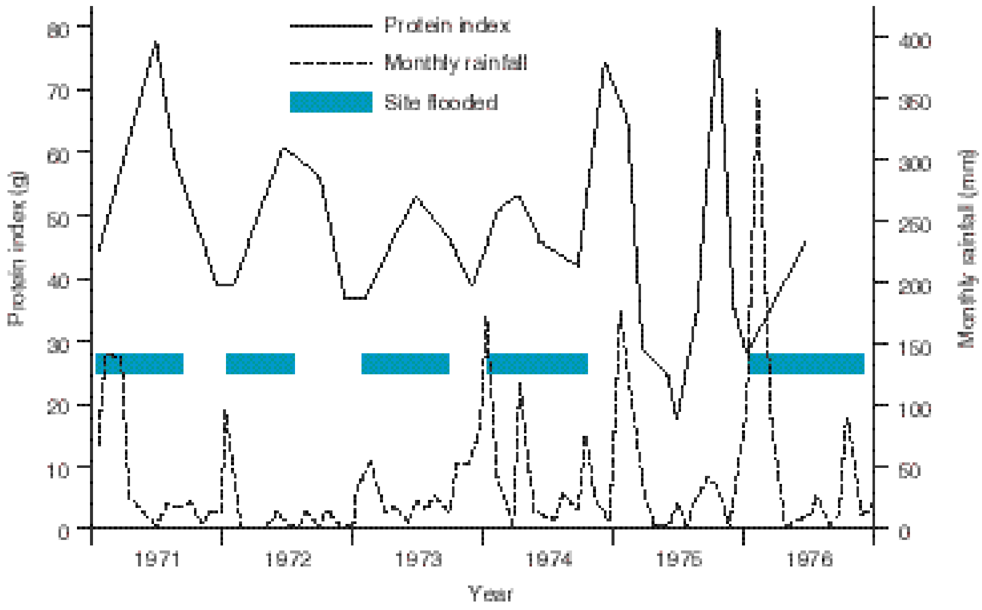
Variations in the rate of change in pig abundance need to be known as they determine requirements for effective management of pig impacts (Section 7.4) and may also influence the capacity of feral pigs to harbour and transmit exotic livestock diseases (Sections 3.6 and 4.3.2). Detailed studies of the dynamics of feral pig populations in Australia have been conducted in the semi-arid rangelands (Giles 1980; Woodall 1983; Choquenot 1994; Dexter 1995), in a subalpine area (Saunders 1988, 1993a), and in tropical woodland and floodplain habitats (Caley 1993; Corbett 1995). Hone (1987) also studied aspects of the population dynamics of feral pigs while evaluating strategies for management of their impacts in a highland forest area in south-east Australia, and on a tropical flood plain in the Northern Territory. What is known of the dynamics of feral pig populations in each of these regions is summarised below.

'Good management requires knowledge of changing rates of population growth and decline.'

The semi-arid rangelands

Giles (1980) studied feral pig population dynamics in the semi-arid rangelands, based on extensive mark–recapture and autopsy of large shot samples. Although Giles used four study sites, most of his information on population dynamics came from two locations: Warren on the Macquarie Marshes and Yantabulla in the Cuttaburra Basin. Both sites were within the wild dog exclusion fence, which separates the sheep rangelands of western New South Wales from the more extensive rangelands of south-west Queensland and north-east South Australia. Hence, feral pigs were not preyed on by dingoes at either site.

Giles (1980) reported population densities which varied between 8.01 and 17.47 pigs



Figur e 3: Variation in protein content of food consumed by pigs in relation to rainfall and flooding at Yantabulla in north-west New South Wales (after Giles 1980).

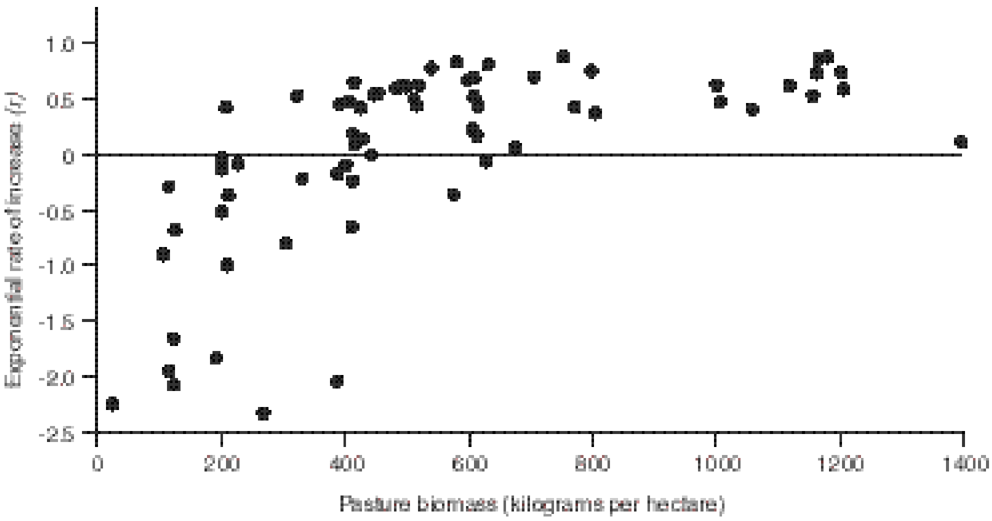
per square kilometre over three years for the Warren study site, and between 0.24 and 0.77 pigs per square kilometre over two years for the Yantabulla study site. Giles concluded that the variability in pig density at both sites was due to chance variation in prevailing seasonal conditions, rate of change in pig abundance being determined largely by the influence of dietary protein availability. Protein was most commonly obtained from fresh green legumes, grasses and forbs. Animal matter, mostly carrion, frogs and earthworms, represented an important secondary source when it was available. Giles linked availability of fresh green vegetation to flooding or heavy rain. Figure 3 relates changes in an index of the protein content of food consumed by pigs at Yantabulla to the incidence of rainfall and flooding over six years. When adequate green feed was not available, pigs consumed mostly roots and tubers which were rich in digestible carbohydrate but contained little protein.

'When green feed is inadequate for feral pigs, their body condition and survival rates decline.'

Giles (1980) found that the flush of green vegetation which followed heavy rains or flooding led to increasing body condition. This improved body condition, and an associated decrease in juvenile and adult mortality, continued as long as favourable seasonal conditions ensured green feed was available. When green feed was inadequate to maintain body condition, adult survival fell and juvenile survival declined dramatically. Using a combination of mark–recapture data and reconstructed age distributions, Giles demonstrated that juvenile survival increased from 0% when little or no green feed was available, to 60% when rains or floods prompted rapid vegetation growth. Mark–recapture studies indicated adult survival varied from 50% to 85% over a similar range of seasonal conditions. Giles suggested that a lack of protein-rich green feed reduced juvenile survival by affecting the quality and/or quantity of milk produced by lactating females, and/or by providing inadequate food resources for recently weaned piglets. In either case, maximum juvenile mortality occurred at or close to weaning. A series of sensitivity analyses indicated that variation in juvenile mortality was the key factor influencing the prevailing rate of population increase, suggesting that food was a primary limiting factor, and rainfall or flooding was an indirect limiting factor for these populations.

Giles (1980) estimated that, under seasonal conditions leading to high survival of adults and juveniles, populations attained an annual exponential rate of increase (r) of 0.6–0.7, equivalent to a finite rate (e^r) of 1.82–2.0, and that this represented a probable maximum (intrinsic) rate of increase (r_m). Hone and Pederson (1980) estimated r to be 0.57 (a finite rate of 1.77) for a pig population at Yantabulla in north-west New South Wales which was recovering following a poisoning program. Although not specifically estimated, data presented by Giles (1980) suggest that, under poor seasonal conditions, pig populations decreased at an annual exponential rate of –0.62. It is not known if this represents a maximum rate of decline for the populations studied by Giles.

Choquenot (1994) described a large-scale field experiment to test the nature of interaction between pig populations and their primary food supply in a western river system. In the experiment the density of pigs was manipulated such that there were three levels of reduction from initial density in a replicated design. Pig abundance and vegetation biomass were estimated quarterly. These data indicated that pigs had little or no influence on the amount or rate of change in pasture available to them, and that pasture availability influenced rate of change in pig abundance. The relationship was a curvilinear numerical response (Figure 4). The maximum instantaneous rate of increase of 0.68 (97% per year) was realised when pasture biomass exceeded about 450 kilograms per hectare. Choquenot (1994) used a series of stochastic population models to demonstrate that the lack of influence which pigs appear to exert over pasture availability in the rangelands was because of their low overall density in the area relative to other herbivores such as kangaroos and sheep. The low abundance



Figur e 4: The numerical response of pigs to pasture biomass along the Paroo River in north-west New South Wales. Pig population data is lagged by three months (after Choquenot 1994).

of pigs relative to other herbivores appeared due to their higher rates of population decline during droughts.

The slopes, tablelands and subalpine areas

Saunders (1993a) described the demography of a pig population in a subalpine environment during a three year mark–recapture study and concluded that the population was relatively stable at a density of 1.6 pigs per square kilometre. Two studies of pig abundance in a highland forest area at a slightly lower altitude than Saunders' (1993a) subalpine study site (Hone 1987; McIlroy et al. 1989) gave similar estimates of density (0.9–2.4 pigs per square kilometre). Seasonal variation in body condition indicated that the subalpine population was limited by food availability and/or quality over autumn and winter. A life table for the population, estimated from the standing age distribution, indicated that mortality was very high for juveniles (85% over the first year of life), declining through middle ages. Saunders (1993a) presented indirect evidence that at least some piglet mortality was due to predation by dingoes. He suggested that this, along with over-winter food shortage, meant populations in subalpine areas probably had lower rates of increase than populations in the semi-arid rangelands.

Saunders et al. (1990) estimated a rate of population increase $r = 0.25$ for a population of feral pigs near Bathurst in the central tablelands recovering from a poisoning program. This estimate encompassed 12 months only, and the increase appeared to have occurred more through recolonisation of the area than by intrinsic increases in the resident population. Hone (1995) monitored the feral pig population in Namadgi National Park (Australian Capital Territory) over 5.5 years and reported a decline in abundance. The observed rate of increase was $r = -0.44$ per year, corresponding to a decline of 64% per year.

The wet-dry tropics

Caley (1993) used the mark–recapture technique to estimate a feral pig density of 2.2–3.5 pigs per square kilometre in a tropical woodland habitat from which he derived estimates of r for the population. Caley (1993) related r to rainfall over the six months prior to and including the interval between successive estimates of population abundance to derive a numerical response. Rainfall was used as an index of food availability because the abundance of food resources was not measured. The numerical response indicated a maximum rate of population increase of $r_m = 0.78$ when rainfall in the six months prior to the interval of population growth exceeded 600 millimetres. Rainfall variation (and hence food availability) in the wet–dry tropics has a very predictable temporal pattern relative to that in rangelands habitats, and Caley (1993) found that this had important consequences for variation in pig abundance. The population he studied moved from phases of population growth to population decline over the regular annual cycle of wet and dry seasons. This is in distinct contrast to the unpredictable variation in rates of change in rangelands habitats (Choquenot 1994).

Corbett (1995) used natural variation in the abundance of primary prey for dingoes and an experimental manipulation of the abundance of feral water buffalo (*Bubalus bubalis*) to test the effects of predation and competition from buffalo on pig abundance in an area of mixed tropical woodland and floodplain in northern Australia. The total response of dingoes to pigs, derived from an estimate of the number of pigs eaten per dingo multiplied by the number of dingoes present, was negatively related to pig density, suggesting an inverse density-dependent relationship. Corbett (1995) concluded that dingo predation could not regulate the abundance of pigs although it could limit the size of the pig population. Pigs increased in abundance following buffalo removal and Corbett (1995) found a significant negative effect of buffalo density on pig density. Both species congregate in the ecotone which moves across the floodplain with the drying of inundated areas as the dry season progresses. Corbett (1995) suggested that where buffalo are present they limit access by pigs to underground vegetation in the late dry season through compaction of the saturated soil in this ecotone. In the late dry season, protein-rich food is scarce and limited access to underground vegetation reduces the ability of pigs to successfully lactate and wean their offspring. Corbett (1995) suggested that such interference competition where buffalo occurred may limit feral pig populations in tropical floodplain environments.

The role of predation

In contrast to the studies of Giles (1980) and Choquenot (1994), the analysis of feral pig population dynamics conducted by Woodall (1983) was based on data from central and western Queensland where pigs and dingoes co-exist. Woodall (1983) used annual trends in bounty payments for dingoes and pigs to index their relative abundance *(N)* between 1949 and 1973. Total mortality rate (M_t)[1] was estimated as the difference in successive $\log_{10}$ transformed abundance indices (Varley and Gradwell 1968):

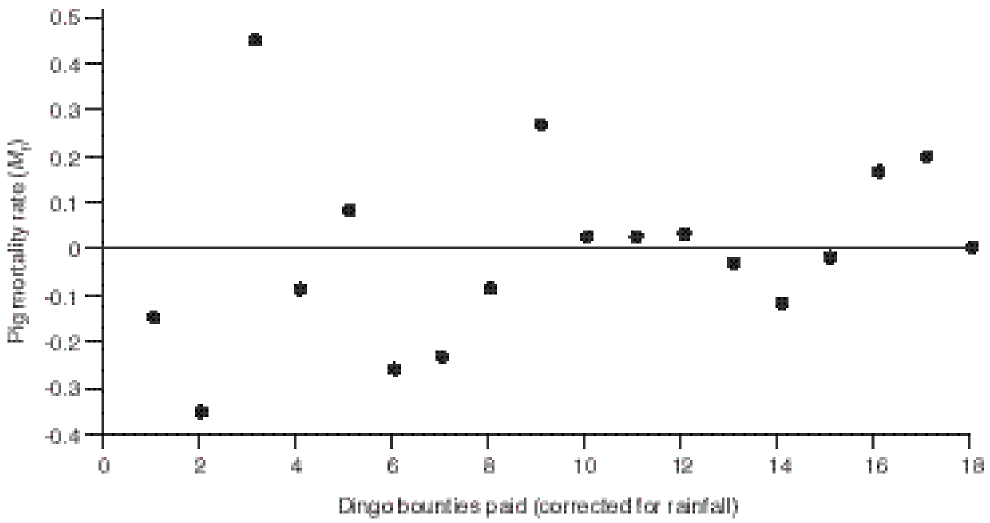
$$M_t = \log_{10} N_t - \log_{10} N_{t+1}$$

Woodall (1983) found:

- a significant positive relationship between pig density and M_t suggesting density-dependent mortality consistent with population regulation;
- some evidence of delay in density dependence from the chronological sequence of changes in density related M_t, which could indicate delayed density dependence and that equilibrium density *(K)* was unstable;
- a significant positive relationship between dingo density and M_t for pigs suggesting predation by dingoes was a limiting and potentially regulating factor for pig populations; and
- a significant negative relationship between rainfall and M_t for pigs suggesting food availability was also a limiting and potentially regulating factor for pig populations.

Unfortunately, Woodall (1983) overlooked the existence of a significant negative relationship between his measure of dingo abundance and rainfall over the previous 12 months ($F = 9.220$, $df = 1,16$, $P > 0.01$). This relationship suggests that high rainfall in the preceding year led to either lower dingo density (Woodall's implicit assumption), or fewer dingoes caught or shot for bounty payment. Because there is no significant relationship between M_t for pigs and the number of bounties paid for dingoes ($F = 2.257$, $df = 1,15$, NS), the latter is probably true. When the annual number of bounties paid on dingoes is corrected for the effects of rainfall, the apparent relationship between dingo density and M_t for pigs disappears (Figure 5) ($F = 0.097$, $df = 1,16$, NS). Hence, Woodall's (1983) study suggests a negative relationship between pig mortality rate and previous rainfall which may show delayed density dependence (consistent with the hypothesis that pig density is limited and potentially regulated by food availability) but no effect of predation.

1 M_t is used for total mortality rather than the usual *K* to avoid confusion with equilibrium density at carrying capacity *K*.



Figur e 5: The relationship between total mortality rate (M_t) for pigs and the number of dingo bounties paid, corrected for rainfall effects (after Woodall 1983).

The wet tropics

Variation in rates of increase in the wet tropics are probably driven by food availability and/or quality. In a sample of 23 mature sows collected from the Cape Tribulation area in northern Queensland in the first half of 1992, half were pregnant and none were lactating (Pav Ecol 1992; McIlroy 1993). Stomach contents of non-pregnant sows indicated insufficient protein to maintain lactation, suggesting that at least some of the time, food quantity or quality affects reproduction. It is likely that if food is of insufficient quantity/quality to maintain lactation, juvenile mortality will be high, and rates of population increase will be low or negative. It is unknown whether the variation in food supply in the wet tropics is regular as in the wet–dry tropics or irregular as in the semi-arid rangelands.

4. Economic and environmental impacts and commercial use

Summary

Feral pigs cause damage to both agriculture and the environment, but they are also an economic resource. Feral pigs are responsible for economic losses in three ways: direct losses to agricultural production; through continuing expenditure of resources on pig control; and the value of lost opportunities to take profit from alternative investment of this expenditure.

Feral pigs eat newborn lambs, reduce yields of crops, damage fences and water sources, and compete with stock for feed by consuming or damaging pasture. There are no reliable estimates of the cost of feral pig damage to agricultural production, although it is likely that the damage is at least of the order of $100 million annually, and it may be much more.

Although feral pigs are often regarded as having deleterious effects on the environment, very little objective information on their impact is available. The most important environmental impacts they are likely to have are habitat degradation through selective feeding, trampling damage and rooting for underground parts of plants and invertebrates, as well as predation on, competition with, or disturbance of a range of animals. Most people's perceptions of environmental damage by feral pigs focus on their rooting up of soils, grasslands or forest litter, particularly along drainage lines, moist gullies and around swamps and lagoons, or after rain, when the ground is softer. Their impact on plants is largely unknown, as is the extent of their role in eating or dispersing seeds, and spreading rootrot fungus (Phytophthora cinnamomi), *responsible for dieback disease in native vegetation.*

Feral pigs eat a range of animal material, but are probably not significant predators of most fauna except for local populations of earthworms. Their habit of feeding on one temporarily abundant food supply, such as fallen rainforest fruits, until the source is almost depleted, could affect specialist feeders, such as cassowaries (Casuarius casuarius) *which are largely frugivorous.*

Feral pigs can act as hosts or vectors of several endemic and exotic diseases and parasites that can affect other animals, including domestic livestock and humans. The major endemic diseases and parasites of concern are leptospirosis, brucellosis, melioidosis, tuberculosis and sparganosis. An outbreak of exotic disease amongst feral pigs, such as foot-and-mouth disease, could delay its detection, increase the rate and extent of its spread, make eradication measures more expensive, time-consuming or difficult, and have severe repercussions for both Australia's domestic and export livestock industries. Although Commonwealth and State authorities have prepared contingency plans for dealing with outbreaks of exotic diseases, as well as maintaining stringent quarantine regulations, recent research indicates that outbreaks could establish in feral pig populations in Australia.

It is estimated that about $5 million of the $10–20 million derived from the export market of wild boar meat is paid to shooters and chiller operators, and that recreational hunting also injects considerable funds into the general community each year through money spent by pig shooters.

4.1 Economic Impact

Economic impacts of pigs are of three types:

(1) value of the direct losses to agricultural production;
(2) value of the continuing expenditure on pig control; and
(3) value of lost opportunities to take profit from alternative investment of this expenditure.

Estimates of the economic impact of wild animal pests are of two types, gross estimates and per capita estimates. Gross estimates value economic losses attributable to the presence of the animal pest. Per capita estimates value economic losses attributable to each individual animal present (or to each unit of pest density). In developing management strategies for animal pests the former measure is of little use because it only gives an estimate of gain related to the total eradication of the pest animal population. In contrast, the second measure allows estimates of economic gain associated with any reduction in pest animal density.

4.1.1 Agricultural damage

Feral pigs are responsible for several types of agricultural damage. Pigs prey on newborn lambs (Plant et al. 1978; Pavlov et al. 1981; Hone 1983b; Choquenot 1993); reduce yields of grain crops (Benson 1980; Caley 1993), sugarcane and some tropical fruit crops such as bananas, mangoes, pawpaw and lychees (McIlroy 1993); damage fences; damage and pollute water sources such as bore drains and dams (Tisdell 1982; O'Brien 1987); and compete with stock for feed by consuming or damaging pasture (Hone 1980). There are no reliable estimates of the cost of feral pig damage to agricultural production, but it is likely that the damage is at least of the order of $100 million annually and it may be considerably more. Feral pig control activities also add to the costs of landholders.

Predation of newborn lambs

The predation of newborn lambs by feral pigs has long been recognised as a significant problem for many sheep graziers (Moule 1954; Rowley 1970). Lamb production is considered critical to the viability of woolgrowing enterprises in many parts of Australia because most flocks are self-replacing, graziers rely on a broad genetic flock base to exercise selection for commercially important wool quality traits, and the sale of excess lambs is an important source of cash flow (Alexander 1984).

Feral pig predation on lambs may be significant in some areas.

Source: P. Pavlov

Quantitative assessment of lamb predation by feral pigs has been restricted to the semi-arid rangelands where the problem is considered most critical. By contrasting the rearing performance of lambing flocks from which pigs were excluded, with flocks to which pigs had access, Plant et al. (1978) measured 32% predation of newborn lambs by feral pigs and Pavlov et al. (1981) measured an average level of predation of 18.7% over four lambing seasons (range 0–38%). Both authors speculated that prevailing seasonal conditions affected the foraging behaviour and demography of feral pigs which influenced the level of lamb predation.

Although both studies demonstrated that lamb rearing rates could be significantly improved by excluding or eradicating feral pigs, neither management option is considered realistic or practical for sheep graziers under rangeland conditions (Choquenot and O'Brien 1989). Usually the effort expended by graziers to manage pig numbers varies according to the perceived impact of the pigs, and the cash flow available to the farmer (Tisdell 1982). Farmers must make essentially ad hoc decisions about the appropriate amount of pig control to undertake because (a) they lack information relating feral pig density and seasonal conditions to rates of lamb predation; and (b) season-to-season variation in predation rates are unpredictable.

'Although lamb survival could be increased by removing feral pigs from rangeland properties, this is not a practical option.'

In two large-scale field experiments, Choquenot (1993) measured pig density to assess variation in lamb predation rates due to pigs, and to prevailing seasonal conditions. In the first experiment, predation rate was found to be proportional to pig density when other sources of lamb loss were experimentally removed from flocks of ultrasonically scanned lambing ewes. Comparison of scanning results with udder-scores allowed the fate of lambs born to individual ewes to be determined. Twin-born lambs were found to be 1.75 times

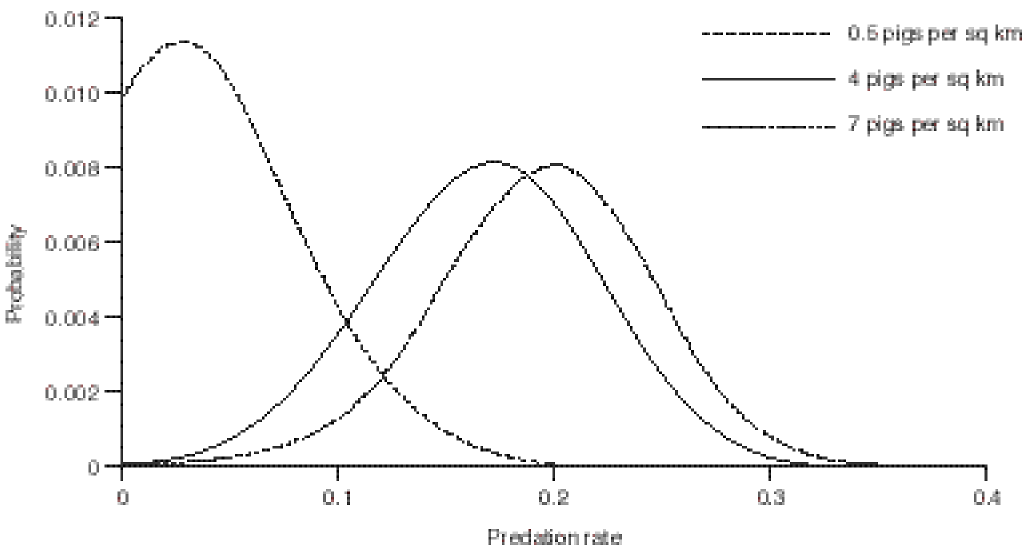
The rooting up of pasture by feral pigs reduces the amount of feed available to stock and may increase the establishment of weeds. *Source: NSWAF* more likely to be preyed on by feral pigs than were their single-born counterparts.

'Graziers' decisions about investment in pig control will depend on their attitude to risk and their financial resources.'

In the second experiment on four properties, seasonal conditions did not significantly affect lamb loss, over and above that due to prevailing pig density. It was possible to calculate the probability of different lamb predation rates at given pig densities (Figure 6). The results suggest that managers could determine specified rates of lamb predation matched to the lamb production requirements of the grazing enterprise. For a given rate of lamb loss, the cost of managing pigs to the density which matches the appropriate probability to the specified rate of predation (Section 7.4) can be directly equated with the value of the lambs saved. The value of lambs saved depends on the lamb production requirements of particular grazing enterprises. In this way, the cost of pig control becomes a premium to insure against unacceptable risks of given rates of lamb predation. Graziers' decisions about investment on pig control will then depend on their attitude to risk and their available finances.

Damage to grain crops

Pigs reduce yields in grain crops by consuming grain or trampling plants to form bedding or to gain access to the centre of the crop. Tisdell (1982) estimated that the overall impact of feral pigs on grain crops in 1979 – 80 was $41.4 million (approximately equivalent to $105 million in 1994–95 values). The greatest economic impact was on the wheat industry (3% of the crop in New South Wales and Queensland, worth $34 million, equivalent to $86 million in 1994–95 values). Significant losses also occurred in sorghum crops (5% reduction in yield, worth $5 million, $13 million in 1994–95 values). Other major losses in grain crops were: barley (1% reduction in yield, $1.5 million loss, approximately $4 million converted to 1994–95 values); oats (1% reduction in yield, $0.5 million loss); and maize (3% reduction in yield, $0.4 million loss). The figures Tisdell (1982) gave for oats and maize are both approximately equivalent to $1 million when converted to 1994–95 values.



Figur e 6: Probability of different rates of lamb predation at three pig densities (after Choquenot 1993).

Tisdell (1982) suggested that pigs also affected rice production, but did not estimate the economic impact or the percentage reduction in yield. Tisdell's data on crop damage were derived from the perceptions of landholders and various experts. On the basis of landholder estimates obtained by a mail-back survey, Benson (1980) estimated that feral pigs reduced wheat yields in north-west New South Wales by 5.6%, somewhat higher than the estimate of Tisdell (1982).

Caley (1993) derived per capita estimates of the damage to maize and sorghum crops in the wet–dry tropics of the Northern Territory, using a combination of exclosure trials and visual estimates of crop damage. Maize and sorghum yields were reduced by 100 kilograms per pig (equivalent to $28.50, or $32 when converted to 1994–95 values) where crops were unprotected. This was equivalent to each pig taking 0.035 hectares out of production. A trapping program which reduced pig density in an area adjacent to cropping areas by 76% reduced estimated crop losses due to feral pigs by 71% in one year. Caley (1993) conducted cost–benefit analyses of various pig control techniques based on these data (Section 7.4.1).

'Feral pigs cause considerable damage to grain crops but few of these economic impacts have been measured.'

Although the economic impact of pigs on grain crop production has only been examined in one study (Caley 1993), it is likely that considerable damage occurs. The lack of specific data on per capita impacts on grain crop production precludes useful discussion of cost-effective strategies for managing these impacts.

Damage to fences and water sources

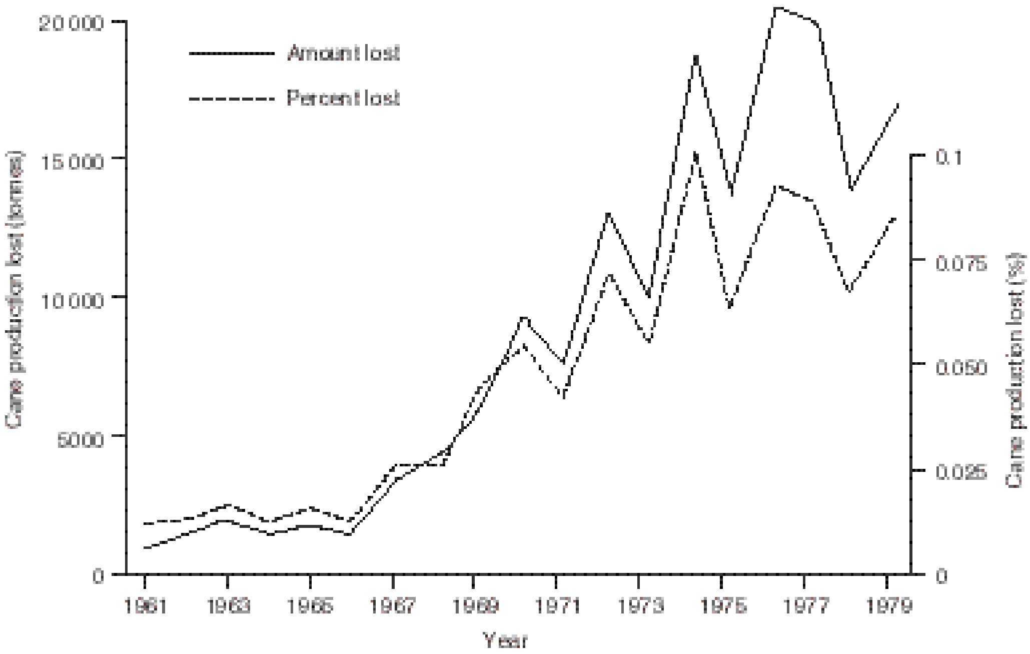
Pigs are known to damage fences by tearing holes in lighter netting, and weakening wires and posts (Pullar 1950). No quantified assessment of these impacts, or the damage caused by other animals passing through breaches in fences has been made. Tisdell (1982) catalogued the impacts pigs are known to have on water sources. These include rooting of bore drains and bore outlets, damage to water supply channels in irrigation areas, damage to flood gates and levy banks around flood-prone property, disturbance to water trough and distribution pipes, and fouling of farm dams and waterholes by wallowing and defecation. Again, these impacts, their cost, and their mitigation through pig management have not been quantified.

Reduced yields of sugarcane, fruit and vegetable crops

Tisdell (1982) reported that the Queensland Sugar Research Stations (SRS), now the Bureau of Sugar Experiment Stations (BSES), encountered problems with pigs reducing yields by consuming cane or knocking it down. In 1982 the SRS estimated that about 20 000 tonnes of cane (0.1 to 0.15% of Queensland production) were being lost annually to pigs. This represented a considerable increase in lost tonnage from the early sixties when estimates of cane damage began (Figure 7).

'Feral pigs were estimated to cause annual losses of 20 000 tonnes of sugarcane in Queensland.'

McIlroy (1993) reported estimates for sugarcane losses to pigs in Queensland between 1989 and 1991 (Table 5). On average these estimates are slightly higher than those reported by Tisdell (1982), indicating that a small increase may have occurred over the intervening eight to ten years. McIlroy's (1993) data also indicate that most sugarcane damage occurs in the wet tropics area in the north of Queensland. Within that area, the Mossman–Herbert River area consistently sustains more damage to cane than other cane growing areas. McIlroy (1993) attributes this to the presence of extensive areas of tropical rainforest adjacent to and adjoining cane farms. No per capita estimates of sugarcane damage caused by feral pigs are available. McIlroy (1993) reported that the main damage to cane crops by pigs occurs from the start of the dry season (April–May) onwards, although some damage to cane



Figur e 7: Sugarcane production losses attributed to feral pigs in Queensland between 1961 and 1979 (after Tisdell 1982).

has occurred as early as January. By the end of October when the cane has been harvested, pigs move back into the rainforest and remain there until the end of the wet season in the following year. Damage predominantly occurs to older plants with a higher sugar content, but some younger first-year plants may also be damaged, preventing their use in the cane harvesting cycle of 2–4 years. It is believed that generally only 1–2 pigs cause damage to cane in one location, but over the course of several weeks they may affect 2–3 hectares of a crop.

Pigs also damage fruit and vegetable crops, although no data on the extent of such damage are available (Tisdell 1982, McIlroy 1993). Crops known to be affected include bananas, pumpkins, watermelons, mangoes, pawpaws, lychees, and pineapples. Tisdell (1982) reports an apparently isolated instance

Table 5: Estimates of feral pig damage to sugarcane in Queensland (after McIlroy 1993).

Area	1989		1990		1991	
	Tonnes lost	Value ($)[a]	Tonnes lost	Value ($)[a]	Tonnes lost	Value ($)[a]
North Queensland wet tropics area	17 272	530 000	24 940	690 000	20 070	485 000
Other areas	1 520	52 000	3 940	117 000	5 440	143 000
Total	18 792	582 000	28 880	807 000	25 510	628 000

a Financial losses to sugar millers and to the industry in sugar foregone are not included in costings. Millers make about $20 per tonne for processing, and seven tonnes of cane makes about one tonne of sugar, valued at $390 per tonne.

of pigs destroying potato crops near Tamworth in New South Wales.

Competition with livestock and damage to pastures

Pigs, being primarily herbivorous, can eat or root up pasture which could otherwise be used by domestic stock to grow wool or meat. Pigs may also affect livestock productivity by initiating trends in pasture species composition which ultimately degrade pasture quality. Hone (1980) assessed the reduction in native and introduced pasture attributable to rooting by feral pigs near Tenterfield in northern New South Wales. On native pasture, rooted areas had green feed reduced by 98%, standing dry matter reduced by 74%, and the abundance of weeds, predominantly bracken fern and blady grass, also declined. On the introduced pasture, green feed was reduced by 74% in rooted areas, standing dry matter by 37%, and the abundance of non-grass matter, predominantly broadleaf weeds, increased ten-fold. The apparent contrast in rooting impact on native relative to introduced pasture was attributed to differences in the standing crop of the two pasture types due to preferential grazing of the introduced sub-clovers. It was concluded that the potential for pig rooting to affect pasture productivity in this environment was considerable.

'Pigs root up and eat pasture and this can affect pasture species composition and also reduce the food supply for livestock.'

Choquenot (1994) could not demonstrate any relationship between feral pig abundance and pasture availability in rangeland habitat in western New South Wales (Section 3.8.2). Similarly, the outcomes of a grazing model (Section 7.4.1) suggest that grazing by unmanaged densities of pigs reduce long-term average pasture availability by less than 3%.

The nature of the competition between feral pigs and livestock for pastures is complex, and is largely dependent on the relative importance of rainfall as compared to grazing pressure in causing variation in pasture biomass in different environments. Theoretically, in more stable environments such as that in which Hone's (1980) study was conducted, the biomass of the standing crop of pasture is closely related to the grazing pressure placed upon it. In such environments, reductions in pasture biomass due to pigs is likely to be important for pasture availability and consequent productivity of domestic grazing animals at any point in time. In contrast, prevailing pasture biomass in less predictable environments such as the semi-arid rangelands, depends upon rainfall such that grazing pressure has a lesser role in determining day-to-day variation in pasture availability (Caughley 1987; Choquenot 1994). In semi-arid environments, reductions in pasture biomass due to pigs will have, at best, a minor influence on pasture availability. Prevailing productivity of domestic grazing animals will be determined predominantly by rainfall-driven variation in pasture biomass. These differences between stable and unstable environments probably account for the different effects of feral pigs on pasture described by Hone (1980) and Choquenot (1994).

Roshier (1993) reported no variation in wool cut per head of sheep and pasture biomass in semi-arid western New South Wales, over a range of pasture availability from less than 10 kilograms per hectare to more than 1500 kilograms per hectare. There was, however, a strong relationship between pasture availability and mortality rates in sheep (indicating a numerical response by sheep). If reduction in pasture availability due to pigs (or any other wild grazer) is to affect productivity in this environment, it will most likely be through impacts on prevailing sheep stocking rates rather than wool production per head. Given the relatively minor potential pigs have to reduce pasture biomass in semi-arid environments, this impact is likely to be negligible.

To assess the impact of pigs on livestock productivity through reduction in available pasture, several relationships must be established, including that between:

- pasture availability and livestock productivity, or alternatively between pasture availability, intake rate of livestock, and subsequent productivity;
- pasture availability and intake rate of pigs;
- pasture availability and rate of change in pig abundance; and
- pasture biomass variation and the influence of climatic factors and grazing pressure.

How all of these factors operate for sheep and pig grazing systems in the semi-arid rangelands is reasonably well known, but much less is known for other environments.

4.1.2 Expenditure on pig control

There has been virtually no assessment of expenditure on feral pig control in Australia. Saunders and Korn (1986) estimated that around $4 million was spent on controlling pigs, rabbits and wild dogs in New South Wales in 1984. This comprised $2.3 million of government expenditure and $1.7 million of landholder expenditure, not including labour costs. They estimated that 428 days of labour and $60 000 were spent by landholders on 1080 programs for feral pigs alone, and this estimate could be doubled to account for expenditure of resources on other forms of control such as shooting from helicopters, trapping and poisoning with CSSP (Sections 7.6.3, 7.6.7 and 7.6.8). If these 1984 estimates are reasonably accurate, and assuming 33% of government expenditure was directed to feral pig related activities, the New South Wales Government and New South Wales landholders spent about $1.1 million on pig control in 1984. This would consist of $750 000 government expenditure[2], and $365 000 of landholder expenditure ($125 000 materials and $240 000 labour at $35 per hour). If Queensland spent a similar amount to that spent by New South Wales, and the Northern Territory spent 20% of what New South Wales spent ($220 000), and Victoria and Western Australia combined spent 10% ($110 000) of this amount, the total expenditure for Australia in 1984 would have been about $2.5 million. Clearly, with so many assumptions, this is an extremely rough estimate.

The return on expenditure on pig control depends upon how it is spent. For instance, government spending goes into research and extension activities, as well as pig control on national parks and state reserves. Accurately estimating the return on this expenditure is very difficult. Similarly, investment in pig control by a western grazier will net a very different return from that arising from investment in pig control by a banana grower in northern Queensland, or a rice grower in the Murray Irrigation Area. No conclusion about the return on current investment in pig control can be made until information is available on the nature of expenditure and per capita estimates of the effectiveness of techniques employed to mitigate damage.

The value of foregone profits from resources expended on pig control can be estimated by calculating the return on capital outlay invested in various commodities such as new farm equipment, new property or off-farm investments such as government bonds. Similarly, the value of labour foregone through investment in pig control can be estimated by calculating the value of time spent on other activities such as repairing fences, tending stock, fertilising pasture or crops, book-work or watching the cricket. The value of these foregone returns on resources expended on pig control must be added to the total cost of control when calculating total expenditure. Total expenditure on pig control is additive to estimates of economic losses through the direct impact of pigs.

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2 Estimates by T. Korn for New South Wales Government expenditure on feral pig control in 1995 totalled approximately $250 000.

4.2 Environmental impact

4.2.1 Real or perceived?

Many members of the public, conservationists and land managers believe that feral pigs have a major impact on the environment in Australia. There are, however, few quantitative data on actual impacts, and perceptions of damage may not always be correct. For example, in the Top End of the Northern Territory, there was concern about the impact of pigs on lowland evergreen monsoon rainforests because the forests typically occur in small patches (0.5 square kilometres) and are of high conservation value. Studies by Bowman and McDonough (1991), though, showed that pigs mainly use the forests for shade during the day and have only limited effects on them, because greater food resources are available in adjacent areas. Similarly, extensive trampling or rooting of vegetation or the ground by pigs and the succeeding invasion of weeds may be dramatic evidence of the presence of pigs, but may not necessarily be important in terms of the long-term processes of plant dynamics or community structure.

'Habitat degradation and predation on native species are probably the most important environmental impacts of feral pigs.'

Measuring or identifying environmental impact by feral pigs can be difficult. In some cases their impacts may be direct or obvious, such as damage to turtle nests and eggs, although the significance of this impact on turtle populations is uncertain, given the intrinsically high juvenile mortality of turtles. In other cases, pig damage could be indirect. For example, rooting up of the ground, which leads to siltation, ultimately affects the habitats of aquatic life. Impacts of pigs can also vary over time. They can be acute, such as the destruction of the last remaining specimens of a rare plant, or chronic, such as the gradual degradation of a subalpine swamp. Impacts can be almost constant in intensity, such as the disturbance of forest floor litter, or periodic, such as differential impacts during dry and wet seasons or impacts on valley floors during winter.

The most important environmental impacts that feral pigs are likely to have are habitat degradation and predation.

4.2.2 Habitat degradation

Most perceptions of damage by pigs focus on their rooting up of soils, grasslands or forest litter. Such disturbance can be locally extensive, such as in or around swamps and lagoons, or after rain, when the ground is softer, and is often associated with sites modified by people, or close to roads, tracks and watercourses.

Mitchell (1993) found that during the late dry season (August–November) lowland areas in the wet tropics of Queensland's World Heritage Area were more affected by rooting than highland areas (8% compared to 2.2% of the ground surface). Coastal woodlands and swamps were more affected than other broad habitat types like rainforests. Overall, he found that only 4.3% of the ground surface at 31 random sites throughout the World Heritage Area had been rooted up, despite other signs of pigs being recorded along 157 (67%) of the transect lines at the sites. Most pig diggings (69%) were within ten metres of a road, track, surface water or a drainage line, particularly along watercourses (36%) and table drains (8%). Only 1% of the ground surface more than ten metres away from roads and watercourses had been rooted up. Although not proven, there appears to be a strong correlation between rooting damage and soil moisture (Hone 1988a, 1995), soil friability and probably the presence of large numbers of earthworms, other invertebrates and bulb-producing plants.

Similarly, Alexiou (1983) found that the areas of subalpine vegetation most susceptible to damage by pig rooting at Smokers Gap, in the Australian Capital Territory, were along drainage lines, in depressions and around grassy flats. About

32% of these areas showed signs of pig damage. Revegetation was slow and the dominant grassy vegetation and some small native herbs were greatly reduced in abundance at disturbed sites. Several native plants, however, became vigorous colonisers of damaged areas. Hone (1988a) found feral pig rooting in Namadgi National Park in the Australian Capital Territory occurred mainly in rocky areas where leaf litter accumulated. He also found the amount of rooting was affected by altitude.

Feral pigs have also damaged the Strzelecki National Park on Flinders Island (Statham and Middleton 1987). Extensive rooting in the moist rich gullies led to erosion, loss of regenerating forest plants and their replacement by thick, impenetrable stands of bracken fern (*Pteridium esculentum*).

'Extensive rooting by feral pigs in moist gullies led to erosion and loss of native forest plants in Strzelecki National Park on Flinders Island.'

The effect of rooting by pigs on soil nutrient cycling and erosion is largely unknown. Feral pig rooting may cause significant erosion of creek banks in the rainforests of Queensland, leading to the silting of downstream swamps (McIlroy 1993) or the lowering of water quality in catchments (Oliver et al. 1992). This may be minor though, compared to the concentration of suspended sediment in streams in the area from vehicles crossing them, and from the widespread overland flow of water and saturated soil profiles associated with torrential rainfall, particularly from cyclones during the wet season (Gilmour 1971; Gillman et al. 1985; Rainforest Conservation Society of Queensland 1986). Rooting by pigs is more likely to affect litter composition directly through its mixing and aeration effects and indirectly through its facilitation of predation on worms.

Feral pigs are known to eat a range of native and exotic plants, including their foliage and stems, fruits and seeds, and rhizomes, bulbs, tubers, roots or other underground parts (Section 3.3.1). The effect of pigs on rare or endangered plants and on plant succession in Australia, however, is unknown. Extrapolation of information on the impact of pigs on vegetation in other countries may not be valid because of differences between the environments, particularly the relative availability of different foods, and between the ecology of feral pigs in these environments. For example, the consensus of opinion is that feral pigs do not damage or eat tree-ferns in the wet tropics of Queensland, in contrast to their behaviour in Hawaii and New Zealand (McIlroy 1993). If correct, this may be because there are more palms for them to eat in the wet tropics of Queensland than in the other countries, or because they have access to other starch-rich foods such as bananas and sugarcane.

The extent to which feral pigs eat or disperse seed is unknown. Feral pigs are likely to eat a much greater range of fruits and seeds than has been reported, but the viability of the seeds in pig faeces may depend on the size of the seeds, the feeding behaviour of the pigs and where the faeces are deposited. The ingestion by pigs of fruit containing small (less than five millimetres diameter) seeds from plants such as trunk-fruiting figs (*Ficus variegata*), umbrella trees (*Schefflera actinophylla*) and guavas (*Psidium guajava*), appears to cause no physical damage to most of the seeds, but there are conflicting reports on the fate of larger, soft seeds (McIlroy 1993). Guava and other unidentified seeds have been observed germinating in pig faeces, but their viability appears to be low (Pav Ecol 1992; Pavlov et al. 1992; Mitchell 1993).

There is growing evidence that feral pigs may help spread rootrot fungus (*Phytophthora cinnamomi*), responsible for dieback disease in native vegetation. Although there is still no evidence of spread via the gut, following ingestion of infected material (Masters 1979), three of four feral pigs examined in Hawaii were found to be carrying the organism in soil on their hooves (Kliejunas and Ko 1976). Pigs could also carry infected material on other parts of their body, particularly after wallowing during warmer conditions when sporulation may occur (Masters 1979). The spread of the fungus has also been associated with soil disturbance and reduction of litter cover by pigs (Brown 1976). Pigs also chew or tusk the bark on buttress roots and lower trunks of trees, which might allow the entry of fungi. They also undermine shrubs and trees by their digging, causing them to topple (Pav Ecol 1992; Mitchell 1993), but it is not clear if other factors, such as cyclone damage, may also have had a contributory effect (McIlroy 1993).

4.2.3 Predation, competition and disturbance of other animals

Live animals reported to be eaten by feral pigs include earthworms, amphipods, centipedes, beetles and other arthropods, snails, frogs, lizards, snakes, the eggs of the freshwater crocodile (*Crocodylus johnstoni*), turtles and their eggs, small ground-nesting birds and their eggs, young rabbits and newborn lambs (Pullar 1950; Tisdell 1984; McIlroy 1990; Mitchell 1993; Roberts et al. 1996).

Earthworms are one of the most common sources of animal protein in the diet of feral pigs and it is possible that pigs could significantly reduce the numbers of worms in some localities. Pav Ecol (1992) found that feral pigs harvested over 95% of the available worms at paired quadrat sites in lowland ephemeral swamps near Cape Tribulation during April–July 1992. Although the number of worms at different sites varied greatly, few adult worms occurred in freshly rooted up areas. Mitchell (1993), in contrast, found identical numbers of earthworms in feral pig diggings and surrounding areas in the same general region south of Cape Tribulation. Frogs may also be a common food item for pigs in some areas. Richards et al. (1993) suggest that feral pigs, through either direct predation or habitat disturbance, may have contributed to the declines in some populations of endemic tropical rainforest frogs.

The effect of pig predation on other invertebrates and small vertebrates in Australia is not known. Without data on what prey are actually eaten, the rates of predation, the density and status of the prey, and whether or not predation by pigs is density dependent, it is premature to judge whether pigs are a serious threat to the animals concerned. This also applies to their impact on larger ground-nesting birds, such as cassowaries (*Casuarius casuarius*), scrubfowl (*Megapodius reinwardt*) and brush-turkeys (*Alectura lathama*), despite reports of pigs destroying their nests and eating their eggs and young (Hopkins and Graham 1985; Crome and Moore 1990; Mitchell 1993). Laurance et al. (1993) and Laurance and Grant (1994) suggested that opportunistic, omnivorous rodents, especially white-tailed rats (*Uromys caudimaculatus*) may be the dominant predators of some bird nests, particularly ground nests, in north Queensland rainforest and secondary forest.

There is also insufficient information to evaluate whether pigs adversely compete with native animals for food. Their habit of feeding on one temporarily abundant food source, such as fallen rainforest fruits, until the supply is almost depleted, before switching to others, such as sugarcane, could affect more specialist feeders, such as the largely frugivorous cassowaries. Tisdell (1984) suggests possible competition with brolga (*Grus rubicundus*) and magpie geese (*Anseranas semipalmata*) for tubers and bulbs in northern Australia.

4.3 Impact of diseases and parasites

4.3.1 Endemic diseases and parasites

Feral pigs can be hosts or vectors of several endemic diseases and parasites that can affect other animals, including domestic livestock and people. The major diseases of concern are leptospirosis (*Leptospira* spp.), brucellosis (*Brucella suis*), melioidosis (*Pseudomonas pseudomallei*), tuberculosis

(*Mycobacterium* spp.), sparganosis (*Spirometra erinacei*), porcine parvovirus, Murray Valley encephalitis and other arboviruses (Pavlov et al. 1992; Caley et al. 1995; McInerney et al. 1995).

'Feral pigs can be hosts or vectors for several endemic diseases that can af fect livestock and people.'

Leptospirosis is the most common bacterial disease in feral pigs. Strains of *pomona*, *tarassovi* and *hardjo* were found by Masters (1979) in 2–9% of pigs examined in Western Australia and in 4–22% of pigs examined by Pav Ecol (1992) in north Queensland. Giles (1980) recorded *pomona* in 2–51% of pigs examined in western New South Wales and Pavlov (1980) found *pomona* in 20% of pigs and *tarassovi* in 6.8% of pigs from the same general area. This bacterium, which causes Weil's disease in humans, was well known in north Queensland as canecutter's disease when sugar was harvested manually. Infection usually follows contact with the urine of infected animals through broken skin, or through intake of urine-contaminated food or water. It can occur from living in close association with infective pigs or handling them during hunting or field butchery. A range of other animals can also be infected with leptospirosis, particularly cattle and rodents. In pigs, leptospirosis can cause infertility, abortions, stillbirths and post-partum death of young piglets.

Porcine brucellosis, a serious and long-lasting illness in people, is a notifiable disease in Australia that results from people coming into contact with animals or animal products infected with *Brucella suis* (Stevenson and Hughes 1988). Infection may occur in people handling raw feral pig meat, such as meat industry workers and hunters. Although the disease is still rare in both people and domestic pigs in Australia, and has a limited regional distribution within the tropical and northern temparate zones, it is being detected in increasing numbers of people (Robson et al. 1993). No evidence of the organism has been found in pigs in Western Australia or the Northern Territory (Masters 1979; Giles 1980; Caley 1993). The risk of people getting porcine brucellosis from eating infected pig meat is extremely low, particularly if it has been well cooked.

Tuberculosis was common in feral pigs in the Northern Territory and also occurred in pigs in Western Australia (Masters 1979; Corner et al. 1981). The main source of infection was probably the carcasses of feral cattle and buffalo. This source is likely to have diminished greatly following the bovine brucellosis and tuberculosis eradication campaign (BTEC) throughout Australia and more intensive management of buffalo. Comparative surveys of feral pigs over an extended period has shown that the prevalence of tuberculosis has dropped dramatically with the eradication of the disease in cattle and buffalo. Pigs are regarded as an end host for the disease (bovine, avian and human types) and are not a significant source of infection for cattle. People can be infected by eating inadequately cooked flesh of pigs suffering from the disease.

People can get sparganosis (caused by infection with the spargana or larval pleroceroid of the tapeworm *Spirometra erinacei*) from a number of sources including eating feral pig meat. While this parasite, which travels through the tissues of the body, is widespread in pigs frequenting many swampy areas of Australia, it is not a human health hazard if meat is adequately frozen or cooked.

4.3.2 Exotic diseases and parasites

Feral pigs are the species of most concern in Australia for their potential to harbour or spread exotic diseases. Feral pigs can act as hosts or vectors of several exotic diseases and parasites of livestock, of which the most significant are described by Geering et al. (1995) and Wilson and Choquenot (1996). These diseases include:

- Foot-and-mouth disease (FMD) is a highly contagious viral disease of ungulates (including pigs, cattle, sheep, goats and deer) that can also infect some rodents. Although not often lethal in adult animals, it causes serious production losses and is a major constraint in international trade in livestock and livestock products. FMD is endemic at a high prevalence in many countries in Africa, Asia, the Middle East and South America. In Europe, FMD prevalence has decreased markedly in recent years, and Pacific nations, and North and Central America are free of the disease;

- Swine vesicular disease is a viral disease and outbreaks have occurred in Europe and Asia. Pigs are the only livestock affected. Infection rates may be high in affected pens, but mortality is negligible;
- African swine fever (ASF) is another highly contagious viral disease that affects only pigs. Mortality rates can be high. ASF occurs in most of sub-Saharan Africa, and in 1957 it spread to Portugal and later to Spain, and over the following decades outbreaks occurred and were eradicated in many European and other countries. Although ASF is now under control in domestic pigs in Spain and Portugal, it remains in feral pig (wild boar) populations, and may be a reservoir for domestic pigs in these countries;
- Aujeszky's disease is a highly contagious herpes viral disease that affects several livestock and wild species, although its greatest economic significance is in pigs. It occurs in most European, and several Asian and American countries, and also in New Zealand and Samoa. Cases in cattle and sheep are sporadic and they are generally regarded as dead end hosts. Rats and wildlife may have some role as reservoirs and vectors. The mortality rate varies with age in domestic pigs, declining from close to 100% in young piglets to low levels in adults;
- Trichinosis (or trichinellosis) is a helminth (roundworm) disease that results from eating raw or improperly cooked meat. All mammals are susceptible, but infestation is most common in carnivores and omnivores, including people, pigs, cats and dogs. Trichinosis is present in many countries in the temperate regions of the world including North Amercia, Egypt, Kenya, Spain, Thailand and New Zealand, and may also occur in the western province of Papua New Guinea. In Australia, an abattoir survey of pigs in the 1960s yielded negative results. One species of trichinosis has been found in wild animals in Tasmania, but this species is not considered to be a risk to public health or production animals (Geering et al. 1995);
- Classical swine fever (CSF) is a highly contagious, generalised viral disease of pigs that is also called hog cholera. It is clinically similar to ASF but is caused by a different virus. Pigs are the only livestock affected. CSF has been eradicated from most of western Europe, although it remains in Germany and eastern Europe. It is also present in east and central Africa, Asia and Central and South America. In the acute form of CSF, the mortality rate may reach 90%. There are also chronic and mild forms, both of which can kill pigs.

Outbreaks of any of these diseases or parasites could have severe repercussions for both Australia's domestic and export livestock industries (Pech and McIlroy 1990). For example, an outbreak of FMD, the exotic disease of most concern, could cost Australia more than $3 billion in lost export trade, even if the outbreak of the disease was eradicated immediately (Wilson and Choquenot 1996). If the outbreak persisted, continuing losses could be $0.3–4 billion a year, depending on whether trade was affected in just one state or territory or country-wide (Barry et al. 1993). Average incomes for beef producers could fall by almost $60 000 annually (Lembit and Fisher 1992; approximately equivalent to $65 000 in 1994–95 values). Significant social upheaval could follow, as well as major changes in land use in some parts of Australia. Less significant exotic diseases which could involve feral pigs are rabies and infestation with screw-worm fly (*Chrysomya bezziana*).

Australia maintains stringent quarantine regulations to prevent the introduction of exotic diseases. Commonwealth and State animal health authorities have also developed a nationally agreed approach for managing contingency plans — the Australian Veterinary Emergency Plan (AUSVETPLAN) — for outbreaks of FMD and other exotic diseases. Ideally, any outbreak would be contained within a small area, affected and in-contact animals would be immediately slaughtered, and the disease organism would be eliminated from the environment by cleaning, disinfection, and spelling the land.

The potential role of feral pigs in an outbreak of FMD is unclear. Although feral pigs are highly susceptible to FMD, and secrete copious quantities of the virus in their urine and saliva for a short period, there is no evidence that they act as a reservoir of infection or cause recurrent outbreaks. Feral pigs are, however, difficult to manage and an outbreak of FMD in feral pigs could delay its detection, increase the rate and extent of spread, make eradication of disease expensive, time-consuming or impossible, and complicate and delay declaration of disease-free status following an outbreak.

'An outbreak of an exotic disease such as foot-and-mouth disease in feral pigs could have severe consequences for Australia's livestock industries.'

The success of an eradication campaign against an outbreak of an exotic disease amongst feral pigs is likely to depend on several factors, including the delay in first detecting infected animals, the prevalence of infection and the size and location of the area to be decontaminated (Pech and McIlroy 1990). Under present policy, an outbreak of a disease, such as FMD, amongst feral pigs could be eradicated by slaughter of all host animals within a tightly managed core area encompassing all detected cases. In a buffer zone outside this, host animals would be tested to ensure the continued absence of FMD. A knowledge of the rate of spatial spread of FMD would be valuable in helping to define these zones in different environments, but this requires information on factors such as the disease transmission coefficient or, failing that, the rate of contact between feral pigs (Pech and McIlroy 1990). This, and other information, is also required to determine the threshold density of susceptible individuals, below which the disease will die out naturally, and the culling rates necessary to eradicate the disease within certain periods of time. A full list of factors likely to affect the progress and management of an outbreak of FMD in a feral pig population is provided by Pech and Hone (1988).

If active disease eradication was not considered feasible or practical as a management option, it could be contained within a confined zone until it died out naturally. Stock movement out of the containment zone would be banned.

Based on studies reported by Hone and Pech (1990), the probability of detecting an individual feral pig infected with FMD using the current opportunistic surveillance scheme is less than 1.5 in 1000. This could mean that, for a feral pig population subject to regular hunting and occupying 100 square kilometres of western New South Wales at a density of 15 per square kilometre, it would take between 23 and 358 days, most probably seven months, to detect an outbreak of FMD. Time to detection could be greater still in sparser populations and in the absence of hunters. Given, however, that FMD is a multi-species disease, and that cattle are more susceptible than pigs, it is most likely that an outbreak would be first detected in cattle.

Not enough is known about the continuity of distribution of feral pigs in different areas of Australia to accurately predict the broad-scale rate of spread of a FMD outbreak. Current estimates suggest an outbreak could spread at a rate of about 2.8 kilometres per day in Namadgi National Park in the Australian Capital Territory (Pech and McIlroy 1990), about 2.5 kilometres per day in Nocoleche Nature Reserve in the semi-arid rangelands of north-west New South Wales (Dexter 1995), and between 0.2–2.3 kilometres per day in the Top End of the Northern Territory, in areas where the distribution of pigs is continuous (Caley 1993).

An outbreak of FMD in pigs inhabiting the Douglas River area in the Northern Territory could establish during any part of the dry season as the predicted threshold densities for FMD establishment (0.6–2.0 pigs per square kilometre, or group sizes of 52–192 pigs, where there is discontinuous distribution) are below the observed population densities (Caley 1993). Outbreaks of the disease in the Northern Territory could die out naturally if they occurred in only small isolated populations of pigs, particularly those in the woodlands where the density of pigs is 0–1.2 per square kilometre (Hone 1990b; Caley 1993), but FMD could establish over a wide area of the coastal open floodplains of the Top End, where densities range from 2.2–10.9 per square kilometre throughout the year (Hone 1990b). Outbreaks of FMD could similarly establish in the hill country of south-east Australia where there are one to two pigs per square kilometre (Saunders 1988, McIlroy et al. 1989) and the threshold density (at least for pigs in Namadgi National Park) is 0.037 pigs per square kilometre (Pech and McIlroy 1990). The probability of an outbreak establishing in western New South Wales, where the threshold density is about seven pigs per square kilometre (range: 2.3–24 pigs per square kilometre) (Pech and Hone 1988) would depend on the density of the pigs occurring at the particular time and site. The threshold densities of feral pigs in semi-arid rangelands was estimated to be 0.24–0.26 pigs per square kilometre (Dexter 1995).

The key to eradication of an outbreak of FMD in feral pigs is to reduce their density below the disease threshold in the given area. Some modelling, however, indicates that this requires very heavy culling, of the order of 95% of pigs for short-term management, but perhaps half this for a long-term (two year) FMD eradication campaign (Pech and Hone 1988). Achieving target reductions to these pig densities has proven difficult. Three full-scale FMD eradication exercises in western New South Wales, the Northern Territory and Queensland, achieved only 40–80% reductions in pig numbers (Davidson 1990). Results of studies by Saunders (1988) and McIlroy et al. (1989) indicate that target reductions can be achieved in the hill country of south-east New South Wales, but a suite of control methods need to be used and it takes considerable time. Other factors that need to be considered include how far pigs move, their propensity to come into contact with other pigs (that is, how isolated the population is), and the presence and density of other potential host animals and their interactions with feral pigs (Wilson and Choquenot 1996). For these reasons, the option of containment of FMD, rather than eradication, might be more practical for managing an outbreak.

'The key to eradication of an outbreak of foot-and-mouth disease in feral pigs is to reduce their density below the disease thr eshold.'

Not only will FMD need to be eradicated from feral pigs, it will also be necessary to demonstrate to Australia's trading partners that all feral pig populations in affected zones are free from FMD. This could be a protracted and difficult process (Wilson and Choquenot 1996).

Little information is available on the likely dynamics and rate of transmission of other exotic diseases between feral pigs in Australia. Research by Hone et al. (1992) suggests that classical swine fever is only likely to establish in pigs occupying good quality habitats such as wetlands and river systems where the carrying capacity for pigs is probably well above the threshold density for the disease. In such cases, eradication of outbreaks would require active culling or vaccination.

4.4 Resource value and commercial use

4.4.1 Introduction

The Australian feral pig is both ecologically and physically similar to the European wild boar and there is a significant export of wild pig meat from Australia to European markets. Commercial use of feral pigs began in 1980 following amendments to the export meat regulations in 1979 to include the export of game meat. Game Management Australia Pty Ltd, a Queensland company, was registered in 1980 for the purposes of exporting game meat. At present, there are three major players involved in the harvesting and export of wild boar meat from Australia (P. Vitolovich, AQIS, Australian Capital Territory, pers. comm. 1996).

'There is a significant export of feral pig meat from Australia to European markets where it is sold as "wild boar" meat.'

The feral pig is regarded as the most important game animal in Australia (Tisdell 1982, 1983/84), and is most commonly taken by hunting on foot, with or without dogs, or from vehicles. Tisdell (1982) reports results of extensive surveys of recreational shooters in the late 1970s at which time the average hunter took 73 pigs per year from 8–11 trips. Most of the hunters act on their own, strongly believing that they have a useful role to play in feral pig control, and that there is potential for wild pig hunting as a tourist attraction. Tisdell (1982) suggested that amateur hunters may kill 15–20% of the feral pig population annually. He estimated that this rate of culling would reduce feral pig populations by about 7.5%, and that if each pig caused $15 (1982 values, approximately equivalent to $30 in 1994–95 values) worth of damage to landholders, then amateur shooters were producing an indirect benefit to landholders of $3.75 million annually (1982 values, approximately equivalent to $8 million in 1994–95 values). Added to this is the flow-on from the expenditure of hunters in the community; Tisdell (1982) suggested that there were about 100 000 feral pig hunters[3], who each spent an average of $447 annually (equivalent to about $950 in 1994–95), giving a total expenditure of $45 million (equivalent to $95 million in 1994–95). No current figures are available.

In October 1994, the Standing Committee on Agriculture and Resource Management (SCARM) considered the development of sustainable industries based on both native and introduced wild and feral animals. SCARM supported the commercial use of wild animals, with due regard to ecologically sustainable development principles and consideration of animal welfare. Further, SCARM agreed that the development of commercial industries using feral pest species should include the objective of controlling damage due to the pest rather than encouraging their propagation in the wild. Both public and private landholders have concerns about some aspects of commercial use of feral pigs. These include problems with trespassing and property damage by hunters.

4.4.2 Industry structure

Commercial harvesting operations are restricted to those areas of New South Wales, Queensland and the Northern Territory where feral pig populations persist despite harvesting and management programs conducted by landholders and government agencies. Australia's feral pig industry has a simple structure consisting of shooters and chiller operators who are based in rural towns, and game meat processors based in Sydney and Brisbane (Ramsay 1994). The total value of feral pig meat exports varies between $10 million and $20 million annually, mostly gained from Australian wild boar[4] exported to Europe (Ramsay 1994). In comparison, Australia's domestic pig meat industry is worth about $700 million annually (B. Ramsay, Pork Council of

3 Tisdell (1982) suggested there were at least 100 000 pig hunters in Australia and that they each took an average of 73 pigs per year — a total of 7.3 million pigs. Tisdell (1982) also suggested that feral pig hunters kill about 15–20% of Australia's feral pigs each year — a total of 0.5 million to 4.7 million pigs based on Hone's (1990a, Section 2.2) estimate that Australia's feral pig population is in the range of 3.5 million to 23.5 million. Given the discrepancy of these total kills, it is probable that Tisdell greatly overestimated the number of hunters or the number of kills per hunter, or both.

4 Wild boar is the preferred term of the export trade because it is understood by clients in Europe. Feral pig is a term with which they are not familiar.

Feral pig meat exports are worth $10–20 million annually.

Source: P. O'Brien, BRS

Australia, Australian Capital Territory, pers. comm. 1995). In 1989, a peak year for feral pig harvesting, game meat companies paid at least $5 million to shooters and chiller operators. In 1993 there were about 200 permanent and intermittently operating chillers spread throughout rural New South Wales, Queensland and the Northern Territory (Ramsay 1994). Wild Game Resources (WGR, previously called Bannergame and owned by Southern Game Meat) is one of the major companies involved in the harvesting of wild boar. In June 1993, WGR had 81 chillers operating permanently at locations in Queensland and New South Wales. Typical prices paid by Australian chiller operators for feral pig meat in 1992 are shown in Table 6.

Most wild boar meat is exported between May and December to catch the winter market in Europe when consumption is greatest. There is a fluctuating demand for feral pig from Australia because of other market factors. For example, eastern European countries such as Poland and Hungary compete against Australia in this

Table 6: Typical prices paid by Australian chiller operators for wild boar meat in 1987 and 1992 (from Ramsay 1994).

Year	Weight of carcass[a] (kg)	Price per kg ($)	Price per carcass ($)
1987[b]	22–30	0.40	8.80–12.00
	31–40	0.60	18.60–24.00
	41–61	0.70	28.70–42.00
	≥61	0.80	≥48.80
1992	23–30	0.30	6.90–9.00
	31–50	0.60	18.60–30.00
	51–80	0.70	35.70–56.00
	≥81	1.00	≥81.00

a Partly eviscerated
b from Takahashi and Tisdell (1989)

market. In addition, seasonal conditions such as prolonged droughts or extensive flooding affect the quality and quantity of the product.

In Queensland commercial feral pig hunters have been required to be accredited, as from May 1995, which allows the sale of pig meat for domestic consumption in Queensland.

4.5 Implications of harvesting for damage control

If intense and frequent enough, commercial harvesting has the potential to lower feral pig densities to a level where the damage they cause is reduced. Annual rates of increase of feral pig populations in Australia can be as high as 86% (Giles 1980), so culling rates would need to be sustained at high levels to keep populations down. There have been no studies in Australia to determine whether current levels of commercial harvesting of feral pigs are reducing agricultural and environmental damage.

'For commercial harvesting to reduce feral pig densities sufficiently for the damage they cause to be reduced, culling rates would need to be sustained at high levels.'

Because harvesting pests reduces their density, it follows that where there is a relationship between pest density and environmental or agricultural impact, commercial or recreational harvesting has the potential to contribute to conservation or agricultural production objectives. Choquenot et al. (1995) developed a conceptual model of how harvesting might reduce the distribution of feral pig damage to the environment, and developed an example based on a hypothetical wild pig harvest. Their example is imaginary because the relationship between pig density and environmental damage is unknown. Choquenot et al. (1995) concluded conventional control is a sensible option where: (a) commercial harvesting does not achieve the reduction in pig density necessary to reduce impacts to acceptable levels or over large enough areas; and (b) where it follows an unsustained harvest of pigs. In the former case, the relative efficiencies of substituting conventional control for harvesting or subsidising the harvest to increase its capacity to reduce pest density should be examined. In Choquenot et al.'s (1995) hypothetical example, a 15% subsidy on the value of harvested pigs increased the area over which acceptable reductions in density occurred by 52%. In a review of such subsidies or 'smart bounties', Hassall and Associates (1996) concluded they were unlikely to result in significant or long-term damage reduction (Section 6.1.1). Choquenot et al. (1995) concluded that commercial harvesting of pigs could contribute to conservation objectives, though there was insufficient data to quantify the contribution, but they also recognised that placing an economic value on pigs through commercial harvesting could (a) encourage maintenance of a pig density sufficient to meet harvesting needs, and/or (b) discourage future attempts at high level control or eradication (Tisdell 1982; Ramsay 1994). If realised, these factors could offset the potential contribution of feral pig harvesting to achieving conservation objectives. These conclusions can be expected to apply equally to impacts of commercial harvesting of feral pigs on agricultural production. It may be easier to quantify the agricultural benefits of commercial harvesting as there are some data on the relationship between feral pig density and agricultural damage (Section 4.1.1).

5. Community attitudes affecting feral pig management

Summary

The feral pig is considered by the community to be many things: agricultural pest; endemic and exotic disease hazard; environmental liability; export commodity; and recreational resource. These attitudes vary with time and location, although the feral pig's status as an agricultural pest was responsible for raising its profile initially. The feral pig management debate has become more complex because of changing values in the community. No longer simply regarded as a threat to agriculture and the environment, the feral pig now also represents a source of significant income to rural communities through recreational hunting and commercial harvesting. Multiple use of feral pigs leads to conflict in the rural community as well as in the general community. Benefits from the game meat export industry and recreational hunting are attractive. Despite arguments from some rural groups that commercialisation and recreational use of feral pigs is incompatible with effective feral pig management, experience suggests otherwise. There is an increasing acceptance among communities that multiple-use management of feral pigs is both practical and appropriate.

Animal welfare groups accept there may be a need to reduce feral pig numbers where they cause agricultural or environmental damage, but consider only humane control techniques are acceptable, and that the goal should always be a sustained reduction in pig numbers.

5.1 Community perceptions

Currently, feral pigs are perceived to be an agricultural pest, an endemic and exotic disease hazard, an environmental liability, an export commodity and a recreational resource (Tisdell 1982). According to O'Brien (1987) and Izac and O'Brien (1991) these attributes can vary with location, time and observer perception, and in so doing give rise to conflict.

5.2 Animal welfare issues

Animal welfare groups aim to protect animals from cruelty and improper exploitation, encourage considerate treatment of animals and denounce practices perceived as causing animals unnecessary suffering. The Australian and New Zealand Federation of Animal Societies (ANZFAS) accepts that some feral animals such as feral pigs cause agricultural or environmental damage, and that where this occurs there is a case for reducing their numbers (ANZFAS 1990). Their view, however, is that only humane methods conducted under the supervision of government authorities, and within long-term population reduction programs, are acceptable.

Generally, the humaneness of techniques associated with the management of introduced pest species has received little attention, with most emphasis being placed upon the methods used to cull native species such as kangaroos and wallabies. The Sub-committee on Animal Welfare (SCAW) of the Standing Committee on Agriculture and Resource Management (SCARM) has produced a Code of Practice on *Feral Livestock Animals — Destruction or Capture, Handling and Marketing* (Standing Committee on Agriculture 1991). Feral pigs are discussed in this publication. The National Consultative Committee on Animal Welfare (NCCAW 1992) has called for the banning of use of yellow phosphorus poison or CSSP against feral pigs (Section 7.6.8). ANZFAS does not support shooting from helicopters, due to the risk of pigs being wounded rather than humanely killed, and suggests the need for helicopters to take a second run over the control area to check for wounded pigs and reshoot them if necessary. ANZFAS only considers trapping is humane if the trap is in a sheltered area, is checked frequently, and the pigs are killed humanely (G. Oogjes, ANZFAS, Victoria, pers. comm. 1995). The use of dogs to pursue and hold feral pigs is opposed by

ANZFAS due to the stress of capture and the injuries inflicted upon pigs prior to death. The dogs used are also subject to a high risk of injury or even death in the struggle with the captured pig (G. Oogjes, ANZFAS, Victoria, pers. comm. 1996). Both ANZFAS and RSPCA Australia strongly oppose the hunting of animals for sport.

'Consideration of animal welfare issues should be an integral part of any feral animal management plan.'

Consideration of animal welfare issues should be an integral part of any feral animal management plan. ANZFAS considers that the current approach to feral animal management, namely ad hoc, opportunistic actions based on short-term reduction in populations, are inappropriate. ANZFAS considers that a well planned and coordinated strategy, as advocated in these guidelines, is likely to be more humane. According to Wirth (1995), public opposition to some pest control operations is based on the lack of objective assessment of the agricultural or environmental impacts of pests, and a belief that the animal welfare costs of the control operations are often unjustified. NCCAW considers that animal welfare issues should be taken into account when management progams are designed and that control techniques must be as humane as is feasible (Wirth 1995).

5.3 Attitudes in the rural community

Rolls (1969) states that pigs were shot in their thousands in the Riverina in the 1880s and again in the 1950s. It is not clear whether they were shot because they were perceived as agricultural and environmental pests or whether they were shot for sport. In some cases it was clear that many lambs were being lost to feral pigs. One property owner in 1954 reported feral pigs were so numerous that high lambing success in the vicinity of the Macquarie Marshes was not possible. Five other properties where feral pigs were present reported either very low (28%) or negligible lambing rates. The owners concluded that unless pig and kangaroo numbers were substantially reduced, they would not be able to show a satisfactory return on their investment in sheep. Other properties, where feral pigs were not evident, had a 79–80% lamb survival rate at marking.

Feral pigs were declared noxious in the first Rural Lands Protection Board district in New South Wales in 1936. Other Boards in north-west New South Wales followed suit until a statewide noxious declaration for the feral pig was made in 1955. This declaration followed submissions from Rural Lands Protection Boards and landholders, and complaints from councils including the Baulkham Hills Shire in north-west Sydney. Councillors stated that feral pigs were present in dense bushland, periodically emerging to raid crops and damage fences and outbuildings on isolated farms. It was further claimed that speculators brought pigs from country areas in western New South Wales, released them in bush country to breed and fatten for sale, and made considerable profits from the operation.

Some farmers suggested recent immigrants were dumping the pigs. This is of interest because it exemplifies the differences in perceptions by different cultures towards use of wild resources. Many immigrants from continental Europe consider game meat a delicacy, unlike many people of British origin. Many indigenous peoples of Australia, such as those living in north-west Arnhem Land, perceive the feral pig as a resource (Roberts et al. 1996; Rose 1995) whereas others in central Arnhem Land see them as a pest because they damage bush tucker (Wilson et al. 1992b).

Rural Lands Protection Boards in New South Wales still view feral pigs with concern, but according to Grant (1982) (Section 6.2.3) this concern is more evident in Western compared to Central and Eastern Boards. From 1979 to 1982, the New South Wales government funded the pilot north-west New South Wales feral pig control scheme described by Bryant et al. (1984).

In general farmers regard feral pigs as a pest requiring some control (Oliver et al. 1992). Due to feral pig mobility, farmers have difficulty controlling pigs when they also live on neighbouring land. This can lead to disputes. Managers of public lands including state forests and national parks also need to account for feral pigs in their management plans.

'Farmers generally regard feral pigs as pests requiring control.'

Feral pigs are not only viewed negatively by the agricultural community because of the damage they cause to livestock and crop enterprises, but also because of their potential role in an outbreak of exotic disease, such as foot-and-mouth disease (FMD). Pullar (1950) and Keast et al. (1963) identified feral pigs as efficient vectors for some diseases, and Wilson and Choquenot (1996) identified them as the species of most concern in relation to wildlife harbouring or spreading exotic disease in Australia (Sections 3.6 and 4.3.2). This has led to considerable Commonwealth funds being allocated to feral pig research through the Wildlife and Exotic Disease Preparedness Program from the mid-1980s to the present.

5.4 Attitudes of the general public

Feral pigs are perceived to have a negative impact on the environment (Section 4.2). Both Pullar (1950) and Tisdell (1984) expressed concern about the environmental impacts of feral pigs and provided some evidence that feral pigs prey on, or have potential to prey on, native fauna (Section 4.2). Conservationists consider feral pigs should not only be prevented from expanding their range but populations should be reduced (if eradication is not possible) in areas where they cause damage to native flora and fauna (Oliver et al. 1992). Damage to newly planted trees also concerns foresters and others involved in tree planting.

There is a strong perception in the community that feral pigs are dangerous, and they have become highly prized hunting trophies. According to Tisdell (1982), they are afforded special status by amateur hunters.

In the wet tropics of north-east Queensland, control of feral pigs was the highest priority issue raised by community groups consulted during the development of the Wet Tropics Plan: Strategic Directions (Wet Tropics Management Authority 1992). This has led to a strategy aimed at defining the problem, filling in knowledge gaps by research at various levels and implementing management strategies with a strong community participation (Section 8.7; McIlroy 1993; P. Salleras, C4, Queensland, pers. comm. 1993) through established groups such as the Consultative Committee for the Conservation of Cassowaries, now the Committee for Coastal and Cassowary Conservation (C4).

5.5 Attitudes to multiple-use management

The main issue associated with commercial harvesting of feral pigs is the conflict which arises between those who seek eradication, those who view feral pigs as a resource, and those who view feral pigs as both a resource and pest.

This conflict exists between management organisations within the same state. For example, New South Wales Agriculture recognises that commercial harvesting has a role to play in feral pig management. However, Rural Lands Protection Boards, who are responsible to the Minister for Agriculture, have a policy of eradication (Section 6.2.3). Even landholders who are highly organised into feral pig management groups are split on this issue. In the Moree Rural Lands Protection Board, about 40 feral pig management groups exist. When the views of group leaders were sought on the desirability of banning commercialisation of feral pigs, their views were evenly split. Pest control agencies generally oppose commercialisation because some believe that it is incompatible with eradication and that it interferes with management programs.

O'Brien (1987) argues that commercialisation of feral pigs has significant social implications because of the injection of funds into rural communities (Section 4.4.1), many of which are economically depressed. Some land managers in north-west New South Wales readily use feral pigs as a resource but others refuse to adopt the multiple-use approach proposed by O'Brien (1987). O'Brien and Meek (1992) argue that commercialisation adds to the present ad hoc multiple-use management of feral pigs. Other components are recreational hunting and pest control (environmental, agricultural, epidemiological). Ramsay and O'Brien (1991) provide a list of generic objections to commercial use and identify elements important to the integration of control and commercial use. Attitudes to commercialisation vary according to economic circumstances of rural communities, individual landholders and the prices paid for feral pigs. A value of $1.00 per kilogram dressed for captured pigs is a strong economic incentive for landholders, their families or staff, to set traps to manage feral pigs or hunt recreationally (Table 6). Most readily deliver pigs to chillers.

The Standing Committee on Agriculture and Resource Management (SCARM) supports the development of commercial industries based on the harvest of feral pigs (Section 4.4), although SCARM considers these industries should not support the maintenance of feral pig populations. In supporting commercial use of feral animals, the position of SCARM differs from that of ANZFAS (Section 5.2). The policy of the National Farmers' Federation is to support control of feral pigs and to allow commercial use where it assists control (R. Hadler, NFF, Australian Capital Territory, pers. comm. 1995).

It is unlikely that the debate between those advocating sustained management of feral pigs to low densities and those supporting their commercial use will be resolved in the near future. The probable answer lies with local landholder management groups who can set their own agenda on the extent commercialisation is to play in local management of feral pigs. There would be little political support to ban commercialisation of feral pigs because of the export income and local employment it generates.

6. Past and current management

Summary

Management of feral pigs has varied depending on the balance between their pest and resource status, their legal definition in different states, and ad hoc policies or regulations developed by different state agencies. Most land managers now view feral pigs as pests and this has led to campaigns in some states and territories to manage them. The legal status of feral pigs differs within and between states and territories, and this affects management practices. Some laws prescribe how feral pigs are to be managed; others merely define them as pests and leave management to the discretion of landholders or the changing policies of public agencies.

State and territory governments provide legislative, technical, policy and possibly financial support for feral pig control, and are also responsible for feral pig management on land held by their agencies. Although management of the feral pig problem has been traditionally ad hoc, there is now a trend towards more strategic management. Before the 1970s, no research had been conducted on feral pig biology, ecology or management and land managers typically used shooting, bounties and poisoning with either strychnine, arsenic or phosphorus, as control tools. Since the 1970s, considerable research has been conducted on trapping evaluation, poison efficacy and bait acceptance, fence design, and shooting from helicopters as control tools. This work coincided with the phasing out of bounties and the introduction of coordinated management using landholder groups. The success of the coordinated approach is validated by numerous programs conducted in New South Wales which produced positive outcomes in the way of decreased lamb predation and crop damage. Both Queensland and New South Wales have a policy of encouraging the use of coordinated management.

Current management is increasingly sensitive to environmental and animal welfare issues associated with control. Considerable effort is made to ensure that techniques and methods are sensitive to the community's needs in this regard.

6.1 Past management

Feral pigs are relatively recent agricultural and environmental pests that have achieved prominence over the last 50 years. They appear to have dispersed widely in eastern Australia following the decade of wet years in the 1950s. In addition, the increased mobility of hunters resulted in the transportation of feral pigs to uncolonised locations in eastern New South Wales and parts of Victoria.

Effective control practices have only evolved over the last 20 years as governments and industry bodies accorded feral pigs a high priority and allocated funds for research and extension. Techniques for the control of feral pigs are described in Section 7.6.

This section provides an overview of control practices as they have developed and been reported in the literature.

6.1.1 Bounties

Pullar (1950) reports that payment of bounties to control feral pigs dates back to 1870 but they were not given government support until 1945 when a two-shilling bounty (about $2.50 in 1994–95 values) was introduced in Queensland. The number of bounties payed in Queensland between 1945 and 1977 annually ranged from 25 504 to 131 740 (Anon. 1980).

Bounties have been viewed favourably at various times as providing several benefits. These include providing:

- additional income for farmers, graziers and trappers, who in some cases depend on the extra income for a living (Laun 1971);
- assistance to farmers and graziers by meeting part of the cost of control (Tomlinson 1957);

- data on distribution, numbers, food habits, taxonomy and other important scientific information (Laun 1971);
- an incentive to agricultural workers/ employees to become more involved in animal pest control than may otherwise be the case (Smith 1990);
- an incentive for individual 'killer pigs' to be destroyed (Tomlinson 1957); and
- a measure of effectiveness or otherwise of current and past control programs (Smith 1990).

It has been recognised for some time, however, that bounties have a substantial number of weaknesses as a means of controlling vertebrate pests. These include:

- susceptibility to fraud (for example, transferring scalps from other areas where there is no (or less) bounty paid and substituting scalps of other animals) (Balser and Moyle 1958; Latham 1960; Rolls 1969; Breckwoldt 1988; Smith 1990; Hassall and Associates 1996);
- failure to cause a significant decrease in pest animal populations (Balser and Moyle 1958; Rolls 1969; Smith 1990; Hassall and Associates 1996);
- deliberately spreading pest animals (for example, rabbits) throughout the continent (Rolls 1969);
- deliberately setting free females and young to provide future income (Balser and Moyle 1958; Rolls 1969); and
- bounties have to be very high to induce participation, at which point costs exceed the total predation losses (Laun 1971).

Bounties may be effective in managing feral animals if bounty payments increase in value substantially as the pest population decreases, thereby inducing hunters to seek out the few remaining animals before dishonest and fraudulent practices creep in (Jacobsen 1945; Gosling and Baker 1989; Smith 1990). For example, bounties could jeopardise more effective management programs if some landholders wish to try other less successful control measures in order to claim the bounty (Smith 1990).

Governments now generally recognise that traditional bounties are ineffective as a pest control method. In 1975, a resolution was passed by the Vertebrate Pests Committee recommending that bounty payments should be phased out completely. This has been implemented for pigs, with the exception of a few small-scale bounty schemes targeted at localised feral pig problems.

'Governments generally recognise that traditional bounty schemes are ineffective for controlling pest animals such as feral pigs.'

Choquenot et al. (1995) investigated how a bounty subsidy could be used to increase commercial harvesting of feral pigs to meet damage control goals (Section 4.5). However, a review by Hassall and Associates (1996) of such 'smart bounties' concluded that while they are capable of 'offering positive benefit–cost ratios', they are a 'clumsy tool requiring considerable supervision' and the authors considered it unlikely that bounty payments would deliver long-term reductions in damage.

6.2 Current management and legal status

6.2.1 Introduction

Feral pigs numbers are greatest in Queensland, New South Wales, Northern Territory and Western Australia, probably in that order. Victoria has far fewer feral pigs, South Australia has isolated populations, including on Kangaroo Island, and there is a permanent feral population on Flinders Island in the Bass Strait.

Historically, feral pigs have been considered an agricultural pest and this has been reflected in their management where large-scale reductions in numbers has been the primary aim. There is an increasing appreciation in rural communities that feral pigs are an important export commodity and an important recreational resource. This has led to conflict and the need to re-assess long-term management of feral pigs (Izac and O'Brien 1991). The attitude to feral pig management taken by various state and territory governments within Australia is reflected in their legislation (Table 7).

6.2.2 Queensland

The official policy of the Queensland Department of Lands is to reduce the impact of feral pigs through coordinated and sustained control programs in areas where feral pigs constitute a high risk to agricultural production and/or the environment. The Department of Lands recognises that feral pigs are the basis of an important commercial harvesting industry and that the harvesting of feral pigs contributes to their management in Queensland.

The *Rural Lands Protection Act 1985* requires landholders in Queensland to destroy feral pigs on their properties. This Act is overseen at a regional level by inspectors of the Land Protection Branch of the Department of Lands. The Inspectors operate from Department of Lands offices and work in Department of Lands regions. The inspectors act as advisers to landholders and provide additional services by issuing poison bait and assisting landholders to form and operate pig management groups.

Despite the pressure of a legal requirement, landholders control feral pigs because they perceive they have a negative economic impact on their enterprises. In one survey (Appleton 1982) not one landholder gave legal liability as a reason for controlling feral pigs.

One of the major concerns about feral pigs in Queensland is their possible involvement in an exotic disease outbreak. In an attempt to improve the preparedness of government agencies for such an event, two major exercises have been conducted within the last ten years: one at Charleville and another at Byfield (Allen 1985). In addition, staff from the Queensland Department of Lands have attended exercises conducted by other states.

6.2.3 New South Wales

Under the *Rural Lands Protection Act 1989*, management of feral pigs on private or leased land in New South Wales is the responsibility of the occupier or owner of the land. On land owned by the Crown, the agency responsible for that land may or may not allocate funds for feral animal management. Most government agencies respond to public pressure and allocate either physical or financial resources to feral pig management. For example, the New South Wales National Parks and Wildlife Service contributes about $350 000 to feral animal control each year. Control of feral animals on unoccupied Crown land is funded through a grant system administered by New South Wales Agriculture.

'New South Wales Agriculture recognises the role commercial harvesting can play in managing feral pig damage.'

The Rural Lands Protection Boards administer the *Rural Lands Protection Act 1989* through Noxious Animal Inspectors and Directors. Noxious Animal Inspectors are trained by New South Wales Agriculture in basic vertebrate pest control, then learn on the job while working with landholders and other government agencies. Rural Lands Protection Boards are autonomous bodies, answerable for their policies only to the Minister for Agriculture. In an attempt to have Boards develop and implement management plans which contain key elements, model plans were drafted by New South Wales Agriculture and distributed to all Boards. The adoption of these plans has met with limited success, despite the fact that the plans were developed in consultation with representatives from the Rural Lands Protection Boards.

New South Wales Agriculture has a policy on feral pigs that is control oriented but which recognises the role that commercial harvesting can play in managing feral pig damage. On the other hand, the formal policy of the Executive Council to Rural Lands Protection Boards is one of eradication. In practice, the eradication policy of Rural Lands Protection Boards cannot be implemented. The Boards do not have the resources to pursue an eradication policy, although they feel an obligation to follow a 1950s legal ruling that eradication is the specified objective under the Act. Notwithstanding this, most Boards accept that damage control is the real objective, even if not explicitly stated; eradication is seen as the ultimate, but improbable objective (Section 8.4.2; Appendix C).

6.2.4 Northern Territory

The feral pig is declared as a pest under the *Territory Parks and Wildlife Conservation Act 1988*. This places no legal obligation on land managers to manage feral pigs, unless the area in which they manage land is a declared area. Landholder attitude is orientated to reducing crop damage which can be significant (Caley 1993). The official government policy is to encourage control of feral pigs by land managers but there are no records of land managers being forced to undertake management programs (G. Davis, CCNT, Darwin, pers. comm. 1994).

Commercial harvesting is an intermittent management tool despite the relatively high density of feral pigs in the Top End of the Northern Territory. Its intermittent nature is simply due to difficulties of access because of topography and weather patterns. Commercial harvesting provides an irregular source of income for some itinerant hunters, including Aboriginal peoples. Recreational hunting is a popular activity, but is considered to have no effect on the feral pig population.

Feral pigs are of particular concern in the Top End because of their potential involvement in exotic disease outbreaks such as foot-and-mouth disease (Section 4.3.2). Several simulated exotic disease control exercises have been conducted in the Northern Territory, in an effort to train staff for such events.

6.2.5 Western Australia

Feral pigs are declared in categories A4, A5, and A6 under the *Agriculture and Related Resources Protection Act 1976* in Western Australia, which means that landholders are legally obliged to comply with the following conditions:

- introduction of feral pigs is subject to conditions and restrictions;
- numbers of feral pigs should be reduced and kept under restriction; and
- keeping of feral pigs is subject to conditions and restrictions.

In Western Australia, direct losses of grain crops are probably the most significant damage and individual losses to lupin crops may reach tens of thousands of dollars. Direct predation on livestock is very rare in Western Australia. There is circumstantial evidence that pigs spread the fungal pathogen (*Phytophthora cinnamomi*) which causes jarrah (*Eucalyptus marginata*) dieback disease in Western Australia (Section 4.2.2).

Baiting with 1080 poison is a major tool in feral pig control and recreational hunting is a popular activity.

6.2.6 Victoria

Feral pigs are declared as Established Pest Animals under the *Catchment and Land Protection Act 1994* and all landowners have a legal responsibility to take reasonable steps to manage them. Feral pigs are dispersed in isolated populations in the north-west, south-west, north-east and eastern parts of the state. However, it is in the last two areas that feral pigs are increasing in both numbers and distribution, and pose a potential major threat in the next five to ten years.

Accessibility and size of populations determine the appropriate control techniques. Where feral pig activity is evident on public land, the setting of cage traps by local staff of the Department of Conservation and Natural Resources is the main method used to protect farmland throughout Victoria. Some opportunistic shooting is conducted by Department staff, but control of populations on private land is predominantly carried out by recreational shooters and adjoining landholders. Shooting is the preferred option when there are scattered sightings, particularly in rough country.

6.2.7 Australian Capital Territory

Leaseholders in the Australian Capital Territory are not legally required to control feral pigs. However, the Parks and Conservation Service provides support and assistance to Landcare groups and individuals for pig control on leasehold land by providing poisoned bait and traps to lessees.

Feral pigs are widespread throughout the forested and pastoral areas of the Australian Capital Territory. They destroy pasture and damage sensitive native plant communities through their feeding and wallowing. They are a high priority for control in the Australian Capital Territory due to their environmental and agricultural impacts and potential as a reservoir or vector for exotic disease.

Since 1985, warfarin poison (Section 7.6.8) has been used successfully in Namadgi National Park, other reserves, pine forests and rural areas. The number of pigs has been consistently maintained at a low level and the impact on the environment has been reduced.

6.2.8 Tasmania

Feral pigs are declared stock under the *Stock Act 1932*. This means landholders can muster animals on their land, and local councils are responsible for the transportation, disposal or destruction of these animals. Due to the need to efficiently control feral pig populations, the *National Parks and Wildlife Act 1970* allows rangers to destroy pigs in national parks. At this stage, funding is not provided for control programs and government coordinated programs have not yet been developed.

6.2.9 South Australia

Pigs are proclaimed in Class 4 (which includes livestock, domestic and companion animals) under the *Animal and Plant Control (Agricultural Production and other Purposes) Act 1986*, for the whole of South Australia. The only provision of the Act which applies to pigs is Section 44 which prohibits the release of pigs into the wild as a wilful or negligent act. Landholders are not compelled to take action to control feral pigs. Control is organised by landholder groups and is carried out on a voluntary basis.

Table 7: Status of the feral pig in Australia

	QLD	NSW	NT	WA	VIC	ACT	TAS	SA
Status of the feral pig	Declared animal A1, A2, A6[a]	Noxious	Pest	Declared animal A4, A5, A6[b]	Established pest animal	Not declared noxious	Stock	Class 4 animal[c]
Agencies responsible for management	Department of Lands; Local Government	New South Wales Agriculture; Rural Lands Protection Board	Conservation Commission of the Northern Territory	Agriculture Western Australia	Department of Conservation and Natural Resources	Australian Capital Territory Parks and Conservation Service	Department of Primary Industry and Fisheries; Department of Environment and Land Management	Animal and Plant Control Commission
Landowner or occupier responsibility	Occupier of private land who fails to control declared animals on that land commits an offence	Duty of occupier of any land to suppress and destroy all noxious animals on such land	Owner or occupier is required to undertake such measures for the control or eradication of pests in their area of control	The occupier of any private land shall control declared animals on and in relation to that land	A landholder must take all reasonable steps to prevent the spread of, and as far as possible eradicate, established pest animals	Discretionary for occupier of land to suppress or destroy	Landholders cannot dispose of or destroy. Landholders can muster animals to be impounded	It is an offence to release pigs into the wild as a deliberate or negligent act
Relevant legislation	*Rural Lands Protection Act 1985*	*Rural Lands Protection Act 1989; Stock Diseases Act 1923*	*Territory Parks and Wildlife Conservation Act 1988;* Territory Wildlife Regulations 1987; *Stock Diseases Act 1994*	*Agriculture and Related Resources Protection Act 1976*	*Catchment and Land Protection Act 1994*	*Rabbit Destruction Act 1919; Nature Conservation Act 1980*	*Stock Act 1932; National Parks and Wildlife Act 1970*	*Animal and Plant Control (Agricultural Production and other Purposes) Act 1986*

a A1, introduction of animal prohibited
A2, animals must be destroyed
A6, keeping and selling these animals is restricted

b A4, animals which can only be introduced under conditions and restrictions
A5, animals whose numbers will be reduced and kept under restriction
A6, animals which can only be kept under conditions and restrictions

c Class 4 includes livestock, domestic and companion animals

7. Techniques to measure and manage impact and abundance

Summary

There are many techniques available to estimate or index pig abundance. Complex techniques require many resources but can provide absolute estimates of abundance with measurable levels of precision. These can be used to compare pig densities between locations, habitats, and times. Such techniques are of use for the more accurate assessment of control operations and research. Simpler techniques usually provide useful indices of abundance which can indicate broad changes in pig density over time.

The assessment of the agricultural impact of pigs should focus on per capita estimates of reduction in yield of the given commodity. Measures of year-to-year variation in reduction of yield, over and above that due to feral pig density and other sources of systematic variation in yield, can be used to predict probabilities of yield reductions associated with given feral pig densities. Probability or risk of impacts represent a more useful basis for managing pig impacts, as they allow measures of acceptable uncertainty and risk to be incorporated into management decisions.

Feral pigs can affect the environment by consuming or destroying native plants and animals or their habitats. The same processes underlying the relationships between pig density and reduction in yield for agricultural enterprises can be used to understand consumptive environmental impacts of pigs. The persistence of destructive impacts complicates their relationship with pig density. This creates problems when contemplating their management through pig control. More information on ecological factors affecting the occurrence of destructive impacts, and their effects on ecosystem processes, is required to resolve some of these management problems.

Management units or control areas must be both sociologically and geographically based and the local land management group, constituting the management unit, must have strong ownership of the project and must set priorities.

Several techniques can be used for controlling pigs. Shooting from the ground is generally ineffective for damage control except where it is intensively conducted on small populations. Shooting from helicopters can protect susceptible enterprises from short-term damage, although annual campaigns are unlikely to result in long-term reductions of pig numbers because the populations generally recover during the intervening 12 months.

Poisoning is a control technique that is widely accepted throughout rural communities. It is perceived as a method which, if properly employed, can produce a quick knockdown of the feral pig population. The negative aspects of poisoning are associated with its non-specificity and welfare implications.

Trapping is best used where poisoning is impractical or as a follow-up control measure after poisoning. Fences are of limited value because no designs keep feral pigs out indefinitely.

No research for biological control of feral pigs is currently being undertaken. While viral-vectored immunocontraceptives have been proposed as a means of controlling some feral animals, no such technique has yet been successfully developed for controlling any pest species.

Integrated management using a range of control techniques produces the best results, but a lack of reliable information on on-farm control costs is seen as a barrier to adoption of some techniques. This needs to be addressed if best practice management is to be widely adopted.

Monitoring techniques exist which permit management programs to be effectively evaluated over time and location. These techniques are more appropriate and

meaningful for evaluating the impact of feral pig management in agricultural enterprises rather than natural or environmentally sensitive areas.

7.1 Introduction

Techniques are described in this chapter for estimating the abundance of feral pigs, for assessing their agricultural and environmental impact, for managing these impacts, and for monitoring the effectiveness of management programs.

7.2 Estimating pig abundance

Estimates or indices of feral pig abundance and distribution will assist planning and implementation of pig management programs. Estimates or indices of abundance and distribution can be used in conjunction with local knowledge to: determine the need for pig management; identify an appropriate management strategy; determine resource requirements for management; and assess the progressive reduction in feral pig abundance over the course of the management program.

Abundance estimates and indices can be complex, requiring systematic measurement, repeated sampling and usually some form of numerical analysis; or simple, requiring less complex measurement and no numerical analysis. Complex estimates are better for formal assessment of the progress or outcomes of management programs, for detailed estimation of resource requirements, and for research. Simple estimates are better for providing simple indices of pig abundance so landholders can monitor the progress of management programs.

7.2.1 Aerial survey techniques

Most research on survey methods for feral pigs has focussed on aerial techniques, primarily counts from helicopters. Hone (1983a) used fixed-wing aircraft counts of pigs to assess the efficacy of a 1080 poisoning program. No attempt was made to derive estimates of true feral pig abundance from these counts. Wilson et al. (1987) counted pigs in wheat fields during fixed-wing surveys of kangaroos in south-west Queensland. Counts were presented as uncorrected indices of abundance and it was concluded that fixed-wing counts would probably be of little value for determining pig abundance in all but the most open habitats. Bayliss (1985) also noted observations of pigs while conducting fixed-wing counts of feral livestock in the Top End of the Northern Territory. Counts were presented as simple occurrences, and Bayliss recommended that helicopter counts be explored as a means of obtaining more accurate population estimates.

Research on helicopter surveys to estimate pig abundance was subsequently conducted by Hone (1987). He used a known-size population of pig carcasses to test two options for correcting visibility associated with counts of pigs on an area of the Top End consisting of a combination of flood plains and open woodland. The project also assessed the effects of cloud cover, time of day, and observer effects on visibility bias. Both methods provided reasonably accurate population estimates. No effects of cloud cover or time of day on visibility bias were detected, although significant observer differences in the shape of sightability functions for line transect counts were detected. Surveys of live pigs in the same area showed them to be less visible than pig carcasses.

Recent research has focussed on development of helicopter survey techniques for estimating pig abundance in semi-arid floodplain habitats (Choquenot 1995). The techniques provide accurate estimates of visibility bias associated with standardised transect counts, and correction factors for the effects of habitat.

7.2.2 Ground survey techniques

Various ground survey techniques for feral pigs have been used during assessment of control techniques and/or campaigns, or in studies of the population dynamics and behaviour of feral pigs (Table 8).

Table 8: Studies using ground survey techniques to assess feral pig abundance.

Study	Technique	Habitat / location
Giles (1980)	Mark–recapture	Semi-arid riverine (New South Wales)
Hone and Pederson (1980)	Counts at water	Semi-arid riverine (New South Wales)
Hone (1983a)	Direct counts	Semi-arid riverine (New South Wales)
Hone (1988a,b, 1995)	Direct counts, dung counts, extent of rooting	Mountain forests (Australian Capital Territory)
Saunders (1988)	Mark–recapture, catch-per-unit-effort	Mountain forests, open farmlands (New South Wales)
McIlroy et al. (1989)	Mark–recapture	Mountain forests (Australian Capital Territory)
Choquenot et al. (1990); Choquenot (1995)	Mark–recapture, trap success, direct counts, bait consumption	Semi-arid riverine (New South Wales)
Saunders et al. (1990)	Direct counts	Mountain forests (New South Wales)
Ridpath (1991)	Direct counts	Tropical woodlands, sedgelands (Northern Territory)
Caley (1993)	Mark–recapture, catch-per-unit-effort	Tropical woodlands (Northern Territory)
Choquenot et al. (1993)	Direct counts	Tablelands forests (New South Wales)
Dexter (1995)	Mark–recapture	Semi-arid riverine (New South Wales)

Four issues are apparent from these studies. Firstly, all ground survey techniques assessed are labour intensive, most involving repeated measures or repeated capture of individual animals, and detailed numerical analysis. As such, an experienced wildlife biologist will usually be needed to plan, implement and interpret the results of ground surveys.

Secondly, the choice of techniques will depend on the context within which the survey is to be undertaken. For example, surveys of ground disturbance will usually not provide an accurate estimate of pig abundance before pigs are controlled. Such a survey may, however, provide valuable information on the rate of reduction in pig abundance as pig control operations continue, and may provide an estimate of pre-control abundance retrospectively.

Thirdly, regardless of the technique used, the design and intensity of the survey will depend on the nature of the information sought. For instance, general information on the broad distribution of pigs will entail widespread application of low-frequency sampling, probably without repeated measures. Detailed information on rate of change in pig abundance, on the other hand, will require intensive directed sampling, probably on marked plots.

Finally, none of the ground survey techniques assessed so far can be used to rapidly provide accurate data on pig abundance and distribution.

7.3 Simple estimates and indices of pig abundance

7.3.1 Surveys of feral pig signs

Pavlov et al. (1992) used a simple scoring system for sign of pig activities along semi-random transects in wet–tropical rainforests to index the relative abundance and distribution of pigs in north Queensland. Simple assessments of the spatial extent and/or frequency of pig signs can be used to provide an index of pig abundance. Because, however, pig activities such as rooting vary with prevailing season (as do habitat preference and rates of movement), assessments should be made as far as possible under similar seasonal conditions and in similar habitats (Hone 1995). The use of pig signs will be much more accurate for monitoring changes in pig abundance at a single location than it will be for comparing pig abundance between locations.

7.3.2 Indices based on responses to management

Several aspects of normal control procedures will vary systematically with pig abundance. Free-feeding carried out before trapping or poisoning provides a useful technique for monitoring changes in pig abundance. If the quantity of bait or percentage of bait trails being consumed before and after poisoning or trapping is recorded, some idea of the effectiveness of the program can be obtained. Conducting periodic free-feeding programs over three or four days throughout the year will allow landholders to identify when pig numbers are on the increase before significant damage occurs. In using this technique, however, care must be taken to ensure that seasonal variations in bait consumption and seasonal habitat use are taken into account (Choquenot and Lukins 1996). This technique has the advantage of having pigs consuming bait when control is considered timely, accelerating the trapping or poisoning program.

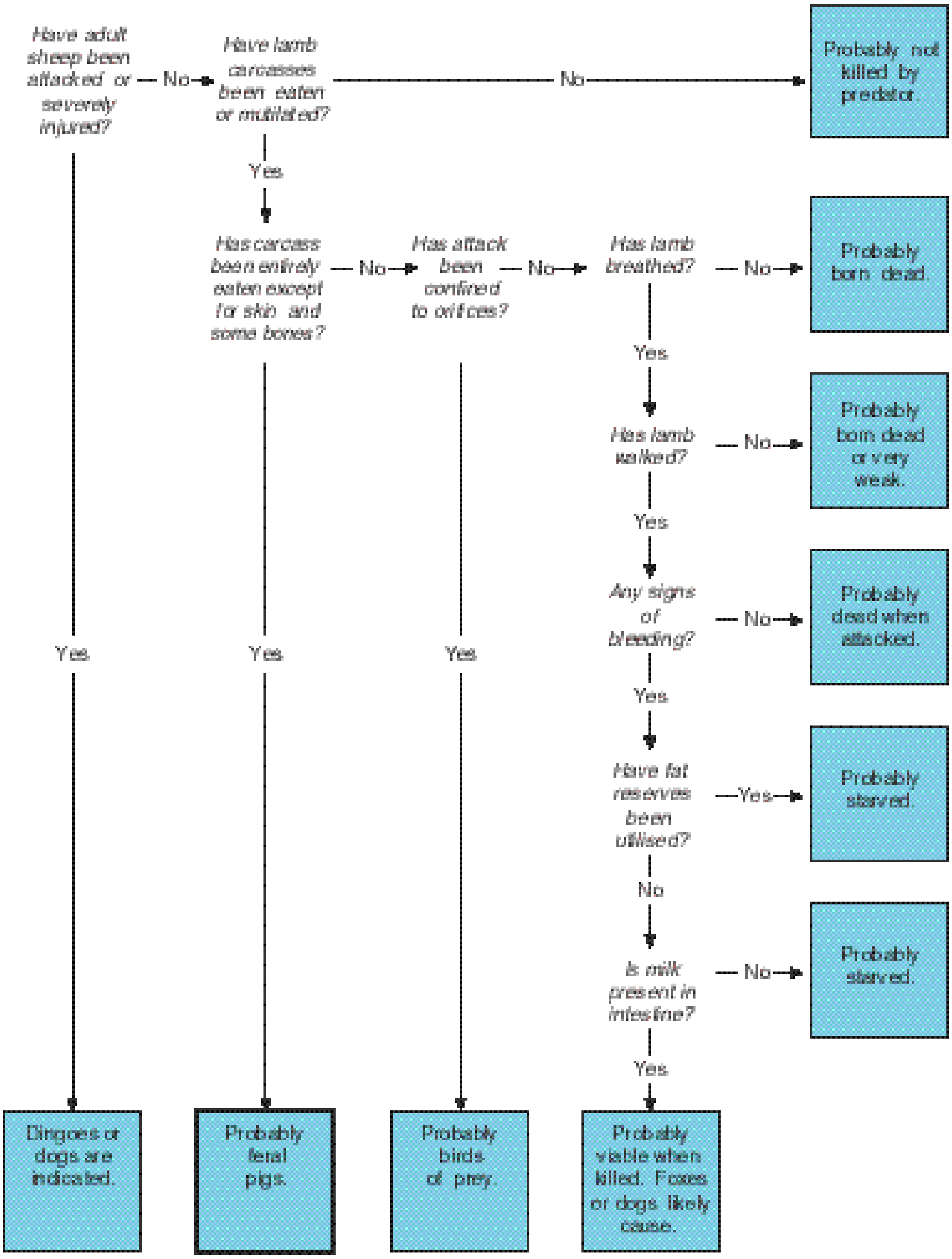
Choquenot (1993) advocates the use of kill rates during shooting from helicopters to index pig abundance. Depending on canopy cover, prevailing kill rate (measured as kills per hour over at least two hours) will start to decrease exponentially at some threshold density. A sudden decrease in kill rate usually indicates that pig density has declined below this threshold density and the cost per kill of continuing to shoot beyond this point will rise dramatically.

7.4 Estimating agricultural and environmental damage

Many factors of experimental design and sampling impinge upon processes for obtaining reliable estimates of pest impacts (Hone 1994). Although this section deals with estimating feral pig impacts, no consideration is given to these factors. Rather, processes involved in estimating the impact of feral pigs on agriculture and the environment are examined, emphasising the consequences of these processes for development of effective management strategies. Damage caused by feral pigs varies both spatially and temporally (Hone 1995), and this needs to be taken into account when estimating impact.

7.4.1 Estimating agricultural impacts

As previously outlined (Section 4.4.1), feral pigs reduce the profitability of agricultural enterprises through reduced yields and/or increased costs. With the exception of damage to fences and water sources, all the agricultural impacts of pigs are the result of their consumptive habits. Pigs eat crops, which would otherwise be harvested; grass, which would otherwise be used to grow wool or meat; and kill lambs. First it is essential to verify that the damage being considered is due to feral pigs. The decision tree in Figure 8 can be used to determine the cause of lamb death. Similar confirmations are required for crop losses, for example, checking to ensure pig signs are present at damage sites.

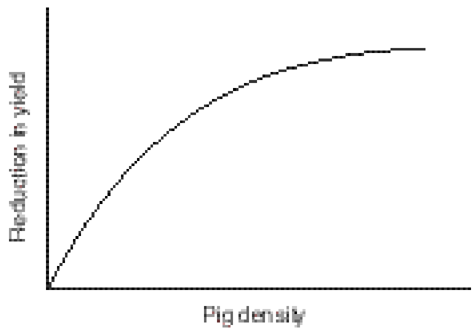


Figur e 8: Decision tree for determining the cause of lamb death (after Agriculture Protection Board 1991a).

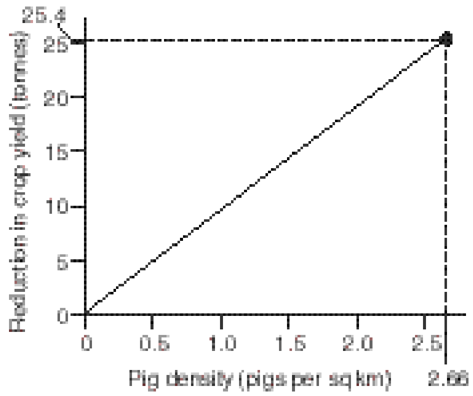
Reduction in yields of commodities due to feral pigs can be estimated on a gross or per capita basis. Gross estimates of impact are of dubious value in developing management strategies. Hence, in this section the derivation of per capita estimates of agricultural impacts is emphasised.

Any assessment of the agricultural impacts of feral pigs must be able to estimate yield in the absence of pigs either directly or indirectly through extrapolation of some density-dependent relationship. Per capita estimates of impact further require that yield in the absence of pigs can be contrasted with that when pigs are present at a range of densities so that per capita reduction in yield can be estimated for each pig density. The relationship between feral pig density and reduction in yield will generally be the same for all consumptive impacts such as lamb predation, damage to grain, sugarcane, fruit or vegetable crops (Figure 9). This relationship reflects the density-related consumptive impacts of most pest species (Southwood and Norton 1973). When the density of pigs is low, crop availability per head is high, precluding inter-pig competition for the resources on offer. While pig density is low enough to preclude competition, the crop intake rate of individual pigs will be satiated (that is, all pigs can eat all they want), and the relationship between reduction in yield and pig density will be linear. When pig density increases past the point where competition for available resources begins to occur, the crop intake rate of individual pigs will no longer be satiated and the rate at which yields are reduced with increasing pig density will slow, eventually reaching an asymptote. The rate of slowing will depend on the functional response of pigs to crop availability. The position of a crop along the line plotted in Figure 9 will depend on the abundance of the crop relative to pig density. Two case studies will illustrate these points.

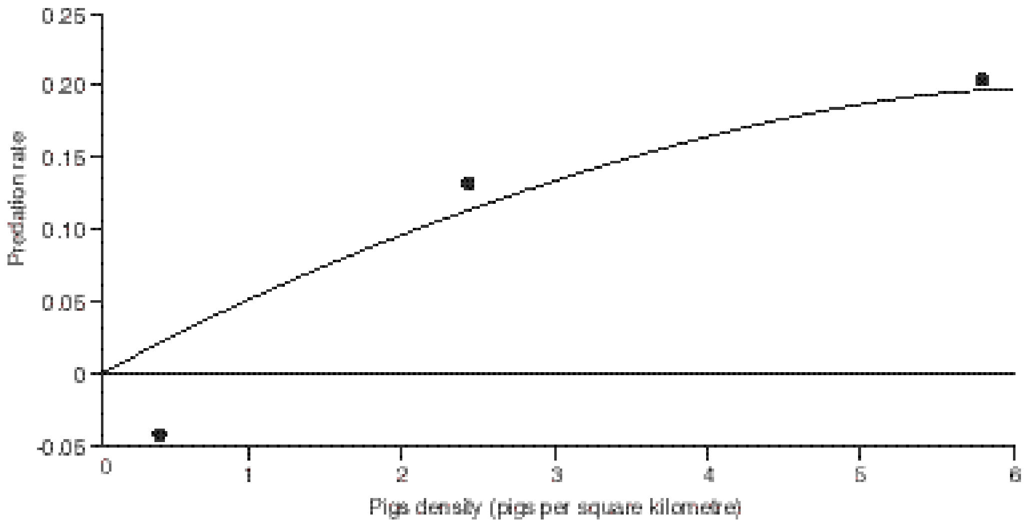
Caley (1993) obtained a per capita estimate of the impact of pigs on maize and sorghum crops in the wet–dry tropics by dividing damage due to pigs by the known number of pigs in the immediate area. This per capita estimate assumes the relationship between reduction in crop yield and pig density is linear, and the line describing density-related reduction in yield passed through its origin (Figure 10). The first assumption is likely to be valid because Caley measured per capita reduction in crop yield where crop abundance would have satiated the intake rate of all pigs present, precluding competition. At higher pig densities where the abundance of the crop would not satiate the intake rate of all pigs present, the relationship between reduction in yield and pig density would become



Figur e 9: Generalised relationship between pig density and reduction in yield.



Figur e 10: Relationship between pig density and reduction in yield implied in a study of impacts on maize and sorghum crops in the wet–dry tropics (Caley 1993).



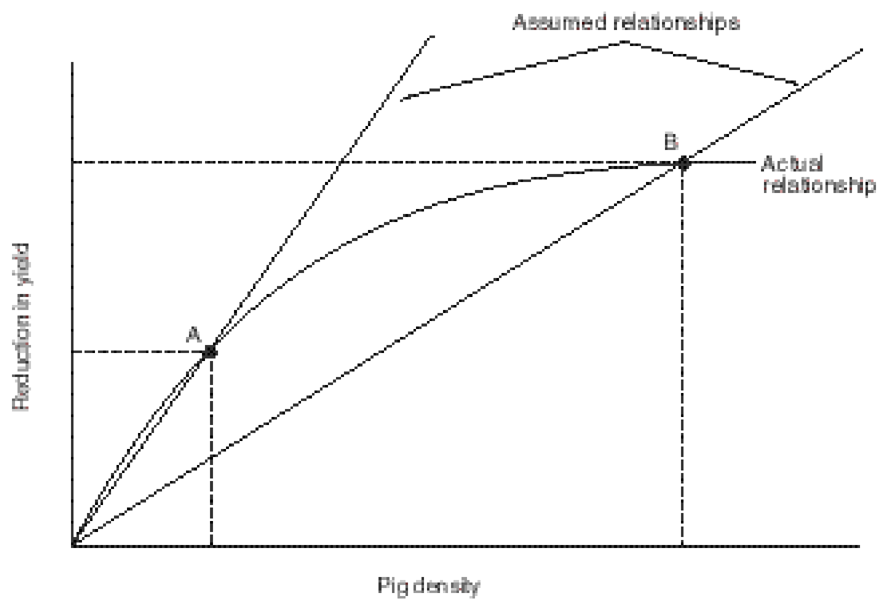
Figur e 11: Relationship between pig density and reduction in yield measured in a study of lamb predation in western New South Wales (Choquenot et al. 1996).

curvilinear. However, reduction of crop abundance to the point where competition between pigs would lead to decreased per capita rate of consumption would involve very high levels of crop damage. The second assumption made by Caley was supported by the behaviour of radio-collared pigs in the immediate area of the crops, all of which spent considerable time feeding in the crop.

If the relationship between reduction in yield and pig density over the range of densities normally affecting a particular crop can be safely assumed to be linear, and all pigs present are likely to contribute to the reduction in yield, the relatively simple technique of estimating per capita reduction in yield adopted by Caley may be appropriate. If, however, a linear relationship through its origin cannot be assumed, a more complex approach to obtaining per capita estimates of reduction in yield will be required. Choquenot et al. (1996) estimated lamb predation by free-ranging pigs at three locations, each with a different pig density. Sites were selected to encompass the normal range of pig abundance encountered in the semi-arid rangelands. At the three sites, two flocks of about 150 ultrasonically scanned ewes were placed alternately in a paddock enclosed by pig-proof electric fencing, or a paddock enclosed by conventional fencing which did not exclude pigs. The two flocks were maintained under identical conditions for the duration of lambing. At the conclusion of the experiment gross lamb production for each flock, estimated from scanning results, was contrasted with net lamb production from counts of lambs leaving each paddock. Because flocks were maintained under identical conditions at each site, differences in lamb production between protected and unprotected flocks directly measured the predation rate of lambs by pigs. Predation rate was expressed as a function of prevailing pig density, and a relationship estimated which allows the impact of pigs on lambing rates to be estimated on a per capita basis (Figure 11). A curved line was fitted to the relationship between pig density and reduction in lamb yield (predation rate) because not all newborn lambs are equally susceptible to predation. Pavlov and Hone (1982) reported that only 23.8% of observed attacks by pigs on lambs were successful.

The curvilinear relationship between reduction in yield and pig density in this study contrasts with the linear relationship inferred in Caley's (1993) study. In the study on lamb predation it was argued that pigs can only catch some of the lambs born (about 20% in this study), because many newborn lambs are sufficiently fast and fit to evade capture. At low pig densities, there are probably sufficient accessible lambs to satiate the intake of the pigs which are present and the relationship between reduction in yield and pig density will be approximately linear. At higher pig densities, however, there are likely insufficient accessible lambs to satiate the intake of all pigs present and the relationship between reduction in yield and pig density will reach a maximum level. In Choquenot et al. (1996), this maximum level occurred at around 5.5 pigs per square kilometre.

The shape of the relationship between reduction in yield and pig density is important when considering how to evaluate agricultural damage due to pigs on a per capita basis. If it can be assumed that the relationship will be linear over the range of pig densities likely to be encountered, and will pass through the origin, a single estimate of reduction in yield due to pigs in relation to the number or density of pigs present will provide sufficient information to derive the relationship. If, however, a linear relationship cannot be assumed, then reduction in yield must be estimated for at least three densities of pigs, preferably with replication, so that an adequate test of curvilinearity can be performed. If the relationship between reduction in yield and pig density is assumed to be linear when it is in fact curvilinear, predicted per capita reductions in yield at higher pig densities will be increasingly overestimated when per capita impact is measured at low pig densities, and underestimated when per capita impact is measured at high pig densities (Figure 12). If all pigs present contribute to the yield reduction, the line describing the relationship between reduction in yield and pig density passes through its origin regardless of whether the relationship is linear or curvilinear. If not all pigs contribute to reduction in yield (for



Figur e 12: Effect of assuming a linear relationship between pig density and reduction in yield when the relationship is actually curvilinear. Per capita estimates of reduction in yield will be increasingly overestimated when per capita impact is measured at low pig densities (above point A), and underestimated where per capita impact is measured at high pig densities (below point B).

Table 9: A subjective assessment[a] of the likely shape of the relationship between reduction in yield and pig density for agricultural products and resources affected by pigs.

Resource	Low density of pigs	High density of pigs
Lambs	Linear	Curvilinear
Grain crops	Linear	Linear
Sugarcane	Linear	Linear
Fruit or vegetables	Linear	Curvilinear
Livestock productivity (temperate environment)	Linear	Curvilinear
Livestock productivity (semi-arid environment)	Linear	Linear
Fences and water sources	Linear	Curvilinear

a That is, not based on measurements.

example if only some pigs kill lambs) the line describing its relationship with pig density will pass through the x-axis, the intercept of the line being negative. If pigs that do kill lambs are removed by trapping in and around lambing paddocks, the reduction in yield would reduce to zero, but there would still be pigs present. If a linear relationship forced through the origin was incorrectly fitted to the relationship between yield reduction and pig density, the line would overestimate reductions in lambing percentages associated with pig densities lower than that where per capita impact was measured and would underestimate reduction in lambing percentages associated with higher pig densities (Figure 13). It is less likely that such an error would be made when a curvilinear model is fitted because the significance of the contribution made by the intercept to explain variation in yield reduction would be tested.

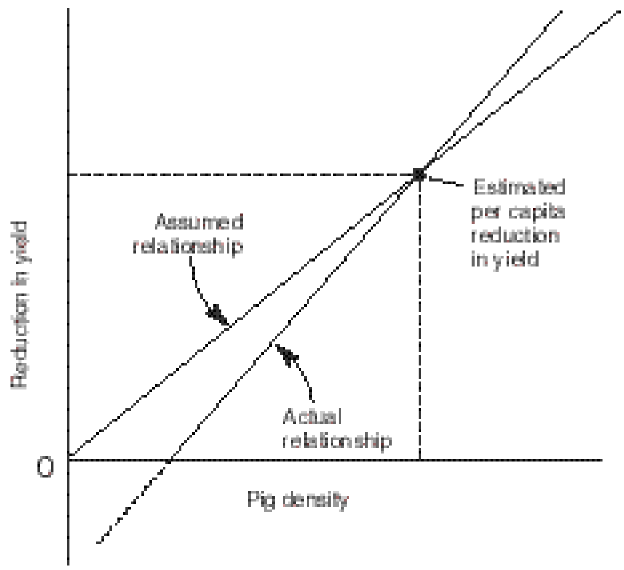


Figure 13: Effect of assuming a linear relationship between pig density and reduction in yield passes through the origin when it actually passes through the density axis (that is, the y-intercept is negative).

Table 9 gives a subjective assessment of the likely shape of the relationship between reduction in yield and pig density for some of the products and resources known to be affected by pigs.

'It may be better to predict probabilities of reductions in yield associated with pig density rather than the average reduction in yield.'

Depending on the degree of the random variation associated with specific agricultural impacts, it may be better to predict probabilities of reductions in yield associated with pig density than average reductions in yield. For example, Choquenot et al. (1996) used a measure of year-to-year variation in estimated lamb predation to construct probability distributions for predation rates expected at given pig densities (Section 4.1.1). They argued that because of the considerable stochastic variation in predation rates over and above that due to pig density, predicted probabilities provided a more useful basis for developing strategies to manage this impact than did predicted average predation rates alone. Predicted probabilities allow producers to incorporate acceptable degrees of uncertainty into development of appropriate pig management strategies. Probabilities of impact can be calculated from between-year variation in the level of impact that is not explained by obvious sources such as pig density, seasonal conditions, or recent pig control activities. The use of probability functions as a means of better managing the impact of pigs on agricultural production should be further explored.

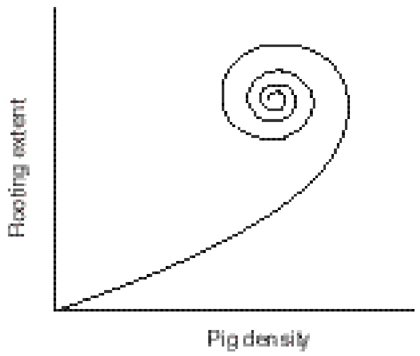
7.4.2 Estimating environmental impacts

The environmental impacts of pigs can be consumptive (that is, predation on the eggs of ground-nesting birds or turtles, or consumption of desirable plant species) or destructive (usually ground disturbance through rooting). Most destructive impacts of pigs are an indirect consequence of foraging activity, so consumptive and destructive impacts may often be closely related. As for agricultural impacts, environmental impacts can be estimated on a gross or per capita basis. Per capita estimates of environmental impacts will be of most use in developing strategies to manage these impacts.

The relationship between pig density and reduction in yield detailed for agricultural impacts in Figure 9 applies equally well to consumptive environmental impacts, except that 'reduction in yield' becomes 'degree of shift from undisturbed condition'. This generic response variable indexes the difference in the environmental characteristic affected by pigs when pigs are absent or present at a range of densities. For example, changes to plover (*Pluvialis* spp.) nesting success when pigs are absent, and present at densities of 0.5, 2.5 and 5 pigs per square kilometre will describe the per capita impact of pigs through consumption of plover eggs. This relationship will allow the increase in plover nesting success caused by given reductions in pig densities to be predicted when pig management strategies are developed. In the same way that the shape of this function depends upon the ratio of pig density to crop availability for agricultural impacts (Figure 9), the shape of the relationship between consumptive environmental impact and pig density will depend on the degree of competition for the available resource[5].

Per capita processes affecting destructive impacts of pigs are more difficult to comprehend. Impacts associated with ground disturbance through rooting may persist beyond changes in the density of pigs, complicating the nature of potential per capita relationships. This in turn

5 Extending the example above, if there were sufficient plover eggs to satiate the intake of pigs at 2.5 pigs per square kilometre but not at 5 pigs per square kilometre, the relationship between the inverse of plover nesting success and pig density would be linear up to 2.5 pigs per square kilometre but curvilinear at 5 pigs per square kilometre.



Figur e 14: Variation in pig density and the extent of new rooting activity predicted for an erupting interactive pig–vegetation system, when rooting activity is negatively correlated with vegetation abundance (after Hone 1988a).

complicates prediction of changes in impact with changes in pig density through management. For example, after a warfarin poisoning program had reduced feral pig density by 94%, Hone (1987) found a 2% reduction in the percentage of experimental plots containing rooting after one month, and a 3% reduction after two months. Longer-term evaluation demonstrated a 59% reduction in the area of ground rooted, and a 22% reduction in the number of experimental plots with rooting up to eight months following the reduction in pig density. Areas of rooting can take months or years to revegetate, particularly in cooler temperate climates. Hone (1987, 1988a) suggested that if the extent of new rooting was negatively correlated with food availability[6], the relationship between pig density and the extent of new rooting as pigs erupt into a new environment (or back into an environment where they have previously been controlled), would be the inverse of that between pig density and food supply (Figure 14). In this situation the extent of new rooting will be related to a range of pig densities, and the effect of pig control on subsequent rooting will be complex at moderate to high pig density. Hone (1987) suggested that more information on the ecological impact of rooting and factors which influence its temporal and spatial distribution is required for formulating sensible management strategies. Management based on the assumption of a simple linear relationship between pig density and the frequency and extent of new rooting is overly simplistic.

'Basing management on an assumed simple linear relationship between pig density and the amount of new rooting is too simplistic.'

Although probability of impact has never been used to develop strategies for managing the environmental impact of pigs, the approach is probably useful for many of the same reasons it is applicable to the management of agricultural impacts:

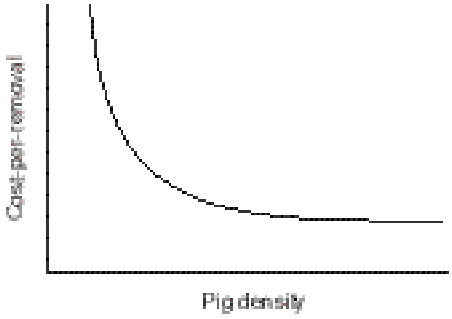
- the approach allows uncertainty to be considered when making decisions about management strategies;
- measures of risk associated with different strategies can be fully integrated into the decision process; and
- effects of environmental stochasticity on the outcomes of management can be explicitly incorporated into decisions about management strategies.

7.4.3 Estimating the cost of pig control

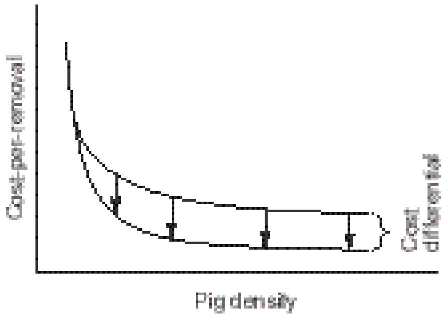
Once a target pig density for a given management program is identified, the cost of achieving it will depend on two factors: the prevailing rate of population increase which will determine the number of pigs which must be removed; and the cost of each removal, which will depend on the techniques available for the environment which the population inhabits.

Choquenot (1993) used a stochastic population model to estimate variation in the required cull of pigs to maintain levels

6 That is, when food availability is high, there is little rooting, and vice versa.



Figur e 15: Generalised relationship between pig density and cost-per-removal.



Figur e 16: Effect of density-dependent cost recovery on the relationship between pig density and cost-per-removal for a given control technique.

of control appropriate to given management strategies for a population in semi-arid western New South Wales (Section 8.8). Simpler models (based on a logistic population growth) are available to approximate variation in rates of population change if information for more complex models is unavailable (Caughley 1976).

'If pigs are sold, or if hunters pay landholders for shooting rights, the financial gains will offset the costs of pig contr ol.'

Having identified the level of control required, Choquenot (1993) used estimates of cost-per-removal depending on density for shooting from helicopters, and poisoning with 1080, to identify the most cost-effective combination of techniques, and the overall expenditure required to achieve the given level of control. Such estimates[7] predict the cost of removing a pig at a given density (Figure 15). Prediction of per capita cost is appropriate for shooting from the ground or helicopters, where variable costs dominate outlay to achieve each kill, and a decision to halt expenditure can be made at any given density. Prediction of unit reduction (pigs killed or reduction in density achieved) for outlay is more appropriate to poisoning programs where fixed costs dominate, and expenditure is made in terms of the full poisoning program. Per capita cost or unit reduction for outlay can be used for trapping programs, depending on how the program is run.

If pigs which are shot or trapped can be sold into the commercial harvesting industry, or if recreational hunters will pay to participate in control programs, the financial gains obtained can be offset against the cost of control. Because returns of this kind will probably, though not always, depend on pig density, the most accurate way of using them in estimates of control costs is to shift the appropriate cost-per-removal down the y-axis to an amount commensurate with the average return per pig received (Figure 16).

7.5 Use of impact, distribution and density measurements

7.5.1 Introduction

The management of feral pig impact can be more effective and economical if plans for the program are based not only on sociological aspects, but also on a thorough analysis of the problem as assessed by measures of feral pig impact, distribution and density. This information can be collated for interpretation in tables but it is best done on

7 That is, density-dependent cost-per-removal relationships.

maps on a whole-property, local or regional basis. This approach has two main benefits:

- it highlights patterns of distribution of damage which can reveal underlying causes, best remedies and the most economical approach to applying management programs; and
- it reveals trends in feral pig damage over time, and helps to assess the effectiveness of remedial action. Detection of time-trends requires a monitoring program that is continuous through the management program.

A major deficiency in current feral pig management is the lack of a simple, readily applied system for measuring feral pig density and abundance and for recording it in a suitable common format for use by land-managers and government agencies.

7.5.2 Recording information

After damage, distribution and abundance have been assessed, the information must be tabulated. The tabulation should be as simple as possible to allow the ready transfer of information into graphs, maps or databases that will assist interpretation. It is also a way of ensuring that all the relevant information is documented.

7.5.3 Mapping

Maps can be of various types: simple hand drawn charts, topographical maps, land system or land unit maps, aerial photographs, or sophisticated interactive computerised Geographic Information Systems (GIS). The choice depends on expertise available, resources, extent of the problem and the scale of the treatment.

Some landholders or staff of control agencies have a strong perception of feral pig density and distribution in an area and may readily map that information. Where, however, little is known about the distribution and abundance of feral pigs in an area, maps are important for determining and recording the relationships between variables associated with the distribution of food sources and features which will need to be identified in planning a feral pig management program. These will include water courses, tanks, dams, fence lines, lambing paddocks, refuge habitats for endangered species, property boundaries, natural boundaries and feeding and shelter habitat for pigs. Correlations between damage and habitat, where they can be identified, will determine where feral pig management needs to be targeted. A lambing paddock is an obvious example but conservation problems are less clear. For an endangered animal species threatened by feral pigs, the species' refuge habitat — which will need to be targeted for pig control if the species is to thrive — may not necessarily be its preferred habitat. In these situations maps can be used to identify the distribution of both the refuge and preferred habitats with efforts to remove feral pigs concentrated in both.

'Entering hot spots of pig activity into a GIS will allow correlations to be identified between these areas and vegetation types or endangered species habitats.'

Some Rural Lands Protection Boards in New South Wales are developing computer-based mapping systems which display densities derived from property inspections. These maps record changes over time, including core inputs such as the amount of poison or other control agents sold to the landholder. Global Positioning Systems (GPS) are being used to accurately locate activity areas on properties, thus allowing hot spots to be easily identified. These activity areas can be incorporated into a GIS which will allow correlations between vegetation types, endangered species habitats and feral pig distribution and abundance.

The primary benefit of mapping is that it allows a picture to be developed of manageable control areas. These areas are decided on the basis of social issues as well as distribution, abundance and impact data. Plastic overlays representing each of the components involved in the decision-making process can be used to identify the best areas for effective feral pig management.

Continuing use of the maps will show patterns over time. These patterns can be correlated to changes in resource inputs or seasonal conditions, permitting a more accurate assessment of the effectiveness of control through time.

7.5.4 Allocating management units

The information collated on maps can be used to identify practical management units. Boundaries in the management unit will be evident from natural and artificial barriers, apparent changes in the distribution of food sources, or social units within the local community. An important difficulty which must be considered is the mobility of feral pigs. This can negate efforts to control feral pig damage due to neighbouring feral pigs moving into vacated areas. This influences the size of the management unit which is in turn influenced by the time frame of the management program. For example, protecting a lambing paddock for two months will be a much smaller operation than protecting a large flora reserve to ensure the long-term survival of an endangered plant species.

Although the distribution and abundance of feral pigs in the management area may not be known, the size of management units based on known figures for density and home range for similar areas can be used as a guide. It is, however, critical that this information be used in the context of social groupings within the local rural community. Group control of feral pigs is now a well established process but its success depends on cohesiveness and a shared common vision (Chapter 9).

7.5.5 Establishing priorities

Priority for treatment of management units (control areas) will depend on several factors including:

- social groupings within the local rural community;
- type and value of resources affected by feral pigs;
- severity of damage;
- presence of, and damage due to, other pests and other threatening processes;
- feasibility of reducing damage in time to make the effort financially or biologically attractive;
- size of the management unit;
- availability of appropriate management techniques;
- availability of funds, time, labour and equipment both for immediate action and for future sustained control;
- ability to coordinate management effort; and
- ability to prevent reinvasion by feral pigs.

7.6 Control techniques

7.6.1 Shooting

Shooting has been long established as a control technique for feral pigs. Rolls (1969) reports that pigs were shot near Mudgee in 1865 and that thousands were shot in the Riverina in the 1880s.

Until about 1980, shooting was a ground-based operation undertaken by recreational hunters and landholders. Since 1980, shooting from helicopters has become an increasingly popular form of control, for reasons outlined by Korn (1986a).

7.6.2 Shooting from the ground

Recreational hunting

The feral pig is commonly taken by shooting from the ground. Tisdell (1982) estimated that amateur hunters may kill about 15–20% of the feral pig population annually (Section 4.4.1).

Landholders

Shooting from the ground by landholders is generally conducted on an opportunistic basis. Occasionally, however, coordinated

Shooting from the ground	
Advantages	**Disadvantages**
• Can remove individual pigs in a disease outbreak • Species-specific	• Rarely effective for damage control • Can disperse pigs • Costs increase greatly as pig numbers decrease • Inexperienced shooters or use of dogs by hunters may be inhumane • Requires skilled operators • Not long-lasting or effective for large-scale control

shooting drives may be conducted. Few data are available on the numbers of feral pigs taken by landholders, although Benson (1980), in a survey in north-west New South Wales, reported that landholders shot 33% more pigs than recreational hunters. In Benson's survey, shooting from the ground was the control technique which removed the greatest number of feral pigs.

Shooting from the ground is generally considered to play an insignificant role in damage control except where it is intensively conducted on small populations (Masters 1979; Allen 1984; Hone 1984). No studies have reported on intensive, strategically timed shooting programs aimed at damage control.

Shooting and dogging

The use of trained pig dogs to locate and catch feral pigs, which are then shot by the hunter, is popular with recreational hunters. Dogging can have a negative impact on sheep enterprises (Tisdell 1982) or native fauna if pig dogs become feral. McIlroy and Saillard (1989) studied the efficacy of hunting feral pigs with dogs, and concluded that hunting is generally not effective for large-scale reductions in populations, but could be useful for obtaining samples of pigs for monitoring disease during the first few days of an exotic disease outbreak, and also for killing pigs that survive other control methods. Caley (1993) reported that hunting with dogs is an effective technique for removing residual pigs after densities have been reduced by other forms of control. He reported a 90% success rate when dogs encountered solitary pigs but that the success rate rapidly declined as the group size of pigs increased. A trial of hunting in jarrah forest in south-west Western Australia showed that at least one-third of all feral pigs encountered escaped from the dog (Oliver et al. 1992). When groups of pigs were encountered, usually only one was caught. The effectiveness of hunting depends largely on the skills of the hunter and dogs. Intensive hunting with dogs might cause pigs to disperse (Saunders and Bryant 1988; Section 3.3.2) which could affect control programs, and be of particular concern in an exotic disease outbreak. The use of dogs to pursue, and hold pigs is considered inhumane by the Australian and New Zealand Federation of Animal Societies (ANZFAS) and also puts the dog at risk of injury or death (G. Oogjes, ANZFAS, Victoria, pers. comm. 1996; Section 5.2).

'Hunting will not achieve large-scale reductions in pig populations.'

7.6.3 Shooting from helicopters

Feral pig control by shooting from helicopters was first conducted in the Moree Rural Lands Protection Board district of northern New South Wales. Its popularity as a control technique spread to other parts of New South Wales and Australia during

Shooting from helicopters	
Advantages	**Disadvantages**
• Ideal for rapid population knockdown over a number of properties • Takes up little landholder time • Low costs per pig killed • Species-specific • Allows control in inaccesible terrain • Unaffected by seasonal conditions	• Can disperse animals • Costs increase greatly as pig numbers decrease • Annual shoots ineffective for keeping pig numbers low • Ineffective in woodland and forest

the early to mid-1980s. The advantages of shooting from helicopters are that it is species-specific, can yield results equal to poisoning programs, has a low opportunity cost in terms of time to the landholder because it is efficient, is more than competitive on a cost-per-pig basis with other methods of control, permits control in marshy country which is difficult to work from the ground, and is not affected by seasonal conditions (Korn 1986a).

The impacts of shooting from helicopters on feral pig populations have been well documented (Hone 1983a; Bryant et al. 1984; Korn 1986b; Saunders 1993b). Because the technique provides a quick population knockdown, it is seen as a valuable control tool in an exotic disease emergency. Bayliss (1986) and Saunders and Bryant (1988) evaluated the use of helicopters in this context whereas Hone (1990c) evaluated pig control in the Northern Territory by applying predator–prey relationship models.

Saunders (1993b) evaluated the technique in the southern Macquarie Marshes of New South Wales over two consecutive years by applying the index–removal–index method. An estimated 80% population reduction was

Shooting from helicopters allows rapid reduction of feral pig populations over a number of properties.
Source: NSWAF

Enterprise substitution	
Advantages	**Disadvantages**
• No expenditure on control programs	• Does not protect resources • May have high economic cost • Not feasible in many areas

achieved in the first year followed by a 65% reduction in the second year, after the population had recovered to 77% of its first year level during the intervening 12 months.

Although annual campaigns involving shooting from helicopters are unlikely to result in long-term reductions of pig numbers, because the populations generally recover before the next campaign, the technique is strategically useful to protect susceptible enterprises from short-term damage. It also gives feral pig control a high profile and has fostered group control of feral pigs over wide areas. This approach is perceived to be more effective than property managers controlling pigs randomly through space and time because it reduces the effects of immigration. Shooting from helicopters is not effective for reducing pigs to very low densities because costs of finding and shooting remaining pigs increase greatly as numbers decline (Figure 15).

'Shooting from helicopters can protect susceptible land from short-term damage, but annual shoots do not give long-term reductions in pig numbers.'

7.6.4 Enterprise substitution

Enterprise substitution is a control technique of last resort. It was used around the Macquarie Marshes in the 1970s when landholders were forced to run wethers instead of lambing ewes. This situation was reversed in the 1980s following an extensive coordinated control program where feral pig numbers were estimated to have been reduced to 10% of their previous levels (Korn 1993). Other landholders running lambing ewes switched to running cattle because of feral pig predation (Hone et al. 1980).

7.6.5 Habitat modification

This technique is not common (Hone et al. 1980), since it often involves destruction of thick vegetation (Hone 1984). Such a practice shows little respect for other benign species using that habitat and supports the slash, burn and destroy philosophy of previous years. It is not recommended other than in very exceptional circumstances.

The conversion from open bore drains to piped water supply from artesian bores in the rangelands might reduce pig habitat and facilitate trapping near point-source waters, especially in dry times. Replacement of open earth tanks with piped waters might further facilitate pig control.

7.6.6 Fencing

Fencing is not a popular control technique for feral pigs except to protect valuable enterprises in relatively small areas (McIlroy 1993). The insignificance of fencing as a

Habitat modification	
Advantages	**Disadvantages**
• Lack of available water reduces all pest numbers	• Often not an effective option used alone • May destroy habitat of conservation value

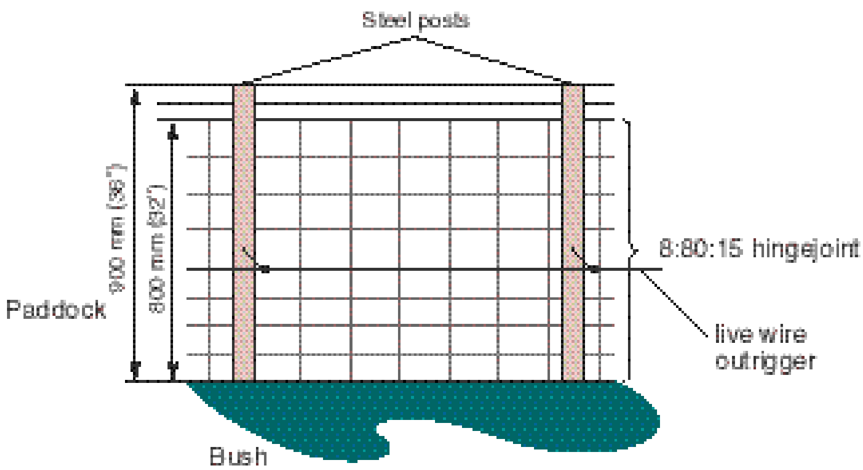
Fencing	
Advantages	**Disadvantages**
• Effective protection for lambing paddocks or small high-value resource areas • More humane than other control methods	• Can be expensive and requires high level of maintenance • Fences will eventually be breached • Not practical for large-scale control

form of control is confirmed by three studies which reported on, among other things, landholder use of control techniques (Benson 1980; Appleton 1982; Bryant et al. 1984). None of these studies, conducted in north-west New South Wales and adjoining areas in Queensland, mentioned fencing as a control technique. This is despite the fact that fencing has been shown to provide effective protection for lambing ewes in north-west New South Wales (Mitchell et al. 1977; Plant et al. 1978; Pavlov et al. 1981).

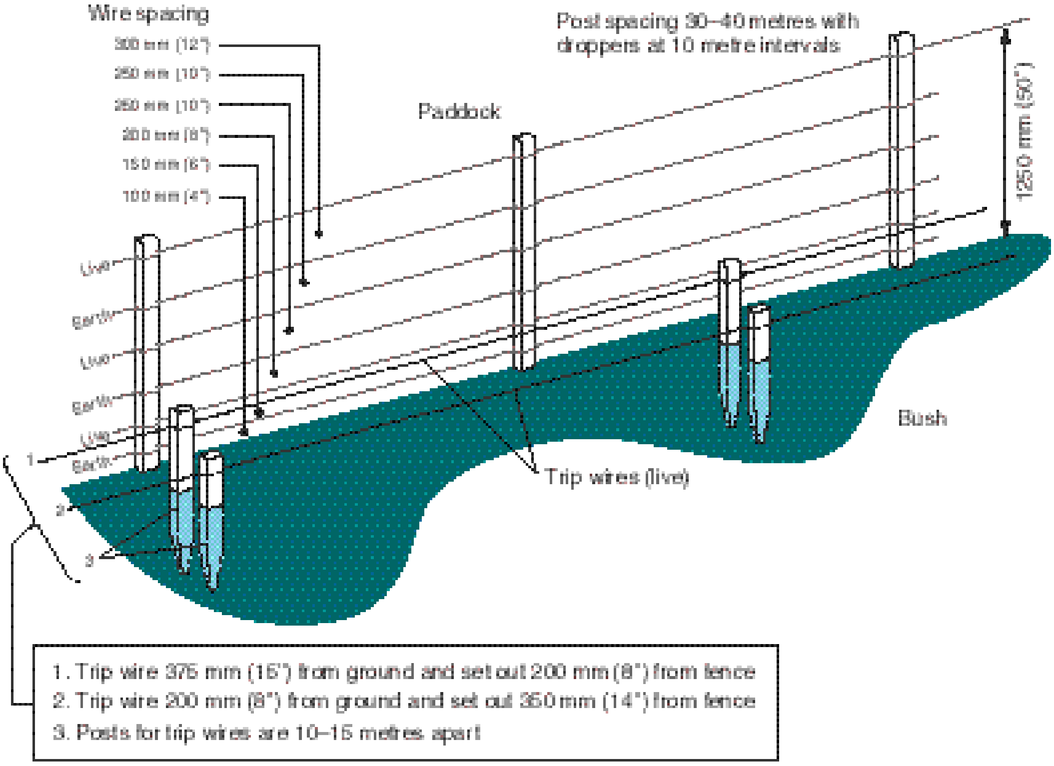
'Fencing is not a popular control technique for feral pigs except to protect valuable enterprises in small ar eas.'

Design of fences is critical for effectively restricting the movement of feral pigs. Hone and Atkinson (1983) evaluated eight fence designs, with and without electrification, under test conditions. Only one fence prevented total movement of feral pigs between paddocks under the test conditions and its design is shown in Figure 17. Electrification significantly reduced the frequency of feral pig movement through fences. Other fence designs have also been developed by New South Wales Agriculture, one of which is shown in Figure 18. No commonly used 'exclusion' fence, electrified or not, has been successful in keeping feral pigs out indefinitely. Breaches eventually result due to human error, physical damage to the fence, electrical failure or lack of maintenance.

The ineffectiveness of fences in the long-term, and thus their low adoption as a form of widespread control, revolves around their maintenance and the fact that if used alone,



Figur e 17: Pig fence constructed with 8/80/15 hingejoint and steel posts. This design totally prevented movement of pigs between paddocks under test conditions (after Hone and Atkinson 1983).



Figur e 18: A fully electrified fence with offset trip wires is considered to be highly effective against feral pigs.

they merely transfer the problem from one paddock to another or one property to another (Allen 1984; McIlroy 1993).

7.6.7 Trapping

The development of trapping as a control technique appears not to have accelerated until the mid-1970s when Giles (1973) described various trap designs and outlined several advantages of trapping over poisoning. The increasing popularity of trapping as a technique is possibly because landholders can see what they get, unlike in poisoning programs, and they can use the trapped pig as a resource if chillers are in their area.

Trapping, trap types and extent of use have been widely described over the years (Giles 1977; Benson 1980; Hone et al. 1980; Appleton 1982; Stevens 1983; Tisdell 1983/84; Allen 1984; Bryant et al. 1984; Hone 1984; Bell 1988; Lukins 1989; McIlroy 1993; P. Salleras, C4, Queensland, pers. comm. 1993). The most comprehensive description of trapping is that provided by Lukins (1989), who lists the advantages of trapping as:

- trapping does not interfere with normal pig behaviour (unlike shooting or dogging);
- the number of pigs is known exactly, and carcases can be removed safely;
- it is a flexible technique and can be fitted into routine property activities, making it economical in terms of labour, materials and number of operators; and
- traps can be moved or re-used as necessary. Good trapping makes use of opportunities as they arise.

Additional advantages are that:

Trapping is becoming an increasingly popular technique for feral pig management, particular - ly where baiting is not practical.

Source: P. Fleming, New South Wales Agriculture

- traps are humane if routinely checked; and
- dogs are not put at risk as they are with 1080 poisoning and dogging.

Landholders often permanently locate traps in areas of feral pig activity and activate the traps when pig signs become evident or on a strategic basis to protect a susceptible enterprise. Hone et al. (1980) list the following points to be considered when trapping:

- type of trap to use;
- number of traps to use;
- where to put traps;
- number of nights each trap is used;
- type and amount of bait to use; and
- amount and duration of free-feeding.

Various trap designs exist and the choice revolves around the experience, knowledge and resources available to the trapper. All traps rely on the proper functioning of the door. This is a key element. Once the trapper is confident that the door works effectively, the rest of the trap should be designed robustly to cope with the pigs likely to be caught. Trap designs are shown in Figure 19. Agriculture Protection Board (1991b) provides additional details of trap designs.

Hone (1984) lists the important steps in trapping:

- feeding sites should be placed where feral pigs are active, for example, water points and pop-holes in fences;
- initially, feed the pigs with bait such as grain (fermented is often attractive), pellets, vegetables or fruit, meat or carrion;
- build the trap where feed is being taken, and leave it open and baited, but not set, for one or two nights;
- then set the trap each night;
- if the feed is being taken, continue to trap until no more pigs are caught;
- leave the trap unset and feed a different bait from that used initially;
- if feral pigs start taking the bait, set the trap

for several nights; and

- once no bait is taken, start feeding elsewhere before moving the trap.

Lukins (1989) elaborates on each of the above points and maintains that trapping is a flexible technique that can be fitted into routine property activities. Bait preferences can vary from area to area especially for meat, carrion and grain baits. In relation to carcase disposal, Lukins states that pigs should be shot in the trap, where they may be left as bait for other pigs. In some areas, leaving pig carcases may deter other pigs from entering traps, and in this case they should be removed completely from the area.

It is time consuming and expensive to construct and maintain traps, therefore trapping is best used where poisoning is impractical or as a follow-up control measure after poisoning (Agriculture Protection Board 1991b). Results are best if alternative food is in short supply. Once a decision is made to trap, interference should be minimised, particularly shooting or disturbance by dogs.

The key point in the evaluation of trapping is whether or not feral pigs encounter the trap. Only if pigs are observed to approach a trap and then either enter or not enter, can a more informed judgement be made. Even then the judgement is open to question because the bait may not be attractive to that pig or some social pressures from other pigs either inside or outside the trap may influence behaviour.

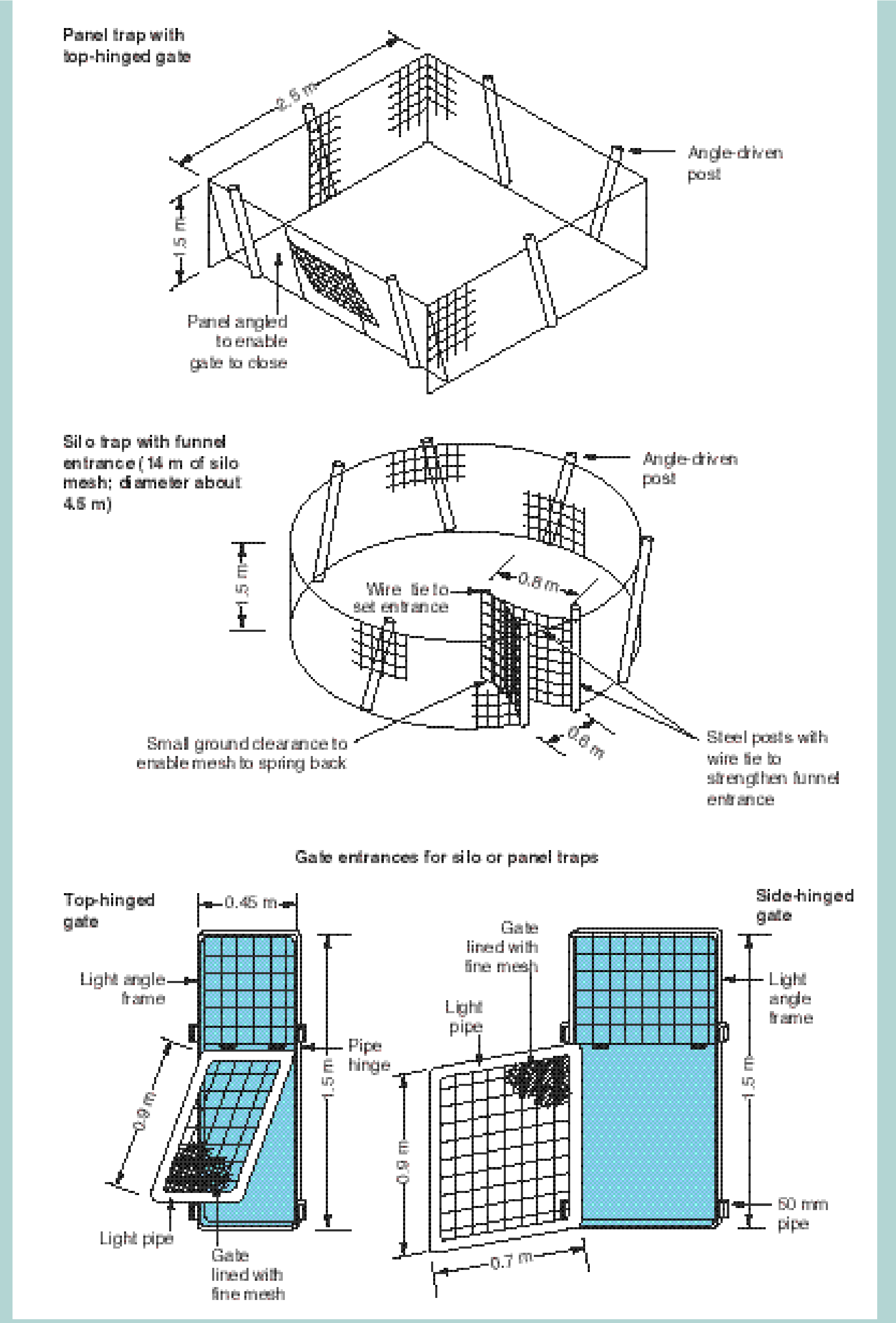
Trapping success was evaluated in the subalpine environment of Kosciusko National Park by Saunders et al. (1993). They found location of traps and season were both important: (a) placement of bait at the treeline, rather than in timber or out on clearings, gave the greatest chance of bait being found and accepted irrespective of the presence or absence of other factors; (b) the presence of recent pig activity improved the chances of bait being found and accepted particularly if bait was placed at the treeline; and (c) bait was more likely to be eaten at firetrails in autumn and away from firetrails in spring. Saunders et al. (1993) estimated that 62% of those animals exposed to traps were caught but that this only represented 28% of the entire population. If, however, Saunders et al. (1993) had kept trapping until bait take fell to zero, it may have been more effective.

Choquenot et al. (1993) tested trapping as a control technique in a central tableland environment in New South Wales. They reported a 100% population reduction over 16 nights when bait take was used as an index of feral pig abundance, and an 81% reduction when spotlight counts were used as the index.

In the wet tropics area of Queensland, particularly the World Heritage Area where choice of control techniques is more limited, many people regard trapping as the most acceptable technique (McIlroy 1993). Problems can be encountered with the endangered cassowary which sometimes enters traps and often cannot be removed without fatal injury. This aspect is being addressed through cooperative efforts of landholders and the Consultative Committee for Cassowary Conservation, now the Community for Coastal and Cassowary Conservation (C4) (P. Salleras, C4, Queensland, pers. comm. 1993), who have developed a cassowary-proof trip-door mechanism.

In a survey of 133 landholders conducted in three districts in north-west New South Wales in 1978 by Benson (1980), trapping was the least used control method (others being poisoning and shooting). Thirty-three of the landholders surveyed used 68 traps to kill 2600 pigs, an average of 38 pigs per trap for the year. This was only 5% of the total number of pigs killed by all methods in the three districts surveyed. There was a bias in the use of traps, with 20 of the 33 landholders that used traps coming from one of the three districts surveyed.

In a survey of landholders a few years later in the Waggamba Shire in southern Queensland, Appleton (1982) found that on



Figur e 19: Feral pig trap designs and specifications (after Lukins 1989).

Trapping	
Advantages	**Disadvantages**
• Can be incorporated into existing management practices • Pig numbers can be monitored • Traps can be re-used • Landholders can offset trap costs by selling trapped pigs • Does not affect normal pig behaviour • More humane than other methods	• Must be checked regularly • Labour intensive; best used as follow-up control • Not practical for large-scale control

smaller properties (less than 2100 hectares) trapping was the most popular control method. An increase in the popularity of trapping on medium-sized properties revolved around switches to cropping and increased machinery use rather than horses, and a wariness about losing farm dogs to 1080 poison. Poisoning was most popular on properties larger than 4960 hectares. No data on the number of pigs trapped were provided for the three control techniques, and it is not possible to compare the results to the New South Wales study by Saunders et al. (1993). In an earlier study at Narrabri, New South Wales, trapping was found to be the most cost-effective control technique if there were less than 30 feral pigs killed per year (Turvey 1978; Bryant et al. 1984).

7.6.8 Poisoning

Poisoning is a control technique that is widely accepted throughout rural communities. It is perceived as a method which, if properly used, can produce a quick knockdown of a feral pig population. The negative aspects of poisoning are associated with its non-specificity and welfare implications (Section 5.2).

Sodium monofluoroacetate (1080)

The first trials on toxicity of 1080 to pigs were conducted at Moree in north-west New South Wales in 1973 (J. Giles unpublished), using concentrations from 0.01%w/w to 0.05%w/w in baits. It was found that a minimum concentration of 0.025%w/w in baits was required to kill pigs, but, in view of the considerable range in intake of poison bait by different sized pigs, 0.05%w/w was preferred. This is the current recommended bait loading in New South Wales although the concentration can be reduced to 0.03%w/w at the discretion of control officers.

The toxicity of 1080 to feral pigs in Australia was first reported by McIlroy (1983), who established an LD_{50} of 1.04 milligrams per kilogram liveweight following field work north-west of Bourke in mid-summer. In a study, by Sheehan (1984) on captured feral pigs, an oral LD_{50} of 1.03 milligrams per kilogram and an LD_{90} of 11.25 milligrams per kilogram was established. O'Brien (1988) obtained a LD_{50} of 4.11 milligrams per kilogram for feral pigs kept in enclosures at Trangie. Possible reasons for the dissimilar LD_{50} values obtained are differences in the ambient temperatures occurring during the trials and different incidences of vomiting by the pigs. For example, only 20% of the pigs in McIlroy's trial vomited, versus 98% in O'Brien's trial. Differences in the length of acclimatisation by the pigs to the trial conditions and the mode of administration of the 1080 (that is, gastric intubation versus consumption in wheat bait) may also have been partly responsible, although stress alone does not appear to affect sensitivity of pigs to 1080 (McIlroy 1983). It is possible that pigs given a concentrated aqueous solution of 1080 may absorb a higher proportion of the ingested dose before vomiting than those which ingest the 1080 in bait; however, this has not been tested.

Vomiting is a common characteristic of 1080 poisoning in feral pigs. This has been observed in all captive pig trials and vomitus is commonly found around 1080 bait stations in the field. O'Brien et al. (1986) reported a mean of 21 episodes of vomiting for each captive feral pig after 2.1 milligrams of 1080 per kilogram was ingested. This high incidence of vomiting has four implications:

(1) vomitus containing 1080 may cause secondary poisoning of non-target species close to, and at a distance from, 1080 bait stations;

(2) secondary poisoning of feral pigs may enhance the effectiveness of the poisoning campaigns;

(3) vomiting may result in sub-lethal dosing of target animals, decreasing the overall mortality and effectiveness of poisoning programs; and

(4) pigs surviving a sub-lethal dose may develop an aversion to 1080 (or enhanced neophobia to baits), decreasing their susceptibility to subsequent poisoning programs (O'Brien et al. 1986).

Because of concern about these implications, the effectiveness of meto-clopramide (an anti-emetic) in preventing vomiting after ingestion of 1080 was assessed. While Rathore (1985) reported complete success with this anti-emetic, Hone and Kleba (1984) found it ineffective, as all pigs they dosed with 1080 vomited, regardless of whether they had also been dosed with the anti-emetic. O'Brien et al. (1986) tested three anti-emetics (prochlorperazine, thiethyl-perazine and metoclopramide) and found that none of them suppressed vomiting in pigs which had ingested 1080. They did find that metoclopramide decreased the amount of vomitus produced (and the proportion of 1080 ejected) and that although typical levels of 1080 in the vomitus would be hazardous to several non-target species, and peak levels hazardous to most, they were unlikely to be hazardous to other pigs.

As a follow-up to this work, O'Brien et al. (1987) examined the toxicity of 1080 to captive feral pigs when administered in different, but commonly used baits, that is, wheat grain and manufactured pellets. Under the test conditions, it was found that wheat produced a significantly higher mortality than pellets (60% compared with 28%). When, however, O'Brien and Lukins (1988) investigated the factors influencing the intake of 1080 by free-ranging feral pigs, they found that pellet bait was ingested in significantly greater quantities than cereal (wheat and barley). This would to some extent counteract the lower toxicity of 1080 loaded pellets identified in captive feral pigs.

The success of a 1080 poisoning program revolves around adequate free-feeding with non-toxic bait to attract pigs. Bryant and Hone (1984) identified problems with free-feeding by landholders during the north-west pilot feral pig control scheme, the main one being that it was often terminated before bait-take plateaued. O'Brien and Lukins (1988), however, question whether this is a problem, arguing that the plateauing could just as likely be due to increased bait consumption by the same number of pigs.

'Successful 1080 poisoning programs require adequate initial free-feeding with non-toxic bait to attract pigs.'

McIlroy et al. (1993) found that pigs in the hill country of south-east Australia readily ate fermenting wheat and pellet baits throughout the year. Trail baiting of pigs is, however, likely to be more effective during late autumn than at other times of year because more pigs are likely to be close to trails then and will more quickly find and eat greater quantities of bait.

Feral pigs are usually offered 1080 at bait stations. If properly constructed, bait stations allow cattle and sheep to be run in the same paddock at no risk. In addition, they can be made permanent structures on properties and activated when necessary. On the other hand, trail baiting can be used only in paddocks which contain no domestic stock, hence it is little used except where cropping is extensively practiced.

Hone and Pedersen (1980) reported a 58% reduction in a feral pig population baited with meat in north-west New South Wales. A later study by Hone (1983a) in south-west New South Wales reported a 73% reduction in the same population when pigs were baited with pellets laid in trails. This estimate was based on aerial surveys. Estimated reductions of 92% and 96% were made by spotlight counts and hide counts respectively. Bryant and Hone (1984) used bait-take as an index in north-west New South Wales to estimate a population reduction of 92% on grazing properties and 99.4% on farming properties.

McIlroy (1983) lists several disadvantages of 1080 as a poison for pigs:

- survival of some pigs after ingesting very high doses;
- frequent vomiting of ingested bait which produces a poisoning hazard to non-target animals, especially farm dogs;
- possible development of bait shyness;
- potential for killing non-target species through primary and secondary poisoning[8]; and
- lack of an antidote to the poison.

Yellow phosphorus (CSSP)

CSSP is a yellow phosphorus-based poison. It contains 4% active phosphorus and is manufactured and marketed in Queensland. It is a widely used poison in New South Wales and Queensland, its popularity stemming from the fact that landholders can use it as a take-home poison. That is, they can buy it in quantity, store it on their property and use it at a later date. This is more convenient than 1080 baits, which cannot be stored. The extent of CSSP use is uncertain, but a survey by Benson (1980) showed that of 63 landholders using poisons, 28 used Sayers Alport Phosphorus (SAP — the precursor to CSSP) either alone or in conjunction with other poisons.

‘Although CSSP poison kills feral pigs it is probably not humane.’

Garner (1987) and O’Brien and Lukins (1990) describe the action of yellow phosphorus poisons. Although it is effective in killing pigs, there are serious doubts about its humaneness (National Consultative Committee on Animal Welfare 1992). No studies have been conducted on its impact on non-target species although there is general concern about them because there is no control over CSSP application rates. Label directions provide crude guidance, but make no allowance for different sizes of animals on which CSSP is commonly used. Phosphorus has an LD_{50} of 5.3 milligrams per kilogram and an LD_{90} of 9.3 milligrams per kilogram and pigs typically take two to four days to die after intoxication (O’Brien and Lukins 1990).

Warfarin

Warfarin, an anticoagulant, is a poison readily accepted by feral pigs. It is very effective providing extended feeding is practiced. Hone and Kleba (1984) achieved a mortality rate of 92% when penned feral pigs were fed at 0.08%w/w for two or three days or at 0.1%w/w for two days. At these concentrations the pigs took from 5.5 to 9.5 days to die. Food intake began to drop about two days after poisoning started. Approximately three days after poisoning started, feral pigs became lame and lethargic. Hone and Mulligan (1982) report that warfarin has a latent period of 4–17 days. McIlroy et al. (1989) evaluated warfarin poisoning in Namadgi National Park in the Australian Capital Territory by trialing 0.13% w/w soaked wheat, bread and acorns for 15 days. They killed 30 of 32 radio-tracked pigs (94%), which took an average of 9.7 (range 6–15) days to die. Hone (1987) separately estimated an 87–90% reduction

8 But see McIlroy (1985, 1986) for further discussion.

Poisoning	
Advantages	**Disadvantages**
• Proven method • Widely accepted in rural community • Fast and effective initial knockdown • Relatively cheap	• Non-target risks • Animal welfare implications • Requires registration • May cause vomiting and result in bait-shy pigs or development of resistance • Usually requires prior free-feeding

in pig abundance during the same period, based on counts of dung pellets before and after the poisoning program. Hone and Stone (1989) reported a significant decline in pig abundance over 18 months at sites in the Australian Capital Territory where warfarin was used. At sites with no warfarin, there was no decline in pig abundance.

'The anticoagulant poison, warfarin, is effective for pig control if extended free-feeding is conducted first.'

Saunders et al. (1990) achieved an estimated 90% reduction in a feral pig population on the central tablelands of New South Wales. This program extended over 57 days, during which non-toxic bait was offered for the first 14 days. They found evidence of a decline of warfarin residues with time, which reduced the chance of secondary poisoning. This evidence supports the previous findings of O'Brien et al. (1987), McIlroy et al. (1989) and O'Brien and Lukins (1990). Warfarin has an LD_{50} of 2.9 milligrams per kilogram and an LD_{90} of 6.1 milligrams per kilogram when two consecutive doses, seperated by 24 hours, are administered (O'Brien and Lukins 1990).

Choquenot et al. (1990) evaluated different feeding strategies (*ad libitum* over 14 nights and intermittent distribution over 14 nights). Average reductions calculated from helicopter and spotlight counts were 63% and 35% for the *ad libitum* and intermittent strategies respectively. Although warfarin has been used experimentally for feral pig control, it would need to be registered with the National Registration Authority (for agricultural and veterinary chemicals) before it could be used routinely. There are some welfare concerns associated with the slow death caused by anticoagulant poisons. Despite interest in the use of warfarin for controlling pigs, no Australian states or territories have proceeded with further tests to determine the hazard warfarin poses to other animals. Such tests are necessary before it can be registered as a pig poison.

7.6.9 Fertility control

It is unlikely that chemical contraceptive compounds would be effective or practical for controlling populations of feral pigs for reasons discussed by Bomford (1990). The main potential problems with this approach are:

- lack of long-acting contraceptive compounds (making repeat dosing necessary);
- high costs of delivery by baits (particularly when repeat dosing is needed);
- less effect on population size than when an equivalent number of pigs are killed; and
- potential effects on non-target species.

The development of immunocontraceptive techniques to cause sterility in feral pigs, similar to that currently being researched for rabbits, foxes and rodents by the Cooperative Research Centre for

Biological Control of Vertebrate Pest Populations (Tyndale-Biscoe 1994), may be considered in the future if the current research projects are successful. It may be possible to package suitable gamete antigens, capable of inducing an immuno-contraceptive response in pigs, within biodegradable microspheres that are orally ingested in baits. This would deliver the immunocontraceptive antigen to the gut, leading to an immune response which would render the animal infertile. If used as part of an integrated feral pig management program, this technique could meet many animal welfare concerns applicable to other control techniques. Although bait-delivered immunocontra-eptives may provide only localised control, they could be useful, if used in conjunction with other traditional methods, to control small isolated populations of feral pigs. Research would also be required to determine the level of sterility that could be achieved and the consequent effect on feral pig populations. No immunocontraceptive research for feral pig control is currently being undertaken, and this type of technology has not yet been developed for the control of any pest species. The main problem with such an approach would be the high cost of delivering baits, and the consideration that poison baits may provide cheaper and more effective population reduction (Bomford 1990). The possibility exists that suitable technology may one day be developed to allow the spread of immunocontraceptives using live organisms as vectors (Section 7.6.10).

7.6.10 Biological control

Biological control of feral pigs in Australia might be achieved either by using an introduced pathogen or by live-vectored immunocontraception (Section 7.6.9).

African swine fever (ASF) and classical swine fever (CSF), for example (Section 4.3.2), are two highly contagious viral diseases for which porcines are the only natural vertebrate hosts (Geering and Forman 1987; Geering et al. 1995). Mortality rates from acute infections of both diseases, passed on by direct contact and fomites, may reach 90% or even approach 100% (Geering and Forman 1987; Hone et al. 1992). Outbreaks of CSF occurred in domestic pigs in Australia in 1903, 1927/28, 1942/43 and in both feral and domestic pigs in 1960/61 (Keast et al. 1963; Geering et al. 1995). As far as can be determined, the outbreaks were eradicated, although Littlejohns (1989) questions whether the causative virus has been eradicated. Prevalence of CSF virus strains of low virulence is increasing, particularly in countries where live vaccines are used and where infected carrier sows have become an important source of virus spread (Geering and Forman 1987). This casts doubts on the usefulness of CSF for control of feral pigs in Australia.

The possibility that the CSF virus could persist in feral pig populations above a certain size, of more than 430 pigs for example (Hone et al. 1992), may lead to concerns that the disease could spread to domestic pigs. In 1992 there were 2.9 million domestic pigs on 5835 farms in Australia (Australian Pork Corporation 1993), and

Biological and fertility control	
Advantages	**Disadvantages**
• May assist eradication of small populations • Some techniques may be humane	• Diseases may spread to domestic pigs and may have international trade implications • Expensive and may be less effective than lethal controls • No suitable technique currently exists • May not be considered humane

with production worth about $700 million annually (B. Ramsay, Pork Council of Australia, Australian Capital Territory, pers. comm. 1995), the domestic pig industry is one of Australia's most important rural industries. The presence of CSF in feral pigs could affect exports of both domestic pig meat (worth over $25 million, mainly to CSF-free countries such as Japan, New Zealand and USA) and 'Australian Wild Boar' (Section 4.4). Australia supplies 20–30% of the total international trade in wild boar meat, worth $10 million to $20 million per annum, depending upon fluctuating market prices (Ramsay 1994). Consequently, the only scenario where diseases such as CSF or ASF might be contemplated for biological control of feral pigs in Australia would be to eradicate an outbreak of a more financially disastrous disease, such as foot-and-mouth disease, which had become endemic in feral pigs in Australia.

It might be possible to genetically engineer a suitable virus specific to pigs to include genes for pig proteins capable of causing an immunological response which prevents conception or implantation. This has the potential to allow immunocontraceptives to be delivered to feral pigs at low cost, which would overcome one of the main constraints to using fertility control to control pest animals (Section 7.6.9).

7.6.11 Judas pigs

The use of radio-telemetered individuals to locate animals with which they associate has been developed as a control technique for strongly social species such as goats (Henzell 1987; Taylor and Katahira 1988; Allen 1991; Williams and Henzell 1992). The radio-telemetered 'Judas' animal joins up with, and is used to locate, groups that are difficult to find by other methods. The located animals can then be shot from helicopters, trapped or poisoned. The technique is usually used for low density populations or for survivors of other control campaigns that have become particularly wary.

Little research has been done on the use of this technique for feral pig control. Soule (1990) considered that the Judas technique would not work for feral pigs because they were less gregarious than species such as feral goats. Choquenot et al. (1993) found that the presence of oestrous sows in traps failed to attract other pigs into the traps, a finding that suggests Judas oestrous sows may also be ineffective. In contrast, Bryan (1994) and J. McIlroy (unpublished data) found the technique successful for eradicating small colonies of feral pigs. Both researchers found the technique works best with sows captured from the same area as the target animals, rather than using males or pigs from other areas as Judas animals. This is presumably because local pigs are familiar with the area and are already part of the social structure of the target population.

7.7 Cost of control

7.7.1 Introduction

Little information is available on the cost of controlling feral pigs in a typical farm enterprise, despite the fact that landholders are vitally interested in costs. The only data

Judas pigs	
Advantages	**Disadvantages**
• May make location of sparsely distributed or wary pigs easier • May assist eradication of small colonies • May help find survivors of previous control attempts	• Unknown effectiveness • Requires expensive equipment and skilled operators • Only useful for small populations

accumulated is that associated with research projects or control programs that have strong government agency involvement.

One reason for the lack of accurate costs for pig control on farms is that feral pig control is not separated from other activities. Almost invariably, activities such as checking water, fences and fence repairs, are performed concurrently and apportioning costs on a time basis is difficult. There is even little information available for on-property expenditure on traps, bait stations, and feed (poisoned and unpoisoned).

7.7.2 Shooting from helicopters

The most accurate feral pig control costs are those for shooting from helicopters. This costing is relatively easy because the cost boundaries are clear for the helicopter, ammunition and contracted shooters (if necessary). Individual landholders spend little time in arranging helicopter shoots because most of the organisation is done by a few key landholders and representatives from some government or semi-government agency (such as the Rural Lands Protection Boards in New South Wales).

The cost of controlling feral pigs by shooting from helicopters depends upon the following variables:

- type of terrain — flat, hilly, mountainous;
- vegetation cover — thick, thin, tall, short, continuous, discontinuous;
- flying conditions — windy conditions limit the manoeuvrability of the helicopter;
- type of helicopter — the cheapest may cost $200 per hour and the most expensive $650 per hour;
- pilot experience — positioning of the helicopter in relation to the target is crucial;
- shooter accuracy — a more accurate shooter will spend less time killing the same number of pigs as an inaccurate shooter; and

Table 10: Comparative costs of feral pig control methods in different habitats.

Control method	Habitat	Cost per pig ($)	Cost per hectare ($)	Source
Poisoning	Slopes, plain scrub	11.40–31.20	–	Turvey (1978)
	Wetland	6.80	1.0	R. Hosie (New South Wales Agriculture, Dubbo, pers. comm. 1986)
	Dryland	3.25	0.10	R. Hosie (New South Wales Agriculture, Dubbo, pers. comm. 1986)
	Dryland	3.35	0.30	Korn (1986a)
Trapping	Slopes, plain scrub	14.70–20.90	–	Turvey (1978)
Shooting from helicopters	Woodland	48.35	0.90	Hone (1983a)
	Wetland	9.55	–	Bryant et al. (1984)
	Wetland	5.00–15.50	0.25–0.35	Korn (1986a)
	Dryland	5.65–15.80	0.10–0.15	Korn (1986a)
	Wetland/ dryland	13.85	1.10	Saunders and Bryant (1988)
	Wetland/ woodland	7.95	0.40	Hone (1990c)

- feral pig density — at high densities the cost per feral pig is relatively low. As density drops, more time is spent searching for targets, and costs rise. However, the cost per hectare would decrease as less time is spent over each hectare.

Korn (1986a) obtained information on costs associated with shooting from helicopters from 1978 to 1986 for various parts of New South Wales and compared them to costs of other control techniques (Table 10).

Saunders (1993b) encountered difficulty when attempting to assess the cost-effectiveness of shooting from helicopters. Costs per kill varied widely each year, despite the fact that there was an obvious reduction in the catch of feral pigs each year.

Caley (1993) obtained a theoretical cost of shooting from helicopters based on reported predator–prey relationships (Hone 1990b). On this basis, Caley concluded that the benefits of shooting from helicopters exceeded the costs for protecting sorghum and maize crops in the Northern Territory from feral pig damage.

7.7.3 Trapping

Turvey (1978) found that trapping in the Narrabri district of New South Wales was the most cost-effective control if fewer than 40 feral pigs were trapped each year. Above this level, poisoning was a better option under the economic circumstances at that time.

The cost per pig caught varies widely depending upon the objective of the program. Turvey (1978) reported an on-property trapping cost of $4.90 to $6.96 per feral pig (approximately equivalent to $14.70–$20.90 when converted to 1994–95 values). On the other hand, Saunders (1988) evaluated the cost of trapping in Kosciusko National Park in south-east Australia in 1986–87 and reported it was $104 per feral pig (equivalent to $148 in 1994–95 values). Stone and Taylor (1984) are quoted as estimating a cost of $US103 per pig in Hawaii Volcanoes National Park (approximately equivalent to A$240 in 1994–95 values).

Saunders (1988) proposes a cost structure model for trapping compared with poisoning and shooting from helicopters which is shown in Table 11. It shows that trapping is consistently the most expensive control technique. Net costs, however, depend on whether pigs are sold or not. If so, trapping may be more cost-effective than Saunders (1988) proposes in his model.

7.7.4 Poisoning

Poisoning is consistently reported to be the cheapest form of control, irrespective of whether or not the toxin used is 1080, warfarin or CSSP. Korn (1986b) lists reported

Table 11: Costs for control strategies associated with varying levels of population reduction (after Saunders 1988).

Population reduction (%)	Poisoning costs ($)	Trapping costs ($)	Helicopter costs ($)
0	504	2 521	804
10	1 679	3 190	1 848
30	2 058	4 657	3 249
40	2 292	5 556	4 109
50	2 567	6 620	5 126
60	2 905	7 921	6 369
70	3 340	9 548	7 974
80	3 953	11 966	10 235
90	5 002	16 009	14 100
95	6 050	20 053	17 965
99	7 978	29 443	26 940

Table 12: Costs ($) per kilometre of fences tested, and their cost efficiencies (after Hone and Atkinson 1983).

Design number	Non-electrified		Electrified	
	Material cost ($)	Cost per kilometre per pig restrained ($)	Material cost ($)	Cost per kilometre per pig restrained ($)
1	1188	–	1378	115
2	1300	1300	1489	106
3	1104	–	1104	86
4	866	–	866	58
5	1690	242	1880	125
6	1802	201	1991	132
7	1857	310	2047	136
8	2294	143	2484	156

poisoning costs on a per pig basis (range $2.10–$10.40, or $3.30–$16.20 when converted to 1994–95 values) which demonstrates that poisoning is at the lower end of the control cost scale. Caley (1993), however, estimated that poisoning was more expensive than trapping, fencing or shooting from helicopters in his study area in the Northern Territory. This is in contrast to a study conducted in the Macquarie Marshes, in which it was estimated that 15 380 pigs were killed at a cost of 76 cents ($1.34 in 1994–95 values) per pig (Bryant et al. 1984).

7.7.5 Fencing

Little information is available on the cost of fencing as a control technique. Several different fences are available as options and the cost of each on a per kilometre basis is listed in Table 12. The cost includes labour.

Hone and Atkinson (1983) evaluated eight fence designs and reported that, of the non-electrified fences, the most effective was the most expensive. This did not apply to electric fences, where the cost per kilometre per pig restrained was directly correlated to the material cost per kilometre.

Caley (1993) reported fencing to be the control technique which gave the best benefit–cost ratio, in his study in the Northern Territory.

7.8 Monitoring

7.8.1 Introduction

A feral pig management program is not complete unless it contains a monitoring and evaluation component. The comprehensiveness of the monitoring component will depend on the objective of the program. A minimum monitoring component for an evaluation of lamb predation or crop damage would involve monitoring lamb losses or crop damage before and after control for one lambing or cropping season only. Conclusions from such a program would, however, be of dubious value given the potential confounding of environmental or other sources of variation. A more comprehensive and definitive monitoring program would involve measurements over several seasons or years, preferably in areas with different levels of pig control and replication, to reduce confounding with other causes of yield reduction. Ideally, monitoring will enable the relationship between pig density and damage to be determined (Section 7.4).

'Monitoring will allow the relationship between pig density and damage to be determined.'

7.8.2 Elements of monitoring

Monitoring the results of a management program, and comparing them to the objectives, enables managers to assess if the program is efficient and effective or whether it requires modification. Financial and physical resources may need to be adjusted according to progress made within a given timeframe. For example, if local eradication is the management objective (Section 8.4.2), it may be decided that if by a given time target population reduction goals are not met, resources may be better allocated to sustained control.

There are two components to monitoring:

- *operational monitoring* — describes the process and extent of control, for example, number of stations treated per year, the money allocated, number of pigs killed, number of pigs killed per unit effort, number of pigs remaining, or the cost per unit reduction. The aim is to improve efficiency; and
- *performance monitoring* — measures the effect of the management program on the resources to be protected. Performance criteria are needed for assessing performance. A reduction in feral pig abundance is not usually adequate as a performance indicator. What is required is a measure of the impact of pigs on the valued resource (agricultural or environmental). Consideration of sample design is needed if performance monitoring results are to be valid. The size, location, security of site tenures, number of replicates, the initial comparability of plots (including untreated plots), and how data is collected can all affect the validity of the results.

The key elements of a management monitoring program for feral pigs are outlined:

- use methods that are easy and rapid, yet reliable and repeatable. In general, a better assessment is given by many crude assessments over many sites than by a few precise assessments over relatively few sites;
- ensure that sampling is not biased;
- record information in standardised format that allows comparisons over time; and
- seek advice of experienced research professionals.

7.8.3 Monitoring techniques

Assessment of impact is more easily measured in an agricultural context than an environmental one. The monitoring technique may simply revolve around lamb marking percentages or crop yields. These two indicators are easily measured by landholders because they are collected as a normal part of management.

Monitoring abundance is more difficult and time consuming (Sections 7.2 and 7.3). Indices of abundance, rather than absolute abundance are the only practical means of measuring abundance in the field. The technique of monitoring abundance is generally confined to research use because it is, or can be, highly labour intensive.

Some techniques that can be used to monitor abundance are:

- feral pig signs — that is, sightings of pigs, number of active wallows, extent of rooting, tracks and droppings (Hone 1988b). This technique is appropriate for use by landholders who are willing to devote time to monitoring over and above normal property management;
- mark–recapture based on frequency of capture (Caley 1993);
- catch-per-unit-effort (Choquenot et al. 1993). This technique has the advantage that no pigs need to be released; and
- bait-take (Bryant and Hone 1984; Saunders et al. 1993). This technique also has some applicability to landholders who are able to give the time.

7.9 Evaluation

7.9.1 Introduction

Feral pig management programs must be evaluated against established objectives. It is preferable for these objectives to be set in terms of damage reduction rather than changes in feral pig numbers. This is because reducing pig numbers may not always lead to acceptable levels of reduction in damage caused by pigs, unless there is evidence to show that there is linear relationship between pig numbers and damage (as in Figure 10 and Figure B1, line B). Often in practice, the relationship between pig numbers and damage is curvilinear (as in Figure 9 and Figure B1, line A), so a moderate reduction in pig density may lead to little or no reduction in damage). Also, some feral pigs (called killer pigs) have been observed to kill more frequently than others (Pavlov and Hone 1982). Therefore, the elimination of a single or a few killer pigs may have the same effect as reducing a local population of feral pigs by 50% or more. Such circumstances can make the assumption of direct relationships between pig numbers and pig damage unreliable. If, however, measuring damage is difficult in practice, it may be necessary to assume that estimates of pig abundance will give an indication of likely levels of pig damage.

'Management objectives need to be set in terms of damage reduction rather than changes in feral pig numbers.'

7.9.2 Evaluating damage

Damage is generally restricted to either grazing or cropping enterprises. A feral pig management program aimed at grazing enterprises can be evaluated in several ways:

- Reduced predation levels on lambs. This involves keeping accurate records of lamb marking percentages before, during and after management programs. Other concurrent changes in management should also be noted because they may also affect lamb marking percentages. An objective for a feral pig management program may be written as follows: To increase the average lamb marking percentage in C division of Walgett Rural Lands Protection Board District to 85% by December 30, 1994, by implementing a feral pig management strategy;
- Reduced areas of pasture rooting. This is more difficult to measure accurately than lamb marking percentages. It is more subjective, being based more on perception than fact, unless accurate sampling methods with random quadrats are used (Hone 1980); and
- Another evaluation technique, popular with researchers assessing changes in feral pig numbers following the use of poison baits, revolves around measuring bait-take (Bryant and Hone 1984; Saunders et al. 1990).

For cropping enterprises, damage to crops can be accurately assessed by differences in yield between or within cropping paddocks over time. Visual assessment can also be used but is subjective and may be very misleading if done from the edge of tall cereal crops. More than 20% of a crop may be flattened, yet only be detected from the air (Wilson et al. 1987).

8. Strategic approach to management at the local and regional level

Summary

This chapter outlines the four stages of a strategic management program at the local and regional level. These are: (1) problem definition; (2) developing a management plan; (3) implementing the plan; and (4) monitoring and evaluating progress. It also addresses the need for economic frameworks for assessing the value of alternative control strategies.

***Defining the problem** is the first stage of strategic management planning. The costs and benefits of pig management for reducing their agricultural impact can both be measured in dollars. In some situations in the semi-arid rangelands, for example, sufficient information is available to estimate the point where the costs of undertaking pig management equal the benefits. Although feral pigs are known to cause significant environmental damage, their management is complicated by the need to value intangible concepts such as biodiversity.*

*The second stage in strategic management planning is the development of a **management plan**. This requires setting management objectives which should include interim and long-term goals, a time frame for achieving them and indicators for measuring performance. Developing a management plan also requires the selection of an appropriate management goal. Options for pest control include local eradication, strategic management, commercial management, crisis management or no management. Strategic management of vertebrate pests is based on the concept of adaptive management, in which the management plan is flexible, responding to changes in economic, environmental and pest circumstances. The management plan needs to integrate control techniques into a systematic program.*

*Group action is an essential element of the third stage which is **implementation**. All those in the locality or region who will benefit from feral pig control, or have a significant stake in the outcome, should be involved in the coordinated development and implementation of the management plan. This will foster a strong sense of ownership of the plan, and enhance the probability of successfully meeting goals.*

*The fourth stage is **monitoring and evaluation**. Operational monitoring ensures the management plan is executed in the most cost-effective manner. Performance monitoring assesses the effectiveness of the management plan in meeting the agricultural or conservation outcome objectives established initially. Evaluation of data from both forms of monitoring enable the continuing refinement of the management plan, where necessary.*

Hypothetical examples of the strategic management of feral pigs at the local and regional level for conservation and agricultural production scenarios are presented.

8.1 Economic frameworks

Economic frameworks are needed to assist managers in assessing the relative value of alternative control strategies and the relative benefits compared with other risks that must be managed. Such frameworks require: definition of the economic problem; data on the relative costs and benefits of different pig management strategies; an under-standing of why the actions of individual land managers may not lead to optimal levels of pig control; and assessment of the means by which governments might intervene to overcome identified market failures. Land managers can use such economic frameworks to select the most appropriate pig management strategy for their circumstances.

Land managers who wish to determine the optimal economic strategy for managing a problem caused by pigs could use the stepwise approach outlined in Appendix B. Ideally, land managers could use this approach to optimise the control effort, but often budgets are constrained by competing demands and sub-optimal amounts are available. But the process outlined in Appendix B is the most sensible way of balancing these competing demands, that is, by contrasting the marginal ratios of different approaches on a common benefit measure, for example, decreasing loss of biodiversity, or increasing farm income. In such cases, managers have to prioritise where control will be conducted. Accurate information to support many of the decisions needed for this process will almost always be absent and managers will often have to make 'best guess' estimates. However, the process will give defensible decisions especially if they are empirically tested by monitoring the outcomes. For example, sheep graziers will need to estimate the losses caused by pigs, both immediately, through predation on lambs or other livestock, and longer term, through contributing to land degradation and consequent losses in future productivity. Future losses would need to be discounted at some appropriate rate. The costs of control would also need to be assessed, examining different control strategies to see which are cheapest and most effective. Alternative options and opportunity costs would also need to be examined. For example, in some areas where feral pigs are difficult to control, and other forms of land use are not very profitable, harvesting feral pigs for sale could be an economically viable alternative to running stock.

'Economic frameworks can assist managers assess the value of alternative control strategies and their benefits relative to other risks that must also be managed.'

Before economic frameworks could be used to assist meeting conservation goals, it would be necessary to estimate the economic value the community places on the conservation of native species and communities threatened by pigs. The cost and effectiveness of implementing pig control techniques to protect conservation values would also need to be assessed so that the most cost-effective pig management strategies for meeting community conservation values could be determined. An example of market failure would be if the community placed a high value on pig control on private land to prevent land degradation, but most individual landholders considered lesser levels of pig control were adequate to meet their livestock productivity goals. An assessment of socially equitable means by which governments could intervene to meet these broader conservation benefits might then be warranted. This would only be the case, however, if scientific data verified that implementing pig control on private land would protect conservation values, and that the costs of such control would equate with the benefits.

Animal welfare organisations would also like the suffering caused by harvesting or control techniques considered as a cost to the Australian community, and taken into account in pig management decisions (G. Oogjes, ANZFAS, Victoria, pers. comm. 1994).

8.2 Strategic approach

The four steps which constitute a strategic approach to pig management are defining the problem, developing a management plan, implementing the plan, and monitoring and evaluating progress (Figure 1). The challenge for local and regional landholders and others with a major interest in feral pig management in the region is to use the information in the preceding chapters, and the processes described in this chapter, and consider how the land is being used, to develop a strategic management plan to address the damage caused by feral pigs.

This chapter explains how this might be achieved, and describes its special features for pigs in agricultural and conservation areas. The process is illustrated for a hypothetical area centred on the wet tropics World Heritage Area of northern

Queensland, including nearby agricultural lands. The process is also illustrated for a wool-growing property in the semi-arid rangelands.

8.3 Defining the problem

8.3.1 Agricultural impacts

Pigs affect agricultural enterprises by reducing profitability through decreased yield and/or increased costs (Section 4.1). Because both the costs and benefits of pig management for reducing agricultural impacts can be measured in dollars, estimating the point where the costs of feral pig management equal the benefits should, in theory, be straightforward. In reality, the only agricultural systems where enough is known about all the complex factors involved to estimate this point, are woolgrowing enterprises in the semi-arid rangelands and grain cropping enterprises in the wet–dry tropics (Section 3.8.2). These factors include: the relationship between pig density and reduction in yield; the dynamics of feral pig populations; and the effect of pig density on the cost-effectiveness of control strategies, such that greatest benefits are derived from the least costs. Until adequate information is available for other enterprises in other environments, decisions about how much to invest in pig management will be based on perceptions of the economic significance of pig damage, and the degree to which this damage is reduced by economically feasible and practicable pig control.

8.3.2 Conservation impacts

Pigs are known to disturb the ground by rooting, and are believed to reduce the abundance of native plants and animals by grazing and predation (Section 4.2). Management of the environmental impacts of pigs is complicated by the need to value concepts like biodiversity, wilderness, and ecosystem sustainability which are less tangible than reductions in yield associated with agricultural impacts. Because these concepts are difficult or impossible to value in dollars, direct cost–benefit analyses cannot be used to decide how much to spend on their management. Techniques to value degradation such as contingent action analysis or cost of restoration are available, but their usefulness is not certain (Braysher 1993).

8.4 Management plan

8.4.1 Objectives

Agriculture

Setting objectives for feral pig management for an agricultural enterprise is complex. An example might be to reduce the level of impact on crops and lambs to a level predetermined by the value of the enterprise and the cost of control. Even where sufficient information exists to conduct informed marginal analyses of different pig management options (Appendix B, Step 6; Section 8.8.3), valuing reductions in yield will not always be straightforward. For example, although the value of a lamb to a rangelands woolgrowing enterprise can be neatly summarised in an economic analysis by its replacement cost (Section 4.1.1), a grazier cannot replace the generations of selection which may have gone into production of that specific lamb, or the lost opportunity to more rapidly increase flock size when the season turns good next month. Attempting to value intangibles in the day-to-day operation of an agricultural enterprise introduces complexities which conventional economic analysis cannot encompass. In these situations it may be best to provide producers with as much information as is available and let them make an informed decision about the reduction in yield they deem acceptable. This will be a particularly valid approach where the per capita reduction in yield in any given season is relatively unpredictable. Using the relationship between pig density and per capita probability of reductions in yield allows producers to build an appreciation of uncertainty and their own attitude to risk into decisions about how much pig control to do.

Conservation

Because it is difficult to determine the environmental damage feral pigs cause, and hence to determine the environmental benefits of control, the temptation is to focus on pig abundance as the ultimate objective of management. For example, a management objective might be to reduce feral pig densities to a level where endangered flora and fauna populations increase to viable densities. Unless, however, abundance has a simple, predictable relationship to the level of pig impact (Section 7.4), its value as a management outcome is dubious.

8.4.2 Management options

For managing feral pig damage, managers have five options, as discussed by Braysher (1993). These are local eradication, strategic management (sustained, targeted or one-off), commercial management, crisis management or no management.

Local eradication

Local eradication involves the permanent removal of the entire feral pig population in a defined area, and maintaining it free of pigs. This option is often unrealistic for feral pigs except in special cases. Examples are on islands where there is no potential for recolonisation or small areas where pig-proof fences can be erected. For local eradication to be a viable option, several key conditions must be met (Bomford and O'Brien 1995). These are set out in Appendix C.

A farm manager may perceive that, although achieving local eradication is likely be extremely costly, the expense will be justified by future freedom from pig damage and from continuing costs of pig control. This strategy may be a sensible management option where:

- complete local eradication is an attainable goal (Appendix C);
- feral pigs are known to be causing high reductions in the yield of a valuable crop;
- the cost of achieving eradication is acceptable;
- discount rates applicable to expenditure on pig control are negligible (Braysher 1993); and
- there is no risk that pigs will reinvade the eradication site.

Such conditions may be difficult to meet for agricultural areas.

Strategic management

Strategic management is necessary where local eradication is not an achievable option, but where it is clear that pig damage will require continuing attention. Three options are possible: *sustained* management; *targeted* management; or *one-off* management.

Strategic, *sustained* management, in which pig numbers are reduced and maintained at a low level, is the best management option when damage can be ameliorated or eliminated by holding the density of pigs below a threshold above which the damage is known or believed to be too great for achieving the desired production or conservation outcome. In most cases, strategic sustained management involves two steps — an initial knockdown effort aimed at killing a very high proportion of the pig population, followed by periodic maintenance control to slow or prevent recovery. Reduction in densities of resource-limited populations induces an excess of births over natural deaths, and these additional pigs must be removed on some regular basis to maintain the desired density.

The target density will vary from place to place according to a large number of factors, including the density–damage relationship (Figures 9, 10, 11 and B1), region (for example, semi-arid or temperate), terrain, climate, land use, and timing of control. It is therefore a complex option, requiring managers to identify resource goals, set target pest densities (which requires some understanding of pest–resource dynamics), and kill enough pigs sufficiently often to ensure the target densities are not exceeded (which requires some understanding of pigs' population dynamics). In most areas, few of these factors are well defined, and all but the general resource protection goals will change both with time and the area of concern.

Strategic, *targeted* management, in which only certain animals or areas are controlled, is an appropriate choice when a specific pig or group of pigs are causing a problem. For example if a few 'rogue pigs' are raiding sugarcane, or if a couple of 'killer pigs' have developed the habit of killing lambs, the particular individuals involved, rather than the entire local feral pig population, will be the target of control action.

An example of strategic, *one-off* management would be building an electric fence around a melon crop to prevent pig depredations, although the fence would of course require maintenance.

Commercial management

A significant but highly variable proportion of feral pigs can be shot by hunters for sale (Sections 4.4 and 4.5). The strategic outcome of encouraging or allowing shooting depends on whether it is seen as a commercial or recreational end in itself or as a first step in the strategic management of feral pigs as pests. In the former case, it will only be economic or enjoyable to shoot populations above a certain density and pig numbers will either be held above that threshold and the natural increase harvested regularly, or as many as possible will be shot and the survivors left to breed-up until their numbers again make shooting worth the effort. Where feral pigs are shot for strictly commercial outcomes, this may help to manage their impact on environmental or economic resources. Commercial shooting can only serve this purpose, however, if it is intense or frequent enough to reduce pig densities to the level where damage is reduced. There have been no studies conducted in Australia to determine whether current levels of commercial harvesting of feral pigs are reducing agricultural and environmental damage (Section 4.5).

Crisis management

All too often managers undertake feral pig control only when populations are large enough to be causing obvious economic or environmental damage. This is called crisis management. There is no clear objective and feral pig numbers rapidly increase to pre-control levels due to immigration and natural increase, with considerable waste of resources and little lasting benefit.

No management

Land managers may perceive that pig control programs cost more than the gains in production resulting from pig control. This may apply in agricultural areas where pigs are not abundant or where they affect production only marginally or sporadically. Where this is so, spending on pig control is not warranted.

In a conservation area, this option is probably adopted where pigs are not considered to be causing significant degradation; other sources of degradation are perceived to be more important than pigs; and/or available resources limit management action to address other sources of degradation. Managers of conservation areas do, however, have a responsibility to take account of the effect of resident and dispersing pigs on neighbouring properties, when assessing the costs and benefits of pig control.

8.4.3 Choice of management goal

Integration of several feral pig control techniques is likely to improve effectiveness if the goal is to reduce pig densities to low numbers. For example, Saunders et al. (1993) found that 20% of feral pigs will not enter traps, while Hone and Pedersen (1980) report only a 58% reduction in feral pig abundance after a poisoning program. In addition, Hone (1983a) showed that a certain proportion of individuals may not eat poison bait or will eat it and not die. Saunders (1993b) found that shooting from helicopters may reduce a population by up to 80%. Thus it is probable that in a population of feral pigs a combination of techniques will be more successful than any technique used alone.

Timing is important for some techniques. Poisoning gives better results when food and water are scarce as pigs visit water points daily. In tableland areas Saunders (1988) found that spring was the best season to trap and that locating traps near tree-lines was more successful than near water. Shooting, especially from helicopters, is not affected by season.

'Integration of several control techniques is likely to improve the effectiveness of feral pig management.'

Pig management strategies should take account of costs and benefits. Regardless of the nature of the impact management seeks to mitigate, its costs can be measured in dollars, albeit with difficulty in some cases. Gains may or may not be directly comparable with costs depending on whether impacts are agricultural or environmental. Consideration of animal welfare issues should be an integral part of any feral animal management plan, including one for feral pigs (Section 5.2).

Some techniques and strategies to manage pests give better outcomes than others, for example, those techniques where a single action gives permanent benefits, and those strategies that aim to eradicate local pests. There is argument about whether a management plan should aim for some ideal outcome or something which is practicable and achievable.

Some people, for example Coman (1993), argue that for three reasons eradication as a management option should not be abandoned just because it is impractical. First, such a goal encourages people to strive for perfection. Second, it avoids changing social or economic perceptions of the goals of pest management. Third, it avoids the need to answer the difficult question of how few pests is few enough to protect some resource, which is usually ill-defined and difficult to measure.

The countervailing argument is that the ends (protecting resources) are confused with the means of achieving them (killing pests). In cases where local eradication is not possible, this can have negative results — where either the resource is still at risk from individual animals which avoid control techniques, or where the degree of damage does not warrant such extreme measures. This was shown by earlier eradication policies against New Zealand rabbits where huge sums of money were spent killing rabbits that were not affecting any resource of value (Gibb 1967). Another risk is that land managers may become disenchanted using a lot of resources and effort controlling a pest for no apparent gain, in terms of achieving the goal of eradication, and consequently give up and cease managing the target animals as pests. This can lead to poor resource protection.

Pragmatists (Caughley 1977; Parkes 1993; Bomford and O'Brien 1995) argue that in cases where local eradication is not possible (based on an honest assessment using the criteria set out in Appendix C) pest management must be driven by identified resource protection goals. The consequence of this is that the nature of the pest's impact must be determined in order to set tolerable densities of pests, however difficult this might be. Usually, an empirical solution is recommended, which is to manage for some measurable density of pests and observe what happens to the resource. Whether the response in the resource is a consequence of the pest management can be tested using large-scale management experiments (Walters and Holling 1990). Managers also need to consider economic issues when selecting the most appropriate management option (Section 8.1).

8.4.4 Performance criteria

Performance criteria need to be formulated in terms of the resource goal (such as trends in lamb production, crop damage or habitat degradation) or some rational index of these.

8.4.5 Management strategies

Flexible management

There are some new approaches to managing complex natural systems. The management of feral pigs, and other vertebrate pests, using best practice suggested in these guidelines embodies many of these new concepts. One such approach is adaptive management. As described by Walters and Holling (1990), this approach is based on the premise that knowledge of such systems is always incomplete. Not only is the science incomplete, the system itself is a dynamic one, evolving because of natural variability, the impacts of management and the progressive expansion of human activities. Hence, management actions must be ones that achieve an increasing understanding of the system as well as the environmental, social and economic goals desired. This has been called 'learning by doing'.

'Adaptive management, or "learning by doing", can achieve an increasing understanding of the system as well as the environmental, economic and social goals.'

Given the paucity of information, including scientific theory, about many of the factors that drive natural systems, Danckwerts et al. (1992) recommend that managers need to adopt a flexible management approach. That is, managers need to learn from their past successes and mistakes (and those of their neighbours), and from technical information, and be ready to change management based on experience and prevailing conditions.

A key to the success of the flexible management approach suggested by Danckwerts et al. (1992) is the monitoring of three key variables in the system: livestock productivity (biological and economic); vegetation changes; and environmental conditions that occur and the management responses to these conditions. For feral pigs, crop productivity would also require monitoring where this is a management goal. These issues are further canvassed in Section 8.6.

There are many ways of managing pigs (Section 7.6), but the challenge is to combine them in an integrated strategy to achieve the desired outcome for the resource being protected. A key factor in developing a management strategy is an assessment of the costs and benefits of the combination of options. This is more easily achieved in a production scenario, because economic costs and benefits are more readily quantifiable than in a conservation scenario.

Management strategies in agricultural settings

The option for pig management described above depends on perceptions about the value of reduction in yield caused by pigs, and the likely effect of control on the magnitude of reductions in yield. Although the 'no control' option will often be identified as appropriate by producers, a significant proportion will adhere to either sustained control or eradication. Managers who enthusiastically advocate eradication as the only sensible objective for pig management mostly represent a special case of cost-effective control. They may perceive a tangible benefit from pursuing very low densities of pigs, and emphasise the magnitude of continuing reduction when considering costs; but they are in fact controlling pigs down to the level where they believe costs equal benefits.

Similarly, producers who elect to do no pig control usually do so because definite economic benefits associated with pig control have not been demonstrated. If, however, producers adopted this management option when reductions in yield caused by pigs were economically significant, they could forego important production opportunities.

Regardless of the management option a producer adopts, the investment in pig control by agricultural producers is, to some degree at least, commensurate with the perceived economic return on that investment. Improving management decisions by agricultural producers involves identifying where these perceptions are wrong, and modifying attitudes to pig control. Improvements in pig management decisions by agricultural producers can only be made by influencing the perceptions on which their management decisions are based.

Pig management in agricultural settings can be improved by targeting points in the chain of decisions made by producers which lead to identification of a pig control strategy, and supplying information which may influence the perceptions upon which these decisions are based. For example, a rangelands sheep grazier contemplating pig control will most probably concentrate control just before lambing. When that time comes, the producer will normally consider the costs of controlling pigs and the perceived increase in lambing they might expect to get from control. Some of the factors influencing their perceptions and subsequent decisions are:

- current financial status;
- neighbours' opinions;
- expected weather until lambing;
- current and forecast commodity prices;
- short- and long-term breeding objectives;
- perception of pig abundance and probable trends; and
- attitude to risk.

Managers will then choose an amount of time and money to spend on pig control which returns to them what they consider is an acceptable risk of a maximum damage level. Having made that decision, they will select the combination of techniques they believe to be most cost-effective. Some graziers will elect to do no pig control, others will expend considerable resources. After lambing starts, graziers will not think about intensive pig control for another eight months. Several issues will impinge upon graziers' perceptions and subsequent decisions. Providing graziers with the appropriate information at the right time will help them make good decisions on pig management. Helpful information includes advice on:

- techniques to measure pig abundance;
- probable reduction in predation risk associated with given control efforts;
- best combination of techniques to use, after the producer makes an informed decision about how much time and money to invest in pig control;
- how to monitor control programs to determine accuracy of pig abundance estimates;
- how to revise pig control programs on the basis of information obtained during control; and
- how to predict changes in pig density which have occurred over the intervening year.

Extension officers can help producers develop management strategies which will return the best measurable results, by informing them about reliable information on the costs and benefits of different pig control strategies, so they do not need to rely solely on subjective perceptions. Better decisions will be made if the processes described in this chapter are used to move from management driven solely by perceptions, to management with some rational intent and measurable success. This process will work best if it is incorporated into an effective monitoring and goal setting program, and will return results more rapidly in the context of a group control scheme.

Given the inadequacy of research information on the costs and benefits of different pig management strategies at the local and regional level, computer models as described in Section 3.8.2 can be of considerable assistance (see also Sections 7.7 and 8.8).

Management strategies in conservation settings

Strategies for managing the environmental impact of pigs are driven by perceptions in much the same way as they are for agricultural impacts. As such, the management options described above could be used to help change perceptions for conservation management. For example, if pigs are perceived to affect the abundance of a local subspecies of plover in a wetland reserve in western New South Wales by predation on eggs, they will represent a potentially important management problem. If an introduced aquatic plant is affecting the integrity of the wetland reserve, this may be seen to take precedence over the perceived impacts of pigs, and most resources available for pest management will be directed toward control of the introduced plant. In this case, because of a relatively low perceived impact, limited resources would dictate a low priority for the management of pigs on the reserve. If, however, it was established that rather than just reducing plover density, pig predation had the potential to drive the population to local extinction, the perception of pigs would change, leading to more resources being allocated to the problem and, probably, a different management strategy. Now the status of plovers in relation to pig control activities would become important, and some sort of plover monitoring program would be likely to drive application of pig control.

'Conservation managers need to identify areas of high priority for feral pig management according to the value of the natural r esources being affected.'

In determining a management strategy for a conservation area, it is important to recognise that local eradication of feral pigs is likely to be technically feasible and economically practical in only a few areas (Section 8.4.2). In other areas, if feral pigs are to be managed, sustained management action for the foreseeable future is required. Due to the extensive areas involved and the limited resources available, this level of control is unlikely to be possible over the whole area where feral pigs occur. Consequently, conservation agencies need to identify those areas of high priority for management according to the relative worth of the natural resources affected by feral pigs.

The Department of Conservation in New Zealand has considered this issue in several National Pest Control Plans, including those for possums and feral goats (New Zealand Department of Conservation 1994, 1996). They have established a procedure for ranking areas according to their priority for pest management.

Initially, agencies divide conservation lands into management units (Section 7.5.4) based on geographic features such as streams, ridges or catchments, vegetation type, or limits of threatened animal or plant distribution. Large areas which are too big to manage as a whole are broken into smaller management areas for ranking. Small reserves pose a different problem, and are ranked separately, not as groups of reserves.

These management units are then ranked according to their conservation value. This is derived as a primary score, which is developed in two steps. The first scores the reserve for its plant or animal values according to the nature of threatened vegetation or wildlife. The second scores management units according to their vulnerability to feral pig or other pest damage.

The criteria for ranking plant and animal values are as follows. Management units have a high score of six for threatened plants or animals of national importance; five for those of exceptional value; four for very highly valuable; three for highly valuable; two for moderately valuable; and one for plants or animals of potential value.

The criteria for ranking management units according to their vulnerability to pest damage has been developed using a score ranging from a low of one, in which pest damage at current levels poses no immediate threat, to a high value of 3.5 where a plant or animal species within the area is at risk of national extinction because of feral pest damage.

The primary score for each management unit is then calculated by multiplying the highest plant or animal score by its vulnerability to feral pig damage. For example, a unit may have a plant score of five, and animal score of four, and a vulnerability weighting of three. The primary score then becomes five (the highest score) times three, giving 15.

Management units with equally weighted scores can be further ranked if needed by considering various land attributes (for example, ecosystem fragility, tenure, size, and cultural values) and management criteria (for example, absence of other pests, past control and accessibility). The New Zealand Department of Conservation attempted to apply these secondary considerations in some order of importance, although only as far as was needed to obtain a distinction between the competing management units. Managers of pests that affect production values might consider comparative cost–benefit analyses to prioritise otherwise equal options.

Ranking management units in this way is a complex task, but necessary to ensure best use is made of available resources. It is advisable to convene a panel of experts to assist in the task. Details of this method for calculating areas for feral goat and possum control in New Zealand were developed by Elliot and Ogle (1985), Shaw (1988) and Parkes (1990).

8.4.6 Scale of plans

Plans to manage feral pigs must be for defined areas of land and can be at any scale — national, state, territory, district, cadastral, or ecological. Because pest management is best driven by communities, small-scale plans (developed within the rules set by governments) need to be primary with state, territory and national plans being the sum of district or cadastral plans.

8.4.7 Market failure

Causes

One of the reasons past and current attempts to sustain efficient and effective feral pig control at a regional or state level have generally failed to deliver optimal outcomes is because the relationships between those who benefit from control and those who pay for it have been unclear. Solutions to such market failures depend on the nature of the failure (Bicknell 1993), and in the case of feral pigs two general causes have been identified:

- *Sharing costs of control* — A proportion of the land with feral pigs has a clear predominant use, either for conservation or for production, and the class of beneficiaries of pig control are therefore also clear — they are either all citizens paying via taxes through government conservation agencies or they are the landholder. However, most of the land with feral pigs in Australia is used for production but also can have significant conservation and environmental value. The problem here is to fairly apportion the costs of control.

  Unfair allocation of costs, for example, by government subsidies to farmers, has adverse effects because it distorts landmanagers' perceptions of all their risks and how they manage them, and it is not sustainable in the long-term if taxpayers are unwilling to meet such costs (Williams 1993). Similarly, expecting farmers to pay the costs of protecting national conservation values on their land (out of their profits) will not lead to sustainable outcomes, especially in areas where production is marginal and risky, and businesses often run at losses.

- *Unintended effects on neighbours* — The second general cause of failure is where one landowner's actions or inactions impact on another's. Such external effects of feral pig management occur when neighbours cannot agree on concerted action (an issue further compounded by the dual status of feral pigs as resources and pests).

Solutions

Solutions to these problems require transparent mechanisms to share costs at national, state and local scales. As a first step, it would be useful to know what proportion of land with feral pigs has a single class of beneficiary — particularly the proportion of land that has reserve status and is not used for grazing stock or for cropping.

On land where feral pigs affect both market and non-market values, the gains to each beneficiary needs to be considered when allocating control costs. A common solution to sharing costs is for landowners to pay for the control costs, governments to pay for extension and coordination costs, and both to share the cost of monitoring their relevant goals. In semi-arid rangelands in Australia, governments have to be careful that their share of the costs are not captured by farmers and used to maintain operations on land that should not be used for production.

The problem of ensuring concerted action is discussed in Section 8.7 and Chapter 9.

8.5 Implementation

Implementation of feral pig management is described in Chapter 9. The value of the group approach to pest management has been discussed in detail in the earlier guidelines for managing rabbits (Williams et al. 1995). The group approach requires local community support, based on an understanding of the damage feral pigs cause and how it can be addressed. The group approach fosters a strong sense of ownership of the management plan, and successful management which satisfies all relevant players.

8.6 Monitoring and evaluation

As described in Section 8.4.5, the key to the success of the flexible management approach is the monitoring of key variables. Such monitoring enables the continuing refinement of the control strategy in relation to desired reductions in resource damage. It is thus important to distinguish between efficiency (operational objectives) and effectiveness (performance objectives) as management can be efficient but ineffectual. For example, 75% of feral pigs may be killed efficiently for little cost, but this strategy would fail if the resource protection goal required at least a 90% kill. The management plan must therefore have two sorts of measurable objectives to be met on time. Operational objectives must be set to answer the question 'Was the planned management action carried out efficiently?'. Performance objectives are set to answer the question 'Did the management action achieve the resource protection goals used to justify management action?'. That is, were the performance criteria met?

8.6.1 Operational monitoring

Operational objectives are developed in the management strategy (Section 8.4.5). Thus, records need to be maintained describing what was done, how many pigs were killed, where, by whom, and at what cost. These measurements need to be taken by the people who do the control as a routine part of their task, and an operational report completed after each operation or annually for larger group operations. The report needs to describe the extent or results of control, for example, number of properties treated per year, money allocated, total number of pigs killed, number of pigs killed per unit effort, number of pigs remaining, or the cost per unit reduction. Mapping some of this information can be helpful. The aim is to improve efficiency.

8.6.2 Performance monitoring

Performance monitoring measures the effect of management on the resources to be protected, by comparing the outcome of management against the performance criteria (Section 8.4.4). Some performance measures can be taken by the landowners or pest managers, but others involve complex ecological relationships that are better measured by researchers. Performance monitoring usually requires a long-term perspective, and some experimental and scientific rigour if results are able to be interpreted (Section 7.8.2).

8.6.3 Agriculture

Good record keeping will allow changes in pig management to be related to any subsequent change in yield. Over time, this information will allow a producer to build a picture of what works, what does not, and how much of an influence pig management has on yield. In developing a feel for effective management, the producer must always focus on yield. Although pig abundance may help in selecting when and where control should be implemented, managing the impact of pigs is the object of the control exercise.

8.6.4 Conservation

Schemes to monitor the extent of degradation due to pigs will help managers understand the relationship between pig control activities and impact. These schemes may often need to focus on ultimate rather than proximate forms of degradation (for example, trends in swan abundance rather than trends in nests preyed upon). They will also provide more information if they are comparative, contrasting trends in degradation in areas where pigs are controlled with trends in areas where they are not.

8.7 Example of the strategic planning process centred on the wet tropics World Heritage Area of north Queensland

Scenario — A typical example of the problems of feral pig management in the wet tropics region of northern Queensland could occur anywhere between Townsville and Cooktown. The region covers about 125 000 square kilometres and consists of three major geomorphic areas: a belt of coastal lowlands; an intermediate Great Escarpment; and the tablelands of the Great Divide. Mean annual rainfall varies throughout the region from 1200 millimetres on the western edge to over 4000 millimetres near the coast, with rain falling mainly during December to April (the wet season). The dominant native vegetation consists of rainforest species, which occur largely as a continuous belt along the Great Escarpment, with outliers on the tablelands and coastal lowlands. Most areas of forest, which represent about 80% of the remaining rainforest in Queensland and contain many plants and animals unique to the region, are included within a World Heritage Area (WHA). Most of the adjacent lowlands are used for production of sugarcane, bananas and other tropical fruits. There are several tourist resorts along the coast only a few hours by road transport from an international airport. Feral pigs occur throughout the area but are mainly confined to the forests during the wet season and roam more widely, particularly to sugarcane crops, in their search for food during the dry season (May to November).

8.7.1. Defining the problem

Feral pigs are estimated to cause at least $0.5 million damage to sugarcane crops in the region each year as well as an unmeasured amount of damage to bananas and other crops. They are also considered to pose substantial threats to WHA values, particularly protection, conservation and rehabilitation of the environment, even though there is little objective information available on their impact. In addition, they may have an actual or potential role as hosts or vectors of several important endemic and exotic diseases and parasites of animals, including people.

The main problem with feral pig management in this region is that adjacent landholders regard the WHA as the source of the pigs affecting their crops and mostly expect the authorities responsible for the WHA to control the pigs within the WHA. This is generally not practical, given the large size (9000 square kilometres) and elongated shape of the WHA, its often rugged, steep topography, and the difficulties and constraints involved in using control techniques for pigs within the WHA, particularly during the wet season.

8.7.2 Management plan

Objectives

The objective of feral pig management in a region including both conservation and agricultural land uses should be to reduce their impacts within and outside the conservation area to acceptable levels, and to maintain this situation. This will require studies to quantify the environmental and agricultural impacts of feral pigs in the WHA and experimental reduction of pig populations, through adaptive management, to determine threshold densities for acceptable levels of impact. It will also require basic research, including modelling, on the likely outcomes of outbreaks of exotic diseases in feral pigs in the region, and greater public education over the risks of people being infected by diseases and parasites from eating or handling feral pigs.

Management units

Because of the large size of many conservation areas, the diversity of values that pigs can affect, and the likely costs of control, some form of ranking system is necessary to decide which particular areas should receive priority pig control. This system could include measures of potential or actual impact on biological, agricultural and other values, and should, at least initially, involve all major interest groups concerned. Once these areas are selected, decisions need to be made on whether local eradication or sustained control of pigs is the appropriate action (Section 8.4.3). In deciding this, the following factors need to be considered:

- level of future financial support;
- when to conduct control;
- degree of population reduction necessary to achieve program objectives; and
- best control methods and strategies.

Decision analysis models can help to determine whether different management or control techniques are economically desirable, technically possible, practically feasible, or socially and environmentally acceptable (Norton and Pech 1988). Norton and Pech also describe pay-off matrices which can be used to determine the outcomes or benefits associated with using particular control methods and strategies for different types or levels of impact by pigs (Appendix B, Step 7).

Control strategy

A combination of techniques may be necessary for effective control of feral pigs in many areas (Section 8.4.3). Poisoning, although potentially the most effective technique for the region, is generally not acceptable in the WHA and sometimes on adjoining properties, where captured or shot pigs are subsequently used for food. Poisoning could be used in certain areas (for example, margins of the WHA) if more specific poisons, baits or delivery systems (including free-feeding) were used. Trapping techniques require extensive free-feeding before traps are established, are very labour intensive and are not practical for larger, more remote areas, but are potentially effective for many small areas or local situations, particularly as part of coordinated programs between government authorities and landholders. Hunting from the ground, with or without dogs, is generally considered to be ineffective for sustained control or eradication and may affect non-target animals such as cassowaries (*Casuarius casuarius*), but is a way of life in the region that will not readily be stopped by legislation. Aerial shooting, previously untried, could be considered in specific areas, including the margins of sugarcane farms. Fencing (including electric fencing) is probably only cost-effective around small ecologically significant areas or for some instances of endangered species protection, but may be useful to direct feral pigs to areas where they can be trapped. Biological control, although feasible, is not likely to be available in the near future. Although individual techniques used alone are thus unlikely to be effective, a carefully selected combination of techniques can work.

8.7.3 Implementation

Group action

The most effective control strategy to use in a region containing both agricultural and conservation land uses is to carry out simultaneous control programs against pigs inside the margins of the conservation area and on adjacent properties (particularly sugarcane farms) during the dry season. Priority should be given to areas where pigs are having significant impacts both within and outside the conservation area, particularly for sustained control or local eradication, during the late dry season when pigs are likely to be at their lowest numbers and many pigs are searching for food outside the WHA. A coordinated approach, using funds that would otherwise be spent separately by control authorities and Cane Boards and farmers during this period could have several benefits for both the WHA and adjoining landholders. These include a closer working relationship and recognition of the 'pig problem' by all major interest groups, with use of legislation if necessary to enforce compliance by uncooperative and uninterested landholders. More coordinated control between various landholders, land management and conservation agencies, and, where practicable, commercial harvesters of feral pigs, could also minimise costs, benefit some landholders with low or negative cash flows, provide a means for disease surveillance and result in more cost-effective control compared to the current, often spasmodic ad hoc efforts.

'Control programs coordinated between landholders, land management and conservation agencies and commercial harvesters result in more cost-effective control.'

Special control programs may also have to be undertaken against pigs deeper within the WHA where they are known to be affecting WHA values. Such programs, which should be funded solely by the authorities responsible for the WHA, should be based on a priority ranking system (Section 8.4.5). Furthermore, because such programs are likely to involve sustained control, they should have guaranteed continuing financial support.

8.7.4 Monitoring and evaluation

Measurements of impact and indices of pig density before and after control programs are necessary to help determine threshold densities and evaluate whether the control programs are achieving their goals or not. If the goals are not being achieved, then improved strategies and community involvement will be necessary. Monitoring and evaluation can also indicate the best techniques to support, help promulgate research results, such as new trap designs or baits (for example, bananas) and provide more motivation and direction to control efforts. It may also indicate whether further research is required, such as on the intrinsic rate of increase of pigs after different levels of population control, including the effects of environmental factors on this rate. These include delays in the onset of the wet season or a poor fruiting year in the rainforests. Such information, along with that on the relationship between effort expended on control and the resulting densities obtained, can be used to evaluate different methods and strategies for sustained control or eradication in different areas.

8.8 Example of costs and benefits of controlling feral pigs in rangelands woolgrowing enterprises

8.8.1 Strategic planning process for a woolgrowing enterprise

Lamb predation by feral pigs is perceived to significantly affect the viability of woolgrowing enterprises in Australia generally, and in the semi-arid rangelands particularly (O'Brien 1987; Choquenot and O'Brien 1989). Where levels of predation are high, loss of lambs reduces:

- viability of self-replacing flocks;
- genetic diversity available for selection of desirable production traits; and
- cash-flow from sale of excess lambs.

Computer simulations of production systems can be used to assess and optimise pig management strategies.

8.8.2 A comparison of four simulated strategies

In the first scenario (see following box) four case studies were constructed and evaluated, representing four different strategies for feral pig management available to woolgrowers in the semi-arid rangelands.

The approach to equating costs and benefits for pig management in agricultural settings described in Scenario One emphasises the contrast between the costs of management and its benefits in terms of increased yields.

In each of the four case studies described, costs and benefits are summed for each year of simulated control and compared directly to contrast the economic efficiency of the different management strategies. Two related elaborations in the way these costs and benefits are equated and how they might influence decisions about pig control strategies are considered further in the following section: the use of marginal analysis to optimise decisions which underlie any control strategy; and identifying points where an enterprise manager can intervene with such a decision.

Scenario One

Comparison of four pig control strategies in the sheep rangelands

This scenario details four identical computer-simulated properties consisting of 45 000 hectares of which 22 000 hectares is riverine floodplain containing potentially high pig densities. The floodplains also represent the only country with enough forage during droughts (pasture biomass less than 250 kilograms per hectare) to allow lambing ewes to successfully wean their offspring. Hence, when pasture availability exceeds 300 kilograms per hectare, ewes can be lambed away from the floodplains and predation will be proportionally reduced. All lambing occurs during spring, and woolgrowers conduct pig control during winter. On each property a different pig management strategy is followed.

S1.1 Defining the problem

For the simulated enterprise, the problem is defined by a series of identical assumptions made for each property. Each property is stocked at 2.5 hectares per ewe giving a total ewe population of 18 000. Of these, 95% (17 100) lamb each year and 21% give birth to twins to give a potential lamb crop of 20 691.

S1.1.1 Economic impact

The problem for each property relates to the potential economic impact of feral pigs due to the costs of control and reduction in lamb production. Costs of control are estimated for the 220 square kilometres of pig-prone habitat according to the control techniques selected in each case study. Costs are the product of the number of pigs removed and the cost of each removal, the latter varying with pig density, and pasture availability for poisoning, and with pig density alone for shooting from helicopters.

Outcomes of control are estimated as decreased lamb predation due to the pig control strategy adopted, expressed as both a rate of, and as absolute lamb loss. Loss of lambs by factors other than pig predation is assumed to be a constant 20%. Lambs lost to pig predation affect income in two ways:

- if predation is extreme the woolgrower may have insufficient hoggets to replace cast-for-age ewes and have to purchase additional sheep; and/or
- woolgrowers will forego any income from the sale of excess lambs which pigs have killed.

Replacement costs or income foregone per lamb killed are assumed to be approximately equal in value at $20 per head. Predation rate in any given year is a random draw from a probability distribution associated with prevailing pig density. The estimated predation rate is discounted by 50% when pasture biomass is greater than 300 kilograms per hectare to account for the ability of graziers to conduct lambing away from pig-prone areas in seasons when forage is abundant.

Models of each enterprise considered in the case studies appraise costs and benefits over 100-years of simulated rainfall. For each case study, costs and benefits are averaged over five runs of the model.

S1.1.2 Measuring impact

No managers measure the economic impact of feral pigs on their property. Thus their attitude to control is driven largely by their perceptions of it. The manager on one property, Dontcare Downs, conducts no pig control in the belief that the investment affords no net economic gain. The manager on the second property, Pragmatic Park considers that pigs at moderate to high density will impose a significant economic burden on the enterprise through their effect on lamb survival. The manager of the third property, Killemall thinks that pigs at even low to moderate levels are a high economic impost. The manager of the final property Doubleup believes any losses due to pigs are unacceptable.

S1.2 Management plan

S1.2.1 Objective

The objective of all four woolgrowers is to maximise economic returns.

S1.2.2 Management options

The woolgrower on Dontcare Downs opts for the no control option. The manager of Pragmatic Park chooses cost-effective control to restrain feral pigs at moderate densities. The woolgrower on Killemall decides on cost-effective control to restrain pigs at a low density, whilst the owner of Doubleup opts to attempt local eradication.

S1.2.3 Management strategy

Pig control techniques available to all four woolgrowers are shooting from helicopters and 1080 poisoning. The manager of Dontcare Downs does not require a control strategy, having opted for no control.

After considering the available information on shooting from helicopters and poisoning, the manager on Pragmatic Park decides that shooting from helicopters once a year should hold pigs in check well enough to largely limit their impact. Because it is realised that the cost-per-removal associated with shooting from helicopters increases dramatically at lower pig densities, the manager adopts a strategy to continue shooting until kill rates drop appreciably. This means that they will stop shooting at pig densities of between four and five pigs per square kilometre. They convince some neighbours to participate in the shoots, reducing the cost of ferrying the helicopter to $500 per year. Because they cannot evaluate kill rates instantaneously, they continue to shoot for three hours after kill rates drop below a threshold of four to five pigs per square kilometre before calling a halt to the operation. Hence, in years when pig densities are already below four to five pigs per square kilometre, total expenditure on shooting from helicopters will be the cost of the ferry plus three hours of shooting.

The manager on Killemall conducts a 1080 poisoning program before lambing in winter wherever pasture availability is less than 750 kilograms per hectare. A free-feeding program is conducted, and if bait consumption exceeds 30%, the woolgrower proceeds to a three-day 1080 program. A thorough free-feeding program (consisting of two 10-kilogram bait trails per square kilometre) over the entire 220 square kilometres of pig-prone country costs $1199 per day in time and transport. The duration of the free-feeding program depends on the percentage bait-take ultimately achieved. The cost of the poisoning program is the same as for free-feeding, with the additional

Table 13: Costs and benefits derived by computer simulation for a *no pig control* strategy on a woolgrowing enterprise.

Parameter	Average	*s.d.*	*c.v.%*
Pigs per square kilometre	2.44	3.59	148.05
Cost of control ($)	Nil	–	–
Predation rate	0.047	0.052	110.82
Lambs lost	782.93	861.86	110.82
Value of lambs lost ($)	15 658	17 237	110.82

expense of enough poisoned bait to replace that consumed during free-feeding. Poisoned bait costs $3.93 for 20 kilograms including bags and warning signs.

The manager on Doubleup conducts a helicopter shoot each winter to reduce pig density to four to five per square kilometre. In years where pasture biomass is less than 750 kilograms per hectare they follow the shoot up with a free-feeding program. If more than 30% of bait is taken during the free-feed, they progress to a full 1080 poisoning program. Costs for the helicopter shoot and poisoning program are as for the other enterprises.

S1.3 Implementation

Initially, each woolgrower implements their own strategy in isolation from their neighbours, although in some cases costs are shared.

S1.4 Monitoring and evaluation

After several years, each woolgrower agrees to attempt to assess the economic impact of their strategies using the information provided. They each derive potential costs and benefits over a 100-year period of simulated rainfall. The results are summarised in Tables 13–16.

The results of the computer simulation of the costs and benefits for the no control strategy pursued on Dontcare Downs are shown in Table 13. Because no pig control was undertaken, pig numbers varied purely according to seasonal conditions. Predation rates varied according to prevailing pig density.

The results suggest that the average annual value of lambs lost to pigs is excessive, with the average maximum over the five 100-year runs of the model being $69 294. Clearly the woolgrower pursuing a no-control strategy would be losing excessive income through the effects of pig predation, and the perception that control would give no net economic gain is incorrect.

For Tables 13, 14, 15 and 16, standard deviations (*s.d.*) and coefficients of variation (*c.v.%*) measure variation between years, averaged across the five 100-year runs.

Table 14: Costs and benefits derived by computer simulation for a *sustained pig control* strategy to restrain pigs at a *moderate density* on a woolgrowing enterprise.

Parameter	Average	*s.d.*	*c.v.%*
Pigs per square kilometre	0.80	1.22	163.93
Cost of control ($)	1547	726	46.91
Predation rate	0.031	0.040	134.81
Lambs lost	509	667	134.81
Value of lambs lost ($)	10 178	13 333	134.81

Table 15: Costs and benefits derived by computer simulation for a *sustained pig control* strategy to restrain pigs at a *low density* on a woolgrowing enterprise.

Parameter	Average	s.d.	c.v.%
Pigs per square kilometre	0.18	0.66	645.65
Cost of control ($)	2572	1537	59.7
Predation rate	0.011	0.016	154.58
Lambs lost	178	260	154.58
Value of lambs lost ($)	3556	5201	154.58

The simulated costs and benefits of pursuing a strategy of sustained control to restrain pigs at a moderate density on Pragmatic Park are summarised in Table 14.

Undertaking an annual helicopter shoot substantially reduces the value of lambs lost to pigs but leaves pig densities high enough for significant predation to still occurr. Shooting from helicopters is, on average, a relatively cheap form of control, although the cost of reducing pigs to low levels in the first year of control (average across the five runs is $8429) is fairly high.

The costs and benefits of implementing a sustained control strategy to restrain pigs at low densities on Killemall are summarised in Table 15.

Poisoning is a considerably more expensive control option than is shooting from helicopters, but has a more pronounced impact on pig density and subsequent predation rates. The value of lambs lost to pig predation is considerably reduced by the ability of an intense poisoning program to decrease pig abundance to very low levels. Again, the cost of initial knock-down is very expensive (average first year costs across the five runs of the model are $17 361).

The costs and benefits derived from the computer simulation of pursuing a pig eradication strategy at Doubleup are shown in Table 16.

The most intensive pig control strategy has marginally increased costs, with no appreciable decrease in the value of lambs lost to pigs. This is because the cost of accessing additional pigs when densities have already been substantially reduced increases exponentially, whereas the benefits of doing so increase linearly. The cost of the initial population knock-down is accordingly excessive (average first year costs across the five runs of the model are $21 206).

To examine ratios of benefits to costs for the four pig control strategies, the difference between the average value of lambs lost to pigs in each strategy where some control was conducted and that where no pig control occurred was divided

Table 16: Costs and benefits derived by computer simulation for a *local pig eradication* strategy on a woolgrowing enterprise.

Parameter	Average	s.d.	c.v.%
Pigs per square kilometre	0.15	0.74	512.87
Cost of control ($)	3074	2103	68.54
Predation rate	0.010	0.020	191.07
Lambs lost	174	329	191.07
Value of lambs lost ($)	3470	6578	191.07

by the costs of each strategy. These comparisons are shown in Table 17.

The ratio of benefits to costs is positive for all forms of pig control examined. However, the ratio begins to decline when pig densities are reduced to very low levels (that is, less than 0.18 per square kilometre). The cost of removing pigs to maintain these extremely low densities increases very rapidly (Figure 15), whereas the benefits of doing so increase more slowly.

Table 17: Comparative ratio of benefits to costs of control strategies.

Strategy	Benefits – costs
Sustained control (moderate density)	3.54
Sustained control (low density)	4.71
Eradication	3.96

8.8.3 Optimising costs and benefits

Although most woolgrowers affected by feral pigs conduct some form of control, lack of reliable information on the costs and benefits of control means decisions about how much control to do are essentially ad hoc. In Scenario Two (see following box), models are used to simulate the costs and benefits of the two pig control strategies (shooting from helicopters and 1080 poisoning) aimed at restraining pig density at the moderate and low levels considered in Scenario One. The purpose is to demonstrate how such strategies can be optimised to provide the best returns to woolgrowing enterprises from investment in pig control. This optimising process emphasises where decisions are made which determine the costs and benefits associated with the control strategies, and how these decisions affect the ratio of the marginal benefits of a control program to its marginal costs. The information available to enterprise managers at the time decisions about pig control are made is also considered in terms of the ability of the manager to vary the intensity of control and/or vary the decision to proceed to the next phase of the program.

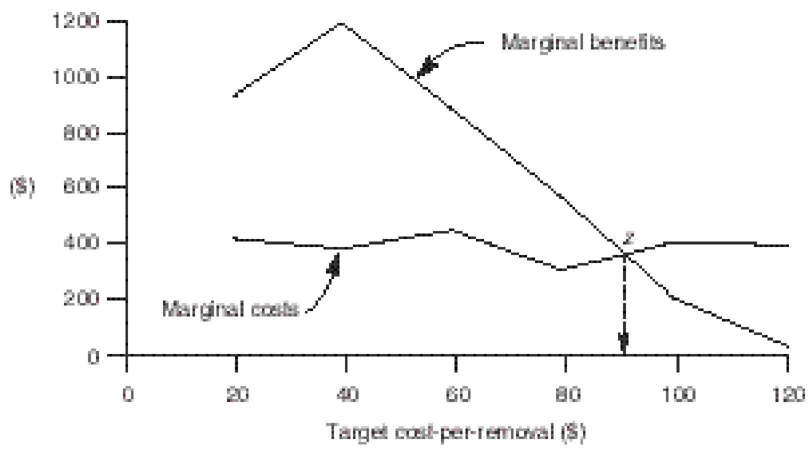
More commonly, economic inputs and outcomes for enterprises are considered in a marginal analysis context. This approach allows net benefits associated with many forms of potential investment in enterprises to be compared.

Scenario Two

Optimising benefits and costs for pig control in the sheep rangelands

S2.1 Shooting from helicopters

Points of a program for shooting feral pigs from helicopters at which an enterprise manager can intervene with a decision which determines the benefits and costs of the program are when initiation of the program is first considered (the manager can elect whether or not to undertake the program); and during the program (the manager can elect to continue or stop shooting). Assuming the manager elects to bring in a helicopter for shooting pigs annually, the only decision they must then make is when to stop shooting. Although this is often decided once a given level of expenditure is reached (for example, ‘I’ll spend $6000 on pig shooting this year’), a more rational basis for deciding when to stop the program would be to identify the point where the marginal costs of continuing to shoot equate with the marginal benefits of doing so. The only information flowing to the manager which might allow them to identify this point is the current cost of killing each pig, which



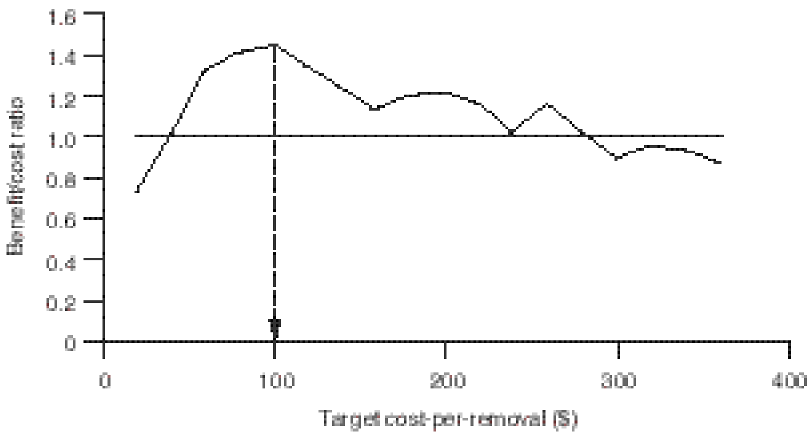
Figur e 20: Variation in marginal benefits and costs of simulated programs for shooting from helicopters as a function of the target cost-per-removal ($) at which the shooting program is halted. The point *Z* is the approximate target cost-per-removal at which marginal benefits of control equate with its marginal costs.

reflects the prevailing density of the pigs. However, because pig density determines both the rate (and value) of lamb predation and the prevailing cost per kill, it should be possible to identify the cost per kill at which a shooting program ought be halted to optimise the ratio of the marginal benefits and costs of the program.

To identify this point for the woolgrowing enterprise described in Scenario One, the average annual value of the benefits arising from pig control and the average annual costs associated with the control strategy were estimated, because the cost per kill at which the shooting program was halted was varied from $100 per kill to $360 per kill. A fixed cost of $500 to participate in the program (the cost of sharing the helicopter ferry charge across four or five enterprises) was assumed for each year. Marginal benefits and costs of the control program were contrasted as cost per kill was increased in increments of $20 per kill (Figure 20). The marginal benefit curve crosses the marginal cost curve (*Z*) at a cost per kill of about $90. This indicates that, for the enterprise modelled here, the economically optimal strategy is to continue shooting until kill rate drops such that it costs about $90 to remove each pig. At a charter cost of $300 per hour, a labour cost of $20 per hour and a fixed ammunition cost of $2 per round, this corresponds to about 3.5 pigs per hour.

The point where marginal benefits equate with marginal costs will maximise the total benefit–cost ratio (Figure 21). This means that adopting the strategy described will maximise the investment made in pig control to increase the value of the lamb crop. If a more complex strategy for shooting from helicopters[9] were adopted the economically optimum frequency or threshold pasture biomass for initiating a program could be identified in the same

9 Where shooting was not conducted each year or was only conducted following years where average pasture biomass exceeded that leading to rapid increases in pig abundance.



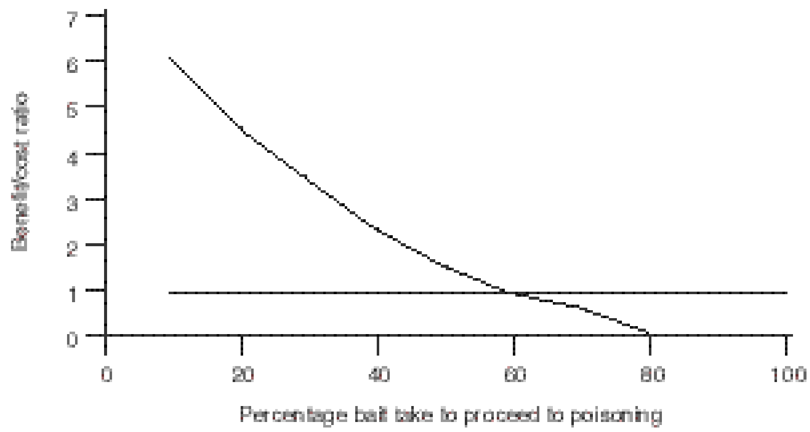
Figur e 21: The ratio of benefits and costs of a simulated program for shooting from helicopters as a function of the target cost-per-removal ($) at which the shooting program is halted. The arrow indicates the approximate target cost-per-removal which maximises the ratio.

way that the optimum cost per kill at which to halt an annual program was identified here. Because a less frequent program would conceivably result in quite different cost and benefit structures, the frequency of initiating a program and the cost per kill at which programs once initiated were halted would have to be optimised simultaneously. This would require a matrix of potential decision increments or thresholds to be constructed, and either marginal benefits and costs or total benefit–cost ratios to be estimated for each possible combination of potential decisions.

S2.2 1080 poisoning

As with shooting from helicopters, there are several points in a 1080 poisoning program where a manager may intervene with a decision about whether or not to continue the program. The first point of potential intervention occurs when deciding to initiate the program in the first instance. Managers may make this decision according to their perception of the number of pigs around, the prevailing availability of pasture over recent months and/or the interval since the last control program. Once deciding to initiate a program, a manager will commence free-feeding, at the conclusion of which they will elect whether or not to proceed to the poisoning phase of the program, usually on the basis of the amount of free-feed taken. To simplify the example here, a free-feed was conducted on the simulated enterprise in any spring where pasture biomass was less than 750 kilograms per hectare. The decision as to whether or not to proceed from free-feeding to poisoning was based on the percentage uptake of bait trails, which was determined by prevailing pig density and pasture biomass. The threshold percentage of bait trail uptake at which to proceed to poisoning was optimised by estimating average benefit–cost ratios in the same way as for the cost per kill at which to halt the program in the shooting example given above.

To cost 1080 programs in the simulation models used in this study, it was assumed that a thorough free-feeding program (consisting of two 10-kilogram bait trails per square kilometre) over the 220 square



Figur e 22: The ratio of benefits and costs of a series of simulated 1080 poisoning programs as a function of the threshold percentage of bait trails taken by pigs at which the program proceeds from free-feeding to poisoning.

kilometres of pig-prone habitat costs $1199 per day in time, material and transport. The duration of the free-feeding phase of the program depended on the percentage uptake of bait trails ultimately achieved. The cost of the poisoning phase of the program is the same as for free-feeding with the additional expense of enough poison to replace the number of trails consumed at the conclusion of free-feeding. Poisoned bait cost $3.93 for 20 kilograms including bags and warning signs.

A plot of benefit–cost ratios as a function of the threshold percentage uptake of bait trails at which to proceed to poisoning (Figure 22) is qualitatively different from that for the shooting example. In the 1080 example, the benefit–cost ratio declines steadily from low threshold bait trail uptake, suggesting that proceeding to the poisoning phase of a program (which will reduce pig density at least to some degree) makes economic sense, regardless of what percentage uptake of bait trails is achieved during the free-feeding phase. The reason for this is that the cost of 1080 poisoning programs is dominated by the cost of free-feeding, the poisoning phase involving both fewer material costs and less time. Hence, deciding not to proceed with poisoning after bearing these costs involves high outlay with no benefit. The decision which may have a more profound effect on the benefit–cost ratio would be at what frequency or at what threshold of pasture availability to initiate such a program in the first instance. Both of these decisions (the former an incremental one, the latter a threshold function) could be optimised in the same way as percentage of bait trail uptake.

Comparing the two control strategies

Using the simplistic assumptions and simulations presented in Scenario Two (see box above), shooting from helicopters achieved a maximum benefit–cost ratio of around 1.5 when shooting halted after the cost per kill exceeded $90. In contrast, an annual 1080 poisoning program returned a maximum benefit–cost ratio of around 6 when poisoning followed free-feeding regardless of bait trail uptake. Although this outcome could change substantially when more complex optimisation matrices are considered (that is, when the frequency or threshold conditions for initiation of programs are considered) it is unlikely that shooting from helicopters will approach the apparent economic returns achieved by 1080 poisoning. Although attempts were made to include realistic estimates of the direct costs of shooting from helicopters and 1080 poisoning in the model described in Scenario Two, it could be argued that poisoning involves more indirect costs. These include: the need to destock paddocks during poisoning, if trail baiting is used; the danger such programs represent to people and dogs; and the potential non-target effects of poisoning on wildlife. If reasonable estimates of the value of such detrimental aspects of 1080 poisoning were available, they could be incorporated into the benefit–cost analyses considered here.

9. Implementing a management program

Summary

Group action to develop and implement feral pig management is essential for several reasons. It gives those responsible for feral animal control, whether private or government land managers, or others with a key interest, a sense of ownership of the problem and its solution. In addition, because individual feral pigs range over areas of up to 50 square kilometres, a management program must, by definition, be at least the size of the maximum average home range for feral pigs in a particular habitat.

Coordination and partnership between groups of landowners and other major stakeholders is the key element. This encourages identification and ownership of the problem and results in group reinforcement, peer pressure, and improved communication, cooperation and efficiency. Effective goal-oriented management is the likely outcome.

Factors contributing to success of feral pig management groups include enthusiasm and commitment of land managers and adequate technical and financial resources in relation to the size of the problem. The extent to which these resources are available from the beneficiaries (generally landowners) or government is also a factor. Support may be needed to ensure concerted action, monitoring and evaluation. It can be beneficial for government agencies to supply some field support to initiate implementation processes. It is important that government support does not distort the incentives for beneficiaries to control and pay for management.

Control agency staff should act as facilitators, ensuring that local land managers have strong ownership of the program so that they manage their own problems and develop their own solutions. National and state agencies should only dictate to land manager groups on what to do if the national interest is at stake.

Improvement in current and future management is limited by the lack of knowledge and skills of front-line staff in extension theory and adult education principles. This is considered to be a serious barrier to the rapid adoption of best practice management.

9.1 The role of extension services

Implementation of the strategic approach to the management of feral pigs, and other vertebrate pests, involves land managers adopting several control technologies and processes. Traditionally, state and territory extension services have been pivotal in assisting the adoption of new technologies and processes by farmers, and they have a key role in the management of vertebrate pests (Appendix A).

The role of extension officers in vertebrate pest management is often broader than the provision of advice, in that they often act as coordinators and facilitators to groups of land managers and other stakeholders in group management schemes. The best methods for this facilitation is a matter of considerable debate, and raises some important issues.

'The role of the extension officer in vertebrate pest management is often broader than the provision of information.'

Given the pivotal role of extension officers in feral pig management, their training is important, particularly for operational staff who advise land managers and facilitate the formation of management groups. Agriculture Western Australia places a high priority on extension skills of all field staff. All Agriculture Western Australia staff with an advisory role are required to be skilled in advisory techniques, and their training includes a Technical and Further Education (TAFE) course.

In New South Wales, field staff are employed by Rural Lands Protection Boards. These staff are required to undertake a five day residential and practical course in biology, control and legal issues associated with pest animals. In addition, new staff are encouraged to spend time with experienced field operators from neighbouring districts. A three-stage legal training program is established to ensure legal evidence is correctly collected and presented in court. These programs are very practical, with one stage actually conducted in a Court House. Regional Officers from the Vertebrate Pest Control Program also conduct regional meetings, at least annually, and the staff of the Boards hold a three-day biennial conference, one day of which is devoted to training.

The level of involvement of officers of the Rural Lands Protection Boards in advisory work is described by Grant (1982); 44% of Boards from the Eastern Division, 70% of Boards from the Central Division and 56% of Boards from the Western Division reported their officers spend more than half their time in advisory roles. Despite this high input to advisory work, the field staff in New South Wales do not receive any training in extension techniques, although this is beginning to change as Rural Lands Protection Board staff are invited to participate in New South Wales Agriculture training courses. A similar situation exists in Queensland.

When evaluating the pilot scheme to manage feral pigs in north-west New South Wales, Bryant et al. (1984) stated that, if Rural Land Protection Boards are to stimulate coordinated interest in feral pig control by landholders in the future, then it is desirable that these officers be more highly trained in advisory techniques. A barrier to providing appropriate training to field staff is that most extension staff trainers within New South Wales Agriculture and their equivalents from other states do not receive formal training in advisory techniques themselves. Most are trained as technical scientists by universities that incorporate little or none of the social sciences into their programs. This is a paradox when many graduates are employed by companies or government departments to change people's behaviour.

Trainers of extension officers need knowledge of the theory and practices of extension to complement the technical expertise in biology and ecology. Extension training should focus on both individual and group skills, including conflict resolution, negotiation, and problem definition. Technical soundness is essential, but has to be complemented by skills which permit front-line extension officers to determine landholder's views quickly and negotiate around that knowledge.

9.2 Around the states

Three contiguous states and territories (New South Wales, Queensland and the Northern Territory) probably contain more than of 90% of Australia's feral pigs, and each has similar concerns about feral pig damage. Currently the Northern Territory has no coordinated program for feral pig management (D. Berman, CCNT, Northern Territory, pers. comm. 1995). Progress in the establishment of the group approach to developing and implementing feral pig management programs has varied between the states.

9.2.1 New South Wales

A significant move towards coordinated group control occurred from 1978 onwards in New South Wales with the formation of the north-west New South Wales pilot feral pig control program. The stated aim of this program was to stimulate coordinated interest in feral pig control (Benson 1980). It consisted of 13 Rural Lands Protection Boards in which 74 groups were formed. A total of 739 properties conducted 1298 poisoning operations.

The importance of group control has been stressed in extension literature in New South Wales since 1973 (Giles 1973). In 1989, New South Wales developed model feral pig control plans for Rural Lands Protection Boards to adopt.

The group approach is written into the model state control plan for Rural Lands Protection Boards (Circular No. PPB 89/53, 13 June 1989) as a strategy of the highest order.

9.2.2 Queensland

Cooperative control programs appeared in Queensland shortly after their use in New South Wales. Appleton (1982) reported that, from 1979 to 1981, 67% of producers on properties of 2100 hectares or more in Waggamba Shire tended to work together to control feral pigs. On properties less than 2100 hectares, only 37% cooperated with neighbours to control feral pigs.

The Queensland Rural Lands Protection Board published a *Feral Pig Control Handbook* in 1984 and a *Pestfact* (titled *Control of Feral Pigs*) in 1987. In neither was there any mention of coordinated group action. Thus, until recently feral pig control in Queensland was often individually focussed rather than group focussed.

There is, however, a new move towards group control through a revised policy requiring pest management plans for declared animals to be developed for each local authority area in Queensland. Plans are to be jointly developed by local authority and Department of Lands staff with appropriate input from local stakeholders. It is intended that these local authority pest management plans incorporate at least long-term and short-term objectives, priorities for action, and a proposed timeframe for achievement of these objectives. In its policy the Department of Lands has included contingency measures to manage local authorities who refuse to participate in the development or implementation of its pest management plan, or part thereof.

Management in the wet tropics area of Queensland is more complicated than in the western areas because of the restriction on controlling feral pigs in the World Heritage Area. Landholders work closely with the Consultative Committee for Cassowary Conservation, now the Community for Coastal and Cassowary Conservation (C4) and have developed cassowary-safe feral pig traps (P. Salleras, C4, Queensland, pers. comm. 1993). The Wet Tropics Management Authority has funded the construction of twelve of these traps for use by farmers.

This program provides a model which should be extended to other parts of Queensland. It demonstrates the effectiveness of a shared vision, something which Senge (1992) considers essential for achieving progress.

9.2.3 Western Australia

Western Australia, which has a relatively small population of feral pigs compared with New South Wales and Queensland, began an organised control program in 1979–80 in forested country in the south-west of the state. This program followed a study which began in 1977 (Agriculture Protection Board 1980).

9.3 Stakeholders

All those who have the potential to influence individual property management practices are stakeholders. The involvement of multiple stakeholders will be more likely to result in shared ownership of the problem and thus commitment to a successful outcome. For example, animal welfare groups should be kept informed of, and encouraged to provide solutions to, the control technology for feral pig management. Conservation groups are likely to be interested in setting the resource protection goals and determining which land is most important for immediate control action. Meat processors need to be involved in the better coordination of commercial harvesting. One means of involving interest groups is to include them on a state or regional steering committee along with landowners and government agencies that have influence on the planning at the local and regional level. This helps ensure appropriate frameworks, and local people must also be involved in all stages to ensure adoption.

9.4 Identification of goals

The key element in identifying goals for feral pig management is involvement of all the relevant stakeholders in defining the problem before the goals for action can be developed. A common understanding of the problem and the complexity of related issues in each local area is essential.

Management of feral pigs needs to be seen within the context of wider goals or visions of what individuals want to do with their land to sustain its production and/or conservation values, and how they can organise themselves to manage the threats that put these wider goals at risk. It is not appropriate in these guidelines to discuss these wider goals for each local region. That is a task for those concerned with developing a land management strategy for their area. Issues that need to be considered include the social, physical, economic and general biological limits to achieving the goals.

'A key element in identifying goals for feral pig management is involving all stakeholders in defining the problem.'

Managers of feral pigs need to understand the scope and nature of the risk posed by feral pigs, and to have relevant knowledge of the biology and behaviour of the animals. Although this may seem self-evident, individual landowners often do not see the need for action wider than their own property, or do not perceive pigs as a threat, or are unaware of the biological principles that must be applied to succeed in managing feral pigs.

The goals or visions of the general community need to be considered as these could be quite different from those of the individual land managers. The community groups with an interest in managing feral pigs are identified in Chapter 5, but the key stakeholders in this community are those owning or managing the land — either as farmers, as managers of conservation areas, or as traditional Aboriginal landowners.

9.5 Government involvement

Government agencies have a legitimate interest in feral pig management as legislators, as representatives of the wider community, and as managers of such areas as national parks.

As a legislator, it is vital that government does not distort the stakeholders' actions to manage pigs by subsidising their management of farming risks (Williams 1993). There is, however, a role for government agencies to encourage landowners to adopt good management practices by providing appropriate incentives, education and training, and research and development to support landowners wishing to manage pigs. The government might provide a program manager to coordinate and oversee the plan developed by the stakeholders. Government support for pest management groups can increase the probability of achieving successful outcomes. Studies indicate that members of Landcare groups in Australia feel a need for more expertise (Chamala and Mortiss 1990) and government-funded facilitators or extension officers can provide this.

'Governments are responsible for feral pig management as legislators, as r epresentatives of the community and as owners of national parks and other lands.'

There is a problem with this beneficiary-pays philosophy on land where the income from production is insufficient to manage the risks. One solution is to commercially harvest feral pigs, but this may be inadequate if it is not commercially profitable to reduce feral pig densities down to levels where damage reduction goals are met. Any support provided by government must be justified by the prospect of a net social benefit. Where income is insufficient to manage risks and provide a positive return on capital and labour employed, then the current land-use may not be viable from a long-term social perspective.

Government also has a role as landowner through its management of conservation areas. Management of feral pigs on state and Crown land needs to be integrated with their management on neighbouring land. That is, the state should be seen as just another landowner and act as a good neighbour.

State and national coordination should be restricted in its scope to major policy issues and funding of worthy initiatives associated with feral pig management. As an example, the Vertebrate Pests Committee (VPC) should encourage states to adopt policies of multiple use instead of policies of eradication. The VPC should also act as a formal coordination body in setting national priorities for feral pest management and lobby government to address these needs by financing initiatives which target priorities. National bodies should not tell local communities how to manage problems; rather, they should encourage and facilitate local communities to manage their own problems, use local knowledge, and develop their own solutions. The exception to this, of course, is if the national interest is at stake through the threat of exotic disease or loss of export trade income.

9.6 Partnerships are needed

The crucial step for effective management of feral pigs is to create a genuine partnership and cooperative action by land managers, government and others who will benefit from the management action or have some other stake in the outcome. The risks posed by feral pigs must to some extent be seen as a community problem to be solved by communities out of self-interest or community spirit. The problem cannot be solved by the government or the next-door neighbour. Although scientists and governments can recognise problems and develop management solutions, it is producers who need to implement these solutions. Feral pigs cross property boundaries, and landholder action, or lack of action, affects neighbours. Therefore cooperative action between groups of producers and government is needed to improve management of feral pigs.

The appropriate involvement of other interest groups should be encouraged. All individuals have a unique perspective on what is a problem and what improvements are appropriate. Incorporating these different perspectives does not create conflict; rather, conflict arises when people do not allow others to hold a different view (Pretty 1994).

'Effective management of feral pigs requires a genuine partnership and cooperative action by land managers, government and others who will benefit.'

Cooperative action between land managers is recognised as an essential strategy for effective feral pig management, and both land managers and control agencies are increasingly identifying this as a key element in reducing the impact of feral pigs. Group action to develop and implement feral pig management is essential for several reasons. Firstly, it gives a sense of ownership of the problem and its solution to those responsible for feral animal control, whether private or government land managers, and to others with a key interest. A second rationale behind this approach to feral pig management revolves around the large home range of feral pigs. Table 4 shows the home ranges of feral pigs from different studies.

Hone et al. (1980) model the effect of selecting small and large control areas. They conclude that, where feral pigs are distributed over large areas, it is essential that land managers undertake coordinated control (Figure 23). Feral pigs have large home ranges and will readily move considerable distances if continually disturbed or stressed for food and water (Sections 3.3.2 and 3.4). A management program must be at least the size of the maximum average home range for feral pigs in the particular area. These control areas may range from at least 50 square kilometres in western New South Wales, 35 square kilometres in the southern highlands of New South Wales and the Top End of the

Northern Territory, down to 11 square kilometres in the central tablelands of New South Wales.

Other advantages of coordinated group action are that it:

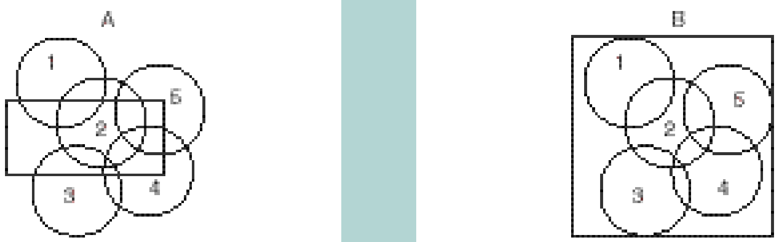
- more effectively uses physical resources such as traps, fencing material, bait layers and helicopters;
- encourages strong ownership of the problem by the group as it develops cohesiveness;
- causes conflicts to surface which can be openly discussed and resolved, thus contributing to group cohesiveness;
- promotes greater interest and awareness of the problem and its solutions within the group and local community;
- results in peer group pressure, thus further contributing to group ownership and reducing the need for regulatory action to be implemented; and
- reduces feral pig impact over a longer period because it leads to more strategic, long-term management.

In a generic sense, Argyris (1970) in Tyson (1989) describes the effective group as having three main abilities:

- to gather relevant data;
- to make sound, free and informed decisions; and
- to implement those decisions with commitment.

Successful formation and maintenance of groups are often difficult tasks requiring skills in conflict resolution, negotiation, mediation, leadership, chairperson skills, team building, planning and evaluation. Conflict resolution skills are particularly important (K. Pines, RLPB, Narrabri; E Dekkers, RLPB, Tamworth; M. Mullins, RLPB, Deniliquin; L. Thomas, RLPB, Dubbo, pers. comm. 1994) and facilitation skills of extension officers need to be sufficiently well honed to ensure that the extension officer 'takes a background role so that the group owns the problem' (M. Mullins, RLPB, Deniliquin, pers. comm. 1994). Although such skills are inherent in some people, and are learnt 'by doing' by most people, performance is often less than optimal. This is because the theory and process are not well understood. Ultimately, flexibility is paramount because each work situation is different. This results in an extension officer being required to use whatever works — because no two groups or pest animal areas are the same (K. Pines, RLPB, Narrabri, pers. comm. 1994).

Feral pig management can only be successful in the long-term if small communities have the zeal and motivation for a management program. The impetus for control should come from the community and not from the pest management authority. The authority should encourage and facilitate group formation but not impose it, otherwise local landholders will not have ownership of the problem or of the proposed solution.



Figur e 23: Selection of control area size relative to the home range of feral pigs. The home ranges are shown by circles, the control areas by rectangles. More pigs will be killed in B than in A (after Hone et al. 1980).

Cooperative action is recognised as essential in pest management for many reasons. As with many other animal pests, feral pigs can be mobile with large home ranges. Group schemes allow better management of pests that easily cross tenure boundaries by providing for broad-scale, synchronised actions to minimise reinfestation problems. Economies of scale are inherent if joint action is taken by landowners, and groups also facilitate peer pressure on those unconvinced of the need for management.

9.7 Facilitation of effective groups

The ultimate aim of implementing feral pig management is to change behaviour and facilitate adoption of sustainable land management practices. It is recognised that new approaches in extension are needed to encourage adoption, especially with the complexities of sustainable land management introduced in the 1990s (Vanclay and Lawrence 1994, Blacket et al. 1995). Involving all stakeholders in planning the program from the start is essential.

A common element in most successful vertebrate pest management has been the development of group or district community schemes (Ryan 1947; Ratcliffe 1959; Chamala and Mortiss 1990). The essential features of these schemes include common understanding of the nature and extent of the problem, and identification of clear, shared goals and objectives. Some government support can be beneficial, especially to start the schemes (Sections 9.5 and 9.6).

Group or community schemes can be developed in many ways and the value of these are the subject of some debate. Various approaches from passive participation to self-mobilisation which involve people in developing land management strategies are described by Pretty (1994). A similar continuum from top-down to bottom-up approaches is discussed by Carr (1994) and Kelly (1995). Kelly defines consultation as the periodic involvement of the community in a government-driven activity, and participation as the continuing partnership between community and government where both parties learn during the process.

9.7.1 Social principles of participation

The development of Landcare over the last decade has done much to improve knowledge of the social dimensions of land management and the role of group dynamics and communities in ensuring successful program outcomes (Campbell 1992; Alexander 1993; Carr 1994). Difficulties can arise when people who need to work together discover they have different points of view, different interests, different ideas and different approaches to solving problems and interacting in social settings. Group management skills and strategies are needed to overcome these potential problems (Chamala and Mortiss 1990).

Kelly (1995) describes some social principles and techniques for community consultation and group participation for pest management and how these can be used to develop a process to achieve best practice pest management at the local community level (Clarke et al. 1990; Clarke and Filet 1994).[10] This ‘participatory problem solving model’ provides a cyclical process for producers to identify problems, plan actions, trial solutions and evaluate results to improve knowledge and skills. Changes in management are more likely to occur if all phases of the model are completed. Kelly (1995) found this participative process motivates land managers and encourages long-term commitment to action.

Kelly emphasises how ‘learning by doing’ (Walters and Holling 1990; Section 8.4.5) and the principle of flexible management, which changes according to changing situations, is important for ensuring the

10 Kelly’s (1995) approach is based on a case study of feral goat management in the mulga lands of south-west Queensland, following a technique developed by the Queensland Department of Primary Industries with cattle producers.

process is relevant to producers' needs, and hence encourages their participation. Also the opportunity for 'doing something' about a problem is often given by landholders as an important reason for joining and staying with groups (Carr 1994).

Encouraging feral pig management groups to undertake large-scale experiments, as described by Walters and Holling (1990), will help to establish cohesion between group members because people develop a stronger commitment to things in which they invest time and money (Lerner 1994). Kelly (1995) emphasises that it is important for producers to feel ownership of the problem as well as the process for solving it.

'Undertaking large-scale experiments helps feral pig management groups establish cohesion because they develop a strong commitment when they invest time and money.'

This participative process includes an evaluation step and, by being flexible, can take account of any relevant social, economic or environmental factors. Initial reports compiled with landholders provide a benchmark to assess changes in local best practice during the project. Kelly (1995) describes a participative partnership between community and government in which communities with local information can monitor conditions and undertake action based on ownership of problems, and governments can assist by ensuring coherence between local, regional and national needs, and providing technical and research information. Government officers need to be involved in the process to understand better the complex social, environmental and economic issues of each local situation within which land managers operate.

Kelly (1995) emphasises the need for government facilitators to resist any temptation to attempt to push producers into action at group meetings. She says 'extension officers and researchers need to realise that often complex changes are needed at a local and regional level and that these changes may take time'. Such changes need to be made voluntarily by well-informed producers, for only then will they own the decisions and be committed to the process.

This process for developing local best practice is new for feral pigs and its long-term value has yet to be established. Government resources to support the process may enhance the probability of success.

9.7.2 Local and regional coordinated management

The first report of coordinated control was by J. Giles (unpublished) from the Moree Rural Lands Protection Board district in 1972. This Board became a leader in coordinated feral pig control, eventually establishing 48 active groups of landholders. The groups initially relied on 1080 poisoning but in latter years have switched to shooting from helicopters (R. Bailey, RLPB, Moree, pers. comm. 1994).

Surveys by Benson (1980) and Appleton (1982) of early cooperative control programs in New South Wales and Queensland confirmed that land managers perceived the lack of coordination amongst themselves as a barrier to effective feral pig management. A major conclusion of Appleton's study was the need for pig control authorities to recognise the variables that motivate producers into some form of action and, in the initial stages at least, incorporate this behaviour into a control strategy. The control strategy which comes closest to this situation is the spasmodic control strategy. Spasmodic control was defined as a response on a needs basis, that is landholders should apply control when either damage, or feral pig numbers, or both, increase.

The benefits of coordinated control have been demonstrated in north-west New South Wales and reported by Bryant et al. (1984), Korn and Shands (1983), Korn (1986a,b) and Korn (1993). During the three-year pilot scheme to control feral pigs in north-west New South Wales, 74 groups were formed. This was in addition to 48 groups that had been established in the Moree Rural Lands Protection Board district before the pilot scheme started.

Effective group action depends upon the establishment and maintenance of cohesive groups (Chamala and Mortiss 1990). Processes associated with the formation and maintenance of effective groups for feral pig control are described by Korn and Fosdick (1992). The processes target control agency staff:

- start with a group of people you feel comfortable with and an area of country which is not too large. The group of people selected should be keen, so that a good example is set. This first successful group can then act as a role model;
- identify an influential landholder from the group and use them to advantage. Such people know the social structure within the district: who works well with whom, what the common needs of the district are and what size is practical for the control area;
- group size depends on topography and especially on social factors, but it is critical that it is a manageable size;
- existing groups such as bush fire brigades or footrot control groups can be used to establish a feral pig control group;
- leaders of successful groups should be used to address prospective groups; and
- it is not always necessary to start by forming a group where pig densities are highest.

Where Rural Lands Protection Board staff in New South Wales acted as coordinators of group control programs, they found that group enthusiasm and effectiveness was enhanced by:

- board staff regularly contacting the group by either visiting or telephoning; and
- mailing major decisions of any one group to all group leaders, if there were several groups in one district.

These findings support other studies in group dynamics. In the case of feral pig control in the Macquarie Marshes, it was found that the following elements were essential:

- a committed Rural Lands Protection Board;
- committed staff;
- good planning;
- realistic goals and expectations;
- strong leadership; and
- coordination and liaison with neighbouring Rural Lands Protection Boards.

10. Deficiencies in knowledge and practice

Summary

The biology and ecology of feral pigs in most major habitats in Australia is reasonably well understood. There is, however, still a scarcity of information about feral pigs in some parts of tropical Australia, especially in rainforests. For example, in the wet tropics of north Queensland, there is a perception that feral pigs migrate from upland rainforests to the coastal lowlands (and the sugarcane crops) during the dry season and then return to the forests at the onset of the wet season; this, however, is yet to be proven by research.

Two basic problems in determining priorities for where to control feral pigs in many areas of Australia are the lack of: (1) objective, quantitative data on the impact of pigs on the natural environment; and (2) a means to compare costs of environmental values affected with agricultural losses caused by feral pigs.

More information is required on the factors likely to affect the progress and control of outbreaks of exotic diseases amongst feral pigs in different environments in Australia.

The two major toxins used to control feral pigs in Australia are 1080 and CSSP. Extensive work has been conducted on the threat 1080 poses to non-target species but no studies are known to have been conducted on CSSP, despite its longstanding and widespread use for feral pig control.

There are no reliable data on the cost of controlling feral pigs in normal on-property control programs. Because the objective of the national guidelines on vertebrate pest management is to change pest management actions by land managers, it is essential to know the current actions in the regions being targeted for change.

Adoption of the national guidelines will revolve around behaviour change at various levels, ranging from land managers up to policy makers in state and territory agencies. Currently, few of these staff have any training in the principles of adult education, sociology or psychology, all of which are important in facilitating a change in behaviour of individuals or groups.

10.1 Biology of feral pigs in Australia

Deficiency

There is a lack of information about the biology and ecology of feral pigs in some parts of tropical Australia, especially in rainforests (McIlroy 1993). The most important ecological information required from a management point of view in these areas is:

- the role of habitat and other factors in governing the seasonal distribution, abundance and movements of pigs; and
- seasonal foods pigs eat at different times of the year (particularly during wet periods), the availability of and nutrient levels in these foods in different areas, and the effect of this on their reproduction and population dynamics, particularly breeding frequency and piglet mortality.

Developments required

One of the key areas of research required in the wet tropics of north Queensland, is to confirm whether the perceived seasonal migration of pigs from upland rainforests to the coastal lowlands (and the sugarcane crops) during the dry season, and their return to the forests at the onset of the wet season does actually occur (Section 3.3.2). Factors that may play an important role include: the temporal abundance and availability of rainforest fruits and other foods (for example, earthworms) and sources of water; weather patterns such as the effect of cyclones or the duration and timing of the wet and dry seasons; habitat disturbance; and hunting pressure.

Research is also required on the population dynamics of feral pigs in these areas, including the effects of environmental factors and different levels of population control on their intrinsic rate of increase. Environmental factors could include delays in the onset of the wet season, or a very short wet season, the effect of cyclones, or a poor fruiting year in the rainforest.

Consequences

This information is fundamentally important in planning where and when to focus control efforts in the region, and for selecting the best methods and strategies to control feral pigs.

10.2 Agricultural impact

Deficiency

The major costs of agricultural damage caused by feral pigs to landholders have never been reliably estimated.

Developments required

Quantifying these impacts.

Consequences

This information will enable landholders to place pig management costs and benefits within the framework of total property planning and farm risk management.

10.3 Environmental impact

Deficiency

There is a lack of: (1) objective, quantitative data on the impact of pigs on the natural environment; and (2) a means to compare costs of environmental values affected with economic losses caused by pigs to agriculture.

Developments required

Some form of ranking encompassing both types of impact. This will require detailed surveys and studies of the possible, perceived and actual ecological impact of feral pigs. One aim of this research should be to identify key threatening processes for valued flora and fauna and both the indirect and direct effects of pigs. Examples may be the impacts of pigs on rare or endangered plants, particularly succulent species, ground orchids or rainforest palms, and certain species of earthworms, endemic snails and frogs, ground-nesting birds and ground-feeding or ground-dwelling birds and mammals. This would include the effects of not only feral pig predation, but also of feral pig competition with other animals, such as with cassowaries for rainforest fruits, and of habitat degradation through selective feeding, trampling and rooting up of the ground by pigs. The last activities could affect plant species composition and density, nutrient cycling and erosion, plant succession and the diversity of fauna in the areas concerned. Other studies could focus on the role feral pigs may play in destroying or dispersing native and exotic plant seeds, particularly those of rainforest species and weeds, and the role they may have in the spread of rootrot fungus.

Other essential information on the environmental impact of feral pigs required for management plans is the extent and intensity of their impact in different areas, and the relationship between pig numbers and levels of impact.

Consequences

Ranking will allow comparisons of impacts and control costs for different areas, which will enable land managers to prioritise where to control feral pigs in many areas of Australia. If a relationship exists between pig numbers (or indices of numbers) and levels of impact, it can be used to determine threshold pig densities for acceptable levels of damage and, ultimately, the percentage reductions of pig numbers or indices required in different areas or circumstances. The objective, then, is to develop or use appropriate control techniques and strategies that will achieve the required reduction in levels of impact.

10.4 Impact of diseases and parasites

Deficiency

There is a lack of information on the parameters and factors likely to affect the progress and control of outbreaks of exotic diseases amongst feral pigs in different environments in Australia for use in exotic disease contingency planning (Pech and Hone 1988).

Developments required

More information is required on estimates of disease transmission coefficients, the chances of detection, the rates of spread, and the threshold densities of pigs below which diseases will die out. It may be possible in some circumstances to extrapolate the required information from studies of other viruses in feral pigs or wild boar in Australia or overseas.

Better information on the distribution and abundance of pigs in particular areas or regions is also required. Emphasis should be on determining the pattern of distribution during different seasons, particularly to identify isolated populations or gaps in pig distribution, and topographical features that could be used as barriers to the spread of an exotic disease. Aerial surveys may be a suitable, if expensive, method of obtaining this information in semi-arid and other generally open areas, particularly if conducted by helicopter. Bayliss and Yeomans (1989) found that sightings of feral pigs from a fixed-wing aircraft provided insufficient information on their distribution and abundance in the Top End of the Northern Territory, but Wilson et al. (1987) obtained useful information on both parameters from fixed-wing surveys of grazing, wheat crop, woodland and forest habitats in south-east Queensland. Caley (1993) suggests a Geographic Information System could be used to indicate the likely distribution of pigs in the Northern Territory, based on simple criteria such as the presence of permanent water within ten kilometres and suitable dense cover (for example, along watercourses). Such a system is not likely to be successful in more thickly vegetated areas, such as the tropical rainforests of Queensland or eucalypt forests of south-east Australia and south-west Western Australia. In such habitats, ground-based survey techniques, using indices such as signs of pig activity, may need to be developed along the lines used by L. Moore (CSIRO Wildlife and Ecology, Queensland, pers. comm. 1992) in the wet tropics of Queensland (McIlroy 1993) or described by Hone and Stone (1989).

Consequences

Improved exotic disease contingency plans.

10.5 Assessment of non-target impact of CSSP

Deficiency

There is a lack of information on the threat the toxin CSSP poses to non-target species and on the relative humaneness of its action on pigs.

There is a strong perception in scientific and government policy areas that the long-term use of CSSP is questionable because of animal welfare considerations (J. Barrett, ANCA, Australian Capital Territory, pers. comm. 1994; A. Bryce, SCAW, Australian Capital Territory, pers. comm. 1994). This perception, however, has persisted for many years and CSSP is still being widely used. The reality is that it is probable that its use will continue.

Developments required

Evaluation of CSSP's non-target impacts and on the humaneness of its action on pigs.

Consequences

Safer use of CSSP for feral pigs and non-target species where this is feasible.

10.6 'Real world' costs of feral pig control

Deficiency

There is a lack of reliable data on the cost of controlling feral pigs in normal on-property control programs. The only data accumulated are those associated with research projects or control programs that have had strong government or quasi-government agency ownership. These costs are not 'real' costs.

Developments required

Specific data are needed on the costs of poisoning, shooting, fencing and trapping so landholders can compare these costs with the benefits of pig control.

Consequences

Factual field data would be useful for establishing a benchmark of landholder behaviour associated with feral pig management. An objective of the national guidelines on vertebrate pest management is to change land manager behaviour, to make pest control more cost-effective.

10.7 Training

Deficiency

Few staff of vertebrate pest management agencies have training in the principles of adult education, sociology or psychology, which are all important in facilitating a change in behaviour in individuals or groups.

Adoption of the national guidelines will revolve around behaviour change at various levels, ranging from land managers up to policy makers in state agencies. Assuming that state and territory policy makers adopt the principles of these guidelines, the onus then falls upon staff to facilitate behavioural change in land managers.

Developments required

Resources *must* be allocated to address this deficiency in knowledge and skills by extension staff of the control agencies in all states and territories.

Consequences

Long-term changes in the attitudes and behaviour of land managers for improved feral pig management.

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Appendix A

Best practice extension in pest management

Quentin Hart and Dana Kelly

Achieving sustainable land management, including pest management, can be facilitated by new approaches to extension. Traditionally, extension has been defined as the dissemination of information. In this definition, it is seen as the link between the producers of information (researchers and others) and the end-users of the information (generally land managers). Researchers, public policy makers and industry tend to refer to research transfer, technology transfer or information diffusion. Bennett (1993) emphasises the need for mutual interdependence and cooperative action combining these two approaches. If extension is to achieve adoption, it must facilitate understanding and involve a participatory rather than prescriptive approach.

Some characteristics and principles inherent in innovative extension programs are:

- ownership;
- benchmarking;
- participatory learning based on principles of adult learning;
- equity and respect for everyone's views (Kelly 1995);
- problem definition with stakeholder consensus (Ison 1993);
- client driven or responsive to the needs of clients (McGuckian and McGuckian 1994);
- consideration of the whole property or whole agribusiness chain (McGuckian and McGuckian 1994);
- incorporation of processes to create learning opportunities that lead to locally meaningful and adaptive changes (Ison 1993), that is, 'learning by doing' (Section 8.4.5 and Walters and Holling 1990); and
- incorporation of an evaluation strategy to ensure the program is flexible and responsive to external changes such as the environment or market (Kelly 1995).

Decreasing state government resources limit the ability of extension workers to target individual land managers. Landcare groups provide a partial solution to this problem in that they allow extension workers to target groups rather than individuals, and the information diffusion process within these groups is relatively rapid. The group approach offered by Landcare can also be used to develop regional rather than individual management plans for pest management (Chamala and Mortiss 1990).

Extension should not dictate solutions but provide the underlying technical information and decision-making framework from which land managers can draw their own conclusions. In this way, both government and land managers will have a greater understanding of the complexity of the problems and the possible solutions. Such participatory learning approaches also provide land managers with ownership of the problems and solutions, and this facilitates adoption.

Involving land managers as co-learners and co-researchers has been encouraged in demonstration projects supported by the Vertebrate Pest Program (VPP) of the Bureau of Resource Sciences. The VPP funded state and territory government agencies and Landcare groups to determine best practice pest management for a particular area. The projects were generally large-scale field trials involving several properties and comparing several management strategies. Rather than simply providing land for the research, land managers were integral parts of the projects and helped determine management options which are practical and economically sensible for their particular area. Their involvement also facilitated the dissemination of project findings to other land managers. One of the roles of extension is to maintain the momentum of such projects once government funding ceases.

Relevance of information to the land manager in a framework of whole-property management needs to be considered by extension workers. Pest damage is a single and often minor issue amongst a wide range of management considerations a land manager has to contend with. This is particularly true for pests which inflict major but infrequent damage such as mice. Pest management is peripheral to most land managers' major activities, and their motivation relates to current rather than potential damage (Salleras 1995).

Extension workers and research workers 'must be able to understand the goals and reasons for motivation or otherwise of the various human stakeholders as well as the habits and habitat of [the pest animal with] the most effective solutions [being] achieved by examining differences in the human dimension rather than concentrating on the pest' (Salleras 1995).

The above assertions by Salleras, a rural land manager from Queensland, are probably a good representation of the attitudes of many land managers and provide an insight into effective extension methodology.

Extension should:

- offer concise information specific to regional needs;
- offer a framework for making management decisions based on generic information combined with local observation;
- offer a range of options rather than be prescriptive;
- take account of the availability of pest management tools (for example, Global Positioning Systems and bulldozers for warren ripping) within a region so that recommended control techniques are appropriate;
- take a whole-property management approach by recognising that managers have to allocate budgets to deal with many risks and opportunities and are rarely able to fund pest control at optimal levels. Given limited budgets, the solution is to use cost–benefit analyses, which are relevant to the local area, to optimise where, when and how much control is conducted. As part of this, pest damage should be quantified and financial situation of land managers should be taken into account where data are available to do this (see Appendix B); and
- ideally, implement local field trials, and from these coordinate regional management strategies to achieve maximum (and hopefully long-term) adoption.

Computer technology may provide a partial solution to decreasing resources for physical extension. It will enable pest management information to be provided electronically and readily updated. This information can be linked to decision support systems to lead landholders step-by-step through a process of 'self-assessment' so that they may determine the best management options based on their own on-ground observations.

However, the potential value of these systems depends entirely on the extent to which land managers adopt such technology. In the foreseeable future adoption rates of best practice pest management, which are currently low and vary between localities, will depend on extension and research officers working with land managers to determine what best practice is for their situation and becoming actively involved in its implementation.

Appendix B

Economic framework for feral pig management

(After Bomford and others 1995)

Land managers who wish to determine the optimal economic strategy for managing a problem caused by feral pigs could use the stepwise approach outlined in this appendix. We recognise that managers will have incomplete knowledge of the information necessary to fully complete many of these steps. Nonetheless, the exercise of attempting to complete the process, and recording the assumptions and best guess estimates that are made, may prove a useful aid to decision making for feral pig management.

Step 1 — Desired outcomes

Identify desired outcomes and estimate a dollar value for each of these. Where outcomes are commodities, such as increasing lambing percentages, this should be reasonably easy. Where outcomes are difficult to measure, such as reduced land degradation, or intangible, such as increased biodiversity, land managers may be obliged to estimate how much they consider is an acceptable amount to spend to achieve that outcome.

Step 2 — Control options

List all control options and how much they would cost to implement. Control options can be different techniques or combinations of techniques, or different levels or frequencies of application of techniques (Section 7.6). It is important that the options for control are expressed as activities that a manager can select either to do or not to do.

Step 3 — Density–damage relationships

Estimate the relationship between pest density and damage for each resource damaged by the pest (Figure B1). For example, if pigs are reduced by 50%, how much will this increase lambing percentages. There may be interactions between pest density and other farm management practices which will need to be taken into account. For example the increase in lambing percentage caused by reducing pig densities by 50% may vary with different levels of availability of shelter for lambs.

Step 4 — Efficacy

Estimate the efficacy of each control option. That is, how much will a given effort using a particular control option reduce pig density.

Step 5 — Cost–benefit relationships

Use the information from Steps 1–4 to estimate costs and benefits of implementing each control option, including options which combine more than one technique. Costs will be the cost of implementing each control option, and may include costs of monitoring pests and planning. Benefits will be the value of the reduction in damage to the valued resource caused by implementing control (that is the desired outcomes listed under Step 1 above), plus

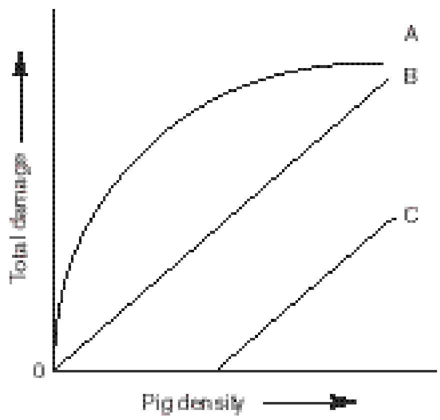


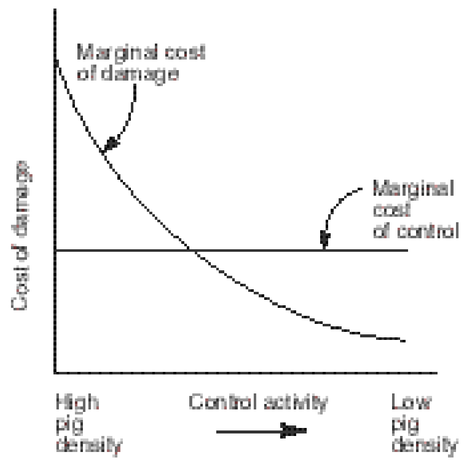
Figure B1: Possible relationships between pig density and the damage they cause. Line A is the relationship shown in Figure 9 and line B that shown in Figure 10. Line C might occur if, for example, only still-born lambs are preyed on by feral pigs at low densities, but if pig density increases, they start to kill healthy lambs.

any profits (for example, those made from selling pigs or from allowing hunters on the property).

Different pest management options will generate a variety of cost–benefit relationships. Estimates of benefits and costs can be discounted back to net present values (usually using a discount rate equivalent to the interest rate the landholder pays on financing the control operation). This will reduce the value of costs and benefits accruing in the distant future relative to those accruing in the near future.

Step 6 — Marginal analysis.

Plot both the incremental change in the cost of pig control and the incremental change in the cost of damage caused by pigs against the level of control activity contemplated (Figure B2). Where the two lines cross is theoretically the optimal level of pest control. Further increases in control activity do not cause commensurate reductions in damage, so at higher levels of control beyond this point, costs will exceed savings in reduced damage. An example of marginal analysis for shooting feral pigs from helicopters is presented in Figure 20.



Figur e B2: Marginal analysis plotting both incremental changes in the cost of reducing pigs to a given density and incremental changes in the cost of damage caused by pigs at a given density against level of control activity. Where the two lines cross is theoretically the optimal level of pest control. At higher levels of control beyond this point, costs will exceed savings in reduced damage.

Note: The x-axis units are for control effort (for example, dollars spent on control, hours of shooting or trap nights) not pig densities.

The problem for managers is that, because they often do not have good information on the density–damage relationship, it is hard to estimate the optimal control point. Further, even if they can make a good guess, it is not usually practical with most control techniques to simply cut off control efforts at some pre-determined pig density. It is preferable to have a range of control options ranked along the x-axis, with their associated cost and benefit values for implementation, so a manager can select which option is optimal. For example, different frequencies of shooting could be put along the x-axis.

Step 7 — Pay-off matrices

Construct a table listing all the control options and their associated costs and benefits (economists call this a pay-off matrix). For example, Section 8.8.3 compares the costs and benefits of two control strategies — shooting pigs from helicopters or poisoning with 1080. Managers may wish to construct different matrices for different conditions, such as different stocking densities, seasonal conditions, or commodity values for wool, lambs or pigs. Managers will also need to consider time-scales when constructing these matrixes — what time span is covered and how will this affect costs and benefits?

These matrices can then be used to select the option(s) which best meet the managers' goals. If the manager is risk averse, the best options will be those that bring in reasonable returns (benefits in relation to costs) under the widest range of conditions (that is, in most seasons and with a wide range of commodity prices). If the manager's priority is to maximise profit, the preferred options will be those that are likely to give the highest returns on investment, even though there may be some risk of having no returns or even a loss if the seasons and prices go badly.

Pay-off matrices can also be used by a land manager to compare returns on investment in pest control with returns on using the money for some other purpose, such as fencing, new stock watering holes or fertiliser.

Steps 1–7 complete the basic model. The model can be made more accurate by adding additional features. Incorporation of such additional features will make the model more complex, but including at least some of them may be necessary to make it accurate enough to be useful.

One way of improving accuracy may be to replace single estimates with a range of possible values, and give associated probabilities for each value in the range.

Managers may also wish to add additional features to the model such as:

- Social benefits could be included in Step 1, such as:
  - off-site effects and good neighbour relations;
  - biodiversity and endangered species management in agricultural areas;
  - retaining rural communities; and
  - animal welfare management.
- Risk management for spread of disease by pigs could also be included in Step 1.
- Effects of government intervention could affect value of benefits (in Step 1) or costs (in Step 2).
- Commercial harvest of feral pigs, as an alternative to control as a pest, could be included as a control option in Step 2.
- Indirect effects of pest control (for example, controlling pigs may lead to an increase in rabbit numbers) could be included as interaction effects in Step 3.
- The form in which benefits come may be significant to a manager (Step 5). For example, cash 'bonuses' from the sale of feral pigs may be more attractive as immediate cash for spending, than future money from increased lambing percentages, which may be committed in advance to servicing debts or meeting farm running costs.

Much of the information needed to follow the steps outlined in this appendix is not available. Some projects funded by the Vertebrate Pest Program in BRS aimed to collect some of these data.

Appendix C

Criteria for eradication

Eradication is the permanent removal of all individuals of a species from a defined area within a defined time.

There are three essential criteria which must be met for eradication to be possible (Bomford and O'Brien 1995). If all three criteria cannot be met, eradication should not be attempted:

- ***Feral pigs can be killed at a rate faster than replacement rate at all densities.*** As the density declines it becomes progressively more difficult and costly to locate and remove the last few animals.
- ***Immigration can be prevented.*** This is possible for offshore islands or small mainland populations which are geographically isolated, or where completely effective barriers can be erected and maintained, such as well-maintained pig-proof fences.
- ***All reproductive pigs are at risk fr om the control technique(s) used.*** If some animals are trap-shy or bait-shy, through either inherited or learnt behaviour, then this sub-set will not be at risk.

There are three additional criteria identified by Bomford and O'Brien (1995) that need to be met for eradication to be preferable to long-term feral pig control:

- ***Feral pigs can be monitored at very low densities.*** This can be difficult to achieve, but the rooting behaviour of feral pigs might allow survivors to be detected.
- ***The socio-political environment is suitable.*** For example, if certain groups object strongly to the eradication of feral pigs they can directly thwart or politically influence the program.
- ***Discounted cost–benefit analysis favours eradication over contr ol.*** Discount rates are used to estimate the value of future benefits against the costs of actions in current dollars. This criterion is difficult to meet because of the high initial cost of eradication and because benefits accrue over a long period. At high discount rates, eradication is unlikely to be cost-effective. Eradication has a large initial outlay but, if it can be achieved, there are no continuing costs apart from maintaining the outer protective boundary. For cost-effective eradication, each situation where eradication is technically feasible should be assessed to determine whether discounted eradication costs outweigh discounted benefits.

ACRONYMS AND ABBREVIATIONS

AHC	Animal Health Committee
ANCA	Australian Nature Conservation Agency
ANZFAS	Australian and New Zealand Federation of Animal Societies
APB	Agriculture Protection Board (Western Australia) (now AWA)
ASF	African Swine Fever
AUSVETPLAN	Australian Veterinary Emergency Plan
AWA	Agriculture Western Australia
BSES	Bureau of Sugar Experiment Stations
BTEC	Brucellosis and Tuberculosis Eradication Campaign
BRS	Bureau of Resource Sciences
CSIRO	Commonwealth Scientific and Industrial Research Organisation
C4	Consultative Committee for the Conservation of Cassowaries (now the Community for Coastal and Cassowary Conservation)
CSSP	Trade name for yellow phosphorus-based poison
CSF	Classical Swine Fever
c.v.%	Coefficient of variation
df	Degrees of freedom
DNR	Department of Natural Resources (Queensland)
ESD	Ecologically Sustainable Development
FMD	Foot-and-mouth disease
FPP	Feral Pests Program
GIS	Geographic Information System
GPS	Global Positioning System
NSWAF	New South Wales Agriculture and Fisheries
RSPCA	Royal Society for the Prevention of Cruelty to Animals (Australia)
SCARM	Standing Committee on Agriculture and Resource Management
SCAW	Sub-Committee on Animal Welfare (a sub-committee of SCARM)
s.d.	Standard deviation
SRS	Sugar Research Stations (now BSES)
VPC	Vertebrate Pests Committee
VPP	Vertebrate Pest Program
WGR	Wild Game Resources
WEDPP	Wildlife and Exotic Diseases Preparedness Program
WHA	World Heritage Area
WTMA	Wet Tropics Management Authority

GLOSSARY

1080: Sodium monofluoroacetate. An acute metabolic poison without antidote.

95% confidence intervals: The maximum and minimum values either side of an estimate, between which there is a 95% probability that the true value will lie.

Ad hoc approach: A reactive approach designed to meet immediate short-term goals (that is, not taking account of broader issues or the longer term).

Ad libitum: Free, without limit (for example, *ad libitum* feeding is allowing animals to eat all they want).

Age cohorts: Animals born in the same breeding season.

Agouti: Animal fur coloured brown or black with lighter tips.

Ambient temperature: Temperature of the surrounding air.

Anoestrus: Non-breeding period, lacking oestrus cycles.

Anticoagulant: Substance that slows or prevents blood clotting.

Antigen: Substance that triggers an immune reaction.

Anti-emetic: Substance that inhibits vomiting.

Arthropods: Animals with hard outer skeleton and jointed legs (includes insects, mites, spiders and crayfish).

Artiodactyls: Animals with an even number of digits (claws).

Asymptote: Where a curvilinear line flattens out and approaches a constant value.

Bait: Attractive substance fed to pest animals that can be used to carry a control agent, such as poison or contraceptive, or to lure them into traps.

Bait station: A place for feeding poison bait that is usually only accessible to target species.

Biodiversity: Biological diversity. The natural diversity of living things, usually defined at three levels: genetic, species and ecosystem.

Cadastral plans: Diagrams or maps which include property boundaries, land tenure, roads and similar information.

Carrier: Animal infected with (and capable of spreading) a disease, but showing no clinical signs.

Carrying capacity: Density of an uncontrolled population that is in equilibrium with its natural resources and competitors.

Chiller: Commercial industry portable freezer for storing game meat.

Coefficient of variation (*c.v.%*): A measure of variance around a mean:

$c.v.\% = 100 s.d./\bar{x}$

where $s.d.$ = the standard deviation of the sample and $\bar{x}$ is the sample mean.

Cohort: Group of animals born at the same time.

Conservation values: Values attributed to maintaining biodiversity, including the preservation of viable populations of native species and natural communities over their natural range, preservation of wilderness, and prevention of land degradation.

Consumptive impacts: Impacts due to resources being consumed (for example, pigs eating lambs or crops).

Corm: Bulb-like underground stem.

Crepuscular: Active at dawn and dusk.

Curvilinear relationship: Curved line relationship between two or more variables.

Demographics: Statistics relating to population dynamics, including birth rates, mortality rates, age and sex ratios.

Density-dependence: Where the rate of increase of a population is dependent on its density, so that as numbers increase, rate of increase declines.

Discount rates: The rate used to calculate the present value of future benefits or costs. They are calculated using the reverse equation to that used to calculate interest rates on invested money.

Disease transmission coefficient: A measure of the rate at which a disease is passed from one individual to another.

Diurnal: Active during the day.

Ecosystem: Ecological system formed by interaction of living things and their environment.

Ecotone: Where two or more distinct habitats overlap (for example, between forest and grassland).

Efficacy/effectual: Producing desired effect.

Endangered species: Species in danger of extinction and whose survival is unlikely if causal threatening processes continue to operate.

Endemic: Restricted to a certain region or country.

Ephemeral: Short-lived.

Eradication: Permanent removal of all individuals from a defined area.

Exotic: Introduced from another country (for example, exotic species).

Exotic disease: Disease which does not occur naturally in a region or country.

Exponential rate of increase (r): r is $\log_e$ of the finite rate of increase of a population (that is $r = \ln(N_{t+1}) - \ln(N_t)$ where N_t is population size at time t, and N_{t+1} is population size a unit of time later).

Extrapolation: Interpreting data beyond the dimensions within which it was collected (for example, assuming conclusions drawn from data collected in one region will be relevant elsewhere).

Extrinsically regulated population: Environmental resources limit population size when they are in short supply.

Farrowing: Giving birth to a litter of pigs.

Fecundity: The number of fertile eggs produced by an individual female or by a species.

Feral: Domesticated species that has established a wild population.

Fertility: The ability to produce young.

Finite rate of increase (e^r): $(N_{t+1}) / (N_t)$ where N_t is population size at time t, and N_{t+1} is population size a unit of time later.

Fixed-wing aircraft: Aircraft with fixed side wings (that is, not a helicopter).

Fomites: Porous articles such as clothes and some equipment which may carry disease.

Friable: [Soil that is] easily crumbled.

Frugivorous: Fruit eating.

Functional response: Relationship between per capita food intake rate and food availability.

Gametes: Sex cells (that is, spermatozoa and eggs).

Generalised relationship: Relationship which describes general features (for example, a computer simulated line between two variables).

Genetic engineering: Use of modern genetic manipulation technology to alter the genes in cell chromosomes so that desired characteristics are expressed.

Geographic information system: Computer-based system for displaying, overlaying and analysing geographic information such as vegetation, soils, climate, land use and animal distributions.

Gestation: Pregnancy.

Global positioning system: Small device that uses satellite signals to accurately locate the user's position (latitude, longitude and altitude).

Gregarious: Living in groups.

Gross estimates of impact: Estimates of total damage caused by feral pigs in an area (as contrasted to per capita impact).

Home range: Area that an animal (or group of animals) ranges over during normal daily activities.

Immunity: An organism's resistance, natural or acquired, to illness caused by infection by micro-organisms or their products.

Immunocontraceptive: Substance that triggers an immune reaction that causes sterility in treated animals, acting as a contraceptive.

Indices of feral pig abundance: Field signs that can give a relative measure of pig abundance (for example, abundance of fresh droppings, tracks, fresh rooting).

Indigenous people of Australia: Aboriginal peoples and Torres Strait Islanders.

Ingested: Taken orally.

Instantaneous rate of increase: Rate at which a population is increasing at a given stage of logistic or exponential population growth. Its value will lie between the maximum rate of increase (when population density is low) and zero (when population density is at carrying capacity).

Intangibles: That which cannot be numerically quantified (for example, that for which it is difficult to estimate a money value).

Interactive computer system: When a computer user can input data and get an immediate response without having to write a program and run a job (for example, word processing spell-check packages are interactive).

Interference competition: Competition between species where one suppresses another's rate of increase by interfering with its ability to procure or use a limiting resource, *or* where one species limits another's use of a limiting resource, not by prior consumptive use, but through preventing access (for example, through behavioural aggression and exclusion).

Intrinsic rate of increase (r_m): The intrinsic rate of increase of a population (r_m) is the natural logarithm of the rate at which the population will grow in a given environment when resources are not limiting (that is, the population's maximum rate of increase).

Intrinsically regulated population: Behavioural or genetic factors cause populations to self regulate their size.

Keratin: Hard, nitrogenous substance that forms basis of horns, claws, nails, etc. Plaques or shields up to three centimetres thick can develop on shoulders and anterior flanks of male feral pigs.

Killer pig: Pig that has developed a habit of killing lambs.

Land degradation: Soil erosion by wind and water; soil salination, acidification or structural decline; loss of soil fertility; stream and lake pollution, infestation by pest plants and animals; loss of biodiversity.

Latent period: Time lag between an action and a response.

LD_{50}: Dose (per kilogram of body weight) that will, on average, kill 50% of treated animals.

LD_{90}: Dose (per kilogram of body weight) that will, on average, kill 90% of treated animals.

Life table: Schedule of age-specific mortality (that is, a frequency distribution table presenting data on age, survival and mortality rates for a population)

Limiting factor: Factor which places some limitation on the density of a population (for example, an environmental resource that limits population growth because it is in short supply).

Linear relationship: Straight line relationship between two or more variables.

Lipids: Fats and oils.

Marginal benefits: The shift in benefit values that occur as incremental changes are made in the factor(s) which affect level of benefits (for example, changes to pig damage that occur as pig density is reduced).

Marginal costs: The shift in cost values that occur as incremental changes are made in the factor(s) which affect level of costs (for example, changes in the cost of finding and removing an extra pig that occur as pig density is reduced).

Mark–recapture: Technique of live catching, tagging, releasing and then recapturing animals, and using a formula to estimate population size from the proportion of recaptured animals that are tagged.

Market failure: When commodity prices set by natural supply and demand have undesirable social or environmental consequences (for example, unsustainable use of natural resources or development of social inequities).

Maximum rate of increase (r_m): The maximum rate of increase of a population (r_m) is the natural logarithm of the rate at which the population will grow in a given environment when resources are not limiting (that is, the population's intrinsic rate of increase).

Melioidosis: Bacterial disease causing pneumonia and septicaemia.

Metabolic body weight: (Body weight)$^{0.75}$.

Microspheres: Microscopic particles of a substance that are coated with a protective layer to delay breakdown in the gut or bloodstream.

Negative correlation: When one variable decreases proportionately as another increases.

Neophobia: Fear or avoidance of new things.

Net production: Final production after all losses and have been subtracted from the gross production.

Nocturnal: Active at night.

Numerical response: Relationship between the rate of change of a population and factor(s) which affect this rate of change (for example, effect of different levels of a consumable resource, such as pasture biomass, on the rate of increase of a population).

Oestrus: The sexual heat of female animals.

Omnivorous: Eating both plants and animals.

Opportunistic feeding: Taking advantage of new foods.

Origin of a graph: Point where the horizontal (x) and vertical (y) axes cross.

Parturition: Birth.

Pasture biomass: Weight of above-ground pasture available per unit area of ground, usually expressed as kilograms per hectare (either wet or dry weight).

Per capita: Per head of population (for example, food consumption per pig is per capita food consumption).

Pericarp: Soft fleshy tissue surrounding seeds in a fruit.

Polyoestrous: Having a succession of oestrous periods in one sexual season or year.

Population: Group of animals of a particular species occupying an area where they are subject to the same broad set of environmental or management conditions.

Post partum: Following birth.

Probability function: Predicted probabilities of an event for a range of values (for example, probabilities of pig damage for a range of seasonal conditions or for a range of control strategies).

Proximal limiting factor: Environmental factor that directly limits population size.

Regression equation: An equation which describes the relationship between two or more variables.

Rooting: Pigs using their snouts to dig up the ground and surface vegetation.

Ruminant: Animal whose stomach is divided into four segments, one of which regurgitates undigested food for further chewing (chewing cud).

Sensitivity analysis: Process for testing simulation models to see whether making changes to parameters or input data significantly alters the model's output.

Simulation model: Computer model that represents a real system, into which data or parameters can be entered to obtain an estimate of what would happen in the real system under these conditions.

Species: Group of interbreeding individuals not breeding with another such group and which has characteristics which distinguish it from other groups.

Species specific: Affecting only the target species.

Standard error (*s.e.*): The standard error of a mean value (*s.e.*) is a measure of the variability of measurements around the mean. The interval ($\bar{x} \pm 2$ *s.e.* (where $\bar{x}$ is the sample mean) will contain the true mean in 95% of large random samples. This interval thus constitutes the 95% confidence limits:

$$s.e._{(\bar{x})} = s.d./\sqrt{n}$$

where *s.d.* = standard deviation and n = sample size.

Standard deviation (*s.d.*): The standard deviation (*s.d.*) of a sample is an estimate of its variability, and is calculated from the square root of the variance (s^2):

$$s.d. = \sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 / n-1}$$

where x_i = value of each measurement from $1-i$; $\bar{x}$ = sample mean; and n = sample size.

Stochastic: Incorporating some degree of natural variation.

Subspecies: Group of individuals within a species, having certain characteristics which distinguish them from other members of the species, and forming a breeding group.

Sustainability: Continuing in present form and at current level in the longer term.

Sustained control: Continued control in the longer term.

Thermoregulation: Ability to regulate body temperature.

Threshold density for disease: Minimum density of susceptible animals at which a disease will persist in a population.

Transect: A rectangular plot in which data collection occurs.

Trap night: One trap set for one night (for example, if three traps were set for two nights each, this would be six trap nights).

Udder scores: Score based on palpation of a ewe's udder, which indicates whether she currently maintains viable lambs.

Ultrasound scanning: Use of low-frequency sound to investigate the internal structure of an animal (used for counting foetuses).

Ungulate: Hoofed animal such as horse, goat, sheep, pig and antelope.

Variance (s^2): The variance of a sample is a random variable which gives an estimate of the distribution of measurements:

$$s^2 = \sum_{i=1}^{n} (x_i - \bar{x})^2 / (n-1)$$

where x_i = value of each measurement from $1-i$; $\bar{x}$ = sample mean; and n = sample size.

Vector: Carrier for spreading disease or biological control agent (for example, mosquitos are a vector for myxomatosis).

Vesicular diseases: Diseases caused by viruses that cause blisters on the skin or hooves.

w/w: Weight per weight (for example, kilograms of 1080 per kilogram pig body weight). Usually expressed as a percentage.

Wild boar: Feral pig (*Sus scrofa*). Australian feral pigs share many characteristics with the Eurasian wild boar.

Wilderness: Land that has been essentially unmodified since European settlement.

x-axis: The horizontal axis on a graph.

y-axis: The vertical axis on a graph.

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