Feral Pigs:
Pest Status and
Prospects for Control

Similar works published by The Cooperative Research Centre for Tropical Rainforest Ecology and Management:

Patch Deaths in Tropical Queensland Rainforests: association and impact of *Phytophthora cinnamomi* and other soil borne organisms.
Paul Gadek

Remote Sensing Requirements for Management Agencies Responsible for Forest and Water Quality Monitoring in the Wet Tropics.
Stuart Phinn, Michael Stanford, Alex Held

The Comparative Assessment of Arthropod and Tree Biodiversity in Old-World Rainforests: The Rainforest CRC / Earthwatch Protocol Manual.
Roger Kitching, Guy Vickerman, Melinda Laidlaw, Karen Hurley

Impacts of Roads and Powerlines on the Wet Tropics World Heritage Area.
Miriam Goosem, Steve Turton

Impacts of Visitation and Use: Psychosocial and Biophysical Windows on Visitation and Use in the Wet Tropics World Heritage Area.
Joan Bentrupperbäumer, Joseph Reser

Feral Pigs:
Pest Status and
Prospects for Control

Proceedings of a Feral Pig Workshop
James Cook University · Cairns
March 1999

Editor: C. N. Johnson

Rainforest CRC

Cooperative Research Centre for
Tropical Rainforest Ecology
and Management

ISBN 086443 6815

Published by the Cooperative Research Centre for Tropical Rainforest Ecology and Management.

Further copies may be requested from the Cooperative Research Centre for Tropical Rainforest Ecology and Management, James Cook University, PO Box 6811 Cairns, QLD, Australia 4870.

This publication should be cited as:
Johnson, C.N. (Ed). (2001) *Feral Pigs: Pest Status and Prospects for Control. Proceedings of a Feral Pig Workshop, James Cook University, Cairns, March 1999.* Cooperative Research Centre for Tropical Rainforest Ecology and Management. Cairns. (75pp)

June 2001

The Feral Pig Workshop and production of this Proceedings were undertaken with the support of the sponsors listed below:

Rainforest CRC

Pest Animal Control CRC

CRC Australia

Queensland Government Natural Resources and Mines

WET TROPICS MANAGEMENT AUTHORITY

CONTRIBUTORS

Mr Brad Dorrington
Land Protection Branch, Queensland Department of Natural Resources and Mines

Dr John Herbohn
School of Natural Systems Management, The University of Queensland

Dr Mike Holland
CRC for the Biological Control of Pest Animals

Dr Jim Hone
Faculty of Applied Science, University of Canberra

Dr Jack Giles
Director, Scientific Policy and Research, Zoological Parks Board of NSW

Dr Chris Johnson
Department of Zoology and Tropical Ecology, James Cook University

Mr Jonathan Lee
Australian Quarantine Inspection Service

Mr Reece Luxton
Land Protection Branch, Queensland Department of Natural Resources and Mines

Dr John McIlroy
Retired, CRC for the Biological Control of Pest Animals

Mr Jim Mitchell
Tropical Weeds Research Centre, Queensland Department of Natural Resources and Mines

Dr Scott Ritchie
Tropical Public Health Unit

Dr Bob Seamark
Chief Executive Officer, CRC for the Biological Contol of Pest Animals

Mr Jack Shield
Queensland Department of Primary Industries

Mr Trevor Stanley
Tropical Weeds Research Centre, Queensland Department of Natural Resources and Mines

Professor Nigel Stork
Chief Executive Officer, CRC for Tropical Rainforest Ecology and Management

Dr Karl Vernes
Department of Zoology and Tropical Ecology, James Cook University

CONTENTS

INTRODUCTION

JOHNSON, C.N.[1,2] and STORK, N.E.[2]

[1]Department of Zoology and Tropical Ecology, James Cook University, Townsville
[2]Cooperative Research Centre for Tropical Rainforest Ecology and Management

---

This volume reports the proceedings of the Feral Pig Workshop held at James Cook University in Cairns in March 1999 and hosted by the Rainforest CRC and the CRC for the Biological Control of Pest Animals. Contributors to the workshop represented the range of issues related to feral pig management in North Queensland. It is probably true that the feral pig problem is more complex in this region than anywhere else in Australia. Consider first that the Wet Tropics World Heritage Area (WTWHA) preserves some of the richest, most complex and ancient ecosystems in Australia. Feral pigs may be the most significant, and are certainly the most visible, introduced animal species in this ecosystem. Their disturbance of soil may affect ecosystem processes in the WTWHA, they prey upon and may compete with a range of native plant and animal species, and they almost certainly contribute to the spread of weeds and exotic fungi. There is some evidence that pigs have caused the spread of feral earthworms, and theyimpact on seedling set. Rooting by pigs of soil along roadsides and streams, and the sight of pigs themselves, is a significant aesthetic impact in some of the most pristine and beautiful environments in Australia.

Neighbouring the Wet Tropics World Heritage Area are a range of valuable crops that suffer economic damage from pigs. The economic impacts of this interaction are significant in themselves, but they also create tensions over the management of the WTWHA, which is often perceived to be a safe refuge and breeding ground for marauding ('government') pigs. Of growing concern is the potential of the feral pig herd in north Queensland to host and transmit a range of exotic diseases threatening human and animal health. Recent incursions of Japanese encephalitis, a potentially fatal human disease spread by mosquitoes, illustrate this: Japanese encephalitis is also hosted by pigs, which amplify the disease and increase the likelihood of transmission to humans. A range of other emerging exotic diseases of humans could become endemic in northern Australia via the feral pig herd. This also applies to livestock diseases such as Foot-and-Mouth, the arrival and establishment of which in the feral pig herd would have crippling consequences for Australia's meat export industries.

Feral pigs therefore pose ecological, economic, aesthetic, medical and veterinary threats, actual or potential, in north Queensland, and their management creates tensions in the relationship between the community and government. However, it is clear that eradication of feral pigs over wide areas is not practical, and even sustained reduction of population size is difficult to achieve. Pigs have flexible behaviour and habitat choice, they are highly mobile, and they have very high reproductive potential. They are good at persisting in inaccessible habitats, and they can recover quickly from reductions in population size, either by immigration or reproduction.

Pig control by conventional means is expensive, especially if the aim is to hold the population at very low numbers : experience from elsewhere in Australia shows that the cost of trapping pigs may range up to approximately $100 per pig (Choquenot *et al.* 1996). Typically, the cost of control of a pest population increases as the population becomes sparser, because animals become harder to find and the remaining individuals may hold out in the most inaccessible sites. Hunting down or trapping the last few pigs in any large area of rainforest would be extremely difficult, and unless total eradication was achieved simultaneously over very large areas any local successes would be quickly reversed by immigration. Since an average litter of pigs is around 10 individuals, repopulation of areas could be very rapid.

Moreover, perceptions of the feral pig 'problem' vary widely. Pig hunting is a significant recreational activity, that contributes to the economies of some small communities. Many recreational hunters, though they believe themselves to be doing a service by reducing the impact of pigs, would probably be unhappy to see pigs disappear entirely. Hunting of feral pigs for human consumption is significant to many remote Aboriginal communities on Cape York: it provides a high-quality food source at low cost and has become culturally significant in the maintenance of traditional forms of wildlife harvesting and interactions of people with country. Eradication of pigs, even if it were practical, could do significant economic and cultural harm to these communities and would be opposed by them.

The papers in this volume consider this range of issues, reviewing our state of knowledge of the biology, impact and control of pigs in north Queensland, and identifying important gaps in our understanding. The volume opens with a review from John McIlroy of the environmental impacts of pigs in Australia, followed by reviews of the economic impacts of feral pigs from Reece Luxton and their economic and cultural significance to indigenous people in north Queensland from Chris Roberts and others. Papers by Jonathon Lee, Scott Ritchie and Jack Shield then examine aspects of the disease threats posed by the feral pig herd in north Queensland, using recent incursions of Japanese encephalitis as a case study. Jack Giles discusses our current understanding of the population dynamics of feral pigs and their ecology and impact on ecosystem processes in the Wet Tropics World Heritage Area are summarised by Jim Mitchell. Jim Hone provides an example of the effectiveness of control and monitoring of feral pigs in a conservation area in the ACT, and Karl Vernes and others evaluate the effectiveness of trapping in reducing abundance of feral pigs in one location in the Wet Tropics World Heritage Area.

The final section considers current and future control of feral pigs in the area. Brad Dorrington describes the existing pig trapping program, and Bob Seamark and Mike Holland consider the contributions that biotechnology might make to the control of feral pigs in the future. Nigel Stork and Trevor Stanley conclude with a summation of strategies and needs for pig control in the Wet Tropics World Heritage Area.

The Workshop shows that understanding of the pig problem in north Queensland, though solid in places, is decidedly patchy. Few people doubt that feral pigs have the potential to do environmental damage to the rainforests of the Wet Tropics World Heritage Area and to key habitats, such as wetlands, elsewhere in north Queensland. Jim Mitchell's work shows that pig feeding has measurable effects on processes such as native plant regeneration in heavily-disturbed sites. However, such impacts are surprisingly subtle. Some potentially important impacts, such as on water quality and in-stream fauna in upland rainforest streams, have either yet to be examined or have not been reported here. Most studies of the effects of pigs on rainforest ecosystems have been conducted at small spatial scales. In future, we should be attempting experiments over larger areas, in which the effects of reducing pig abundance on populations of key taxa or indicators of ecosystem function (such as water quality) are examined at something like a whole-catchment scale. Although feral pigs are capable of threatening the survival of native species – they almost exterminated the Lord Howe Island woodhen, for example, and probably had more to do with the extinction of the dodo than did hunting by Dutch and Portuguese sailors (Caughley & Gunn 1996) – there is as yet no clear statistically validated evidence that they are causing declines of any native species in the Wet Tropics World Heritage Area. However, studies of the effects of pigs on the demography of potentially vulnerable species (such as ground-nesting birds, narrowly endemic earthworms, or stream-dwelling frogs) are needed. It is of particular interest that the density of pigs in rainforest in north Queensland is low, perhaps surprisingly so. Densities of around three pigs per square kilometre have been estimated for lowland swamp/forest habitats, and abundance appears much lower than this in upland rainforests. Elsewhere in Australia, pig populations tend to be limited by high temperatures and low water availability (Choquenot *et al.* 1996); what limits pig abundance in the cool wet environmen under the rainforest canopy?

Similarly, there is no doubt that feral pigs do economic damage to horticultural industries in north Queensland, but the full extent of this has not been systematically measured. There are some subtleties in the interaction between feral pigs and horticultural industries. For example, pigs represent an economic cost to banana growers when banana prices are high, but when prices are low pigs provide a service to growers by cleaning up banana dump areas and scrap piles which would otherwise harbour fruit flies. While Aboriginal people recognise the benefits of pigs, they also realise that pigs do damage to some native bush resources. What is needed in these cases is an understanding of the relationship between different levels of reduction of pig abundance and the magnitude of the economic and environmental benefits gained. It is quite conceivable that there is a threshold population size of pigs, above which they do significant harm, but below which their impact can be tolerated and their services enjoyed. Discovering the position of this threshold, and evaluating the cost of holding a population below it, can only be achieved by large-scale experiments in control within the framework of adaptive management. Certainly, given the near-impossibility of eradicating pigs, we must learn to live with them.

Particularly in the rainforest of the Wet Tropics World Heritage Area, few options for pig control are available. Pig trapping and hunting (by shooting and dogging) are widely practiced, especially in the coastal lowlands adjacent to the World Heritage Area. The community based pig trapping program provides a coordinated approach to pig control over this area, and small-scale evaluations of pig trapping show that it can produce major reductions (around 80%) in local abundance of pigs. However, it is not clear what levels of population reduction are currently being achieved by the prevailing regime of large-scale pig trapping. Although there is strong community support for shooting and dogging as control techniques, the effectiveness of these forms of hunting have not been compared with trapping.

The papers on biotechnology and fertility control make it clear that such approaches, used in combination with conventional techniques, could make pig control more effective, more flexible and cheaper. Better understanding and manipulation of the pheremonal biology of pigs might enhance pig trapping rates. Strategic field immunisation of pigs could reduce the need for massive (and perhaps unachievable) population reductions to limit the spread of disease epidemics; and immuno-contraceptive methods similar to ones currently under development for rabbits and house mice could slow the rate of population growth and make it more feasible to hold populations below thresholds of acceptable damage. There is now enough experience in the development of such approaches in Australia to make their application to feral pigs seem an achievable goal, but only after a considerable research effort.

Finally, the colossal damage that the accidental introduction of Foot-and-Mouth has caused to British farming and possibly to the rest of Europe, is a timely warning of the potential threat that feral pigs offer to Australia's livestock industry. If Foot-and-Mouth were accidentally introduced then it might be impossible to eradicate it in the near future.

PART 1

IMPACT OF FERAL PIGS

Overview of the impact of feral pigs, *Sus scrofa*, on the Australian environment

McILROY. J.C.

38 Hempleman Drive, Akaroa
Canterbury, New Zealand

ABSTRACT

Feral pigs, *Sus scrofa*, with their large robust bodies, specially developed snouts for rooting up the ground, omnivorous diet and opportunistic feeding habits, adaptability to a wide range of habitats and gregarious behaviour, have the potential to detrimentally affect the Australian environment. Few studies, however, have been undertaken to identify and measure the types of impacts they are having, including their severity, extent and location. Their most likely impacts are habitat degradation and predation on, or competition with, native animals. More quantitative information is needed on the relationships between pig abundance and the degree of impact (and effort spent on control) in different natural areas to determine *if*, *where* and *at what cost* control measures are justified.

INTRODUCTION

Pigs, *Sus scrofa*, introduced into Australia by the early European settlers, quickly established feral populations, particularly in New South Wales and Queensland (Choquenot *et al*. 1996). Today there are possibly about 13.5 million of them inhabiting 38% or so of Australia (Hone 1990). The size of the population, however, probably varies considerably each year depending on environmental conditions, such as floods and droughts.

Human attitudes towards feral pigs range from regarding them as a resource, such as for recreational hunting or export of their meat, to considering them a serious pest because of their damage to crops and livestock or their potential role in spreading exotic diseases. This paper focuses on the impact that feral pigs are known to have, or could be having, on the Australian environment.

DESIGNED FOR IMPACT

The biology and ecology of feral pigs are major predisposing factors in the impact they may be having on the environment. Their large robust bodies, specially developed snouts for rooting up the ground, omnivorous diet and flexible activity patterns allow them to live in a wide range of habitats. These include subalpine grasslands and forests, dry woodlands, tropical rainforests, semi-arid and monsoonal floodplains, swamps and other wetlands in many parts of Australia. 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. Apart from adult males, feral pigs are mostly social, gregarious animals. 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 (Choquenot *et al*. 1996). Densities range from less than one pig per square kilometre in semi-arid rangelands, woodlands and open forests to 10-17.5 km^{-2} in swamps and other wetlands.

All these factors mean feral pigs have the capacity to adversely affect the environment but the type and severity of their impact may vary in both space and time.

IDENTIFYING AND MEASURING ENVIRONMENTAL IMPACTS BY PIGS

Identifying and measuring the impacts that feral pigs have on the environment is a crucial part of feral pig management plans. The type, severity, extent and location of their impacts determines whether control should be carried out, and if so, when and how much control is necessary to reduce or eliminate these impacts. If the impact of pigs in any area is not clearly known, then expensive control measures may not be justified. Measuring or identifying environmental impacts by feral pigs can be difficult and affected by perceptions. In some cases their impacts may appear *direct* or obvious, such as predation on turtle eggs or rooted up leaf litter and soil in a rainforest. However, while such 'damage' may be dramatic evidence of the pigs' activities, they may not necessarily have a significant effect on populations or ecosystems. Juvenile mortality amongst turtles, for example, is intrinsically high while patchy disturbance of the rainforest floor may not affect the long-term processes of plant dynamics or community structure. In other cases the impacts may be *indirect*, such as pig rooting on hillsides causing siltation in streams, which may ultimately affect aquatic life. Impacts of pigs can also vary over time. They may be *acute*, such as if pigs suddenly rooted up the last known clump of the subalpine herb *Gentiana baeuerienii* in Namadgi National Park near Canberra. Alternatively, they may be *chronic* such as wallowing by pigs causing the gradual degradation of a small swamp. Pig impact can also be *roughly constant in intensity* (eg. rooting up of leaf litter) or *periodic* such as feeding on water lilies or other plants in a northern lagoon during the "dry" season or rooting up valley floors during winter in southern hill country areas.

The most important environmental impacts that feral pigs are likely to have are habitat degradation and predation. Habitat degradation could occur through selective feeding, trampling or rooting by pigs and affect plant species composition and density, nutrient cycling, rates of erosion and nutrient losses, plant succession and the diversity of fauna (particularly soil invertebrates) present. Pigs may also have a role in the dispersal of exotic plant seeds and the destruction of native plant seeds.

HABITAT DEGRADATION

The most obvious signs of 'damage' by feral pigs are patches of ground, grassland or forest litter rooted up by them in their search for underground food. Such disturbances can be locally extensive, especially around swamps, lagoons and watercourses or after rain when the ground is softer. For example, Alexiou (1983) found that most pig rooting in a subalpine area near Namadgi National Park occurred along drainage lines, in depressions and around grassy flats. Altogether, 32% of such sites showed evidence of pig damage, particularly a large reduction in the abundance of the dominant grassy vegetation and some small native herbs. Several native plants, however, had become vigorous colonisers of the rooted up areas. Hone (1998) found that plant species richness in a nearby area of grassland declined as pig rooting increased. He concluded that if the pig rooting covered more than about 25% of the area, then species richness could decline rapidly, but at this stage the long-term and large-scale effects of this impact were unknown.

There is a similar lack of knowledge about the long-term effects of feral pigs on soil nutrient and water cycling, rates of erosion and nutrient losses, soil micro-organisms and invertebrate populations and plant succession in Australia. Statham and Middleton (1987) described how extensive rooting by feral pigs in moist gullies in Strzelecki National Park on Flinders Island led to erosion, loss of regenerating forest plants and their replacement by thick stands of bracken fern, *Pteridium esculentum*, but provided no quantitative details.

The extent to which feral pigs eat or disperse seeds is also unknown. Feral pigs are likely to eat a much greater range of fruit and seeds in Australia than has been reported (eg. McIlroy 1993) 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) seed 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, softer 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). Weeds may also be spread to new areas, particularly freshly dug up or trampled areas, through the attachment of their seeds to pigs' coats or in soil clinging to the pigs' snouts or feet.

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 by the gut following ingestion of infected material (Masters 1979), the pigs can carry 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 of the fungus 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.

PREDATION, COMPETITION AND DISTURBANCE OF OTHER ANIMALS

Feral pigs can eat a range of animals, including earthworms, amphipods, centipedes, beetles and other arthropods, snails, frogs, lizards, the eggs of the freshwater crocodile, *Crocodylus johnstoni,* turtles and their eggs, small ground-nesting birds and their eggs and young rabbits, *Oryctolagus cuniculus* (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 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. At the moment we don't know what effect rooting or wallowing by feral pigs may be having on amphibians, such as the corroboree frogs, *Pseudophryne* spp. which are now endangered species very close to extinction in the Australian Capital Territory and Snowy Mountains. W. Osborne (pers. comm. 1996) has found no evidence so far of pigs destroying the species' breeding sites in Kosciusko National Park, but he has witnessed their tadpoles being splashed out of a pool by a wallowing pig. The pigs' extensive rootings could cause patches of the frogs' habitat to dry out, but equally may create ponds for the frogs. W. Osborne has found corroboree frog eggs under rooted up tussock grasses but there is no information on whether eggs in such situations survive.

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). Instead, in north Queensland rainforests and secondary forest, opportunistic, omnivorous rodents, especially white-tailed rats, *Uromys caudimaculatus*, may be the dominant predators of some bird nests (Laurance *et al*. 1993, Laurance and Grant 1994).

Despite conjecture, there is no evidence that feral pigs (*Sus scrofa*) adversely affect the survival of cassowaries in the wet tropics region of Queensland. The greater ability of pigs to switch or move to alternative food supplies once the seasonal flush of rainforest fruits wanes, however, may provide them with some competitive advantage over the more sedentary, frugivorous cassowaries, particularly sub-adult birds forced to fend for themselves away from parental territories. This may have repercussions in terms of rainforest regeneration, dispersal of exotic weeds and the continued presence of cassowaries in many areas of the wet tropics. Feral pigs may also compete with the northern bettong, *Bettongia tropica*, brush-tailed bettong, *B. penicillata*, rufous bettong, *Aepyprymnus rufescens*, long-footed potoroo, *Potorous longipes*, long-nosed potoroo, *P. tridactylus*, and musky rat-kangaroo, *Hypsiprymnodon moschatus* for underground fruiting bodies of mycorrhizal fungi, underground stems of grasses, roots, bulbs and tubers, seeds, rainforest fruit and insects in different parts of Australia.

CONCLUSION

It is clear that there is very little known about the impact of feral pigs on the environment in Australia. More often than not there are *perceptions* that they are detrimentally affecting the environment. While rooted up forest floors, grassy valleys or swamps may not be aesthetically acceptable, particularly in major tourist areas, such activities by pigs may have little ecological impact. What is required before any management plans are contemplated is a clear assessment of what actual damage the pigs are doing, particularly the severity of the damage, its extent and location and how acceptable this is, publicly or scientifically. This is fundamental for deciding whether the pigs are a problem or not and which impacts or particular areas should receive priority control. The relationship between pig abundance and degree of impact also needs to be measured to determine what levels of population reduction must be achieved and maintained to obtain acceptable levels of impact. If, at the same time, the relationship between the abundance of pigs and efforts spent on control in different areas is quantified, it would then be possible to determine how much would be needed to be spent on control to prevent or stop any unacceptable impacts by feral pigs on the environment.

Economic impact of feral pigs in the Wet Tropics

LUXTON, R.

Land Protection, Department of Natural Resources and Mines
South Johnstone

ABSTRACT

The Wet Tropics region is categorised by the large tracts of World Heritage protected areas. Feral pigs are regarded as a significant agricultural pest in the region. This is reflected in management practices to reduce numbers where a direct economic loss is involved. For some primary producers, farming would not be economically viable without an effective/ intensive feral pig control program. Recently however the trend is changing to allow a reduction in impact, as seen through the success gained with the Community-based Feral Pig Trapping Project.

This paper intends to draw together various sources of current information on economic impacts of feral pigs in the Wet Tropics. This is a topic without specific statistical data further than reports from McIlroy (1993) and Mitchell (1993) but I hope to draw a defined picture. Economically we can look at the direct costs/losses, indirect cost/losses including the management costs and the benefits of control techniques available.

In Queensland it is estimated that $1.1 million was spent on feral pig control in 1984, which equates to $2.2 million in today's dollar values (McGaw & Mitchell 1998). This amount includes both government and private expenditure on control, although it does not include amounts spent by recreational hunters. Despite the pressure of legal requirements to control feral pigs, landholders control pigs principally because they are seen to have a negative economic impact.

DIRECT LOSSES

Sugar Cane

Feral pigs in cane can cause severe but localised damage. Cane in the Wet Tropics is usually grown in close proximity to feral pig habitat. The main problem occurs with trampling of cane setts and plant cane, and the physical destruction in paddocks.

This industry accounts for the majority of primary production in the region, with numerous follow-on benefits for local communities. Damage by pigs is certainly a direct cost, with various Cane Protection and Productivity Boards (CPPB) reporting on hectares damaged and tonnes lost on an annual basis. Some boards also cover a 50% subsidy on the provision of trap material, on the basis of 1 trap per farmer (Edwards pers comm 1999).

To give an example of the damage wrought on cane farmers, figures are provided from the expanded cane areas of the Upper Murray and Warrami districts, 30 km south west of Tully. On the South Johnstone Mill areas, 100 pigs have been trapped in the last six month period in a 2000 ha area. This is in an area highly regarded and utilised for recreational hunting pursuits as well. A farmer relatively new to the area was also astonished with figures of 40 pigs shot on his property in a 2 month period (Barnes pers comm.1999). The damage is severe in discreet locations, and ranks third after cane grub and rat damage. Damage is difficult to measure, costed on a district basis. In 1991 the cost to sugar cane crops was in the vicinity of $628 000, equating to a reduction in yield of 25 510 tonnes (McIlroy 1993). However economic hardship to individuals is the problem, not losses to the industry as a whole.

Bananas
Feral pigs are also regarded as an economic pest to this industry. Particularly when banana crop prices are high, significant losses are regarded as sustained on a localised basis. For example, average losses in the Tully area include up to 20 bunches lost per month, at a cost between $600 to $1800 (Noble 1996). When prices are low, the cleaning up of banana dump areas and scrap by pigs is considered a benefit.

Tropical Fruit
Damage to trees, fruit loss and irrigation equipment is reported regularly. Fruit loss is significantly high due to the access to low hanging fruit – a preferred practice for farmers is to have specific fencing and trimming lower hanging branches. Pawpaw plants are easily damaged when tusked or rubbed.

Small crop production
Although not a large industry in the Wet Tropics area, damage does occur. Irrigation piping and mulching seems to be disturbed in areas close to prime pig habitat, where losses anywhere up to 50% losses are reported.

Livestock
For this industry, the impact of feral pigs is negligible. However pig activities reduce pasture availability and can promote weed spread (McGaw 1998). Diggings can also contribute to damage to farm equipment, with the example of rocks being brought up by pigs damaging slasher blades.

Damage to infrastructure
Feral pigs are also regarded as damaging infrastructure such as roads, drains, easements etc. Damage to roads through pig digging is particularly evident in the wet season.

INDIRECT LOSSES

Recreational hunting
Hunting is seen to be a highly regarded activity for people in the region, particularly when chiller boxes are open, and for some individuals, pig hunting is a viable commercial business.

Commercialisation
While seen as a possibility, the biggest problem with major commercialisation is the consistency of supply of pigs – this apparently is not possible given the difficult terrain and limited access. The chiller boxes in the region are only open for indefinite periods of time. The biggest constraint to commercialisation is the requirement for hunters to be licensed game meat harvesters, the Queensland Meat and Livestock Association is regarded as having unreasonable requirements for accreditation.

Transmission of diseases
Feral pigs are regarded as significant vectors for numerous diseases impacting on agricultural production and human health. Pigs are also implicated as vectors in transmission of plant diseases such as *Phytophthora cinnamoni* (root rot fungus) (Mitchell 1993).

Potential impact of diseases
There are feral pig populations within a 2 km radius of international air and sea ports in the Wet Tropics, and the risk of entry of exotic disease through these areas is quite significant. Along with this, local tourist resorts can be affected thus impacting one of the largest industries in the region (Pavlov *et al.* 1992).

Economics of control
Fencing is used predominantly to protect sugar cane crops. However this is only regarded as effective if fences are erected prior to feral pigs moving into crops. The Tully CPPB have spent $8000 to protect a seed block adjacent to a pig habitat area (Noble 1996). Electric fencing is also widely used in the cane industry to inhibit damage from feral pigs.

Trapping is regarded as best practice for the Wet Tropics area (Mitchell 1993). Coordination is the key. To give a perspective on the costs for control in the Wet Tropics, funding and in-kind contributions can be looked at with the Community Based Feral Pig Trapping Project. To run the program successfully, the funding from various sources including the Wet Tropics Management Authority, Department of Defence, Environmental Protection Agency, Department of Natural Resources and Mines, and various Cane Protection and Productivity Boards. The in-kind contributions from landholders and trappers equates to $30 000 each per year – with 30 trappers involved in this totals nearly $1 million (Dorrington and James, 1999).

The Cairns City Council under their Pest Management Plan has an operations budget of

$10,000, which goes towards trapping in response to requests from residents, and to monitor pig activity and trap in key areas (Murray pers. Comm. 1999).

Poisoning using 1080 baits is seen as appropriate where high levels of damage occur in a localised area, but is not regarded as effective for long term management objectives. Also it is seen as impossible on a broad scale level because of the presence of endangered fauna and tourists. Shooting is highly inappropriate and discouraged due to the high vegetative cover in the area. Dogging is effective for the capture of trap-shy animals, but on the whole is regarded as ineffective for control.

Bounties are used by CPPB throughout the area, and are seen to generate goodwill between farmers and the board (Clarke pers. comm. 1999). This is seen as one of the best ways to induce control of feral pigs and thus reduce numbers. However the Department of Natural Resources and Mines is against the use of bounties, and has a particular policy regarding the issue. A study by the Bureau of Resource Sciences (BRS) in 1998 also concluded that 'the use of a financial incentive in the form of a bounty payment as a general tool to reduce vertebrate pest damage is inappropriate'. Hence control methods used in the Wet Tropics vary with habitat, size and location. The best option is to balance all factors for the most efficient control plan.

KEY POINTS

Since the reports produced by McIlroy and Mitchell in 1993 to the Wet Tropics Management Authority, and Noble's report to the BRS in 1996, perceptions have not changed dramatically. The impact of pigs and their damage varies according to seasonal conditions and the perceptions of landholders. On the whole the World Heritage Area is still regarded as a harbour for feral pigs.

For agricultural industries, maximising economic return is the key objective. Attitudes to control in the Wet Tropics is driven largely by perceptions of the problem. There are four different control strategies available to landholders (Choquenot *et al.* 1996) - 1) no pig control as no net economic gain; 2) restrain pigs at a moderate level; 3) restrain pigs at a low level; and 4) local eradication. Each of these options is practised in the Wet Tropics area, dependent on the perception of the landholder. There is danger in allowing the management of feral pigs in the Wet Tropics to steer towards commercialisation. In this, there would be a change in perspective from hunting being a recreational pursuit to a likely income supplement; further to this, the hunters will feel they aren't covering the costs (Edwards pers. comm. 1999).

CONCLUSION

Reduction in impact is the key, and this is reflected by landholders affected economically by feral pigs. An understanding of keeping the impact down through improved management practices will hopefully bring a change in the perception of landholders.

Also, the continued coordination of management of feral pigs is critical, as population levels are likely to return to pre-management levels if funding is withdrawn. Communication is vital between those bodies involved in the policy, management and on-ground control of feral pigs in the Wet Tropics. There is a need to investigate an incentives program for expanding the Community Based Feral Pig Trapping Project to a wider range of rural industry groups.

The issue of how to compare environmental, agricultural and other values on an equal basis is still unresolved, and requires further study for the benefit of structuring sound planning and management.

Strategic sustained control is the most likely scenario utilised by primary producers, whereby populations are reduced to a level where benefits are maximised compared to costs. Constant funding and maintenance of coordinated programs is crucial, particularly on the perimeter of the World Heritage Area in order to reduce the economic impact to adjacent primary production (Mitchell 1993).

Feral Pigs - Indigenous perspectives

ROBERTS, C.[1]. AKEN, R.[2] TAISMAN, A[3]., CHEVATHON, J.[4]

[1]Author - Balkanu Cape York Development Corporation
[2]Reader - Cape York Land Council
[3]Wik Presentation - Aurukun
[4]Translator - Cairns

ABSTRACT

The views of feral pigs held by indigenous and non-indigenous people differ widely. While conservationists and non-indigenous landholders might like to see pigs eradicated, pigs are a highly regarded food source for indigenous people, and they provide an important outlet for the maintenance of aspects of traditional culture. Planning for pig management, especially on Cape York, should take this diversity of interests into account.

Feral animals and plants are a contentious issue on Cape York. Most people of a developmental mind want them removed. Most conservationists (including national parks) see extermination of pigs as part of their mission. Roving shooters think they are doing the world a favour as they stitch up their dogs and clean their knives or guns. Those in the health profession have little patience for the pig. Even the government gets emotional about these so called uninvited guests. For these reasons, we see substantial amounts of funding being allocated to getting rid of pigs.

It is relevant to compare the origins and evolution of the views of Aboriginal people with the views of non-indigenous people as far as feral animals and plants are concerned. If we take both views a long way back they would probably be quite similar (even 200 years ago). Food. It seems that the essential difference is that Aboriginal people are still in survival mode, literally. At the same time Aboriginal culture accords respect to the animals, plants and cultural practices that feed them.

At this point we refer you to a study that was produced by Bruce Rose and the Aboriginal people represented by the Central Land Council in Alice Springs. The work provides some interesting insights into the perspectives of indigenous people in relation to the feral animals that are found in that area. Attitudes relating to camels, rabbits, cats, donkeys, are easily transportable to the Cape York situation. Several of these animals have been incorporated into "story" or mythology as it is called by White Fellas.

We have previously embarked on the beginnings of a study with the Department of Natural Resources and Mines in Brisbane. We were invited to participate in a study of pigs on Cape York after the body of NHT proposal concerned had already been written. This sequence of events is not ideal, and we did address the matter with DNRM. The bottom line is:

Do not assume that everyone wants pigs dead: they have value and that value varies from place to place.

This concern along with others precipitated a workshop in Cooktown where some relevant points were made by all participants. We encourage further intentions to address the pig issue to revisit them. We have been over some of this ground before.

It is very important to realise that the perspective from which Aboriginal people see feral pigs is very different from the Western view and this is primarily because of the cultural base from which this vision comes. "White people" have been educated using Darwinian principles as their main paradigm or "creation story" and with that the concept of biodiversity or "plenty different tucker". Aboriginal people understand how things work in a practical way. They are more effected by this Darwinian reality than non-indigenous people are. The way in which they arrive at caring for this biodiversity is really quite different from the way in which white people arrive at that end. Scientists seem to be of the opinion that feral animals disturb the great scheme. The Aboriginal belief is very similar except that it is not based on the Darwinian principles supporting biodiversity as such, but the more urgent survival instinct based on food for family.

Food is a mighty powerful motivation and it is difficult to appreciate bioregional theory when one's very culture is threatened by other arms of the same mind set. Politics in general does not favour the maintenance of Aboriginal culture. There are no sporting shooters in indigenous Cape York that I know of.

In central Australia, it seems from the report done by Bruce Rose (1995), that Aboriginal people had incorporated new arrivals into their landscape and into their resource base. As a consequence these new animals have in fact been elevated to the spiritual realm of Aboriginal existence. This is very different from the way these animals are viewed in the scientific world. Ferals are seen essentially as a nuisance, as destroyers of environment, carriers of disease etc. For Aboriginal people feral animals often provided something new to eat. The main reason that there is any dispute about "what should be done about pigs" is that many of these communities still rely on pigs for food. They have no argument about where this food came from, it is a resource that they can use and to some extent they are even keen to look after that resource, to preserve that option.

There is a spectrum of responses to feral animals among the Aboriginal and Islander communities on Cape York. In general feral pigs are a highly regarded food and are commonly used in festivities. In fact people who shoot pigs without permission from the local Aboriginal people can find themselves in trouble. This issue revisits the ownership question. Who owns these things on the land? Who has the right to kill them? Do outside people have a right to come and harvest them without getting permission? There are a number of complex issues here.

Feral pigs do dig up the ground. There is no argument there. They dig yams which is an important activity of Aboriginal women. In areas such as Lockerbie scrub (the northern most rain forest on Cape York) you will find extensive damage from pigs along the waterways. However; the Lockerbie scrub is a prime pig hunting area for the local people at the top of Cape York. Further south along the east coast at Lockhart River people hunt pigs for food also. There does not appear to be any "recreational" hunting of pigs by Aboriginal people, they are hunting specifically for food.

Whilst the more fortunate population sectors in Australia can pontificate about the awkwardness and embarrassment of having pigs in national parks and other areas of Australia, we really need to get down to reality when considering subsistence and survival on the land. There are few economic enterprises that provide a living and life is hard. The truth of the matter is that Aboriginal people still rely heavily on hunted food.

Other protein sources such as beef have been considered, however, the logistics, carrying capacity of the country, fencing, environmental cost, feasibility and absence of "the hunt", are significant barriers to what might appear to be a simple solution.

Pig hunting is not only about food. It provides an outlet for men to practise an important part of their culture. I have some figures provided by Andrew Roberts which illustrate the dynamics of hunting at the top of Cape York. Hunting pigs can take a good deal of pressure off other species.

Recently two graduates did work in the Cooktown/ Hope Vale area and managed to terrify the locals by explaining the various diseases that occur in pigs. Now this is all very well but these explanations need to be measured against social effects, and they also need to be realistically measured against the health consequences. Before rushing in and telling people how unhealthy or healthy such and such an activity might be, we really need to get our facts straight. For example in the last two decades, how many people from Hope Vale have been hospitalised because of a pig-related illness? This same logic might be applied to the remainder of Cape York. We are not saying that people should carry on regardless, but we do need to consider the statistics. Perhaps selection and cooking processes reduce risks. Humans are after all one of the few predators that pigs have. Enquiries to Bamaga Hospital, Cooktown Hospital and Tropical Health did not reveal a single disease case directly attributable to pigs within the experience of the staff spoken to.

Human predation appears to be a relatively important control factor in the number of pigs on the Cape. At Aurukun, there appears to be a measured approach to pig numbers and through brief conversation with people from there it seems that when there are a number of good wet seasons one after the other, pig numbers can get quite high and in such cases the community may well be in favour of a culling program. On the other hand when the wet seasons are not so good, having a bit of extra meat running around on Aboriginal country is quite useful. The importance of lily bulbs as a cultural food it relevant here.

The new spectre of Japanese encephalitis appearing on the Cape is of great concern to all the Cape communities and their service agencies (eg Cape York Land Council, Apunipima Cape York Health Council, Balkanu etc). Aboriginal people use dogs for hunting and generally use a firearm only to kill the pig once it has been bailed up. A pig of course can be a very dangerous animal and for this reason it is necessary to use firearms at the end of the hunt to be on the safe side. There have been some rather simplistic arguments as to whether Aboriginal people should be using spears or guns during their hunting, but essentially it is the hunt itself that is most important. Pig numbers on Cape York haven't been well established. Somewhere there is a balance between having too few and too many pigs on the Cape.

Pigs armed with strength, a powerful sense of smell and high intelligence are very good at finding food. They eat an astonishing array of food items (beach crabs, bird eggs, carrion including pig skulls etc). With a wide variety of dental equipment (teeth) they create several problems for predators and prey. Their ability to learn about traps is well recorded by bush people.

For Aboriginal people the effects of pigs on bush tucker - digging up of turtle eggs, yams, bulbs, water lilies - are an issue in some cases. For conservationists predation of ground nesting bird eggs such as the Red Bellied Pitta is a concern. We need to discover what effect feral pigs have on traditional resources of Aboriginal people if we want support for culling. At the moment there are no statistics, no figures that will allow for an objective comparison between having this new animal on the landscape and what losses it might be causing in relation to cultural resources.

Unless these things are addressed, management authorities will have a difficult task convincing Aboriginal people that feral pigs do more harm than good.

There are several research directions necessary to provide this information and we should work towards that end together so that we not only pursue the "precautionary principle" but also provide Aboriginal people with both the cultural and physical benefits that feral pigs provide on the Cape.

PART 2

FERAL PIGS AND DISEASE THREATS

The role of the Northern Australian Quarantine Strategy

LEE, J

Australian Quarantine Inspection Service
Airport Administration Building, Cairns

BACKGROUND

The Northern Australia Quarantine Strategy (NAQS) is a program conducted by the Australian Quarantine and Inspection Service (AQIS), and was established in 1989 to assume responsibility for quarantine surveillance in northern Australia. This was due to the recognition of the clear and present dangers of incursions of exotic human, animal and plant diseases and pests into northern Australia from countries to our north.

NAQS has three arms: NAQS Operations, NAQS Scientific and NAQS Public Awareness.

- NAQS Operations provides border security in the Torres Strait and northern Cape York Peninsula region, and uses indigenous personnel to address the specific problems posed by the close proximity to PNG and the traditional movement of indigenous people between the two countries, which is allowed under the Torres Strait Treaty.
- NAQS Scientific is the investigative arm and provides the epidemiological information on exotic diseases and pests.
- NAQS Public Relations provides support to the other two arms by producing public awareness materials and resources.

NAQS SCIENTIFIC

The mission of NAQS - Scientific is to identify and evaluate quarantine risks to northern Australia, and to provide early warning of quarantine pests and diseases through a program of monitoring, surveillance and public awareness across northern Australia and in neighbouring areas of Papua New Guinea, East Timor and Indonesia.
NAQS has most recently been reviewed in 1995 and again as part of the AQIS review in 1996. As a result of these reviews. It's role and importance in the surveillance and early warning of exotic diseases, has been recognised and this has resulted in increased funding and an expansion of capabilities.

STRATEGIES

The NAQS - Scientific Strategic Plan outlines the strategies designed to address the mission outlined above. These are:

(1) Identification and assessment of risk, and

(2) Surveillance activities.

Risk assessment is a formal process involving scientific working parties evaluating the risk of entry and resulting impact of a range of exotic animal diseases and pests. This process results in the production of a NAQS animal disease target list. The provision of a target list enables available resources to be focused on the most significant threats to enhance the likelihood of providing early detection and early warning of potential incursions.

Using the resulting risk assessments and NAQS exotic disease target lists as a reference, NAQS veterinarians and scientists develop operational plans to provide comprehensive surveillance for these target list diseases both onshore and offshore. Although specifically aimed at target list diseases, these surveillance activities are also designed to detect emergent or aberrant exotic diseases or strains. The NAQS veterinarians and scientists use their findings and experience to fine tune these surveillance activities to optimise the results obtained.

Surveillance activities covered by the animal program are structured around two main concepts. These are
(a) the use of sentinel animal herds and strategically sited insect traps both onshore and offshore, and:
(b) a series of targeted surveys (survey frequency is correlated to risk levels for the geographic areas covered).

The sentinel animal herds utilise serologically naive pigs or cattle, from which blood samples are regularly analysed for evidence of exposure to subclinical exotic diseases. These sentinel herds are also regularly checked for evidence of clinical disease due to other exotic pathogens or myiasis due to screw worm fly.

Targeted surveys are conducted along the northern Australian coastline from Cairns to Broome and are coordinated by the NAQS staff in each of these States and Territory. Surveys are also regularly conducted in Papua New Guinea, East Timor and Indonesia with joint participation by scientific staff from those countries.

NAQS Scientific also funds scientific research aimed at developing new techniques to improve risk assessment and enhanced surveillance.

The NAQS Japanese encephalitis surveillance program is a good example of how activities undertaken by NAQS contribute to identification, assessment and response to an exotic disease threatening Australia and all those who live here.

Japanese encephalitis - a case study of exotic animal disease incursion

LEE, J

Australian Quarantine Inspection Service
Airport Administration Building, Cairns

ABSTRACT

As outlined in the previous paper, the Northern Australia Quarantine Strategy (NAQS) conducts surveillance activities as part of its role in the detection and provision of early warning of exotic human, animal and plant diseases and pests. Sentinel herds are an integral part of the strategies used to fulfil this role. The value of the NAQS approach has been demonstrated by the success of the Japanese encephalitis (JE) sentinel pig program, which has provided essential early detection and epidemiology of the multiple JE incursions into Australia since 1995.

EPIDEMIOLOGY OF JAPANESE ENCEPHALITIS

Japanese encephalitis (JE) is an exotic animal and zoonotic disease threatening the NAQS area of responsibility. It is a mosquito-transmitted flavivirus, closely related to several existing endemic Australian flaviviruses, which include Murray Valley encephalitis (MVE), Kunjin, Alfuy, Stratford, Edge Hill and Kokobera (Hall *et al*, 1986).

The most common natural hosts of JE are Ardeid water birds (herons and egrets). Pigs however act as amplifying hosts by developing high levels of viraemia when infected. They can readily act as a reservoir for mosquitoes to transmit JE virus to susceptible humans and horses, which are end hosts and may develop fatal encephalomyelitis in a small percentage of infected individuals. JE is currently endemic throughout most of South East Asia including Indonesia (J. Mackenzie, UQ, pers. Comm. 1999).

RISKS OF ESTABLISHMENT IN AUSTRALIA

Serological studies indicate that JE is probably now endemic in the Western Province of Papua New Guinea, Irian Jaya and Timor (J. Mackenzie, UQ, pers. Comm. 1999). NAQS is concerned that there is a significant risk of an incursion from PNG, via the Torres Strait islands, or directly from Timor or other parts of Indonesia into northern Australia.

If JE becomes established in Australia, there would be significant social and economic implications. The mechanism of spread of JE is unclear, but potential vectors include wind borne spread of infected mosquitoes, or movement of infected avian hosts.

Factors favouring JE gaining a foothold and becoming endemic include the presence of viable vectors and vertebrate amplifying hosts. *Culex annulirostris*, an endemic mosquito and viable vector for JE, is common through northern Australia and its summer range extends as far as Victoria. Another important mosquito vector, *Culex gelidus*, has recently been identified in Queensland and the Northern Territory (Whelan, P., NT Dept. of Health and Haseler, B., AQIS, pers. comm. 2000). Feral pigs are considered to be the vertebrate host of primary importance and the greatest population densities occur in the Gulf of Carpentaria, Cape York Peninsula and the top end of the Northern Territory (Choquenot, McIlroy & Korn 1996). Once established the disease would pose an immediate threat to the human population of northern Australia, which is primarily confined to coastal regions where there is favourable habitat for vectors and amplifying hosts. From here JE could potentially spread to encompass the same geographical range as Murray Valley Encephalitis virus.

PAST JAPANESE ENCEPHALITIS INCURSIONS INTO AUSTRALIA

1995

An epidemic of JE erupted through the northern half of the Torres Straits in March/April 1995, causing three human clinical cases, of which two were fatal. A relatively high number of people (35/215) sampled were seropositive for JE indicating widespread exposure to the virus throughout the top, western, central and some of the eastern islands of the Torres Strait (Hanna, Ritchie, *et al.* 1996).

In May 1995, an extensive serological survey of domestic pigs located in the Torres Strait was undertaken by the Australian Quarantine and Inspection Service (AQIS), the Queensland Department of Health (Q Health), the Queensland Department of Primary Industries (QDPI) and the University of Queensland Department of Microbiology. Eight outer Torres Strait islands, three inner islands and two mainland communities were surveyed. Between 33-100% of pigs in the outer islands were seropositive as were 7 out of10 horses on Badu Island (at this stage only Badu Island had a population of horses), although no horses were observed displaying any clinical signs of JE. Following this, it was decided to utilise pigs on the Torres Strait islands as sentinel animals to monitor for any future incursions.

As a result of these findings, a joint operation was developed by the four organisations noted above, to set up a network of sentinel herds in the Torres Straits and the northern peninsula area. The rationale behind this move was to attempt to detect any incursion thought to originate in the Western Province of PNG where the disease was believed to be recently established, and transmitted by either infected mosquito vectors or migratory waterbirds.

1996

Sentinel pigs were established on Badu, Saibai and Darnley Islands in 1996 by NAQS, in co-operation with Q Health, as a response to the previous year's widespread outbreak of JE. The herds were supplemented by survey visits by NAQS staff to the other islands where pigs, horses and poultry were tested as well. In March 1996, 12/13 sentinel pigs on Saibai Island had sero-converted. No other sentinel pigs or animals tested during surveys of the Torres Straits or Northern Peninsula Area sero-converted in 1996. As the majority of human inhabitants of the northern Torres Straits had been vaccinated by Qld Health in 1995 in a response to the initial outbreak, only the sero-conversion of sentinel animals could provide the necessary indications of JE activity in the area.

In preparation for the 1996/97 wet season, NAQS established a testing regime of domestic pig herds on Saibai and Badu Islands as well as in five mainland communities located in the NPA. A sentinel cattle herd was established at Bamaga and used to provide serological data on JE, although the sensitivity of cattle as sentinels for this disease has not yet been established. The sentinel animal herd operations were supplemented by a series of surveys covering the Torres Straits, Northern Peninsula Area and Cape York Peninsula.

This was a collaborative program with samples collected from the NAQS sentinel herds, while the serological testing was performed by Q Health. Duplicate samples were tested for other exotic animal pathogens by the Australian Animal Health Laboratory (AAHL), Geelong. Results were distributed to all participating and interested agencies and feed back was provided to the local inhabitants. In addition to these activities, samples of serum from wild migratory waterbirds collected by cannon netting were tested for JE as well as other avian diseases.

1997

Results from the 1996/97 NAQS program indicated sero-conversion of sentinel pigs on Saibai Island only. These pigs sero-converted in March 1997, showing that infection of the top western islands was a repetitive event probably linked to the seasonal changes present at this time of year. A general animal survey was conducted by NAQS staff of the PNG border region with Irian Jaya in July/August 1997. Serological results indicated widespread exposure of domestic and feral pigs to JE, particularly in Western Province. This information was shared with Q Health and John Mackenzie's group at The University of Queensland who were conducting human serosurveys, mosquito trapping and virus isolation studies in this area. Their results also indicated that a potential epizootic of JE was occurring in southern PNG (Siba, P. and Mackenzie, J. pers. comm. 1998).

Due to the threat posed by the huge potential reservoir of JE virus in PNG, consultation between all participating agencies resulted in the decision that NAQS should increase JE surveillance for the 1997/98 program, to provide better early warning of any major incursion into the Torres Straits and northern Australia.

It was generally acknowledged that usually the JE virus tended to cycle a couple of times in previously naive pigs, before spilling over into the human population (Chu & Joo 1992). However, due to the lag in the development of protective antibodies by the pigs and processing times for the samples, diagnostic results may not give much advanced warning prior to development of clinical disease in unprotected humans. In spite of this, results from sentinel pigs are invaluable for confirming an incursion and delineating its distribution. This information is essential for the planning of response actions by health authorities as well as State animal health authorities.

1998

The 1997/98 NAQS operational plan expanded the sentinel pig herds to include Saibai, Boigu, Badu, Moa (St. Pauls community) Mabuiag and Yam Islands. Other islands were covered by six monthly surveys. However since the 1995 outbreak on Badu, island communities had been steadily reducing numbers of domestic pigs on most islands, partly due to fears of pigs harbouring JE, which could be transmitted to humans. This caused some problem with low numbers of pigs of a suitable age available for sentinel herds or bleeding as part of surveys. Yam Island had to be dropped from the sentinel herd program as there were no suitable pigs present, while islands such as Boigu had a total of only four pigs of a suitable age (3 -12 months) for JE testing.

In spite of these difficulties, sufficient numbers of pigs were tested in December 1997 and January 1998 to ensure that there were no indications of JE in the Torres Straits at that time. The monsoonal wet season commenced somewhat later than usual, in February with a tropical low centred in the Gulf of Carpentaria. This produced strong north-westerly winds to sweep across the Torres Straits and Cape York Peninsula accompanied by torrential rain. PNG had previously been suffering from an extended drought for much of 1997.

A popular hypothesis used to explain the sporadic incursions of JE into the Torres Straits and the Australian mainland is that of wind borne infected mosquitoes. Optimum conditions for an incursion are thought to include high populations of mosquito vectors in Western province of PNG following stagnation of water due to drought and a strong low - pressure weather system established in the Gulf of Carpentaria. These conditions are thought to enable large quantities of infected mosquitoes to be carried from southern PNG and to be deposited over host-rich portions of the Torres Straits and Cape York Peninsula (Ritchie, S. pers. comm. 1998).

The first indication of an incursion of JE into Torres Straits was the nearly simultaneous seroconversion of sentinel pigs on Badu and Moa Islands and the diagnosis of a clinical case in an eleven year old unvaccinated boy resident on Badu in March 1998 (Hanna, Ritchie, *et al.* 1999). This was rapidly followed by seroconversions of sentinel pigs on Saibai, Mabuiag Islands and at Seisia on the Australian mainland (March – April 1998).

This evidence from the NAQS sentinel herds indicated that an incursion of unprecedented proportions was occurring. NAQS personnel immediately initiated a response aimed at determining the extent of the incursion and the rate of spread. Surveys were conducted to sample all pigs on islands and regional mainland communities not containing sentinel animals. Results indicated that all of the islands in Torres Straits contained pigs which had seroconverted except for Warraber and Kadel Islands. Pigs on Hammond Island were also seropositive when tested, causing some alarm there, and on nearby Thursday Island.

As only residents on the northern islands had previously been vaccinated, the results from the NAQS surveillance resulted in prompt action from Q Health to extend its human sero-surveillance and response actions beyond Badu Island to other communities. Within weeks of the initial human clinical case and seroconversion of pigs, a second human case was diagnosed (23/3/98) in a fisherman in the Mitchell River region of Cape York (Hanna, Ritchie, *et al.* 1999).

The NAQS response activities were extended as a result of discussions with Q Health and QDPI to include surveillance of areas on the west coast of Cape York and the Gulf of Carpentaria. This response centred on the rapid collection of sera from domestic and feral pigs in the Pormpuraaw and Kowanyama area to confirm the incursion and to discover the extent of its spread. Concurrently Q Health conducted a sero-survey of human residents of this area while other NAQS staff conducted cannon netting operations in the Karumba region to sample waterbirds for JE and other avian diseases. The joint NAQS / QDPI helicopter and ground based survey of the Mitchell River area, commenced at the beginning of April 1998, and collected 114 feral pigs and 20 domesticated pigs, from which sera was obtained. This was sent to Q Health's laboratory in Brisbane and to AAHL. Results from the adult feral pigs were complicated by concurrent exposure to endemic flaviviruses, but 6/20 of the domestic pigs showed serological evidence of exposure to JE only. This result coupled with the recovery of JE virus from sentinel pigs on Mabuiag Island and at Seisia confirmed the extent of the incursion.

Human serological testing failed to detect any further unequivocal human cases, however the seriousness of the incursion prompted the decision by Q Health and Commonwealth Health to hold a conference to discuss the current situation and determine future courses of action (Hanna, J. pers. comm. 1998). The conference, which was held in Cairns on the 8th and 9th July 1998, included all the major stakeholders. The participants of the conference recognised the value of the AQIS / NAQS sentinel animal and survey activities and requested a major extension of the sentinel animal program to cover coastal mainland areas south of the existing sentinel herds. AQIS agreed to implement new sentinel pig herds at the following locations; Badu Island, Bamaga, Old Mapoon, Wathaneen (Aurukun), Baas Yard (Pormpuraaw), Normanton and Hopevale in Queensland; two pig herds in the Darwin region of NT and pig herds at Kununurra and Broome in WA. These new herds were established in late 1998, in time for the 1999 wet season.

1999

No evidence of any Japanese encephalitis (JE) activity was detected from serological monitoring of the NAQS sentinel herds in QLD, NT or WA during the 1999 wet season. However there is serological evidence that an epidemic of Kunjin caused sero-conversion of most sentinel pig herds in Queensland during this period. Summary results from testing conducted by Q Health from samples obtained from the NAQS sentinel herds are presented in Table 1.

Table 1. Seroconversions due to Kunjin in Queensland sentinal pig herds, 1999

Site	**Date of Initial Seroconversion**
Normanton	2 March 1999
Baas Yard	23 March 99
Wathaneen	18 April 99
Old Mapoon	5 May 99
Injinoo	31 May 99
Badu Island	Not detected.
Hopevale	Not detected.

Serological data suggests that the initial focus of the Kunjin epidemic originated in the Gulf (Normanton) and progressed steadily northwards along the west coast of Cape York Peninsula but failed to cause seroconversion of the sentinel pigs on Badu Island. However there is further evidence of flavivirus activity in pigs in Umagico (near Bamaga) and on Moa Island (Kubin) recorded from NAQS survey conducted in June 99. The exact cause of these serological results cannot be determined but it is likely that this was a further extension of the previously described Kunjin epidemic.

2000

Flavivirus activity was detected very early in 2000, with the most significant event being the seroconversion of sentinel pigs on Badu Island to JE. These pigs were negative on the 7th January and yet by the time of the next bleed on the 17th January, all had significant haem-agglutination inhibition (HAI) titres indicating exposure to JE. Concurrent testing of sera at AAHL confirmed the incursion through positive competitive enzyme linked immuno-sorbent assay (C-ELISA) and serum neutralisation test (SNT) results. However polymerase chain reaction (PCR) results were negative. Further sampling of the sentinel pigs over subsequent weeks showed greater than fourfold increases in the JE titres indicating that JE was the most likely cause of the seroconversions. Testing of samples by serum neutralisation and virus isolation confirmed the diagnosis with three isolates of the virus being detected.

Subsequent serological sampling of domestic pigs from Moa Island was conducted in May 2000, as part of the annual NAQS survey of Torres Strait. Results indicate that these pigs had also been exposed to the JE virus. Analysis of these results is continuing.

On the mainland, all other sentinel pigs (except those at Injinoo airport and those near Hopevale) also seroconverted over February and March. However, serological analysis indicated that these seroconversions were most likely due to the endemic flaviviruses; Kunjin and MVE rather than to JE. HAI titres in the order of 320 - 640 were recovered from the sentinel pigs to these viruses, indicating considerable vector activity over this period.

CONCLUSIONS

Sentinel animals form an essential part of exotic animal disease surveillance and complement survey activities conducted by NAQS. Results from these activities can provide early warning and monitoring of exotic disease incursions, allowing the early implementation of response activities.

There is a need to further elucidate the epidemiology of Japanese encephalitis, in epidemic regions, particularly with reference to the role played by arthropod vectors and non-human hosts including wild birds and feral pigs. Little is known about the migratory habits of various waterbirds and their potential to act as amplifying hosts for JE. This data will need to be added to the existing information about the epidemiology of the disease involving humans, domestic pigs, horses and mosquitoes, in endemic areas.

The role of JE resistant animals, such as cattle in providing potential zooprophylaxis, is unknown, but could be an important factor in the epidemiology of a JE incursion into northern Australia.

The development of high serological titres to MVE, Kunjin and other domestically occurring flavi viruses by sentinel pigs, certainly complicates serological diagnosis of potential JE incursions, and better serological techniques are urgently required to clearly distinguish between these viruses. It is unknown whether exposure to domestic flaviviruses produces any cross protectivity in animals and humans to JE.

While these issues are being investigated, NAQS is continuing to conduct surveillance for JE using sentinel animals and survey activities. This information will be crucial to understand how the disease spreads and to assess the risks of potential incursions of JE into Australia.

GLOSSARY

amplifying hosts. Hosts which, when infected by a virus, have a limited immune response which allows the virus to replicate in vast numbers within the animal's tissues. These hosts then become a virus reservoir and allow vectors such as blood sucking mosquitoes to pick up an infectious virus load when obtaining a blood meal from these animals.

clinical disease. The animal has been infected (or affected) with the disease and is showing signs indicative of the disease (eg. fever, coma).

cross reactive serology. A serological test which may produce a positive result when it detects antibodies to a number of closely related diseases. The ELISA test for JE will also produce positive responses to antibodies which protect against MVE or Kunjin. Hence a positive result can not differentiate which disease the animal has been exposed to.

flavivirus. A member of the genus *Flavivirus* in the family Flaviviridae. These are Group B arthropod-borne viruses. Most are transmitted by mosquito vectors. There are approximately 80 different members but include the important arthropod-borne viruses. Most are transmitted by mosquito vectors. There are approximately 80 different members but include the important viruses of medical and veterinary interest, such as - Japanese encephalitis (JE), Murray Valley encephalitis (MVE), Kunjin, West Nile, louping ill & Wesselbron viruses.

neurological sequelae. Damage to the central nervous system (brain & spinal cord) which results in histo-pathological or clinical signs (eg. with JE, sequelae may include loss of memory, fine motor control, blindness, or coma).

seroconversion. The infected anima's immune system has responded to the infection by producing antibodies which can be detected in the serum by serological testing.

serological data. A collection of results from serological testing of animals or humans.

serologically naive. The same as immunonaive - the animal has not been exposed to the disease and has not developed protective antibodies to the disease and is negative when tested by serological techniques.

seropositive. An animal which give a positive result to serological tests used to detect specific antibodies.

subclinical exotic disease. The animal or human has been infected with the disease but is not showing any overt signs of the disease.

viraemia. When a virus is circulating in the blood and tissues of an infected animal or human.

virus isolation. Techniques used to attempt to recover live intact virus from animal (or human) blood or tissues. The techniques usually attempt to grow these recovered viruses in tissue cultures or embryonated eggs, so that they can be identified either by characteristic lesions produced or serology or electron-microscopy.

zoonotic disease. A disease which can be transmitted from animals to humans.

zooprophylaxis. The use of animals to control or prevent infection (of humans) by a specific disease. For example, cattle are attractive targets for potentially JE infected mosquito vectors but as they do not develop high levels of viraemia and are not affected clinically by JE. They therefore can act as immunological "sponges" to "soak up" many of the potentially infective doses of JE before they are transmitted to susceptible amplifying hosts such as pigs or susceptible end hosts such as humans or horses.

Mosquitoes and pigs: the critical mix for Japanese encephalitis

RITCHIE, S., JOHANSEN, C., VAN DEN HURK, A., LEE, J., MACKENZIE, J.

[1]Tropical Public Health Unit, Queensland Health, Cairns
[2]Department of Microbiology and Parasitology, The University of Queensland, St Lucia
[3]Australian Quarantine Inspection Service, Airport Administration Building, Cairns

ABSTRACT

This paper compares rates of infection of pigs by Japanese encephalitis in the Torres Strait and on Cape York Peninsula. Pigs may become infected with JE if bitten by mosquito vectors, and this may then increase the risk that the disease will be transmitted to humans. During 1995 and 1998 when rates of infection of domestic pigs on Badu Island was high, seroconversion of pigs on Cape York was low. The difference may be due to the high exposure of domestic pigs on Torres Strait Islands to mosquito attack, relative to wild pigs on Cape York, and suggests that feral pig populations may not induce epidemics of JE on Cape York.

INTRODUCTION

Japanese encephalitis is a severe neurological disease that afflicts nearly 50,000 people a year, primarily in tropical and temperate Asia (Burke & Leake 1988). JE is fatal in 25% of clinical human cases, with a remaining 50% suffering neurological sequelae ranging from coma and paralysis to psychological disturbances (Burke & Leake 1988). JE is caused by a flavivirus, with birds, especially ardeid waders, as the natural host. Mammals tend to be incidental hosts, although pigs develop a high transient viraemia, serving as the major amplifying host (Burke & Leake 1988). Although there are outbreaks in areas with low numbers of pigs, most severe outbreaks have been in rural areas with large populations of domestic pigs. JE is transmitted by mosquitoes, especially *Culex tritaeniorhynchus* in SE Asia.

Prior to 1995, JE was unknown in Australia. In April of 1995, three human cases of JE, two ultimately fatal, occurred on Badu Island in the Torres Strait (Hanna *et al.* 1996, Lee *this volume*). Subsequent investigation showed that most Torres Strait Islands from Badu to the Papua New Guinea border had JE activity that year (Hanna *et al.* 1996), and that the mosquito *C. annulirostris* was the probable vector (Ritchie *et al.* 1996).

The intensity of the outbreak on Badu Is. was, in part, due to the large numbers of domestic pigs (*n* = 200) that lived in close contact with the residents (Ritchie *et al.* 1997). On Badu Is. JE virus infected 17% of the human population while 1 in 300 *C. annulirostris* carried JE virus. Nearly every other house had a backyard piggery and it was estimated that all 200 pigs became infected with JE (Hanna *et al.* 1996, Ritchie *et al.* 1997). Furthermore, clogged drains, stagnant swamps and overflowing septic tanks created ideal breeding grounds for the vector mosquito within the community. Thus the residents of Badu Is. were literally living within a maelstrom of JE virus (Ritchie *et al.* 1997).

After a two year hiatus (excepting the northernmost islands of Saibai and Boigu), JE virus returned in 1998 with the largest outbreak to date. Sentinel pigs throughout the Torres Strait tested positive for JE virus, and the outbreak extended as far south as the Mitchell River in western Cape York, where the first human case of JE on the Australian mainland was recorded (Hanna et al. 1999, Lee *this volume*). Again, activity on Badu Is. was intense, with all pigs tested seroconverting, 43 isolates of JE virus from mosquitoes and, despite vaccination of most of the residents, a human case.

However, the story was quite different on Cape York. The Mitchell River case was the only evidence of JE virus infection among 700 people whose blood was tested (Hanna et al. 1999). Although domestic pigs bled from Baa's Yard near the Mitchell River and the sentinel pigs in the northern peninsula area of Cape York (NPA) did indeed seroconvert for JE virus, the level of JE virus activity waned in comparison to Badu (Table 1). Pigs seroconverted slowly, with sporadic seroconversions among NPA pigs over a three month period from March – May 1998. Some pig herds in the area (e.g., Bamaga) did not show a single seroconversion! Why was the JE activity in Cape York so different, so much lower, than on Badu Is.? This paper addresses this issue and, in doing so, explores the role that feral pigs may play in the natural history of JE virus on the Australian mainland.

FERAL PIGS, DOMESTIC PIGS AND MOSQUITOES

The potential key to the difference in JE activity in Cape York and Badu Is. can perhaps best be elucidated by contrasting JE activity and the major components associated with JE virus transmission for Badu Is. and Cape York (Tables 1, 2). We can clearly see that on Badu Is. the virus activity was greatest in 1998, reflecting the fourfold increase in mosquito populations over 1995. Because of the vaccination program (ca. 90% of population of 800 received at least one dose of JE vaccine), humans were not bled to estimate the human infection rate. However, as a single unvaccinated person did develop clinical JE, the rate of human infection can be estimated using the clinical/subclinical ratio for JE in man.

In the 1995 outbreak, it was estimated that only 1/50 infections resulted in clinical symptoms. So in 1998 the single clinical JE case suggests that 50 of the unvaccinated people (80) may have been exposed to JE virus, a total of 62%. To be conservative, we suggest that 50% may have been infected. This is backed up by the high number of virus isolations (43) obtained in 2 nights of mosquito trapping on Badu.

Table 1. Comparison of Japanese encephalitis activity in Badu Is. and selected regions of Cape York.

Parameter	Badu Is. (1995)	Badu Is. (1998)	Cape York (Kowanyama, Pormpuraaw 98-99)	Cape York (NPA 1998)
Pig seroconversions (ca.%)	100%	100%	65%	50%
Mosquito JE virus isolates	8	43	0	0
Duration of seroconversion	< 2 months	< 2 months	?	> 2 months
Human cases (ca. % infections)	**3 (17%)**	**1 (50%)**	**1 (0.2%)**	**0 (0%)**

Table 2. Comparison of key parameters associated with JE virus transmission in Badu Is. and selected regions of Cape York. Note, it is assumed that there are numerous dogs and humans as "alternative hosts" to swine in all communities.

Parameter	Badu Is. (1995)	Badu Is. (1998)	Cape York (Kowanyama, Pormpuraaw 98-99)	Cape York (NPA 1998)
***C. annulirostris* population**	100 – 500/trap	500 – 2000/trap	500 – 1000/trap	100 – 500/trap
Domestic pig population	Ca. 200	Ca. 120	Ca. 5	Ca. 50
Feral pigs	Yes, ? number	Yes, ? number	Yes, locally high	Yes, high locally
Livestock	Horses	Horses	Cattle	Cattle, horses
Other alternative hosts	No wallabies	No wallabies	Many wallabies	Many wallabies
% feeding on pigs by *C. annulirostris*	33%[1]	33%[1]	1%	20%

[1]*Based on data from mosquitoes collected in 1996.*

In the NPA, mosquito numbers were lower (Table 2) but comparable to those on Badu Is. during the 1995 outbreak. Thus mosquito abundance does not seem to account for the low JE activity in the NPA. However, there are some critical differences in vertebrate host populations. Domestic pig populations were high on Badu, with most of the pigs in backyard piggeries. NPA pigs were in larger communal piggeries (ca. 10-20/ site), with many located outside urban areas (Bamaga, Umagico). This may account for the lack of human infection, but does not explain why JE virus activity itself was low in the NPA.

Perhaps a high level of alternative hosts on the NPA dampened JE transmission, a situation termed zooprophylaxis. In Sri Lanka, Pieris et al. (1993) observed that in rural areas with high populations of domestic pigs, pigs are subject to synchronous JE transmission: all pigs seroconvert within ca. 2 cycles of the virus in pigs (ca. 1 month), a situation comparable to Badu Is. However, in areas where cattle are common, pig seroconversion is spotty and staggered (termed asynchronous), much like the situation in the NPA in 1998.

Could zooprophylaxis have reduced JE transmission in the NPA? The Badu community did have many horses but no other large vertebrates except man, dogs and pigs. In the NPA, cattle were common and horses and wallabies were also observed. Perhaps most telling is the study of feeding preferences of *C. annulirostris* in Kowanyama by Kay et al. (1979) where in stable traps baited with pigs, dogs, calves, chickens, kangaroo and man, pigs were 2nd in preference after calves to bloodfeeding *C. annulirostris*. However, bloodmeals from wild mosquitoes contained few (ca. 3%) feedings on pigs, with most (ca. 60%) on dogs. This, to a large extent, reflects the fact that mosquitoes were collected within the community where dogs were common.

Bloodmeal analysis of mosquitoes collected in the Cape during the 1998 JE outbreak demonstrated that *C. annulirostris* did not feed predominantly on pigs. Less than 2% of the *C. annulirostris* collected in rural areas near Kowanyama and Pormpuraaw had fed on pigs, with a majority of feeds upon marsupials (39% and 90% for the respective communities). However, where mosquitoes were trapped near penned domestic pigs, such as Baa's Yard near the Mitchell River and Seisia in the NPA, feedings on swine were higher (86% and 20%, respectively).

These data, together with the low rate of seroconversion in the NPA in 1998 despite an immunonaive pig population, suggest that feral pig populations may not induce epidemics of JE in Cape York. Why? Certainly populations of feral pigs are high in the NPA and Cape York area. Also crossreacting flaviviruses common to the area, such as Kokobera, Alfuy and Kunjin virus, may serve to protect pigs from infection by JE. Zooprophylaxis induced by other fauna such as cattle and, especially, wallabies may reduce JE virus transmission. But perhaps the most important factor is the relationship between feral pig populations and *C. annulirostris*. While this mosquito readily feeds on pigs, few mosquitoes collected away from penned swine contained pig blood. It may be that feral pigs are not as good a host as domestic pigs. Feral pigs are generally active at night (J. Shield and J. Lee, personnel communication) and may actively engage in anti-mosquito behaviour or flee from mosquito-infested areas. Domestic pigs are confined in small pens and, as they are fed during the day, may sleep during much of the night. This would lead to numerous full bloodmeals by mosquitoes, enhancing virus transmission. Finally, feral pigs wallow in mud, creating a coat of crusty soil that may protect them from mosquito bites (J. Shield, personal communication). Further work is needed to elucidate the enigmatic role that ferals pigs play in the ecology of JE virus in Cape York.

Veterinary status of feral pigs on Cape York

SHIELD, J.

Queensland Department of Primary Industries
Cairns

ABSTRACT

Feral pigs carry several zoonotic diseases of significance to public health. They are also of inestimable significance as potential hosts of exotic animal disease plagues like Foot-and- Mouth and Swine Fever. This papers lists and discusses some infectious disease conditions that are prevalent in feral pigs on Cape York.

INTRODUCTION

Although it is the most abundant of the mammals on Cape York and is relatively large and conspicuous, the feral pig has not been well studied as a subject of veterinary interest. There have been only a few surveys on its health; much of what we know is based on assumption and speculation. Some of the assumptions and speculation are soundly based on the knowledge that the animal is the same basic *Sus scrofa* as our domestic pig, and we do know a lot about the disease problems in our piggeries. Many of the other perceptions on feral pig health, however, are poorly founded on emotive and non-scientific judgements not unlike those that keep half of the world's population from eating any pig meat. The current situation is slightly ridiculous, where most (non indigenous) people on Cape York would rather starve than eat even the choicest porker running wild on his property, and yet foul-smelling old boars from the same place find a ready market on sophisticated dinner tables in Europe.

Feral pigs carry a number of zoonotic diseases of high importance to public health; they are also of inestimable significance as potential hosts of exotic animal disease plagues like foot and mouth and swine fever. With these qualifications however, infectious disease does not appear to be a huge factor in the population dynamics of the feral pig. On Cape York Peninsula, infectious diseases have a minor impact on populations compared with the effects of seasonal (un)availability of food. The reproductive success of a Cape York sow is more dependent on her ability to find food, and on the predations of birds, dingoes and snakes than it is on her exposure to leptospirosis or parvovirus.

Notwithstanding the above, the following attempt is made to list and discuss some infectious disease conditions that do or may infect the feral pigs of the region.

ENDEMIC DISEASES

Tuberculosis (TB):
TB has just recently been eradicated from the Queensland cattle herd, with the use of massive testing programs and slaughter of large numbers of cattle. Throughout the program (20 years), there was a fear that feral pigs would be infected through close contact with tuberculous cattle or through eating the bodies of infected slaughtered animals. There was never any evidence that this happened in Queensland although it was a feature of some of the infected areas of the Northern Territory where there was a lot of TB in the buffalo and a very close association between pigs, swamps and buffalo.

Brucellosis:
The same national (BTEC) disease eradication scheme that eradicated TB also removed bovine brucellosis. Pigs however have their own brucellosis and the bacterium *Brucella suis* is present in many feral populations including those on Cape York. It causes reproductive disease and other problems in the pigs. The main impact on us however is that *Brucella suis* can:

- Cause human disease
- Infect cattle where it may create 'false positive' tests in disease surveys for bovine brucellosis

Leptospirosis:
Feral pigs commonly contract leptospirosis because it is a disease of wet conditions and pigs choose such conditions. Leptospirosis is also very important because it is a dangerous zoonosis: people handling live or dead feral pigs should take precautions to prevent becoming infected particularly through contact with the pigs' urine or other body fluids.

Melioidosis:
This is another bacterial disease found in feral pigs and capable of causing serious illness in man. In pigs it causes usually small abscesses and no significant illness; in humans however the abscesses can be severe and sometimes fatal. Humans are more likely, though, to contract the disease from infected soil in cuts and scratches, than from contact with even an infected pig.

Sparganosis:
This is a condition caused by a small tapeworm that cycles through cats, invertebrates, tadpoles and frogs. Pigs become infected through eating one of the above smaller animals carrying an intermediate stage of the tapeworm; humans can become infected similarly by ingesting one of the smaller hosts or while slaughtering or eating an infected pig. Sparganosis is listed because it is frequently discussed and historically quite significant; it is however of little clinical importance and now rarely found.

There are a host of other endemic diseases that may affect the feral pig; in some cases, serological tests on blood samples show that exposure does occur but without any evidence that this is of more than academic interest.

EXOTIC DISEASES
It must be assumed that every pig disease that is not already in Australia is an exotic threat and that it is capable of infecting the feral pigs of Cape York. Some of these, like foot and mouth disease, represent agricultural disaster of the highest order, while others would have such a small impact that their introduction would not even be noticed. For the purpose of brevity, I have selected, from a long list, only a few diseases for special mention: *Foot and mouth disease, Swine vesicular disease, Vesicular exanthema, Vesicular stomatitis, Classical swine fever, African swine fever, Aujeszky's disease, Porcine reproductive and respiratory syndrome, Transmissible gastroenteritis.* These are the most feared of the exotic viral diseases of pigs. They are highly infectious, spreading from pig to pig through close contact. They occur throughout many parts of the world and some of them are relatively close to us in parts of South East Asia. All of these diseases would be expected to produce high morbidity in pigs. More importantly, their presence in Australia would cause immediate trade effects, which would damage the embattled pig meat industry severely.

Screw worm fly (SWF):
SWF is endemic in Papua New Guinea in areas only a few kilometres from Australia's northernmost islands. This lethal blowfly lays it's eggs in a wound on any warm-blooded animal and the resulting fly 'strike' can cause severe injury and often death. If SWF reached Cape York it could be expected to affect feral pigs as well as cattle, horses and other domestic, wild and feral animals; humans too can become victims.

Japanese encephalitis:
This mosquito-borne disease reached the mainland of Australia in 1998 when it was found in the Mitchell River area and near the 'Tip'. It has not yet been determined if this was a transient incursion or if JE is now endemic in Cape York. While primarily a human disease problem, JE does also affect pigs (causing reproductive problems) and horses (causing encephalitis), but the impact of this effect is not likely to be noticed in the Cape York population. The paper by Dr Ritchie elaborates on the interdependence between the JE virus, pigs and the *Culex* mosquito.

The arrival of JE has once again focussed public attention and imagination on a desire for Cape York to be free of feral pigs. Like any disease control agency, the Department of Primary Industries would like nothing better.

Cysticercosis and trichinosis:
These are serious diseases caused by worm parasites. Cysticercosis is caused by the pork tapeworm *Taenia solium* and it can cause severe illness and death in humans. It is now endemic in Irian Jaya and could spread throughout the island of New Guinea and threaten the islands of the Torres Strait.

Trichinosis is caused by tiny *Trichinella* nematode worms. It is widespread throughout the world and causes disease and even death in humans.

Both of these diseases affect people who eat the improperly cooked meat of infected pigs: they therefore are commonest in areas where these diet habits are accepted in culture and tradition. In the islands of the Torres Strait and in parts of Cape York, cysticercosis and trichinosis could be expected to survive and cause human suffering.

EXOTIC DISEASE RESPONSE

An Australian outbreak of any of these would trigger a response involving all states and the Commonwealth and the implementation of an existing framework of actions under AUSVETPLAN, The Australian Veterinary Emergency Plan. AUSVETPLAN outlines in detail the strategies required for each disease, each industry and each agency.

In the past Australia has successfully eradicated outbreaks of a number of these diseases including Foot and Mouth and Classical swine fever. In recent years AUSVETPLAN has been tested in successful eradication programs against poultry exotic diseases.

One thing that is repeatedly demonstrated by disease outbreaks and by simulations, is the extreme difficulty of eradicating a disease once it becomes established in a wild or feral population. This is considerably more of a problem if the terrain is inaccessible. Cape York, because of it’s large pig population and huge areas of inaccessible country, represents perhaps the worst place to have to eradicate an exotic disease.

Feral pig in wallow

Pig damage to lowland swamp vegetation in Edmund Kennedy National Park: the fenced area has been protected from pigs

Pigs captured in a fence trap in Edmund Kennedy National Park

The ecological damage of pigs tends to be highly concentrated in certain micro-habitats like the fringes of swamps and wetlands in Malaleuca woodland

Photographs: Jim Mitchell

Pig caught in a trap operated by the community based feral pig trapping program, approximately 2000 pigs are killed annually under this scheme (*Photograph: Jim Mitchell*)

The feral pig (*Sus scrofa*)
(*Photograph: Jim Mitchell*)

Pigs, when in close proximity to human populations and exposed to mosquito attack, as in domestic piggeries on Torres Strait Island, increase the risk of transmission of Japanese Encephalitis to people (*Photograph: Jonathan Lee*)

PART 3

POPULATION BIOLOGY AND CONTROL OF FERAL PIGS

The dynamics of feral pig populations in Australia: implications for management

GILES, J. R.

Conservation and Research
Zoological Parks Board of New South Wales

ABSTRACT

This paper reviews studies of the population dynamics of feral pigs, and considers the implications of the population biology of pigs for effective control. Pigs have a capacity for rapid population increase. Unless populations are reduced by 70% or more, recovery to pre-control levels is likely within two years. This rapid recovery means that control efforts must be able to achieve very large reductions over short periods of time if control is to be effective. Otherwise, control programs are likely to end up as expensive sustained yield harvesting operations of little value in reducing unwanted impacts of feral pigs.

INTRODUCTION

There have been several large, long-term studies of the dynamics of feral pig populations. The most comprehensive have been by Giles (1980) and Choquenot (1994) in semi arid rangelands in NSW, Saunders (1988, 1993a) in sub-alpine NSW and Caley (1993) in the Wet Tropics. These studies have yielded broadly similar pictures of the biology and ecology of the species with regional and temporal variation in its population dynamics, and have been drawn upon heavily in the material presented in this brief review.

DISTRIBUTION AND ABUNDANCE

Choquenot *et al.* (1996) gave an excellent summary of contemporary information on distribution and abundance. Feral pigs are widely distributed in Australia with the major populations associated with river systems and floodplains.

Estimates of population densities are summarised by Choquenot *et al.* (1996). These range from less than one pig per km^2 in semi-arid rangelands (Giles 1980, Choquenot 1994) to up to 20 km^2 in wetlands, swamps and sub-tropical floodplains (Giles 1980, Saunders 1988, Hone 1990, Dexter 1990). Local population densities around crops can reach higher levels.

Giles (1980) reported considerable temporal variation in population density in both the Macquarie Marshes and on an ephemeral floodplain in western NSW, with numbers rising sharply after drought, peaking and then declining as seasonal conditions deteriorated. Pigs born at around the time of the population peak had low juvenile survival rates and grew to be much smaller in both adult liveweight and skeletal size than those born early in the post-drought eruption.

Essential requirements for permanent populations include water, shelter and suitable food. As monogastrics, pigs have a poor capacity to digest cellulose and cannot survive on hayed-off grasses and forbs. They are opportunist omnivores with a strong preference for succulent green vegetation, a wide variety of animal material, fruit and grain. They also utilise seeds, bulbs, roots and corms, particularly during dry periods.

Protein requirements of pigs are high compared to ruminants. At dietary crude protein intake below 15%, Giles (1980) found that pre-weaning mortality was high. The energy requirements of pigs are also relatively high: this is particularly true of sows in the last month of pregnancy and during lactation.

Periodic protein shortage is probably the factor which most commonly limits feral pig population growth in Australia. This is likely to occur in the dry season in the Wet Tropics, during winter at high elevations and during periods of low rainfall or lack of flooding in the rangelands, particularly when populations are at relatively high density.

REPRODUCTION

Giles (1980) found that feral pigs in western NSW first bred at 20 -25 kg liveweight if they were under about 18 months of age, and at 25-30 kg if they were older. Unlike the Eurasian wild boar, which has a distinct breeding season, feral pigs have not been found to exhibit a non-breeding season, except in the Southern Alps of NSW where Saunders and Giles (1995) found a seasonal anoestrus in autumn and early winter, as occurs in wild boar in northern latitudes.

Table 1 summarises key reproductive data from three habitats in NSW presented by Giles (1980) and Saunders and Giles (1995). It is notable that mean litter size is much smaller than in domestic pigs.

MORTALITY PATTERNS

Table 2 summarises age specific mortality found by Saunders and Giles (1995) and Giles (1980) in three NSW habitats.

The table shows that, in these habitats:

i) a high proportion of pigs die in the first year of life;

ii) few animals survive beyond four years of age

iii) juvenile mortality on the flood plain was higher than in the other habitats but, otherwise, the mortality patterns are broadly similar.

Table 1. Key reproductive attributes of feral pigs in three habitats in NSW (from Giles 1980, Saunders and Giles 1995). Numbers of samples are given in parenthesis.

Attribute	Kosciusko National Park	Macquarie Marshes	Western NSW (ephemeral floodplain)
Mean litter size at birth	6.25 (66)	6.92 (93)	6.29 (145)
Birth frequency per year	0.84	1.93	1.93

Table 2. Mortality patterns of feral pigs from three habitats in NSW (after Saunders and Giles 1995 and Giles 1980). Statistics tabulated are age class at commencement of the year, probability of surviving to age x (l_x), probability of dying between ages x and x+1 (d_x) and mortality rate q_x, the proportion of animals alive at age x that die before age x+1 (d_x/l_x).

	Kosciusko NP			Macquarie Marshes			Western NSW floodplain		
Age class	l_x	d_x	q_x	l_x	d_x	q_x	l_x	d_x	q_x
0	1.00	0.85	0.85	1.00	0.89	0.89	1.00	0.94	0.94
1	0.15	0.06	0.40	0.11	0.03	0.27	0.06	0.02	0.34
2	0.09	0.02	0.22	0.08	0.02	0.28	0.04	0.01	0.25
3	0.07	0.02	0.29	0.06	0.03	0.45	0.03	0.01	0.28
>4	0.05	0.02	1.00	0.03	0.33	1.00	0.02	0.02	1.00

RATES OF INCREASE

The instantaneous (exponential) rate of increase (r) is the most common statistic used to describe the rate of population growth. The finite rate of increase (e^r) is the ratio of population size from one year to the next. A population will grow or decline in response to births, deaths, immigration and emigration. The instantaneous rate is zero when population size is static, positive when it has increased and negative when it has declined.

In planning pig control programs, one is centrally interested in the rate that the population will increase after the control program. At this time, resources available per surviving pig are likely to be high, favouring rapid population growth. Rates of increase of feral pig populations have been estimated in several studies, and found to vary with prevailing seasonal conditions and the size of the population relative to carrying capacity.

Giles (1980) estimated maximum rates of increase of pig populations in the Macquarie Marshes and on a semi-arid floodplain in western NSW to lie around 0.6-0.7. Hone and Pedersen (1980) reported a rate of increase of 0.57 over the year following a 58% population reduction in the population on the same western NSW floodplain. This is equivalent to a finite rate of 1.76 (i.e a 176% increase in numbers).

Caley (1993) reported a maximum rate of increase in a Wet Tropics population to be 0.065 per month, which is equivalent to 0.78 per year (a finite rate of 2.18 per year). Saunders (1993b) reported a rate of increase after a helicopter shooting campaign in the Macquarie Marshes to be 1.34 (a finite rate of almost 4.0) but noted that immigration into the study area possibly contributed to this very high rate.

Rates of increase (in the absence of immigration or emmigration) are highly dependent upon mortality in the first year of life, and mortality around the time of weaning varies greatly in response to availability of high protein food.

Table 3 shows the relationship of juvenile mortality rate ($q_{0.5}$) to the instantaneous (exponential) (r) and finite annual rate (e^r) of increase in a western NSW population (Giles 1980). Also shown is the numerical response two years after an instantaneous reduction of 70%, as might occur in a control program.

EFFICACY OF CONTROL PROGRAMS

Poisoning, trapping, shooting (from the ground and from helicopters) and dogging are the most common techniques used in Australia to manipulate feral pig populations. While population reductions of 90 to 100% were achieved b. McIlroy *et al.* (1989), reductions of 60-80% have been most common (Hone and Pedersen 1980, Hone 1983, Hone 1987, Mitchell 1988, Choquenot *et al* 1993, Saunders (1993b), McIlroy and Gifford 1997).

Table 3. The relationships in a western NSW population between juvenile mortality and rate of increase, and between rate of increase and predicted population size two years after a 70% reduction in initial population size (from Giles 1980).

Mortality rate in the first year of life ($q_{0.5}$)	Instantaneous rate of increase (r)	Finite rate of annual increase (e^r)	Predicted population size two years after 70% reduction. (N_0=100)
0.5	0.920	2.509	189.0
0.6	0.804	2.235	149.8
0.7	0.663	1.941	113.0
0.8	0.410	1.507	68.11
0.9	0.194	1.214	44.2
0.99	-0.225	0.799	19.1

From Table 3, it can be seen that a population reduction of the order of 70% or below, is likely to result in recovery to pre-control levels within a couple of years if r is about 0.6 or above. Several studies have shown that maximum rates of increase of this level and above are likely after control programs.

Because of the capacity of pig populations to increase rapidly after a control program, it can be difficult to avoid control efforts ending up as expensive sustained yield harvesting operations. Maximum population reduction over a short period of time is clearly fundamental to effective control. This is often difficult to achieve over large areas and in difficult terrain. A capacity to reduce the maximum rate of increase would be of great advantage. This would require one or more of the following: reduction in frequency of birth, reduction in litter size and reduction in first year survival rates.

Ecology and management of feral pigs in the Wet Tropics

MITCHELL, J.

Department of Natural Resources and Mines
Charters Towers, Queensland

ABSTRACT

Information on the ecological impacts of feral pigs (*Sus scrofa*) in the world heritage listed tropical rainforests of northern Queensland, Australia, is limited. This study quantifies and qualifies aspects of the ecological impact, spatial and temporal digging activities and home range and seasonal movement patterns of feral pigs. Digging by pigs varies seasonally and according to microhabitat, with the highest levels of digging occurring in moist microhabitats at the start of the dry season. Feral pigs in this region have defined sedentary home ranges and their distribution patterns appear to be influenced by microhabitat factors, including earthworm populations and water availability. Digging activity decreases seedling survival rates in moist microhabitats by 36%. Management strategies should concentrate on a coordinated, regional, community based approach.

INTRODUCTION

The World Heritage Area (WHA) listed rainforest of the wet tropics region of northeast Queensland, Australia, covers over 9,000 km^2 and is regarded as natural heritage of outstanding universal value and one of the most significant regional ecosystems in the world. Feral pigs have been accused of posing many diverse threats to the conservation values of the World Heritage Area. To understand the "threat" to World Heritage values, information is required on the actual impact of feral pigs on this environment. Clarification of the impact of feral pigs in relation to season, severity, diversity and situation is a fundamental component of developing a management plan.

This paper summarises research currently being undertaken to acquire quantitative knowledge on the ecological impact and ecology of feral pigs within the rainforests of northern Queensland. The research is presented as four studies: spatial and temporal digging patterns, ecological impact of pig diggings, home range and seasonal movement patterns, and biological parameters.

STUDY SITE

The study site is situated near Cardwell, north Queensland, Australia (18° 16′ S, 146° 2′ E). This area was selected, as significant feral pig populations existed in the area (Mitchell and Mayer 1997) and a variety of habitat types were available within the region, ranging from highland rainforests to lowland dry rainforest, open woodlands, marine swamps and mangroves. The variety of habitat types was ideal for assessing the influence of microhabitat and macrohabitat factors on feral pig spatial patterns.

The study region was divided into three broad macrohabitats defined by broad biogeographical "areas"; these include highland rainforests, the ecotone between rainforests and cropping systems, and the coastal lowlands. Within each of the three areas, a number of key microhabitats termed "strata" were selected based on the presence of pig activity, previously established microhabitat preferences (Mitchell and Mayer 1997) and the major microhabitat types represented in the area.

RESULTS

Spatial and Temporal Digging patterns

Patterns of feral pig digging (rooting) activity, both spatially (between macro and microhabitats) and temporally (between seasons) were monitored over a two year period. Associations between these digging patterns and soil moisture and earthworm population levels were also examined.

Three macrohabitat areas were assessed: highland rainforests, transitional or ecotone between rainforest and lowland open forests, and coastal lowland. A range of microhabitat strata was selected within each macrohabitat area, such as swamps, old logging tracks, dirt roads and creeks. Monitoring at 6 -week intervals, assessed digging activity on 195 line intercept transects (50m). A digging index (proportion of each transect disturbed) was established for each transect for each of the 10 recording events. The analysis assessed patterns in the digging index across seasons (wet and dry) and across microhabitat strata, within and between the three macrohabitat areas. An index of earthworm populations was also monitored to determine their association with the digging index.

Spatial and temporal patterns of feral pig digging activity were detected within the study area, specific microhabitats were found to have significantly higher digging activity overall and in specific seasons. Rainfall (soil moisture) appeared to be the major influence on these digging patterns; higher rates of diggings occurred in the early dry season and predominantly in moist microhabitats (swamp and creek microhabitats). The mean digging index over all strata within the three areas was 6% of the soil surface being recently disturbed by feral pigs.

Differences in the mean digging index between the three areas were apparent, with the highland rainforests recording the highest digging index. This suggests either that there were higher pig population densities in the highland rainforests or that digging is a more prominent foraging activity in this area. Differences in digging activity between the various microhabitats were also observed in all of the three areas. In the highlands there was a significantly higher digging activity in the swamp and creek strata. Overall ranking of stratum preference was for highest digging index in swamp (19.3%), creek (9.7%) road (8.0%) track (3.0%) and the lowest preference for the forest floor (0.1%).

In the transitional area, the creek stratum had significantly higher digging activity (8.5%) than the track stratum (0.6%). Digging activity was significantly associated with soil moisture in this creek stratum and tended to be strongly seasonal with higher digging activity occurring in the dry season. Digging activity increased in the creeks when soil moisture levels dropped sufficiently for earthworm populations to survive and repopulate the creek bed. Dropping water levels also exposed fresh soil surface and flood debris material, which is attractive to foraging pigs.

No significant differences in overall digging activity were detected among the strata in the lowland area. Overall ranking of digging preference was for most diggings in the swamp (8.0%), creek (6.7%), tracks (4.9%) and the lowest preference for the woodland stratum (0.7%). This pattern of digging preferences in the moistest strata was similar to those observed in the highland and transitional areas.

Patterns of digging activity over time were also observed. In general the highest digging activity tended to occur at the cessation of the wet season (start of the dry season). A distinct trend of increasing digging activity was evident as the soil started to dry out; this was very distinct in the table drains of the road strata. This trend may be due to the soil becoming more compacted when dry, making digging more difficult, therefore drawing pigs to areas where soil is easier to dig such as the moist soils in the swamps or creeks. Another possibility is that earthworm populations increase when soil moisture levels are optimal, thus pigs may be increasing their digging activity to reach this high protein food source (French *et al.* 1957). Root mass also increases with optimal soil moisture levels (especially the fine feeder roots) and pigs may be digging more to reach this high energy food source.

The importance of earthworms in the diet of pigs is unknown in this region. Dry soil conditions tend to force worm populations to move to deeper soil horizons, beyond the reach of pigs (Lee 1985). The non-availability of earthworms in some strata during the dry season may encourage pigs to move to alternative microhabitats where conditions are more favourable. This may be linked to nutritional requirements, especially in relation to protein. Earthworms have a high protein content (50 to 60%) (French *et al.* 1957). The effects of the seasonal fruiting cycle may also be important. McIlroy (1993) believed that nutrition may be the dominant factor influencing pig movements in this area.

The frequency of diggings within the microhabitats was also used to compare with the digging index.

For the highlands a mean of 77% of transects were effected by some pig diggings for each sampling event (transitional area 58%; lowland area 85%). Over all three areas, a mean of 59% of transects were affected by some new pig diggings at each sampling event. Mitchell and Mayer (1997) found 63% of their transects had some diggings, although this represented total diggings and not just recent diggings.

Significant variation in mean frequency of diggings among strata was also detected for the highland and transitional area; no differences were detected for the lowland area. In the highland area, all strata had significantly higher frequencies of diggings then the ridge stratum. In the transitional area the creek stratum had a significantly higher frequency of diggings than the road stratum.

The magnitude of differences in frequency of diggings among strata was influenced by season. For the highland area significant differences between strata were detected in the dry season. For the transitional area significant differences in frequency of diggings between strata also occurred in the dry season. In the lowland area only one sampling event (dry season) recorded significant differences in frequency of diggings between strata. Thus it appears that feral pigs concentrate in the wetter microhabitats during the dry season and spread out evenly over all microhabitats during the wet season.

Ecological Impacts of Feral Pig Diggings

The aim of this research was to quantify aspects of the ecology of feral pig diggings using exclosures. The recovery of selected ecological parameters in exclosure plots protected from feral pig diggings was compared with control plots not protected from pig diggings.

Pig-proof exclosures (10m x 10m) were established in two microhabitat strata (wet areas and dry tracks) in the highland rainforest area only. For each microhabitat three sites were selected and for each site two replicate exclosures were established giving a total of 12 exclosures. Indices representing four ecological parameters were measured in each exclosure and in two (unfenced) control plots established adjacent to each exclosure. The ecological parameters were seedling germination and establishment, above ground biomass, below ground biomass and earthworm biomass. Exclosures were monitored at 4 to 6 weekly intervals over a 2-year period. The exclosures have now been protected from feral pig impact for 4 years.

Feral pigs were shown to have a substantial impact on seedlings of rainforest tree species. The mean number of seedlings that were alive at each sampling event within the exclosures was 36% higher then recorded in the control plots where feral pig digging activity had been occurring (27% dry stratum, 44% wet stratum). Results also indicated that seedling germination and survival rates within the exclosures were 20% higher than the controls. No significant differences were detected in above ground biomass, below ground biomass and earthworm biomass between the exclosures and the control plots.

Feral Pig Movement Patterns

The aim of this research was to develop a model of feral pig movements in relation to seasonal influences and to document home ranges and habitat usage in the coastal lowlands. A total of 41 feral pigs (19 females and 22 males) were captured in traps and fitted with radio collars, 8 in the highlands, 19 in the transitional zone and 14 in the lowlands. Collared pigs were located from the ground at least once per month. Any pigs which could not be located from the ground (generally in the highland rainforests area) were located from aircraft.

No evidence of large-scale seasonal movements was evident for the pigs in the lowlands and the highlands. The transitional zone did record movements from the lowlands to the top of adjacent peaks (400m), however in all cases the pigs returned to the lowlands within a couple of days. The 8 pigs in the highlands did move into the western rainforest/open forest ecotone (movement of 3 km) and spent a considerable amount of time there. Observation revealed that the pigs were using the riparian vegetation along streams as travel corridors between rainforest and sclerophyll habitats.

For the wet and dry season, individual pigs on the lowland and transitional areas were radio located at 3 hr intervals continuously for 36 hours, and this was repeated each week for 3 weeks. A total of 11 feral pigs were collared, with sufficient data obtained for home range estimations on 7 in the transitional zone and 3 in the lowland zones. In general, males have a larger mean home range

(8.95 km^2) then females (2.35 km^2) and both have a larger mean home range in the dry season (9.94 km^2) then the wet season (3.1 km^2).

Biological Parameters

A trapping program was instigated in the three areas to capture feral pigs for biological investigations. A total of 317 pigs were captured over a two-year period. Ecological data on morphometrics, reproduction, diet and growth rates were collected. In the lowland area a mark- tag - release program was used for population estimation. Preliminary data suggest a pig population of 2 per km^2 exists in the lowland areas.

Backdating age estimation of known age pigs (less then 36 months) to determine birth dates revealed a significant peak in births in January, the start of the wet season. Dietary items seen from gross examination include earthworms, fruits, centipedes, grass, roots and plant material. Growth rates and morphological information suggest feral pigs within this rainforest region have faster growth rates and are on average 10 to 20 kg heavier then feral pigs in the dry tropical regions.

DISCUSSION

Feral pigs have been identified as a major issue facing the management of the wet tropics World Heritage Area. However the ecological effect of feral pig activity is difficult to quantify. Simple measurement of soil disturbance (diggings) is inadequate in understanding what “true” damage or otherwise is being imposed on the processes involved in the ecosystem. The main visual impact of feral pig damage is soil disturbance due to their searching behaviour for plant roots and soil invertebrates. Although animal signs do not necessarily correlate with population density or activity (Hone 1988), rooted ground has been used as an index of the impact of feral pigs on various environments.

Spatial and temporal patterns of feral pig digging activity were found within this study area for the two years of this study. In general particular microhabitats were found to have significantly higher digging activity overall and at specific sampling times of the year. Rainfall (through its effect on soil moisture) appeared to be the major influence on these digging patterns, with higher rates of digging occurring, for all of the strata, in the early dry season and predominantly in moist microhabitats (swamps and creeks). The impact of pig diggings on ecological processes is difficult to quantify over a short time frame. However pig diggings appear to influence the survival of seedlings, especially in the moist areas such as swamps and creeks. Although germination rates were similar in plots exposed to pig digging and plots protected from diggings, the number of surviving seedlings was 36% higher in protected plots. Although rainforest seedlings have a naturally high attrition rate, an increase in the attrition rate by 36% when pig digging impacts are added, may have important ecological implications for plant regeneration.

The absence of seasonal movements in the feral pig population is contrary to the general community perception. Most landholders within the region believe that feral pigs migrate down from the highlands to the coastal lowlands in the dry season to forage on the ripening sugar cane and banana crops, and return to the highlands in the wet season when the sugar cane is harvested. The results of this study do not support the existence of such a “seasonal migration”; rather, this seems to be a perception created by local movements by feral pigs inhabiting the transitional area, the rainforest-crop boundary. Home range studies suggests that feral pigs move greater distances and forage further when food and water becomes scarce in the dry season. This increased movement activity would put them in greater contact with humans especially during the sugar cane harvest season. During the wet season, feral pigs are more sedentary, food and water are abundant, and human activity is minimised within the crops. Thus human / pig interaction is lower in the wet season. This has lead to the perception of more pigs present in the dry season compared to the wet and the community perception that these pigs had to come from somewhere: the highland rainforests.

The formation of the WHA is perceived by many members of the public as primarily responsible for the economic losses incurred by the rural industries adjacent to the WHA and attributed to feral pigs. Pigs are an acknowledged pest of cane, bananas and other small crops on the north tropical coast. However the results of this study suggest that feral pig adjacent to and in some cases living on landholders’ properties are mainly responsible for this economic damage.

Control techniques on the WHA fringe need to be fully coordinated; poisoning, trapping, hunting and fencing techniques can all be implemented if the activities are integrated into a control strategy. For example large scale trapping programs can be established in environmental sensitive areas, or feral pig concentration areas where landholder groups are available to interact with the program. Hunting by licensed hunters would be suited to areas with low pig populations, or areas inaccessible to other control techniques. Fencing can be employed in high-return cropping or intensive agriculture situations where the cost is warranted. Fencing may also be an option in small sensitive conservation areas or where rare or endangered species are localised, although the impact on other species needs to be considered.

The implementation of a feral pig management strategy must rely on a clear understanding of the severity of ecological impact of pig diggings on WHA values and also the level of population control required to protect these values. Additional research information is required on "best practice" control techniques to develop efficient, cost effective and specific population control. A sound management plan needs to coordinate, monitor, evaluate and continually evolve with developing strategic directions.

Monitoring impacts and control of feral pigs: A case study in Namadgi National Park, A.C.T.

HONE, J.

Applied Ecology Research Group
University of Canberra, A.C.T.

ABSTRACT

This paper is an overview of the monitoring of the occurrence of feral pig (*Sus scrofa*) impacts, such as ground rooting, and pig abundance in Namadgi National Park, ACT. The park has an area of about 1060 km^2 comprising mountain forests and woodlands ranging from 800 m to 1900 m in elevation. A series of commonly asked questions about the monitoring and pig control are posed and answered.

Monitoring of other impacts, such as crop and pasture damage and lamb predation, will require different methods. However like monitoring pig rooting they also require use of elements of sampling theory and the principles of experimental design. Choquenot *et al*. (1996) provide an overview of many such monitoring methods, and they distinguish between operational and performance monitoring. The monitoring in Namadgi is performance monitoring - measuring the effect of management.

WHAT ARE THE IMPACTS?

Ground rooting decreases plant species richness in grassland in the short-term (Hone unpublished data). Rooting can also cause the abundance of some plant species to increase and other plant species to decrease (Alexiou 1984). Pigs are accused of other impacts such as erosion but this has not been studied. Another impact is on visitor's enjoyment of the park. Visitors complain to park rangers when they find large areas of grassland rooted over by pigs. This is a visual impact.

WHAT RELEVANT MANAGEMENT AND RESEARCH HAS OCCURRED?

Feral pig control occurs annually in Namadgi National Park in autumn using wheat soaked in warfarin. Details of the pig control work, which started in 1985, are described in Hone (1987), McIlroy *et al*. (1989) and Hone and Stone (1989). The management aim is stated in the Park Management Plan of 1986 as "to protect the park and adjacent areas from damaging effects of pest plants and animals." The pig control work is based on considerable field research in Namadgi, and nearby Kosciuszko National Park, and earlier pen experiments. That research has been on the effectiveness of the poison, warfarin, in pen (Hone & Kleba 1984, O'Brien & Lukins 1990) and field studies (McIlroy *et al*. 1989), and by theoretical modelling (Hone 1992); evaluation of bait consumption (McIlroy *et al*. 1993, Saunders *et al*. 1993) and other methods such as hunting with dogs (McIlroy & Saillard 1989), and trapping (Saunders *et al*. 1993); pig demography (Saunders 1993); pig movements (McIlroy *et al*. 1989, Pech & McIlroy 1990, Saunders & Kay 1996); and non-target aspects of warfarin poisoning (McIlroy *et al*. 1989, McIlroy *et al*. 1993).

WHAT IS MONITORED?

Two parameters are monitored; extant ground rooting and pig abundance. The frequency of occurrence of rooting is positively correlated with the extent of ground rooting in each month, except December, of the year ($P<0.05$) (Hone 1988a) and the frequency of dung counts is positively correlated with observed pig density (R^2 = 0.66, $P<0.01$) (Hone 1995). The abundance of dung and the frequency of occurrence of dung are highly positively correlated ($P<0.05$) (Hone 1998a). It is emphasised that the monitoring was started to answer questions about short-term effects of pig control on rooting and abundance, largely relating to exotic disease contingency planning (especially for foot and mouth disease) rather than to conservation of biodiversity. Also the sampling intensity required was estimated based on pig abundance in 1985, which was many times higher than that it is in 1999.

HOW IS IT MONITORED?

In summary, there are 700 set plots which were semi-randomly selected across a range of vegetation types in the eastern half of the park. The placement and orientation of plots were randomly selected within each of seven sites. The frequency of monitoring was initially monthly (1985-1986), then seasonally (1986-1988), and now annually (to 1999). The variables are monitored on set plots using the line intercept method (for extant rooting) on lines each 10 m long, or area counts (for fresh dung) on plots 10 m by 2 m. Dung are cleared off plots after counting. In most analyses data are collated across all 700 plots. Details of monitoring methods are described in Hone (1988a), Hone and Stone (1989), Hone (1995) and Hone and Martin (1998). Estimates of the short-term effects of poisoning on pig abundance have been compared between data using dung counts (Hone 1987) and data using radio-tracking (McIlroy *et al*. 1989) and found to be very similar (about 94%). The monitoring could be used to detect small changes in pig rooting and abundance but would require an increased number of plots.

WHAT IS THE RELATIONSHIP BETWEEN IMPACTS AND PIG ABUNDANCE?

Choquenot *et al*. (1996) discuss the central role of the relationship between impacts and pig abundance in the effect of pig control on impacts. In Namadgi there is a positive curved (concave down) relationship across years between the abundance of pigs and the frequency of occurrence of pig rooting (R^2 = 0.49, $P<0.001$) (Hone unpublished data). The implication of this is that a large reduction in pig abundance is needed to get a substantial reduction in pig rooting. A small reduction of pig abundance, when that abundance is initially high, would give little or no change in pig rooting. There is a negative curved relationship between plant species richness and extent of pig rooting (R^2 = 0.53, $P<0.001$) (Hone unpublished data).

There is also a positive relationship between pig abundance and the monthly change in rooting (R^2 = 0.48, $P<0.05$) (Hone 1995). Hence when pigs numbers are high, then rooting increases and when pigs are few then rooting decreases. In between there is an estimated equilibrium level of pig abundance (dung on 3% of plots) at which the frequency of pig rooting does not change month to month. The relationships between impacts and costs need to be specified more closely. This will aid determination of the most cost-effective or cost benefit level of pig control.

WHAT ARE THE BENEFITS AND COSTS OF MONITORING?

The benefits are that managers learn the short and long term consequences of their actions, namely that pig abundance and rooting have declined substantially since 1985. The observed instantaneous rate of increase (r) of pig abundance is -0.15 (R^2 = 0.36, $P<0.01$) during 1985 to 1999 (Hone unpublished data). Hence monitoring is important to improving management and is part of the adaptive management used for pig control in Namadgi National Park. The monitoring has demonstrated a seasonal pattern in pig rooting, with peaks in spring and autumn (Hone 1987), which may be related to seasonal altitudinal movements of the pigs, and the planning and evaluation of pig control needs to take account of this pattern.

Monitoring has also identified the sites - high elevation ($P<0.05$) and low slope ($P<0.05$) - most likely to suffer pig rooting (Hone 1988b, 1995), so pig control can be strategically focussed at those sites. Pig control did not occur in 1989 and 1990 and monitoring showed pig abundance increased during those years. During 1996 and 1997 distribution of bait from helicopters ceased. Pig abundance did not increase but rooting did increase. The costs of monitoring are my time and equipment. These are about $2,600 per year. Note that the monitoring is independent of the pig control work. I do the monitoring and Environment ACT does the pig control work. An opportunity cost would be incurred if monitoring ceased, and historically would probably have stopped pig control.

PREDICTIONS FOR THE FUTURE

There are several predictions about future trends in rooting and pigs depending on whether pig control continues or ceases. Monitoring can allow testing of these predictions. If pig control continues there are two short-term predictions; one, pig rooting and pig abundance stay low as the baiting stays very effective, two, pig rooting and pig abundance slowly increase because of increasing bait aversion and or, development of warfarin resistance. If pig control ceases, for example because of funding cuts, there are three short-term predictions; one, that rooting and abundance stay low because pigs are limited by predation by wild dogs and maybe foxes, two, that rooting and abundance increase slowly because predators reduce rate of increase but do not stop it, and three, rooting and pig abundance increase at the intrinsic rate of increase (r_m). In the long-term there are three predictions for pig abundance; one, that it increases then reaches an equilibrium point (logistic growth, as assumed in Pech and Hone 1988), two, that it increases but then shows damped oscillations to an equilibrium point (as assumed in Hone 1988b) and three, that it oscillates over time around, but not reaching, an equilibrium point. Pig rooting would broadly follow the same patterns.

SUMMARY

We have learned that pig control can reduce pig rooting and pig abundance. The frequency of rooting and pigs are positively related, as are the monthly rate of change in pig rooting. Methods of ground survey have been developed and partly evaluated. A set of predictions of future short and long-term trends in pig rooting and abundance have been developed and could be tested.

We have not learned much about long-term impacts on specific plant and animal species, whether the conservation of any species is threatened by pigs, whether erosion is significantly increased by rooting, or about effects not related to rooting, such as from grazing and predation, and about non-target effects of baiting. Research overseas, especially in Hawaii and Great Smoky Mountains National Park (USA), suggest these could be important and worth study.

ACKNOWLEDGEMENTS

I thank the manager and staff of Namadgi National Park for support, and the University of Canberra for financial assistance.

The effectiveness of trapping in reducing pig abundance in the Wet Tropics of north Queensland

VERNES, K.[1], JOHNSON, C. N.[1], MITCHELL, J.[2]

[1]Department of Zoology and Tropical Ecology, James Cook University, Townsville
[2]Tropical Weeds Research Centre, Queensland DNR, Charters Towers

ABSTRACT

The ability of trapping to reduce pig numbers in the wet tropical lowlands of North Queensland was tested and the sensitivity of several indices of abundance of pigs (rate of production of diggings and dung, and disturbance of bait stations) to changes in pig abundance were compared. Reduction in pig abundance over three consecutive culls yielded an overall 82% decrease in the rate at which new diggings were made. In contrast to digging, the number of dung pellets observed on transects did not show a clear relationship with changing pig abundance. Visitation by pigs to bait stations did not show any obvious relationship with the reduction in pig numbers, probably due to the problem of contagion between bait stations. This study suggests that trapping should be useful in protecting environmentally sensitive areas from the mechanical impact of feral pigs, and may also provide a model for monitoring the effectiveness of trapping in intensive control operations in the Wet Tropics.

INTRODUCTION

Feral pigs *(Sus scrofa)* are believed to cause significant environmental damage to the rainforests of the Wet Tropics World Heritage Area (WTWHA), through a variety of processes including habitat destruction and alteration, dispersal of weeds, promotion of soil erosion (Mitchell and Mayer 1997), competition with native species (Pavlov et al. 1992; Laurance and Harrington 1997), and egg predation on sensitive bird species such as the cassowary, scrub turkey and scrub fowl (Hopkins and Graham 1995; Crome and Moore 1990). In addition, pigs are reservoirs of many endemic diseases and potential vectors of several exotic ones (Pavlov et al. 1992; Mitchell and Mayer 1997), and a variety of agricultural crops bordering the WTWHA are adversely affected by feral pigs (Mitchell 1993).

Options for reducing pig populations in the wet tropics are limited. Poisoning may be unacceptable because of its potential effects on non-target species, shooting may have little effect because of the inaccessibility of pigs in the difficult terrain and dense vegetation typical of much of the Wet Tropics, and hunting with dogs is inefficient because of low rates of encounter with pigs (Mitchell 1993). Trapping may be a useful technique for pig control, especially in the wet tropical lowlands. In this area access for trapping is easier than in the highlands and valuable conservation areas border sugar cane and banana farms that sustain high impact from pigs.

In this study we carried out a trial trapping program in the wet tropical lowlands of North Queensland. We trapped pigs in three intensive sessions spread over a four month period. Our objective was to reduce the pig population in our study area in three steps, producing four levels of abundance. Several indices of abundance of pigs (rate of production of diggings and dung, and disturbance of bait stations) were measured before and after each trap session, so that we could compare the ability of these indices to detect reductions of the pig population. This design also enabled us to calculate the number of pigs on the study area before and after trapping, using the index-removal-index method, and thereby to estimate the reduction in absolute abundance of pigs achieved by trapping.

METHODS

Study Area

The study was conducted at Edmund Kennedy National Park (18˚11'S, 145˚59'E), a lowland coastal region of the Australian Wet Tropics comprising a complex mosaic of woodland, dry rainforest, swamp and mangrove forest. The elevation of much of the park is less than 15 m above sea level. Swamp and mangrove occur at or near sea level, while rainforest and woodland occur along a series of ancient sand dunes (sand-ridges) throughout the park.

Two sites approximately 3 km apart were selected, each consisting of swamp and adjacent ridge habitats. The area around Dallachy Swamp (hereafter 'Dallachy') in the centre of the park was the control site, where pig abundance was not manipulated. The area around Duck Swamp (hereafter 'Duck') in the south of the park was the experimental site, where pigs were trapped. At each site, pig activity was surveyed over an area of approximately 80 ha, and at the Duck site pigs were trapped over an area of approximately 625 ha centred on the survey area. Pig control had not been attempted within this region of the park for several years.

Activity Transects

Belt-transects, each measuring 5 x 50 m, were established to monitor pig diggings and dung. At each site ten such transects were established on sand-ridge habitat, and ten in swamp habitat. Transects were spaced at least 50 m apart, and aligned roughly parallel to one another in each habitat type. Each transect was partitioned into 5x5 m segments, which were then each further subdivided into quarters. The percentage cover of pig digging (in 5% increments) was estimated for each of these quarters, and the coverage of existing diggings marked onto a diagrammatic representation of the transect.

In this way, diggings could be compared between census periods at a sufficiently fine scale to obtain precise estimates of the area of new diggings. The presence of dung in each 5x5 m transect segments was also recorded. Dung pellets were counted and removed at each census. Activity transects were established in June 1998, and all pig activity recorded. The transects were surveyed before the first trapping session, then re-surveyed after each trapping session. Each survey consisted of two passages over the transects 4-6 weeks apart, with the two passages used to estimate rate of deposition of dung and rate of production of diggings over that time interval.

Bait Stations

Bait stations were deployed and monitored daily along roads and tracks in each site during a period before and after each cull. Each station was baited with a small bunch of bananas. Thirty such stations were deployed at Dallachy and 35 at Duck. Bait stations were positioned approximately 100 m apart. Stations were monitored and re-baited daily until the rate of bait-take reached a level which was maintained for several consecutive days. On each occasion, this was achieved within seven days.

Trapping of Pigs

Nine circular 'silo' traps (Choquenot et al. 1996), each with a diameter of approximately 3-4-m, were positioned at Duck during August 1998. Traps were located adjacent to roads and tracks, and were spaced several hundred metres apart. Initially, traps were liberally baited with bananas and wired open to allow pigs free access. When a trap showed signs of pig usage (generally after a few days), it was set. Traps were set in the late afternoon and cleared early the following morning. All captured pigs were killed in the traps. Three culls were undertaken at approximately 4-6 week intervals.

Estimates of Abundance

The index-removal-index method of Caughley (1977) was used to obtain estimates of total numbers of pigs present on the Duck site before and after each trapping session. Individual estimates were calculated for swamp and ridge areas, as well as for both habitats combined. This method uses the following equations:

$$N_1 = x_1R/(x_1-x_2) \qquad \text{(Equation 1)}$$

$$N_2 = x_2R/(x_1-x_2) \qquad \text{(Equation 2)}$$

where N_1 is the population estimate before removal of pigs, N_2 is the population estimate after removal of pigs, x_1 denotes the rate at which new pig-sign is detected before pig removal, and x_2 denotes the rate at which new pig-sign is detected after removal of R pigs.

RESULTS

Removal of pigs

Pigs were removed from the experimental site (Duck) at three time periods throughout the study (Table 1). The third cull yielded pigs only on the first day, and over the following two days, no baits were disturbed, and no fresh pig tracks were seen around traps or on the roads which connected trap sites. This absence of pig-sign was taken to indicate low pig numbers in the area, and so trapping was stopped.

Rate of production of diggings

The percentage of ground dug by feral pigs throughout the study prior to any culling of pigs was 2.3 ± 0.4%. Swamps were dug on average twice as much (3.1 ± 0.3%) as ridges (1.4 ± 0.6%). Repeated measures ANOVA showed that treatment and habitat type had a significant effect on digging rate (Table 2a). The rate of digging was significantly lower on the sites where culling occurred, and lower on swamp transects than on ridge transects (Fig. 1). When the repeat factor (census period) was considered, the only significant effects on digging rate were census period and the interaction between census period and treatment (Table 2b). Digging rate declined significantly throughout the study, and did so only on transects where pig culling had occurred (Fig. 1).

There was a significant correlation between the rate of digging between census periods and the corresponding number of pigs removed (r=-0.964, df=2, p<0.05) (Fig. 2).

Table 1. Trapping periods, showing the number and sex of pigs removed.

Start date of Cull	Duration (days)	Pigs	Males	Females
05/08/98	9	9	6	3
01/09/98	6	8	4	4
18/10/98	3	2	2	0
Total	18	19	12	7

Table 2. Repeated measures ANOVA tables for the effects of treatment (pigs culled or not culled) and habitat (swamp or ridge) on the observed rate at which new diggings were added to transects during each of the four census periods.

(a) Between Subject Effects

Source	SS	DF	MS	F	P
Treatment	1.7341	1	1.7341	7.4181	0.01
Habitat	4.8766	1	4.8766	20.8609	<0.0001
Treatment*Habitat	1.1908	1	1.1908	5.0938	0.03
Error	8.4156	36	0.2338		

(b) Within Subject Effects

Source	SS	DF	MS	F	P
Census Period	2.6324	3	0.8775	10.45	<0.0001
Census* Treatment	2.5606	3	0.8535	10.16	<0.0001
Census* Habitat	0.1570	3	0.0523	0.62	0.60
Census* Treatment* Habitat	0.2900	3	0.0967	1.15	0.33
Error	9.0704	108	0.0840		

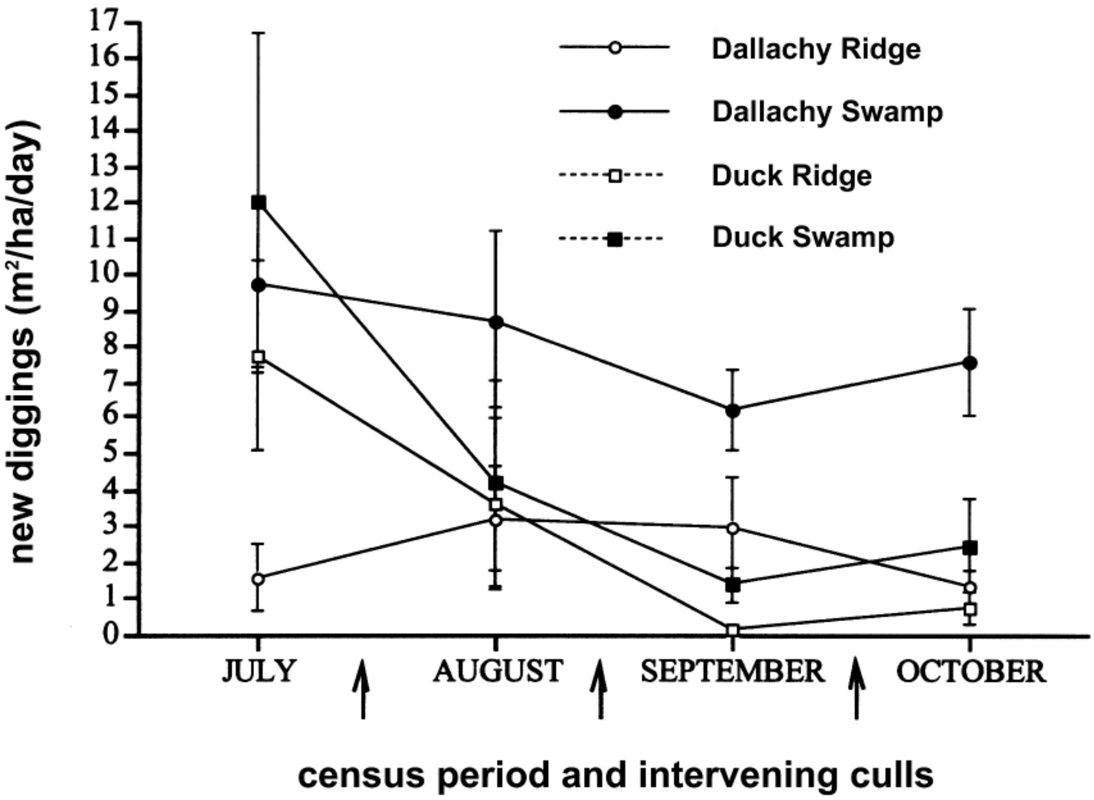

Figure 1. Changes in the rate at which new diggings were made at the Dallachy (control) and Duck (experimental) sites before and after each trapping session (indicated by arrows). Pigs were trapped only at the Duck Swamp and Duck Ridge sites.

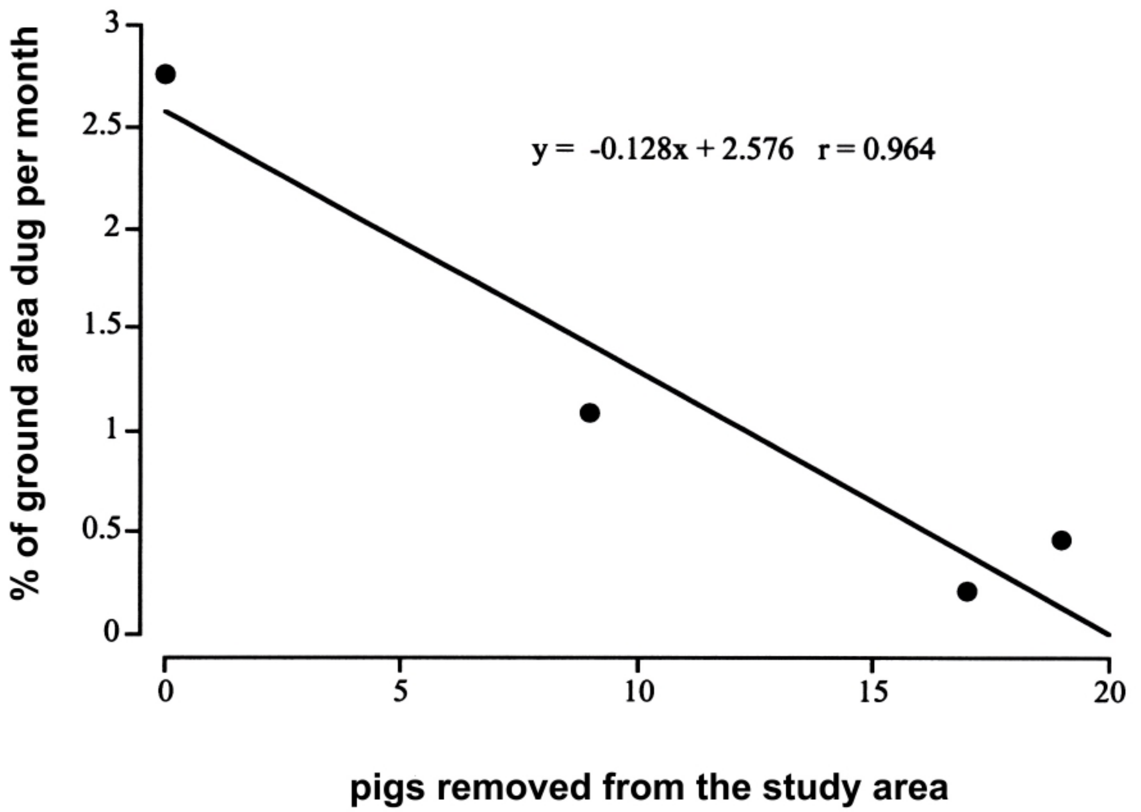

Figure 2. Relationship between the cumulative number of pigs removed and the percentage of ground disturbed per month by new diggings.

Rate of dung deposition

In contrast to digging activity, the number of dung pellets observed on transects did not show a clear relationship with number of pigs removed. Declines in the number of dung pellets at Duck were observed throughout the study (r=0.954, df=2, p<0.05), indicating this may have been in response to culling. However, declines were also observed on ridge transects at Dallachy, while in the swamp transects at this site, the amount of dung detected throughout the study increased considerably. Due to small number of transects where dung was actually recorded (most transects recorded zero), we were unable to examine these changes statistically using repeated measures ANOVA. It is clear, nonetheless, that the relationship between dung and numbers of pigs culled is far weaker than the relationship between new diggings and numbers of pigs removed.

Disturbance of bait stations

Disturbance by pigs of bait stations did not show any obvious relationship to the reduction in pig numbers brought about through culling. Before the first cull, consumption of baits at both control and experimental sites was 100% . Following each cull, however, consumption at the experimental site continued to peak at or near 100%.

Absolute abundance of pigs

The index-removal-index calculation (Equations 1 and 2) was used to obtain estimates of total numbers of pigs before and after each cull, using the rate of production of diggings as the index (Table 3). This suggested that approximately 15 pigs were using the transects before the first cull, and that 6 remained afterwards. Approximately 10 pigs were present before the second trapping session, and 2 remained after it. Only 2 pigs were trapped during the third cull. No dung was collected after this cull, but the digging data suggested that pigs were in fact still present in the area in roughly equivalent numbers to the period before the cull. Our traps were distributed over an area of approximately 600 ha, suggesting an initial density of 2-3 pigs per square kilometre.

Table 3. Estimation of the total numbers of pigs using swamp and ridge transects at the Duck site before and after each cull, based on the index-removal-index method. An estimate of total numbers of pigs at the Duck site was also calculated. Estimates could not be calculated on diggings before or after the October cull, due to a slight (and non-significant) increase in digging activity, resulting in negative estimated abundances.

Survey Month	Pigs Removed	Numbers present	
		Before	After
August	9	15	6
September	8	10	2
October	2	-	-

DISCUSSION

Monitoring techniques

The study tested several indices of feral pig abundance (rate of production of dung, diggings, and visitations to bait stations) against actual changes in the number of pigs. The rate at which new pig diggings were added to transects was the most meaningful of these indices. There was a significant and approximately linear negative relationship between the rate at which new diggings were added to transects and the cumulative number of pigs removed from the study area. This shows that production of diggings was indexing pig numbers. Some past studies have found a positive correlation between pig digging and observed pig density (eg. Ralph and Maxwell 1984 in Hone 1988b; Katahira *et al.* 1993). However, Hone (1988a) observed no significant correlation between these variables, and suggested that linear relationships reported in previous studies were unreliable (Hone 1988b). Two factors, however, distinguish the current study from many others. First, the rate at which new diggings were created was measured; other studies have simply recorded existing diggings of unknown age in one-off surveys. Second, this study compared rates of production of diggings with actual numbers of pigs removed through trapping, instead of with estimates such as numbers of pigs seen along a transect, which may themselves be subject to bias. Disturbance of bait stations proved to be of limited use during this study. This technique has been used in the past to monitor the abundance of large mammals including foxes (Thompson and Fleming 1994; Fleming 1997) and feral pigs (Choquenot *et al.* 1990), but we found that all bait stations were disturbed even when other evidence suggested that the number of pigs had been reduced.

This presumably was due to contagion, such that bait stations were not independently sampling pig activity and a small number of pigs were able to visit all stations. The likely cause of contagion in this study was the short 100 metre distances between bait stations. Also, bait stations were placed along roads. Pigs clearly utilize roads, and this would have made it more likely that a single pig could detect a series of bait stations during normal wandering.The rate of dung deposition has been used in several other studies as an index of abundance of feral pigs (Hone 1988; Aplet *et al.* 1991; Bowman and McDonough 1991; Bowman and Panton 1991; Anderson and Stone 1993; Katahira *et al.* 1993; Hone and Martin 1998). In our study, the number of dung pellets deposited per month at experimental (Duck) sites declined as pigs were removed from the study area. This relationship, however, was statistically significant primarily because dung was found in the first and second census periods, and not in the third and fourth census periods. Furthermore, dung collection at the Dallachy Ridge site also declined as the study progressed, whereas dung deposition at the adjacent Dallachy Swamp site increased markedly. Thus, numbers of dung pellets detected at different census periods showed no clear relationship with treatment (ie. sites where pigs were culled versus not culled). The underlying problem with our data on dung was that many transects recorded no dung at all, so that mean values of rates of dung deposition were highly variable and difficult to analyse. Hone (1988a, and pers. comm.) found that when large numbers of small plots are surveyed, the proportion of plots containing dung may be a useful index of pig abundance.

Effectiveness of trapping

Our results suggested that almost all the pigs using the trapped area at the beginning of the study had been removed by the end of trapping. This demonstrates that trapping can be very effective in reducing the local abundance of pigs in the Wet Tropics. The result of this removal was that by the end of the study the rate at which soil was being disturbed by pigs had fallen to only about 18% of the rate measured before trapping. Many of the ecological impacts that pigs are presumed to have on ecosystems are related to their disturbance of soil. It follows that trapping may significantly reduce the environmental impact of pigs. Trapping of feral pigs has previously been evaluated by Choquenot et al. (1993) on the central tablelands of New South Wales and Saunders *et al.* (1990) in Kosciusko National Park, where it achieved reductions of pig abundance of 80% and 71% respectively, results similar to the 82% reduction in pig activity produced by our trapping program. These figures compare well with evaluations of shooting from helicopters (80% reduction, Saunders 1983), and poisoning (reductions of between 60% and almost 100%; see Hone and Pedereson 1980 in Choquenot 1996, Hone 1983, Bryant and Howe 1984 in Choquenot et al. 1996, McIlroy et al. 1989, Saunders et al. 1990).

The fact that some evidence of pig activity remained at the end of trapping could have indicated that there was immigration into the area during the study, or that animals living on the edge of the area made occasional incursions but did not use the area consistently enough to encounter traps during the trapping sessions. This latter explanation is very likely, considering that traps were distributed over an area that was about equivalent to the feeding range of an individual pig and that there is a high degree of home range overlap among pigs (J. Mitchell, unpublished data): many pigs using the area would have also ranged outside it to varying degrees. However the effect of this on levels of pig activity in the trapped area was quite small over the five months of this study.

Many of the most pressing concerns over the impact of feral pigs in the Wet Tropics relate to their effects on environmentally sensitive areas, such as wetlands, habitats of threatened species (for example, the northern bettong *Bettongia tropica*, Laurance and Harrington 1997) or areas rich in endemic species. This study suggests that trapping should be useful in protecting such areas from the impact of pigs, and may also provide a model for monitoring the effectiveness of trapping in intensive control operations.

ACKNOWLEDGEMENTS

We thank Maria Morlin for assistance in surveying transects, and Bill Dorney and Warren Price for help in trapping pigs. Warren Price also provided valuable technical support and advice. The Queensland Department of Environment and Heritage gave permission for the work to be conducted in Edmund Kennedy National Park, and provided equipment and personnel when required. The study was funded by the Wet Tropics Management Authority.

PART 4

IDENTIFYING MANAGEMENT OPTIONS

Community based feral pig trapping in the Wet Tropics of Queensland

DORRINGTON, B.

Land Protection Branch, Department of Natural Resources
South Johnstone

ABSTRACT

The community based feral pig trapping program provides a regionally coordinated system for control of feral pig populations in the Wet Tropics. The program enjoys a high level of community support and involvement by landholders and members of the public, and benefits from in-kind contributions from registered trappers. The program uses about 500 traps, and around 200 pigs are trapped each year. This paper describes the operation of the program, and discusses its successes and limitations.

BACKGROUND

Feral pigs have been recognised as a significant threat to the conservation values of the Wet Tropics World Heritage Area (WHA), as well as having a substantial economic impact on the neighbouring rural industry. Following the World Heritage listing of the WHA in December 1988 public perception was that Wet Tropics Management Authority (WTMA) had caused the problem by “locking up” the WHA and creating a breeding ground for feral pigs, safe from outside disturbances.

In implementing the recommendations of a number of consultancies to WTMA a management strategy was developed and implemented. This strategy was to utilise local community knowledge and support in addition to the other factors recommended in feral pig consultancies to WTMA.

This strategy evolved into a management plan termed the *‘COMMUNITY BASED FERAL PIG TRAPPING PROGRAM’* and has now been operational since April 1993. The program has undergone continual refinement over the last 6 years through an adaptive management process which has increased effectiveness and efficiency of the techniques used and has allowed the adoption of new management information as it becomes available. This approach has also enabled the program to respond rapidly to other issues as they arise, such as non-target captures and animal welfare issues.

The program is designed to achieve WTMA feral pig management objectives;

1) To reduce the impact of feral pigs upon the conservation values of the WHA.
2) To reduce the impact of feral pigs upon neighbours of the WHA.
3) Demonstrate WTMA commitment to feral pig management.
4) Foster public involvement and ownership of the problem.
5) To encourage the adoption of Best Practice principals of feral pig management.

The implemented management plan encourages a regional approach, utilising an environmentaly acceptable control technique. As well as assisting the conservation and protection of the WHA, the program has provided a framework for a regionally coordinated approach to feral pig management, with more stakeholders becoming involved as the program evolves.

METHODOLOGY

Organisation is achieved by dividing the program into a series of Trapping Systems. A trapping system is defined as a group of traps within a certain local area operated by a trained Trapper. The trapper is responsible for organising the day to day management of traps within his area, which is performed by either landholders, himself or other feral pig harvesters (hunters). This promotion of trapping as a control technique, together with fostering community ownership of feral pig management is of far greater importance than simply catching large numbers of feral pigs, due to the long-term benefits obtained.

The trapper is also responsible for the collection of all scientific and management data on his operations. The trapper reports to a local community group or rural organisation that act as a Management Group. The individual management groups direct the trapper in locating the traps, liaise with landholders and act as a link between the trappers and program management. This approach encourages community ownership of feral pig management and makes good use of the invaluable local knowledge of these people.

The Department of Natural Resources and Mines provides overall management of the program in consultation with an advisory committee of stakeholders, all management groups and the WTMA. The program is closely associated with DNR's feral pig research unit, lead by Mr Jim Mitchell, who has received two DNRM achievement awards for establishing the program.

During the 12 months to March 1999, 44 trapping systems were active. A total of 36 systems were operated by 32 program trappers, with some trappers operating more than 1 system. Trapper fees ($200 per month) were paid for 26 systems and 10 were operated on a voluntary basis. Of the paid trappers 6 received matching payments from their local management groups, mainly the Cane Protection and Productivity Boards. The remaining 8 systems were operated by others, such as QPWS rangers as part of their duties.

Management groups participating in the program include;

- The Cane Protection and Productivity Boards
- Queensland Parks and Wildlife Service
- Community Environmental Groups
- Department of Natural Resources
- Local Government
- Aboriginal Communities
- Non-Aligned Groups

The program also has a commercial contract with the Australian Defence Force to provide feral pig trapping systems at all 6 of their training areas within and adjoining the WHA.

Approximately 500 traps are available, however only about 60% - 80% are in use at any given time. The main reason for this is that when feral pig activity in an area ceases the trap(s) there will often be closed, until the pigs invariably return. An additional 155 private traps are reported as being directly within the program, with the same amount estimated to be operating in the area but outside the program's direct control. A large percentage of these traps have been constructed as a result of the program's extension activities.

In excess of 8000 feral pigs have been documented as being captured from the commencement of the program up to the end of 1998, with the annual total remaining stable at about 2000 per year since expansion to the current level occurred. A pronounced peak in captures usually occurs in April/May and October/November, the end of the wet and dry seasons.

COMMUNITY INVOLVEMENT

A feature of this program is the high level of community support and involvement by landholders and other members of the public. An attempt to quantify the value of this in-kind contribution has been made recently, with 20 trappers asked to complete a detailed written survey of their in-kind contributions. A total of 13 completed surveys were returned and the data analysed. Trappers were asked about their weekly contribution in terms of hours spent, kilometres of vehicle usage and out of pocket expenses. The average trapper was found to spend 29.9 hours (range 14 – 54), 288 kilometres (range 74 – 615) and $13.70 in expenses operating his trapping system each week. This information has been extrapolated in Table 1 to obtain an average annual in-kind contribution per trapper. When multiplied by 32 trappers the amount to be considered is $ 1,018,304, a ratio of $14.51 worth of services provided for every $1 spent on trapper fees. The motivation for the trappers to undertake this work are many and varied, however a majority were feral pig hunters pior to induction into the program. This link to the hunting fraternity has proved invaluable in promoting trapping as a control technique by demon-stration.The vast majority of feral pig hunting conducted in the Wet Tropics is a recreational pursuit and of little value to control efforts. In many cases it has a negative impact on control by disrupting coordinated control measures.

Table 1. In-kind Contribution per Trapper

	Per Week	Per Year	Rate	Value
Hours	29.9	1 554.8	$15 p/hr	$ 23 322
Kilometers	288	14976	52c p/km	$ 7 788
Expenses	$13.70	$ 712.40	-	$ 712
			TOTAL	**$ 31 822**

Management groups were surveyed in person and by telephone, with a sample of landholders being surveyed using the same method. Due to the relatively small sample number of the latter group the data obtained could be considered approximate, however the purpose is only to give an idea of the level of community involvement in, and ownership of the program. The figures obtained have been extrapolated to give the annual contributions detailed in table 2 below.

Table 2. Annual in-kind Contributions

Group	Labour	Vehicles	Other	Total
Trappers	$ 23,322	$ 7,788	$ 712	$ 31,822
Man. Groups	$ 54,600	$ 18,200	$ 14,352	$ 87,152
Landholders	$ 780,000	$ 104,000	$ 12,500	$ 896,500
TOTAL	$ 857,922	$ 129,988	$ 27,564	**$ 1,015,474**

INFORMATION FLOW CHART

A further positive benefit of this level of community involvement and the organisational structure of the program is the excellent communication network that has evolved. As can be seen from the flow chart on the following page, there is a two-way flow of information and data between land managers, researchers, landholders and the general community. A detailed communication plan has been developed to fully exploit this network.

LIMITATIONS

Inadequate Monitoring Systems

The monitoring systems in place do not fully address the program objectives.

Action Taken - A detailed monitoring program, "Monitoring Systems for Feral Pigs" is proposed by Mr Jim Mitchell. Funding is being sought under the National Feral Animal Control Program component of NHT. An alternative system is being developed as a fall back position should funding not be obtained.

Environmental Impacts not Quanitified

Although the general perception is that feral pig impacts upon the WHA are negative and numerous, these remain unqualified.

Action Taken - Current research into the ecology of feral pigs in Tropical Rainforests is nearing completion.

Program Scale Insufficient

The resources allocated to the program are insufficient to address its objective on the scale required. In areas where a trapping program has been in place for 2-3 years, there is anecdotal evidence from landholders and land managers that visible feral pig impact has been reduced by at least 50%, however these areas represent only a small percentage of the WHA.

Action Taken - Initiatives of the Feral Pig Advisory Committee have identified and are pursuing several alternative funding sources. It is proposed that any expansion of the program facilitated by this funding will be targeted at areas of high environmental significance.

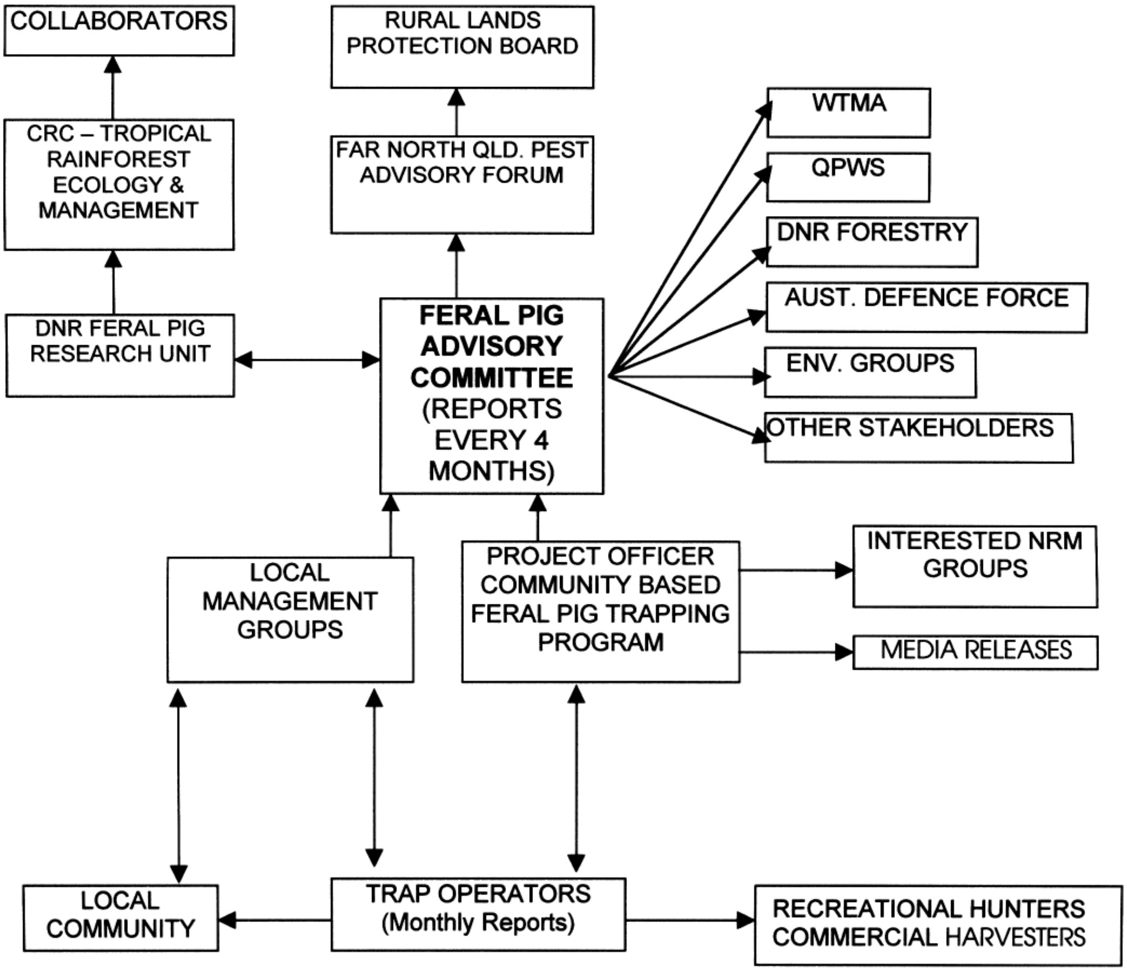

Figure 1. Information Flow Chart showing communication network which has evolved from the Community Based Feral Pig Trapping Program

RESEARCH PRIORITIES

Bait – Bananas are the main bait material used throughout the program, with other fruits, carcasses and offal being used in areas where bananas are unavailable or unsuccessful. When pigs are feeding on a crop or have a plentiful natural food source available, trapping efficiency will drop off dramatically until the alternative food source is exhausted or removed. Several other attractants including molasses, aniseed, vanilla essence, yeast and even creosote have been reported to be used with varying degrees of success. Controlled trials should be conducted to fully investigate these and other potential baits as an improved bait could potentially result in a quantum leap in trapping efficiency. Should biological control methods proceed to the field trial or implementation stage this research could be valuable. The program does not have the resources or expertise to conduct this research.

Trap Design – The majority of traps used by the program (400) are silo type traps with most having side swinging doors and pig-specific trigger bars. About 100 are portable or mobile traps with 60 of these built to a standard box trap design developed by the program. This design is a compromise between several factors including size, weight, ease of use and effectiveness. Should further expansion of the program occur more portable traps will be required. Design refinements are proposed to the standard design to improve effectiveness. A trap design competition has even been proposed, which would have the added benefit of increasing public awareness and acceptance of trapping as Best Practice management. The program can conduct this development.

Prospects for pig control: A biotechnology perspective

SEAMARK, R. F.

CRC for the Biological Control of Pest Animals, CSIRO Wildlife and Ecology
Canberra. A.C.T.

ABSTRACT

Biotechnology may not provide the solution to feral pig control, but biotechnological innovations may increase the effectiveness of existing management programs. This paper explores the ways in which an understanding of the chemical signals which influence pig behaviour - their pheromonal biology - and the way in which they sense their environment by smell - their olfactory biology - could be used to improve pig control by trapping.

Biotechnology, as the name implies, is a technology which builds on biological knowledge – the more complete the knowledge base the better the technical offering. Given the present deficits in knowledge of the feral pig in Australia, the development of biotech solutions will be somewhat constrained!

However, there is a considerable body of knowledge of pigs generally – their nutrition, reproduction and diseases – gained by studies of domesticated pigs which suggests some biotechnical possibilities.

THE FERAL PIG PROBLEM - CURRENT SOLUTIONS

As discussed elsewhere in the workshop, Australian feral pig populations prosper in response to opportunities provided by the environment through their natural high fecundity, adaptability and social flexibility, and the lack of many natural constraints including predators and diseases; all possible targets for potential biotechnical control measures. These would, ideally, aim to prevent a pig problem rather than react to the problem once it is established.

This contrasts with the focus of most current control measures which are only implemented after pig populations have built up to levels where they are having an adverse impact. Thus most current control measures, which include physical barriers, chemical poisons, shooting and trapping or a mixture of the above, aim at reducing the impact of an established problem rather than prevention.

Such reactionary means are costly, often pose significant environmental (and human) risk and, unless managed in a coordinated, strategic manner, have limited long term impact.

The chemical poisons used in broad scale pig control baiting program are of particular concern – non-specific poisons such as 1080 for safety issues and vitamin K antagonists such as Pindone, for ethical (humane) reasons.

THE FERAL PIG PROBLEM - PROSPECTIVE SOLUTIONS

Control of many insect pest population is now achieved through a biotechnology approach based on new knowledge of olfactory processes and in particular, specific knowledge of the messenger chemicals (pheromones) involved. Biotechnologists have used this knowledge to attract pest insects to toxic baits or to disrupt their normal socio-biological behaviour. Could we use a similar approach to feral pig management?

Pigs live in a world which they primarily sense through olfaction, thus management of the impact of feral pigs through manipulation of the olfactory senses could be a sound base on which to build a biotechnological approach. Many mammalian pheromones (Singer 1991) are known which excite or depress physiological and socio-biological activities and can be used to disrupt feeding, mating and social interactions. Altered socio-biological parameters are also known to adversely affect the health status and impact of disease on many mammal populations, including pigs.

It is of interest that the earliest mammalian pheromone identified, in 1960, was from the pig. This was a factor identified in the scent produced by boars which caused female pigs in estrus to adopt and hold a mating stance allowing the boar to mount. This substance, a simple testosterone metabolite, androstenone, is commercially available and is already being used to modify the mating behaviour of domesticated pigs (see Booth and Signoret 1992).

If not androstenone, then other pheromones or olfactory substances could be useful in a feral pig management campaign. Recent developments in biotechnology allow putative substances to be rapidly screened. One approach is to instrument a pig so that when it is excited by a particular substance, it can be sensed by the neurophysiological recording instruments as a change in the activity of a key brain centre coordinating the particular response eg. feeding, mating etc. The active substance can then be isolated and now easily identified using mass-spectrometry or other analytical techniques. Alternative approaches, under development, plan to use artificial noses to identify such active substances through coupling isolated olfactory-cell receptors to micro electronic sensors (see Bargmann 1997, for links to the extensive literature in this area).

These substances, once identified, can then be synthesised in the amounts required for field use using available biotechnology. Such developments would offer completely new horizons of possibility in the management of the pig problem. Similar approaches are being considered for rabbit (Mykytowcz 1985), fox (Whitten et al. 1980) and rodent control (Gao and Short 1993). An early target for such studies would be to identify attractants to draw pigs to (or steer them from) specific areas eg. bait stations or traps.

Pheromones and other olfactory stimuli can be highly species specific and attractants could be sought that would in themselves provide a high degree of species-specificity in use, for example by only attracting pigs to a bait station, thus reducing the risk of non-target bait uptake or inadvertent trapping of native animal species. If additional safeguards are required these could be engineered into the bait containing the toxin (or vaccine) as the attractiveness of the bait would now be independent of the usual food characteristics. Manipulating the bait size, texture and digestibility could all be used to discourage ingestion by non target species.

Alternatively, more sophisticated solutions to the issue of bait safety could be developed through engineering additional features into the bait to ensure target specificity. This is now a real prospect offered through the new knowledge of details of the molecular and cellular biology of the pig which distinguish it from other target species.

The olfactory trail is one of many pathways that could be explored in the search for new approaches towards pest management. As discussed by Mike Holland in the following paper, the Pest Animal Control CRC is exploring other possibilities raised through recent discoveries in molecular medicine of how host organisms respond to diseases. On the basis of this emerging knowledge, the Pest Animal CRC is now engaged in the development of a new generation of pest control agents aimed at controlling the fertility of pest animals. The aim is to create fertility control vaccines which can dispensed in baits or be self-distributing through using naturally disseminating, infectious organisms as vectors. The feasibility of this approach has recently been demonstrated in laboratory studies with mice. Hopefully this important demonstration can now be built on to develop control agents and management strategies for a range of Australia's introduced animal pests, including the feral pig,. Hopefully too, these agents will be more efficacious, safer and more humane than those presently in use through being designed, from the onset, to prevent rather than cure pest problems.

Fertility control for feral pigs: options and status

HOLLAND, M. K.

CRC for the Biological Control of Pest Animals, CSIRO Wildlife and Ecology
Canberra. A.C.T.

ABSTRACT

Reduction of the fertility of wild pigs would make control by techniques such as trapping or poisoning more effective, by slowing the rate of population recovery after application of control. Population-wide fertility reduction can potentially be achieved by immunocontraception. In this approach, the immune systems of females are 'tricked' into raising antibodies against proteins found normally in sperm or oocytes. Vaccination could be achieved by oral delivery of antigens in baits, or by the dissemination of antigens in a genetically engineered organism. These approaches are being developed for use against wild rabbits and mice, and might also be applied to pigs.

The damage caused by feral pigs to the environment and the threat they represent to the domestic pig industry as potential reservoirs of exotic disease have been reviewed by Choquenot *et al.* (1996). Other concerns such as the possibility feral pigs might host human diseases such as Japanese encephalitis that might impact on industries such as tourism have more recently emerged. There are thus strong and clear gains to be achieved in a range of industries through control of feral pig populations.

FERAL PIGS - CURRENT CONTROL PROCEDURES

Current control procedures for the minimising the deleterious impacts on the environment of fecund species such as feral pigs rely either on increasing the rate of pig mortality through shooting (with or without the use of dogs), poisoning or trapping, or exclusion methods such as fencing or habitat modification, or some combination of these. There are a number of disadvantages to these approaches ranging from target species specificity to concerns regarding humaneness and acceptability, to practical issues such as cost and maintenance. Biological control can overcome some of these objections but in the case of pigs no agent has been identified which is of high lethality, humane, and which would not present a problem either to our own domestic pig industry or to our export markets.

FERTILITY CONTROL - IS IT AN OPTION?

Another option for control of fecund species, which has received varying degrees of attention, is to decrease the birth rate. Feral sows produce two weaned litters every 12 –15 months with an average litter size of 4.9-6.3 piglets (Giles, 1980, Pavlov, 1983). This fecundity has been directly compared with that of rabbits rather than other feral ungulates (Choquenot et al, 1996). Recent studies (Williams & Twigg 1996), have indicated that fertility control of rabbits affects population dynamics and over time causes a decline in rabbit numbers. Could a similar result be achieved for pigs?

Studies on pig population dynamics in different environments show that rates of increase are highly variable from year to year and are driven by factors like rainfall which determine green feed availability and thus protein intake (Giles 1980, Hone 1987, Saunders 1988, Caley 1993, Choquenot, 1994). Insufficient protein intake by sows compromises lactation with obvious implications for survival of piglets, and also increases susceptibility to disease. Other factors such as predation by dingoes or wild dogs can also have an impact on rate of increase. Thus fertility control applied judiciously in seasons of naturally low reproduction might be expected to have a significant negative impact on population dynamics. A similar response would be expected if conventional control procedures were used to lower pig numbers and then followed with fertility control. How successful fertility control might be in preventing pig population increases in good seasons in the absence of other control procedures remains for the moment a matter of conjecture. However, fertility control technologies in general should not be viewed as replacements for all existing control methodologies but rather as additional methods which provide further power to an integrated management approach.

FERTILITY CONTROL - HOW MIGHT IT WORK?

Fertility control can be achieved in a number of ways. In selecting the optimal approach the reproductive biology of the target species needs to be well understood. Fundamental decisions such as whether targeting the male or the female or both need to be considered. In highly monogamous species, for example, it may not matter which sex is targeted but generally the female is the prime target because she is the breeding unit. Given that decision we need to carefully examine what we know about reproduction in the female. Are there species specific aspects that could be targeted? Options such as disruption of gametogenesis, prevention of ovulation, inhibition of fertilization, interference with implantation or even inhibition of lactation need to be considered. In the case of pigs we have substantial background data on these processes thanks to intensive attempts to optimise reproduction in domestic pigs.

One option would be to use agonists or antagonists of hormones regulating the process of ovulation such as leutenising hormone releasing hormone (LHRH), or steroid analogues that interfere with endogenous steroid function thus affecting gametogenesis or ovulation. A similar approach could also be developed to interfere with implantation (Nie *et al.* 1997). The limiting feature of all these approaches is that they utilise chemicals which must be delivered to the target animal. This would have to be through some sort of bait. This immediately raises difficulties, the principal one of which is to ensure species-specific delivery. This is critical as many of these hormone analogues are active across a wide range of mammalian species and perhaps even in some non-mammalian species. Practical considerations like palatability, number of doses required and cost of both the baits and also their distribution means that such an approach to fertility control applied to feral pigs probably has little chance of success.

A different approach can be developed which relies on the fact that the reproductive system, and in particular the gametes, are shielded from the animal's immune system. Thus components of the sperm and oocyte will provoke an immune response in immunised animals and this response can cause infertility. This approach can potentially be made species-specific by selecting appropriate proteins to be used as antigens to provoke the immunocontraceptive response. The limitation comes in selecting the delivery system. Two broad options exist:

- Oral delivery systems in which the antigen is either packaged in an inert system such as microencapsulation or is incorporated in a live but genetically crippled delivery system such as the bacterium *S. typhimurium* or a virus such as vaccinia;

- A disseminating micro-organism which is genetically engineered to express the antigen of interest.

Oral delivery of a genetically engineered vaccinia virus has been successfully used to immunize foxes in Europe and now in North America against rabies, and so this approach has had some success at the field level. Nevertheless, the same limitations that apply to conventional baiting also apply here and it will need a new approach such as the pheremone based strategy described by Seamark in the previous paper before baiting will have broad applicability to feral pig control in Australia.

The second approach is one in which the CRC for the Biological Control of Pest Animals has developed expertise and is applying to control of wild rabbits (Holland & Jackson, 1994) and mice (Chambers et al, 1997, Jackson et al, 1998). Species specificity would be achieved both through selection of a pig specific pathogen and pig specific antigen. This minimises the risk to non-target species. In the case of pigs an appropriate virus might be swinepox. This virus can be genetically engineered to express foreign antigens, is species specific and is endemic to Australia. Domestic pigs can be prevented from contracting swine pox simply through good husbandry procedures and the disease is almost never a problem in commercial piggeries. The disease itself is not fatal, although infected animals show significant loss of condition and develop papules on the abdomen and legs which become pustular then scab and crust. Development of a vaccine that would offer protection against infection is possible. Thus the virus would represent little threat to our domestic or export industry. Swinepox is normally transmitted by the pig louse (*Haematopinus suis)* although presumably other arthropod vectors might also play a role. Thus it is conceivable that feral pigs, which are social animals, would transmit the infection. Indeed, it is possible that swinepox infects feral pigs at high incidence already. No serological data on this point are available. If most animals are already seropositive, techniques must be developed which ensure that the immunocontraceptive virus can transmit successfully in competition with wild type strains currently circulating in the environment. This is the same situation currently being addressed by the CRC for Biological Control of Pest Animals in the case of rabbits and myxoma virus. Much of what is learned there will be applicable to pigs. However, if seropositivity is low in feral pig populations the immunocontraceptive virus will establish more easily. Thus a potential species-specific delivery system could readily be developed. If the search, currently underway with PRDC support, for a specific antigen succeeds the basic components for development of a viral vectored pig immunocontraceptive vaccine exist.

LIMITATIONS TO FERTILITY CONTROL

Bomford (1990) in her comprehensive review of fertility control listed four major limitations to the success of fertility control:

- The lack of a long acting agent, which makes repeated dosing necessary
- High cost of delivery, especially if baiting is involved
- Less effect on the population than when an equivalent number of animals are killed
- Potential effects on non target species

Viral-vectored immunocontraception, which has been developed subsequent to 1990, largely overcomes these limitations. Immunocontraception is potentially a technology with long term efficacy. Jackson and coworkers (1998) have reported mice remain infertile for at least 12 months after one exposure to a recombinant virus. In their system the response can be boosted by subsequent re-exposure to recombinant virus. If a disseminating virus is used the issue of oral delivery is obviated, although there may still be situations (see below) where oral delivery may be economic. The question of impact is harder to assess although the Williams and Twigg (1996) data for rabbits suggest there are significant long-term benefits. This would need to be investigated early in any project to develop fertility control for pigs. The real limitations to lethal procedures are cost, the need for regular reapplication to maintain efficacy, and the issue of humaneness. These problems are not as applicable to viral vectored immunocontraception. Finally in response to Bomford's final point, I have already dealt with how species-specificity can be maintained in immunocontraception through judicious choice of both antigen and delivery system.

In conclusion, viral vectored immunocontraception represents for some species an important potential addition to the integrated suite of techniques required to ensure adequate control of a pest species.

POTENTIAL ADDITIONAL BENEFITS

Development of viral delivery systems that are pig specific provides opportunities beyond fertility control. Swinepox could be engineered to contain antigens that would induce an immune response which would be protective against endemic diseases like brucellosis, leptospirosis, tuberculosis and Murray Valley encephalitis or exotic diseases such as foot and mouth, African swine fever, Aujeszky's disease or classical swine fever. In such a case the utility and economics of oral delivery change and it becomes possible to consider a recombinant vaccinia system analogous to that used for rabies control described earlier. Thus fertility control combined with disease prevention through the use of genetic engineered delivery systems provides a new opportunity for development of a novel approach to feral pig management

Control of feral pigs in the Wet Tropics

STORK, N. E.[1], STANLEY, T.[2]

[1]CRC for Tropical Rainforest Ecology and Management, Cairns
[2]Tropical Weeds Research Centre, Queensland DNR, Charters Towers

The papers in this volume identify problems caused by the feral pig population in the Wet Tropics. Feral pigs cause widespread impacts on the ecology of tropical rainforests and also cause damage to agricultural systems neighbouring rainforest areas. By far the most important concern is the potential for feral pigs to transmit diseases such as foot and mouth, Japanese encephalitis and rabies should any of these reach Australia. The impact of such outbreaks could be devastating for the Australian livestock industry. The ability to control populations of feral pigs is therefore of vital importance to the Australian Quarantine Inspection Service, to the farming industry, and to other industries such as tourism which benefit from the Wet Tropics World Heritage Area and Cape York wilderness area.

There is a strong push from the hunting community to be allowed access to hunting in National Parks and the World Heritage Area. There are definite concerns that if this were allowed, it would cause major impacts on the environment and could even lead to an increase in pig impacts by disrupting their movement patterns and social organisation.

Internationally, feral pigs are a problem for a number of countries such as Malaysia, New Zealand and USA (Hawaii). In some research areas we have greater expertise and have advanced further than researchers in some of these countries. In other areas we are less advanced.

Feral pigs are a problem for a wide range of organisations and communities. Currently resources being used to tackle feral pigs are spread thinly and we need to produce a combined program with wide support in order to produce effective action and to give greater leverage to existing activities. Joint international programs would enhance our own effectiveness as well as creating the potential for new partnerships in other areas of environmental concern.

The **goal** of research into feral pigs in the Wet Tropics should be to develop strategies to reduce or control feral pig populations in the Wet Tropics, or parts of the Wet Tropics, and reduce their impact on natural ecosystems and on agricultural systems.

The following crucial issues can be identified:

1. Potential for spread of human and animal diseases by feral pigs
2. Biodiversity and ecosystem impact of feral pigs
3. Land use and other socio-economic value impacts
4. Development of management strategies
5. Rehabilitation of areas affected by feral pigs
6. Development of a community education program

STRATEGIES

Potential for spread of diseases by feral pigs

- The likelihood of diseases being introduced to feral pig communities in the Wet Tropics and Cape York needs to be addressed. Collaboration with AQIS sentinel pig program is essential here. An education program is needed to make land owners and legislators aware of the scale of the problem.

Biodiversity and ecosystem impact of feral pigs

- Some research has been carried out by Jim Mitchell to show the impact of feral pigs on native vegetation and invertebrate communities (particularly earthworms) but a more complete understanding is needed. For example, how do pigs impact on the species composition of forests through time? How does their feeding affect the pattern and dynamics of vegetation mosaics? What threats are there from pigs to particularly vulnerable species and communities?

Land use and other socio-economic value impacts

- Land owners in some parts of the Wet Tropics and Cape York are concerned about the damage caused by feral pigs to their crops and infrastructure. At present few data are available to allow an evaluation of the extent and cost of this damage and its impact on livelihoods. Pigs also affect the aesthetic value of Wet Tropics areas and this needs to be evaluated.

- Prediction of the social and economic costs of introduction of diseases to feral pig communities is a priority as the potential impact could be huge.

Development of management strategies

- A monitoring system for feral pig numbers and impact needs to be created and implemented. Some progress has been made towards the development of a monitoring index.

- There is a need for the development of the delivery of a safe baiting system that will target pigs and not affect native species. This means that a variety of alternative attractants that are easy to deliver will need to be tested.

- There should be an evaluation of the existing pig management programs to determine whether they reduce pig numbers and their impact in the short, medium and long-term. For example does pig trapping/shooting cause a breakdown in pig social structure and eventually lead to increase in pig numbers?

- Immuno-contraception is being developed as new technology to reduce numbers of foxes, rabbits and mice by the CRC for the Biological Control of Pest Animals. Some initial trials have been undertaken to identify the potential use of this technology to control feral pigs.

Rehabilitation of areas affected by feral pigs

- Once feral pigs have been removed from an area there is a need to rehabilitate the area to prevent weed development. Some evaluation of the extent of this problem needs to be undertaken.

Development of a community education program

- There are many misconceptions about feral pigs and it is essential that the facts are presented to communities in order to allay their fears and to gain greater community support for the course of action being undertaken.

REFERENCES

Alexiou, P.N. (1983) Effect of feral pigs (*Sus scrofa*) on subalpine vegetation at Smokers Gap, Australian Capital Territory. *Proceedings of the Ecological Society of Australia* **12**: 135-142.

Anderson, S.J. and Stone, C.P. (1993). Snaring to control feral pigs *Sus scrofa* in a remote Hawaiian rain forest. *Biological Conservation* **63,** 195-201.

Aplet, G.H., Anderson, S.J. and Stone, C.P. (1991). Association between feral pig disturbance and the composition of some alien plant assemblages in Hawaii Volcanoes National Park. *Vegetatio* **95,** 55-62.

Bargmann, C.I. (1997). Olfactory receptors, Vomeronasal Receptors, and the organization of olfactory information. *Cell* **90**, 585-587.

Bomford, M. (1990) *A role for fertility in wildlife management?* Bulletin 7 Bureau of Rural Resources. Australian Government printing Office, Canberra.

Bowman, D.M.J.S. and McDonough, L. (1991). Feral pig (*Sus scrofa*) rooting in a monsoon forest-wetland transition, Northern Australia. *Wildlife Research* **18,** 161-765.

Bowman, D.M.J.S. and Panton, W.J. (1991). Sign and habitat impact of banteng (*Bos javanicus*) and pig (*Sus scrofa*), Cobourg Peninsula, northern Australia. *Australian Journal of Ecology* **16,** 15-17.

Brown, B.N. (1976) *Phytophthora cinnamomi* associated with patch death in tropical rainforest in Queensland. *Australian Plant Pathology Society Newsletter* **5**: 1-4

Burke, D.S. and Leake, C.J. (1988). Japanese encephalitis. Ch. 28 *In:* Monath, T.P. (Ed.) *The arboviruses: Epidemiology and ecology.* CRC Press, Boca Raton, Fla.

Caley P (1993) *The ecology and management of feral pigs in the wet-dry tropics of the Northern territory.* M. Appl Sci thesis, University of Canberra

Caley, P. (1993) Population dynamics of feral pigs (*Sus scrofa*) in a tropical riverine habitat complex. *Wildlife Research* **20,** 625-636.

Caughley, G. (1977). *Analysis of Vertebrate Populations*. (Wiley & Sons: London.)

Caughley, G. and Gunn. A. (1996) Conservation Biology in Theory and Practice. Blackwell Science. London.

Chambers L., Singleton, G.R. and Hood G.M. (1997) *Immunocontraception as a potential control method of wild rodent populations.* Belg J. Zool 127 (Supplement 1) 145-56.

Choquenot, D. (1994) *The dynamics of feral pig populations in Australia's semi-arid rangelands*. PhD Thesis, University of Sydney.

Choquenot D., McIlroy J. and Korn T. (1996) *Managing vertebrate pests: feral pigs.* Bureau of Resource Sciences, Australian Government Printing Service, Canberra.

Choquenot, D., Kay, B. and Lukins, B. (1990). An evaluation of Warfarin for the control of feral pigs. *Journal of Wildlife Management* **54,** 353-359.

Choquenot, D., Kilgour, R. J. and Lukins, B. S. (1993) - An evaluation of feral pig trapping. *Wildlife Research* **20**, 19-22.

Choquenot, D., McIlroy, J. and Korn, T. (1996) *Managing Vertebrate Pests: Feral Pigs*. Bureau of Resource Sciences, Australian Government Publishing Service, Canberra.

Chu, R.M. and Joo, H.S. (1992) 'Japanese B encephalitis'. Chap. 21 In: *Diseases of Swine 7th Ed.* 286- 291. Wolfe Publishing, London.

Crome, F.H.J. and Moore, L.A. (1990). Cassowaries in north-eastern Queensland: report of a survey and a review and assessment of their status and conservation and management needs. *Australian Wildlife Research* **17,** 369-385.

Dexter, N. (1990) Population density and management of feral pigs at Aurukun, North Queensland. Bureau of Rural Resources, Report R/11/91, Canberra.

Dorrington, B. and James, P. (1999) *Community Based Feral Pig Trapping Program – Annual Report 1998.* Report presented to the Wet Tropics Management Authority. DNR, South Johnstone.

Fleming, P.J.S. (1997). Uptake of baits by red foxes (*Vulpes vulpes*): implications for rabies. *Wildlife Research* **24,** 335-346.

French, C.E., Liscinsky, S.A. et al. (1957). Nutrient composition of earthworms. *Journal of Wildlife Management* **21**, 348.

Gao Y and Short R.V. (1993) The control of Rodent Populations. *Oxford Reviews in Reproductive Biology* **15**, 265-310

Giles J.R. (1980) *The ecology of feral pigs in western New South Wales.* PhD Thesis, University of Sydney

Hall, R.A., Burgess, G.W. and Kay, B.H. (1986) Detection of Australian flavivirus antigens using monoclonal antibodies in ELISA. *Arbovirus Research in Australia, Proceedings Fourth Symposium* May 1986: 118 - 122.

Hanna, J., Ritchie, S., Phillips, D., Shield, J. *et al* (1996) An outbreak of Japanese encephalities in the Torres Strait, Australia. *Med. J. Aust*. 165: 256-260.

Hanna, J., Ritchie, S., Phillips, D., Shield, J. *et al.* (1999). Japanese encephalitis in north Queensland, Australia, 1998. *Med. J. Aust.* **170:** 533-536.

Hassall and Assc. P/L. (1998). *Economic Evaluation of the Role of Bounties in Vertebrate Pest Management*. Prepared for the Bureau of Resource Sciences. BRS, Canberra.

Holland M.K. & Jackson R.J. (1994) *Virus vectored immunocontraception for control of wild rabbits: identification of target antigens and construction of recombinant viruses.* Reproduction, Fertility & Development 6: 631-42

Hone J. (1987) *Theoretical and practical aspects of feral pig control.* PhD Thesis, Australian National University

Hone, J. (1983). A short-term evaluation of feral pig eradication at Willandra in western New South Wales. *Australian Wildlife Research* **10,** 269-275.

Hone, J. (1988a). Evaluation of methods for ground survey of feral pigs and their sign. *Acta Theriologica* **33,** 451-465.

Hone, J. (1988b). Feral pig rooting in a mountain forest and woodland: distribution, abundance and relationships with environmental variables. *Australian Journal of Ecology* **13,** 393-400.

Hone, J. and Kleba, R. (1984). The toxicity and acceptability of warfarin and 1080 poison to penned feral pigs. *Australian Wildlife Research* **11,** 103-111.

Hone, J. and Martin, W. (1998). A study of dung decay and plot size for surveying feral pigs using dung counts. *Wildlife Research* **25,** 255-260.

Hone, J. and Stone, C. (1989). A comparison and evaluation of feral pig management in two national parks. *Wildlife Society Bulletin* **17,** 419-425.

Hone, J. (1987) *Theoretical and practical aspects of feral pig control*. Ph.D. Thesis, Australian National University, Canberra.

Hone, J. (1990) Notes on seasonal changes in popoulation densities of feral pigs in three tropical habitats. *Australian Wildlife Research* **17**, 131-134.

Hone, J. (1990) How many feral pigs in Australia? *Australian Wildlife Research* **17**: 571-572

Hone, J. (1992). Modelling of poisoning for vertebrate pest control, with emphasis on poisoning feral pigs. *Ecological Modelling* **62,** 311-327.

Hone, J. (1995). Spatial and temporal aspects of vertebrate pest damage with emphasis on feral pigs. *Journal of Applied Ecology* **32,** 311-319.

Hone, J. (1998) Island biogeography theory and feral pig disturbance of grassland. Abstracts. Australasian Wildlife Management Society 11th Annual Meeting, Gatton College, The University of Queensland.

Hone, J. and Pedersen, H. (1980) Changes in a feral pig population after poisoning. In *Proceedings of the 9th Vertebrate Pest Conference.* Ed. P. J. Clark. Davis: California.

Hopkins, M.S. and Graham, A.W. (1985) A preliminary assessment of problems and control measures of feral pigs in the rainforests of the Field Force Battle School, Jarra Creek via Tully, north Queensland. Internal Report P5/297, CSIRO Division of Land and Water Resources, Canberra.

Jackson R.J., Maguire D.J., Hinds, L.A. and Ramshaw I.A. (1998) Infertility in mice induced by a recombinant ectromelia virus expressing mouse zona pellucida glycoprotein three. *Biology of Reproduction* 58: 152-59.

Katahira, L.K., Finnegan, P. and Stone, C.P. (1993). Eradicating feral pigs in montane mesic habitat at Hawaii Volcanoes National Park. *Wildlife Society Bulletin* **21,** 269-274.

Kay, B.H., Boreham, P.F.L., and Williams, G.M. (1979). Host preferences and feeding patterns of mosquitoes (Diptera: Culicidae) at Kowanyama, Cape York Peninsula, northern Queensland. *Bull. Ent. Res.* **69:** 441-457.

Kliejunas, J.T. and Ko, W.H. (1976) Dispersal of *Phytophthora cinnamomi* on the island of Hawaii. *Phytopathology* **66**: 457-460.

Laurance, W.F. and Harrington, G.N. (1997). Ecological associations of feeding sites of feral pigs in the Queensland Wet Tropics. *Wildlife Research* **24,** 579-590.

Laurance, W.F. and Grant, J.D. (1994) Photographic identification of ground-nest predators in Australian tropical rainforest. *Wildlife Research* **21**: 241-248.

Laurance, W.F., Garesche, J. and Payne, C.W. (1993) Avian nest predation in modified and natural habitats in tropical Queensland: an experimental study. *Wildlife Research* **20**: 711-723.

Lee, K.E. (1985). *Earthworms: Their Ecology and Relationship with Soils and Land Use.* Sydney, Academic Press.

Masters, K. (1979) Feral pigs in the south-west of Western Australia. Final Report to Feral Pig Committee. Agriculture Protection Board and Department of Conservation and Land Management, Western Australia.

McGaw, C.C. and Mitchell, J. (1998). Feral Pigs *(Sus scrofa*) in Queensland. Pest Status Review Series – Land Protection. DNR, Brisbane.

McIlroy, J.C. & Saillard, R.J. (1989). The effect of hunting with dogs on the numbers and movements of feral pigs, *Sus scrofa*, and the subsequent success of poisoning exercises in Namadgi National Park, A.C.T. *Australian Wildlife Research* **16,** 353-363.

McIlroy, J.C. (1993). Feral pig management problems in the Wet Tropics of Queensland World Heritage Area. Cairns, Wet Tropics Management Agency.

McIlroy, J.C. and Gifford, E.J. (1997) The "Judas" pig technique: a method that could enhance control programs against feral pigs, *Sus scrofa*. *Wildlife Research* **23,** 483-491.

McIlroy, J.C. Braysher, M. and Saunders, G. R. (1989) Effectiveness of a warfarin-poisoning campaign against feral pigs, *Sus scrofa,* in Namagdi National Park. *Australian Wildlife Research* **16,** 195-202

McIlroy, J.C., Gifford, E.J. and Forrester, R.I. (1993). Seasonal patterns in bait consumption by feral pigs (*Sus scrofa*) in the hill country of south-eastern Australia. *Wildlife Research* **20,** 637-651.

McIlroy, J.C. (1993). *Feral Pig Management in the Wet Tropics of Queensland World Heritage Area.* Final report to the Wet Tropics Management Authority, Cairns. CSIRO, Canberra.

McIlroy, J.C. (1990) Feral pig. In: C.M. King, (Ed.), *The Handbook of New Zealand Mammals*. Oxford University Press, Auckland, New Zealand.

McIlroy, J.C. (1993) *Feral pig management problems in the wet tropics of Queensland World Heritage Area.* Final Report to the Wet Tropics Management Agency, Cairns.

Mitchell, J.L. (1993.) *Feral Pig Management in the Wet Tropics.* Systematic assessment of Feral Pig damage and recommended Pig control methods in the Wet Tropics World Heritage Area. Department of Lands, Charters Towers.

Mitchell, J.L. (1998) The effectiveness of aerial baiting for control of feral pigs (*Sus scrofa*) in North Queensland. *Wildlife Research* **25**, 297-303.

Mitchell, J.L. and Mayer, R. (1997). Diggings by feral pigs within the Wet Tropics World Heritage Area of north Queensland. *Wildlife Research* **24,** 591-601.

Mykytowcz R. (1985) Odour signals in the life of the rabbit. *Australian Science Magazine.* Issue 1

Nie, G.Y., Butts A.R., Salmonson and Findlay J.K. (1997) Hormonal and noon-hormonal agents at implantation as targets for contraception. *Reproduction, Fertility & Development* 9:65-77

Noble, K. 1994. *Sustainable Best Practice Feral Pig Management in the Queensland Wet Tropics.* Final report to the Vertebrate Pest Program. DNR, Townsville.

O'Brien, P. H. & Lukins, B. S. (1990). Comparative dose-response relationships and acceptability of warfarin, brodifacoum and phosphorus to feral pigs. *Australian Wildlife Research* **17,** 101-112.

Pav Ecol. (1992) *Investigation of feral pig populations and control measures; Cape Tribulation Section of the wet tropics World Heritage Area.* Consultancy report to Wet Tropics Management Authority, Cairns.

Pavlov P.M. (1983) Feral Pigs. In: (Ed) R Strahan. *The Australian Museum Complete Book of Australian Mammals.* Angus & Robertson Publishers, Sydney.

Pavlov, P.M., Crome, F.H.J. and Moore, L.A. (1992). Feral pigs, rainforest conservation and exotic disease in north Queensland. *Wildlife Research* **19,** 179-193.

Pech, R. & McIlroy, J.C. (1990). A model of the velocity of advance of foot-and-mouth disease in feral pigs. *Journal of Applied Ecology* **27,** 635-650.

Pech, R.P. & Hone, J. (1988). A model of the dynamics and control of an outbreak of foot and mouth disease in feral pigs in Australia. *Journal of Applied Ecology* **25,** 63-77.

Pieris, J.S.M., Amerasinghe, F.P., Arunagiri, C.K., Perera, L.P. *et al.* (1993). Japanese encephalitis in Sri Lanka: comparison of vector and virus ecology in different agro-climatic areas. *Trans. Roy. Soc. Trop. Med. Hyg.* **87:** 541-548.

Pullar, E.M. (1950) The wild (feral) pigs of Australia and their role in the spread of exotic diseases in Australia. *Australian Veterinary Journal* **26**: 99-109.

Richards, S.J., McDonald, K.R. and Alford, R.A. (1993) Declines in populations of Australia's endemic tropic frogs. *Pacific Conservation Biology* **1**: 66-77.

Ritchie, S., van den Hurk, A., and Shield, J. (1997). The 1995 Japanese encephalitis outbreak: Why Badu? *Arbovirus Res. Aust.* **7:** 131-136.

Ritchie, S.A., Phillips, D., Broom, A., Mackenzie, J. *et al.* (1996). Isolation of Japanese encephalitis virus from *Culex annulirostris* in Australia. *Am. J. Trop. Med. Hyg.* **56:** 80-84.

Roberts, A., Klomp, N. and Birckhead, J. (1996) Monitoring marine and terrestrial hunting in an Aboriginal community in north Queensland. In: M. Bomford and J. Caughley, eds, *Sustainable Use of Wildlife by Aboriginal Peoples and Torres Strait Islanders*. Bureau of Resource Sciences, Australian Government Printing Service, Canberra.

Saunders G (1988) *The ecology and management of feral pigs in New South Wales.* MSc Thesis, Macquarie University

Saunders, G. and Giles, J. (1995) - Ecological comparison of two wild pig populations in semi-arid and sub-alpine Australia. *IBEX, Journal of Mountain Ecology* ***3**: 152-55.*

Saunders, G. & Kay, B. (1996). Movements and home ranges of feral pigs (*Sus scrofa*) in Kosciusko National Park, New South Wales. *Wildlife Research* **23,** 711-719.

Saunders, G. (1988) *The ecology and management of feral pigs (Sus scrofa) in New South Wales.* M. Sc. Thesis, Macquarie University, Sydney.

Saunders, G. (1993). Observations on the effectiveness of shooting feral pigs from helicopters in western New South Wales. *Wildlife Research* **20,** 771-776.

Saunders, G. (1993). The demography of feral pigs (*Sus scrofa*) in Kosciusko National Park, New South Wales. *Wildlife Research* **20,** 559-569.

Saunders, G., Kay, B. & Nicol, H. (1993). Factors affecting bait uptake and trapping success for feral pigs (*Sus scrofa*) in Kosciusko National Park. *Wildlife Research* **20,** 653-665.

Saunders, G., Kay, B. and Nicol, H. (1993). Factors affecting bait uptake and trapping

Saunders, G., Kay, B. and Parker, B. (1990). Evaluation of a Warfarin poisoning program for feral pigs (*Sus scrofa*). *Wildlife Research* **17,** 525-533.

Singer, A.G. (1991). A chemistry of mammalian pheromones. *J. Steroid Biochem. Molec. Biol.* **39**, 627-632

Statham, M. and Middleton, M. (1987) Feral pigs on Flinders Island. *Papers and Proceedings of the Royal Society of Tasmania* **121**: 121-124.

Thompson, J.A. and Fleming, P.J.S. (1994). Evaluation of the efficacy of 1080 poisoning using visitations to non-toxic baits as an index of fox abundance. *Wildlife Research* **21,** 27-39.

Tisdell, C.A. (1984) Feral pigs threaten native wildlife in Australia. *Tigerpaper* **11**: 13-17.

Whitten, W.K. (1980). Induction of marking behaviour in wild red foxes *(Vulpes Vulpes L.)* by synthetic urinary constituents. *J. Chem. Ecology* **6**, 49-55

Williams CK & Twigg L (1996) Responses of wild rabbit populations to imposed sterility. *In:* R Floyd, R Shepherd nas PJ DeBaro (Eds) *Frontiers of Population Ecology.* pp547-60. CSIRO Publishing, Melbourne.

Wilson, G. Dexter, N. O'Brien, P. and Bomford, M. (1992) *Pest animals in Australia - a survey of introduced wild animals.* Kangaroo Press and Bureau of Rural Resources, Canberra.