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A Review of the Impact of Sheep Predators in Australia and New Control Methods Under Development

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ABSTRACT: The economic impact of introduced predators, principally wild dogs, foxes, and feral pigs, on agriculture in Australia varies across space and time but is estimated to be in excess of US\$120 million annually. Australian farmers and the government spend a further US\$30 million annually attempting to manage the predation and disease impacts of introduced predators on stock and wildlife. The principal chemical tool used to control each of these species is sodium fluoroacetate ('1080'). Issues relating to target-specificity and perceived inhumaneness of the toxin have led to heavily restricted use of the compound in the U.S. and a recent registration review in Australia. Three current proactive research projects are addressing this issue. The first is investigating a chemical, *p*-aminopropiophenone or PAPP, that appears to be selectively toxic for introduced carnivores, as well as rapid acting and relatively humane in its mode of action. The compound acts by interfering with oxygen transport in the blood of foxes and wild dogs, resulting in an effect similar to carbon monoxide poisoning. The second project involves testing and commercializing powerful fox, wild dog, and feral pig attractants that may help increase the efficacy and target-specificity of control programs. The first product from this project is FeralMone[®], an aerosolized formulation of synthetic fermented egg that is highly attractive to canids. The third project has involved developing a manufactured target-specific feral pig bait package, PIGOUT[®]. Initial research has focused on the delivery vehicle that contains sodium fluoroacetate centralized in an internal core, whilst current research is developing a recently identified humane alternative feral pig control agent. This paper will report on the economic impact of introduced predators in Australia, the recent Australian sodium fluoroacetate review recommendations, as well as summaries of current research into new predator control tools.

KEY WORDS: *Canis lupus dingo*, *Canis lupus familiaris*, control, feral pig, *Ovis aries*, predators, red fox, sheep, *Sus scrofa*, *Vulpes vulpes*, wild dog

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INTRODUCTION

The main predators of sheep in Australia are dingoes (*Canis lupus dingo*), wild dogs (*Canis lupus familiaris*) and their hybrids, foxes (*Vulpes vulpes*), and feral pigs (*Sus scrofa*). All three exotic predators are by nature elusive, highly mobile, intelligent, and wary, and thus difficult to detect and manage. Notwithstanding, proactive research and management strategies must balance the economic cost of developing and registering new control products with the benefits of control to maximize profitability for the industry (Choquenot and Hone 2002). To do this effectively, one must first know the economic impact of each species.

The distribution of dingoes and wild dogs in Australia historically has dictated the geographical distribution of sheep production in the country (Newsome and Coman 1989). This process continues today as wild dogs, including dingoes, establish and increase in previously dog-free areas (Anon. 2003). Detailed studies on rates of wild dog sheep predation indicate that they vary widely

between properties (Fleming *et al.* 2001), and that wild dog density does not necessarily correlate with their impact on sheep production (Allen and Sparkes 2001). Rates of predation reported thus far range from 0.1% (Backholer 1986) to 33% (Thomson 1984), however the more common finding is around 1% sheep losses on properties studied (Schaefer 1981, Fleming and Korn 1989). A recent economic impact study, commissioned by the predecessor to the Invasive Animals CRC, reported US\$12 million in direct sheep losses annually. An estimated additional US\$10 million, including the Dingo Barrier Fence, is spent annually by sheep farmers and the government trying to protect stock from wild dog attack (McLeod 2004).

The European red fox (*Vulpes vulpes*) inhabits at least half of mainland Australia and as of recently, Tasmania. Most of the species' range directly overlaps with sheep farm land. Studies detailing predation rates of lambs by foxes range from a minimum of 0.25% in areas where foxes were regularly controlled (Greentree *et al.* 2000) to

30% (Lugton 1993) in areas without fox control. However, relatively consistent findings of predation of viable lambs have been reported as 2% (McFarlane 1964), 2.7% (Dennis 1965), 1-2% (Mann 1968), 2.9% (Rowley 1970), and 1.5% (Greentree *et al.* 2000). Therefore, a nominal estimate of lamb losses throughout Australia at 2% predation (the average of the previous five studies) of the 35 million lambs born annually (ABARE 2003) would be 700,000 lambs. This would cost the sheep industry a minimum of US\$13 million annually (based on an average price of US\$19/head), not including future lost earnings from wool and genetic improvement. In addition, ongoing control and research costs are estimated at US\$15 million annually, although much of this is for native wildlife protection (McLeod 2004).

Feral pigs (*Sus scrofa*) occupy near 40% of the Australian mainland, much of which is grazing land, and cost Australian agriculture greater than US\$100 million annually (Choquenot *et al.* 1996, McLeod 2004). Investigations of perinatal lamb losses in the rangelands have reported that 11 to 70% of pregnant ewes miscarried or lost their young at birth, many as a consequence of harassment by feral pigs (Plant *et al.* 1978). Quantifiable losses by sheep producers are principally from newborn lamb predation, which has been estimated to range between 0% and 38% (Plant *et al.* 1978; Pavlov *et al.* 1981; Choquenot *et al.* 1997) and averages between 7% (western NSW; Benson 1980) and 18.7% (central NSW; Pavlov *et al.* 1981). As feral pigs co-occupy nearly all sheep grazing lands in NSW and Queensland (7 million lambs born per annum; Meat and Livestock Australia 2004), this equates to lamb losses approximating 0.5 to 1.3 million lambs or greater than US\$9 million annually. A further US\$5 million is spent each year on control and research costs. Feral pigs also indirectly effect sheep production through pasture consumption and damage, infrastructure damage, and disease transmission.

The most cost-effective broad-scale control method for controlling sheep predators is integrated baiting campaigns that predominantly use sodium fluoroacetate ('1080') in fresh, dried, or manufactured meat baits (all species) or grain (feral pigs) (Saunders *et al.* 1995, Choquenot *et al.* 1996, Fleming *et al.* 2001). The compound is relatively cheap to use and is very effective in killing sheep predators. However, it can also be toxic to some native species. In addition, sodium fluoroacetate can be relatively slow to act. Symptoms of poisoning can be visually distressing, leading to ongoing debate about whether it causes unacceptable suffering to affected animals. This combination of concerns has led to use of sodium fluoroacetate being severely restricted for use in canid control in the U.S. (in Livestock Protection Collars only), and its registration for this purpose in Australia has recently been reviewed.

The Australia Pesticides and Veterinary Medicines Authority (APVMA) conducted the review '*The Reconsideration of Registrations of Products Containing Sodium Fluoroacetate (1080) and Their Associated Labels*' between 2004 and 2006. The basis for the reconsideration was whether the APVMA could be satisfied that continued use of products containing sodium

fluoroacetate in accordance with the instructions for their use "would not be likely to have an unintended effect that is harmful to animals, plants or things or to the environment" (Anon. 2005). The review examined poisoning of non-target animals (native species and domestic animals), potential secondary poisoning impacts, the humaneness of the toxin as related to efficacy (humaneness assessment per se is beyond the scope of the APVMA), and concerns over instructions for use not being followed. The initial findings of the review were released in May 2005. They are contained in a draft report that is now available for public comment (<http://www.apvma.gov.au/chemrev/1080.shtml>). The review is recommending the strengthening of label instructions and controls on the use of sodium fluoroacetate to provide a greater margin of safety to minimise off-target species damage. The initial review findings have highlighted that, with certain improvements, the APVMA can be satisfied that the continued use of sodium fluoroacetate is safe for the environment (Anon. 2005).

Australia is one of the world's leading producers of lamb and sheep, both for wool and meat. As such, the sheep industry requires tested and sound additional toxins and baits to sustain sheep predator management practices for use in the event that current control tools are restricted or withdrawn. This paper reports on 3 new control methods that are aimed at assisting sheep producers retain or improve their commercial viability.

CANID BAIT PROJECT

Australian Wool Innovation Ltd signed a contract with the Pest Animal Control Cooperative Research Centre (now Invasive Animals CRC) in June 2003 to evaluate and develop a new toxic agent for control of wild dogs and foxes (canids). The candidate toxin in question is *p*-aminopropiophenone, or PAPP. The US Department of Agriculture had previously investigated the compound as a predicide, and it appeared to be selectively toxic for introduced carnivores, as well as rapid acting and relatively humane in its mode of action (Savarie *et al.* 1983). Further development of the compound was discontinued following the re-approval of sodium fluoroacetate in Livestock Protection Collars. PAPP acts by inhibiting oxygen transport by hemoglobin, through formation of methemoglobin in the blood of foxes and wild dogs, resulting in an effect similar to carbon monoxide poisoning (Marks *et al.* 2004). Historical trials had shown that eutherian carnivores, including coyotes, cats, and foxes, were the most susceptible family of animals, with rodents, birds, and especially humans some orders of magnitude less sensitive (Savarie *et al.* 1983). Investigations have also occurred in parallel into synergist agents for both sodium fluoroacetate and PAPP that may further increase the species specificity of either agent to canids, while further reducing non-target susceptibility.

Pen trials of the new toxin commenced on wild-caught captive Australian wild dogs in October 2003. Initial trials indicate wild dogs are highly susceptible to the toxin as predicted. Administration of PAPP to dogs using the M-44 mechanical ejector was demonstrated to cause rapid death of animals, with onset of symptoms observable

after approximately 30 mins, and an average time to death of approximately 90 mins. Symptoms of intoxication preceding death appear to be painless and include loss of coordination, drowsiness, and coma. Affected animals do not display hyperactivity or convulsions, although short seizures did occur in some animals. Sub-lethal doses of the toxin in wild dogs showed no abnormalities in the pathology of euthanized survivors. Similar trials have since been undertaken on farmed (genetically and physically homogenous) foxes (*V. vulpes*) in Finland to develop an accurate dose response model. Results for both species are consistent with data from administration of PAPP to foxes by the same means (Marks *et al.* 2004). Currently, bait-delivered formulated PAPP is being trialled on captive wild dogs and foxes prior to embarking on field trials for both species.

Non-lethal non-target testing of PAPP is currently being undertaken in various locations within Australia. Where possible, this is being done in the field to replicate natural exposure and effect conditions. Concurrently, bait formulation, stability, and environmental fate trials have commenced. Should the new toxin prove efficacious in forthcoming field trials on foxes and then dogs, and be

humane in action and show minimal non-target susceptibility, it will be registered and commercially released according to the timeframes in Table 1.

AEROSOLIZED SYNTHETIC LURES

Canid lures, either natural or synthetic, are used widely throughout the world to attract and trap dogs and foxes. Lures are typically a mixture of biological substances that are designed to evoke a particular response in the target animal, such as visiting, biting, pulling, or digging. The response evoked by each lure generally depends on whether it is sexual or gustatory in nature. Synthetic canid lures, such as those identified by the U.S. Department of Agriculture, can offer an effective and relatively consistent tool in evoking a required response, such as visitation to a trap or bait station (Kimball *et al.* 2000). Recent pen trials undertaken by Pestat Ltd (www.pestat.com.au) on captive red foxes showed that one synthetic lure in particular, synthetic fermented egg (Bullard *et al.* 1978), was a particularly powerful fox attractant (Figure 1). This finding is consistent with reports by Saunders and Harris (2000).

Pestat Ltd has developed an aerosolized formulation

Table 1. Timeline for development of p-aminopropiophenone as a new fox and wild dog toxin in Australia.

Activity	2003	2004	2005	2006	2007	2008	2009
Fox and dog sensitivity trials							
PAPP synergist trials							
Assessment of PAPP regulatory requirements							
Non-target sensitivity trials							
Bait delivery pen trials							
Bait matrix field trials							
Fox field trials							
Bait stability trials							
Environmental fate trials							
Fox bait registration							
Wild dog field trials							
Wild dog bait registration							

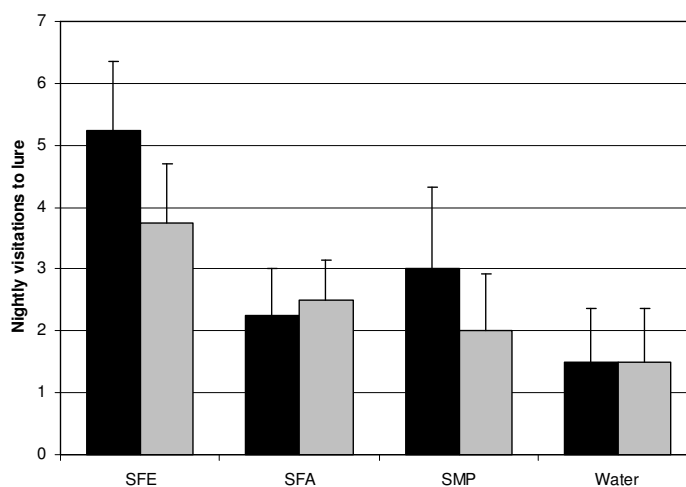


Figure 1. Mean (±S.E.) attractiveness of three synthetic lures and water to captive male (black bars) and female (grey bars) red foxes as measured by remote still photography. SFE was significantly more attractive for both sexes ($P < 0.05$) and lure preferences did not significantly differ between sexes ($P > 0.05$).

Key: SFE = synthetic fermented egg, SFA = synthetic fatty acid, SMP = synthetic monkey pheromone (Hunt *et al.* 2007)

of the attractant, marketed under the name FeralMone[®], in collaboration with the NSW Department of Environment and Conservation and with financial assistance from Australian Wool Innovation Ltd. This product provides a method of consistent delivery of the volatile constituents of the synthetic lure and greater ease of use for operators. Cans of the aerosolized lure were field tested in various locations around New South Wales, with increased fox and wild dog trapping success, bait station visitation, and bait uptake resulting (Vine 2004; Hunt *et al.* 2007; A. Glen, Univ. of Sydney, pers. commun.). The aim of this project is to provide an additional tool to land managers for attracting and detecting foxes, particularly at low densities such as in Tasmania, and wild dogs. Aerosolized lures can potentially serve the added purpose of reducing the area and number of baits required for effective canid baiting programs, although this is yet to be empirically proven. FeralMone[®] became commercially available in Australia in 2005 and has been well received by the market since its release. Pestat Ltd is currently also instigating field trials of a potential synthetic feral pig lure.

FERAL PIG BAIT PROJECT

Unlike the case for other sheep predators, there is no commercially available manufactured feral pig bait to assist land managers in controlling feral pigs. As such, farmers are generally reliant on government personnel to supply sodium fluoroacetate for addition to field-prepared baits. This process is time-consuming, has difficulty in delivering a sufficient toxin load to pigs (72 mg of 1080 required, as compared to dog and fox baits of 6 mg and 3 mg of 1080 respectively), and potentially exposes a suite of non-target species to the large doses of toxin involved.

O'Brien (1986) proposed a framework for the design of a feral pig-specific package bait— in essence, one that identifies differences between the ecology and behaviour of feral pigs and potential non-target species. The framework and prior research of O'Brien (1986) reached a point of pen testing grain packaged baits. This was the starting point for the development and commercialisation of feral pig baits in the current project; however, an omnivore sausage bait has been chosen over grain to reduce the bait's attractiveness to herbivores, as there are fewer native omnivorous species in Australia compared to herbivores. One reason O'Brien's research did not reach the point of commercialisation was due to the lack of a commercial partner, something that has been rectified in the current application through collaboration with Animal Control Technologies Australia P/L. Meat and Livestock Australia Ltd and the National Feral Animal Control Program fund this two-year project, which commenced in January 2004.

Pen trials were undertaken on wild-caught captive feral pigs in January 2004 to test 7 manufactured bait prototypes against 2 controls (fresh meat and wheat). Baits were assessed for feral pig initial preferences and palatability, with results showing that 3 manufactured bait prototypes were slightly more attractive than fresh meat and wheat in terms of feral pig first preferences (in 144 paired samples using 18 individuals) and time until consumption (Lapidge *et al.* 2004). The 3 most

promising prototype baits from pen trials and the 2 controls were subsequently repeat tested in paddock trials (1 ha) whereby pigs had access to native vegetation and habitat. Results did not significantly differ between the 5 bait types tested, indicating that prototype baits performed as well as currently used feral pig bait substrates (Lapidge *et al.* 2004).

Throughout 2004 and 2005, PIGOUT[®] baits have undergone extensive testing throughout the range of feral pigs in Australia. Many trials are currently the subject of journal manuscripts, and are not detailed here (e.g., Cowled *et al.* 2006). Trial locations, habitats, seasons, delivery and assessment methods, target specificity, and efficacy of all population level field trials are summarized in Table 2. Additional target specificity trials were undertaken in Namadgi National Park (Australian Capital Territory), Arthursleigh farm (New South Wales), and Marengo State Forest (New South Wales) (Cowled *et al.* 2006). All trials have indicated that the PIGOUT[®] baits offer a high level of target specificity in a variety of feral pig habitats, and that use of the product should reduce non-target susceptibility, compared with using grain and meat baits, without the need to fence baiting areas. Furthermore, all field trials indicated PIGOUT[®] baits are as efficacious as natural baits, if not more so, for population control of feral pigs.

A registration dossier has recently been submitted to the Australian Pesticide and Veterinary Medicines Authority for PIGOUT[®]. It is anticipated that the project will culminate in late 2006 with the release of a quality-assured and cost-effective feral pig bait package (bait + toxin delivery system) with increased target specificity. Baits will initially contain sodium fluoroacetate, as it is currently used in approximately 75% of feral pig baiting campaigns, but can be readily adapted to incorporate other active agents. Sodium fluoroacetate is incorporated into baits using an innovative centralized core, which ensures a maximum buffer zone between the bait surface and internal toxin. PIGOUT[®] baits are also currently being trialled to deliver disease vaccines, such as those for Aujeszky's disease (pseudorabies) in America (Campbell *et al.* 2006), and contraceptive agents for non-lethal control of feral pigs in America and Britain.

An 'Achilles heel' review (Marks 2001) was undertaken in 2004-05 by one of the authors (B. C.) through reviewing veterinary literature from the last century and searching for substances that were uniquely toxic to pigs. In essence, the review examined the physiology and biochemistry of feral pigs to look for 'chinks in their armour'. Desirable attributes of a new toxin included safety for human operators, high toxicity for feral pigs, ready acceptability and deliverability in baits, target specificity, humaneness (including mechanism of action, speed of action, pathology, clinical signs and duration, sub-lethal doses, reports from humans), absence of residues or bioaccumulation, antidote availability, cheap and ready availability, existing registration (for other purposes, i.e., food product), literature published already to expedite registration, and acceptability to trading partners. Following an extensive search, 3 candidate new actives or active combinations were recently trialled on wild-caught captive feral pigs.

Table 2. Field assessment methods, efficacy and target-specificity of PIGOUT[®] manufactured feral pig baits.

Location	Habitat	Season	Delivery Method	Active	Assessment	Target Specificity	Efficacy
Cunnamulla, Queensland	Rangelands	Wet summer 2004	Aerial	Biomarker	Aerial shoot, biomarker uptake	100%	80%
Wrotham Park Station, Queensland	Savanna	Spring 2004	Aerial	1080	Activity change	100%	42%
Kangaroo Island, South Australia	Riverine	Spring-summer 2004	Ground	1080	Activity change	High, although 2 non-target deaths recorded	79%, 77% & 65% (3 sites)
Welford National Park, Queensland	Rangelands	Dry summer 2005	Ground	1080	Telemetry, carcass recovery	100%	75%, 78%, 89% & 100% (4 mobs)
Kingsville, Texas, U.S.	Game Ranch	U.S. spring 2005	Simulated aerial	Biomarker	Trapped, biomarker uptake	Low, 22%*	74%
Toorale Station, New South Wales	Rangelands	Wet spring 2005	Aerial & ground	1080	Telemetry	98%	56% [#]

* Result was due to a high abundance of sympatric omnivores.

[#] Relates to radio-tagged animals only. Aerial surveys conducted throughout the trial site pre- and post-baiting indicated no significant change in the overall population.

One of the actives was particularly quick acting and humane, and it addressed all of the above criteria. Development of this new active for feral pig control will be the subject of a further research project over the coming years.

DISCUSSION

The true extent of sheep and lamb predation in Australia is impossible to assess accurately, as it is affected by a multitude of factors including property location, control efforts, season, stock, enterprise, and behaviour of individual predators. Figures presented above, however, do indicate it is likely to be in the tens of millions of dollars (US) per annum. Perhaps more disturbing is that the impact of predators such as wild dogs is increasing, not decreasing (Anon. 2003), with an associated decline in sheep production in some areas (ABARE 2003). As such, it is essential that industry and pest animal researchers do not relax efforts in this area, but rather redefine what is required to effectively control introduced predators and take the necessary steps to see products and practices through to fruition.

Products discussed within this paper are predator management tools under development that are aimed at assisting sheep farmers and other land managers to effectively control wild dogs, foxes, and feral pigs. They are not designed to replace existing technologies, but rather provide additional tools to what currently exists. Each tool has its own advantages and disadvantages over currently available techniques and should be used in combination with existing toxic baits, shooting, trapping, fencing, and habitat manipulation for an integrated approach to managing sheep predation.

Although the Australian Pesticide and Veterinary Medicine Authority has re-approved sodium fluoroacetate and C.S.S.P. Phosphorous pig poison, potential increases in target-specificity and visible humaneness offered by the products under development dictates that their registration is still desirable. New, innovative products can also have the added bonus of re-energizing farmers to undertake predator control. The purpose of the canid

and feral pig projects is to ensure farmers are not left without tested and registered technologies or products for the management of sheep predators.

Predator management is a way of life for many farmers, both in Australia and overseas. Unfortunately, due to the genetic and physiological similarities between dingoes, wild dogs, domestic dogs, and foxes, and feral and domestic pigs, biological control of sheep predators in Australia is not an option. As such, ongoing ground control will remain indefinitely as a part of sheep management practices. Whilst none of the products discussed in this paper are 'silver bullets', hopefully they will assist farmers in effectively managing the impact of sheep predators in the near future.

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