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A strategic approach to mitigating the impacts of wild canids: proposed activities of the Invasive Animals Cooperative Research Centre

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Abstract. Wild canids (wild dogs and European red foxes) cause substantial losses to Australian livestock industries and environmental values. Both species are actively managed as pests to livestock production. Contemporaneously, the dingo proportion of the wild dog population, being considered native, is protected in areas designated for wildlife conservation. Wild dogs particularly affect sheep and goat production because of the behavioural responses of domestic sheep and goats to attack, and the flexible hunting tactics of wild dogs. Predation of calves, although less common, is now more economically important because of recent changes in commodity prices. Although sometimes affecting lambing and kidding rates, foxes cause fewer problems to livestock producers but have substantial impacts on environmental values, affecting the survival of small to medium-sized native fauna and affecting plant biodiversity by spreading weeds. Canid management in Australia relies heavily on the use of compound 1080-poisoned baits that can be applied aerially or by ground. Exclusion fencing, trapping, shooting, livestock-guarding animals and predator calling with shooting are also used.

The new Invasive Animals Cooperative Research Centre has 40 partners representing private and public land managers, universities, and training, research and development organisations. One of the major objectives of the new IACRC is to apply a strategic approach in order to reduce the impacts of wild canids on agricultural and environmental values in Australia by 10%. In this paper, the impacts, ecology and management of wild canids in Australia are briefly reviewed and the first cooperative projects that will address IACRC objectives for improving wild dog management are outlined.

Introduction

Wild dogs, which include dingoes (*Canis lupus dingo*), feral domestic dogs (*C. l. familiaris*) and their hybrids, are estimated to cost the livestock industries of Australia AU$66.3 million per annum in production losses and control activities and have additional unquantified social and environmental impacts (McLeod 2004). Concurrently, dingoes are afforded protection as a native species in many State jurisdictions (Allen and Fleming 2004; Fleming *et al*. 2001). This contemporaneous dichotomy of status causes difficulties in managing wild dogs because stakeholders often have conflicting objectives.

The relatively recently introduced European red fox (*Vulpes vulpes*) is distributed throughout mainland Australia, primarily south of the Tropic of Capricorn (Edwards *et al*. 2004; Saunders *et al*. 1995). The fox is estimated to cost AU$227.5 million per annum in costs of control and in livestock and biodiversity losses (McLeod 2004). The objectives of stakeholders involved in fox management are usually similar, regardless of whether the impacts to be minimised are environmental or agricultural.

Given the extensive costs of wild canids to Australia, the recently formed Invasive Animals Cooperative Research Centre (IACRC) has a major objective of delivering to livestock industries and the environment a benefit of AU$29 million per annum by reducing the impacts of foxes and wild dogs. The IACRC brings together about 40 partners representing private and public land managers, universities,

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and training, research and development organisations in Australia, New Zealand, the United Kingdom and the United States of America.

This paper outlines the extent of the wild dog and fox problems in Australia, briefly summarises knowledge of their ecology and behaviour (more detail can be found in Saunders *et al*. 1995; Fleming *et al*. 2001 and Corbett 2001), outlines the strategic approach (Braysher 1993) to managing wild canids and details IACRC projects, both current and planned, to address the wild dog component of the objective.

Defining the issue: distribution, ecology, behaviour and impacts of wild canids in Australia

The dingo proportion of the wild dog population in Australia is native to Asia (Corbett 1985; Savolainen *et al*. 2002). Dingoes are thought to have been brought to northern Australia by traders (Corbett 2001) and the successful introduction may have come from a single pregnant female about 5000 years before present (Savolainen *et al*. 2004). Wild domestic dogs have been present since the first European settlement in 1788 (Fleming *et al*. 2001) and hybridization with dingoes has been occurring ever since (Corbett 2001; Wilton *et al*. 1999). Wild dogs are dispersed over most of mainland Australia (Fig. 1), except the intensively farmed areas of south-west Western Australia (Woolnough *et al*. 2005), South Australia, New South Wales (West and Saunders 2003) and Victoria. Abundance is generally low south of the wild dog barrier fence (Fig. 1). There are also shorter exclusion fences in Western Australia, Victoria, and along the eastern edge of the Great Dividing Range in eastern NSW and within the exclusion fences, wild dog numbers are generally low (Cross 2005; Fleming *et al*. 2001; West and Saunders 2003)

Foxes were introduced into mainland Australia in the 1860s and quickly spread (Jarman 1986; Rolls 1984). This dispersal and establishment corresponds with the introduction and spread of European wild rabbits (*Oryctolagus cunniculus*) (Saunders *et al*. 1995). Except in Tasmania, where introductions appear to have been unsuccessful until 2001 (Lapidge 2004), and in northern Australia, where the climate is thought unsuitable and rabbits are essentially absent, foxes have become established throughout in most habitats including urban and residential environments (Saunders *et al*. 1995). Foxes are viewed as a pest of agriculture (Saunders *et al*. 1995) and as a key threatening process to endangered small mammals (e.g. Biodiversity Group Environment Australia 1999; NSW National Parks and Wildlife Service 2001). Edwards *et al*. (2004) have noted a recent northwards increase in distribution of foxes in the Northern Territory and this is thought to be hazardous for small species that previously were not exposed to fox predation. Foxes also devalue agricultural and environmental land by spreading weeds such as blackberry (*Rubus*

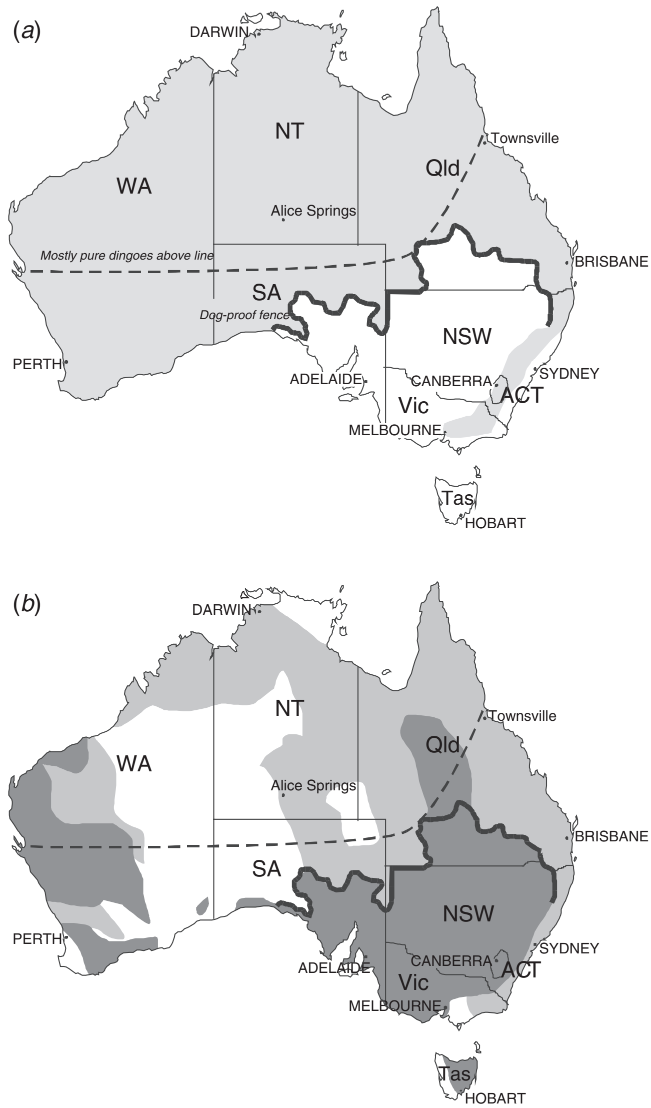

Fig. 1. The distribution of (*a*) wild dogs and (*b*) livestock in Australia (from Fleming *et al*. 2001). Wild dogs above the dashed line are mostly pure dingoes (from Corbett 2001). The solid line is the 'barrier fence'. In (*a*), wild dogs are present at varying densities from naturally sparse to common (light grey shading) to mostly absent (no shading). In (*b*), livestock distribution is shown as follows: sheep, cereals and cattle production (dark grey shading); cattle predominant (light grey shading); livestock mostly absent (no shading).

friticosus) and bitou bush (*Chrysanthemoides monilifera*) (Meek 1998).

Because of their long presence and historic distribution through every ecosystem in mainland Australia (Corbett 2001; Fleming *et al*. 2001), dingoes are often regarded as a 'native' species (Davis 2001). Despite the native status of dingoes, all wild dogs and foxes are regarded and managed as pests on agricultural lands. In most States and Territories, dingoes are afforded protection, at least in areas set aside for conservation (Davis and Leys 2001; Fleming *et al*. 2001).

Within conservation areas, feral dogs and hybrids effectively enjoy the same protection as do dingoes because they cannot be managed separately (Allen and Fleming 2004). The greatest threat to the survival of dingoes as a subspecies is hybridisation with domestic and feral dogs (Corbett 2001).

Daniels and Corbett (2003) argue with some justification that policies for protection of dingoes should concentrate on cultural significance and ecosystem function rather than genetic purity. However, the role of all wild dogs and foxes in different environments and their interactions have not been determined (Dickman 2003; Glen and Dickman 2005; Fleming *et al*. 2001).

Wild dogs live in small packs in territories where the home ranges of individuals vary between 10 and 300 km^2, and these are larger in the more arid regions (Thomson 1992*a*) and smaller in the more productive areas in south-eastern Australia (Harden 1985; A. Robley, unpublished data). Packs are usually stable (Thomson *et al*. 1992*a*) but some wild dogs will disperse (Allen 2005; Thomson *et al*. 1992*b*). Foxes often live in family groups centred on the breeding pair with a stable home range (Saunders *et al*. 1995). In times of drought, fox home ranges may temporarily break down (Saunders *et al*. 2002). Dispersal is usually by young animals and occurs in autumn or during breeding in early winter (Saunders *et al*. 1995).

Wild dogs eat a diverse range of foods, prefer medium-sized and large vertebrates (Corbett 2001; Newsome *et al*. 1983) and their diet partly overlaps with foxes (Corbett 2001; Fleming *et al*. 2001; Glen and Dickman 2005; Mitchell and Banks 2005; Saunders *et al*. 1995). They can change hunting tactics to suit the size of available prey (Corbett 2001; Thomson 1992*b*). Larger groups of wild dogs are more successful when hunting large kangaroos and cattle (Corbett 2001; Thomson 1992*b*), and solitary dogs are more successful when hunting rabbits (Marsack and Campbell 1990) and smaller macropods (Robertshaw and Harden 1986). Single wild dogs can easily pull down sheep (Thomson 1984*a*), although groups of dogs will cooperate in kills (Thomson 1992*b*), and all wild dogs that enter sheep-grazing lands will eventually attack or harass sheep (Thomson 1984*a*). Predation of livestock is greater when alternative food is scarce (Corbett 2001; Allen and Gonzalez 1998).

Foxes eat a broad range of mostly smaller prey than wild dogs (see review of fox diet in Appendix 1 in Mitchell and Banks 2005), usually hunt alone, and kill lambs and kids. When prey numbers are already low, predation by foxes may limit the abundance of prey such as rabbits (Banks 2000; Pech *et al*. 1992), small macropods and the joeys of larger species [e.g. eastern grey kangaroos, (*Macropus giganteus*) and common wallaroos (*M. robustus robustus*)] (Banks *et al*. 2000; Newsome *et al*. 1989).

Until recently, production losses from wild dogs were considered highest in the sheep industry, followed by the cattle and the goat industries (Allen and Fleming 2004; Fleming and Korn 1989). However, the increased value of the cattle and calves in recent times has increased the importance of losses caused by wild dogs to the cattle industry (AU$32.4 million per annum; McLeod 2004). In 1962, sheep graziers in the northeast of New South Wales showed annual losses to predation by wild dogs of 1.3% per property and a control effort of 39.5 hours per property per annum (New England Rural Development Association undated *c*. 1963). A later sample of graziers in the same area reported average sheep losses of 0.9% per property per annum (Schaefer 1981), which was similar to those reported in 1984–85 (0.7% per property per annum; Fleming and Korn 1989). When a random sample of livestock producers ($n = 109$) in north-eastern New South Wales was surveyed monthly over an 18-month period in 1984–85, losses were variable and the relationship between density of wild dogs (as measured by a mean monthly index of sign) was only weakly related to sheep production losses (AU$ per property, Fig. 2; P. J. S. Fleming, H. Nicol, unpublished data). Backholer (1986), in a mailed questionnaire survey of 809 properties in eastern Victoria, reported mean losses per property of between AU$400 and AU$4230 per annum in the previous 5 years, which was 0.1–24.9% of the total value of the enterprises. A Western Australian study (Thomson 1984*a*) showed predation of sheep to be variable, with periods of few losses and instances of many attacks in a short period. Over 18 days during winter 1978, losses of 33% of available sheep on 1 property and 16% of a second were attributed to predation by wild dogs.

The impact of wild dogs on cattle production in Australia is even more variable (Fleming *et al*. 2001). Attacks on young calves are the major cause of wild dog losses to cattle, but weaners and older cattle are sometimes killed or injured by packs of wild dogs (Allen 2005; Fleming and Korn 1989; Rankine and Donaldson 1968). Damaged animals

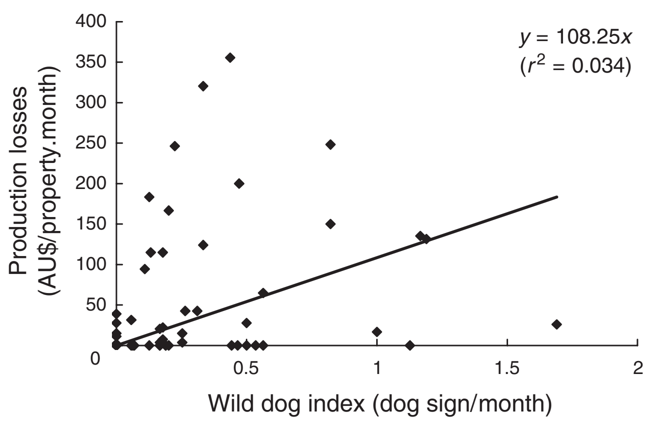

Fig. 2. The weak relationship between the density of wild dogs (expressed as a mean monthly index of wild dog sign) and the mean monthly sheep production losses caused by wild dogs ($n = 40$ sheep properties). Regression forced through the origin.

are valueless for the expanding live cattle export trade from northern Australia (G. Edwards, pers. comm.). Estimates of predation losses of calves and weaners in normal conditions in rangeland grazing areas are in the range of 0–29.4% per annum (Rankine and Donaldson 1968). A 1995 questionnaire survey of about 67% of cattle graziers in the Northern Territory estimated annual calf losses attributable to predation by wild dogs between 1.6 and 7.1% (Eldridge and Bryan 1995). In south-eastern Australia, where sheep and cattle are cograzed in wild dog-inhabited areas, predation of cattle is rare (Fleming and Korn 1989). However, in some coastal areas of New South Wales, predation of calves and steers by wild dogs is becoming more apparent. For example, in the Kempsey Rural Lands Protection Board district, up to 1460 cattle per annum were attacked by wild dogs during the past 4 years (J. Gwalter, unpublished data). Studies of reproductive failure in cattle herds undertaken in Queensland have reported up to 30% loss of calves caused by predation by wild dogs (Allen and Gonzalez 1998; Rankine and Donaldson 1968).

Relatively few of the livestock that are killed or mauled by wild dogs are eaten, and, often little of the animal is consumed (Fleming 1996; Thomson 1984*a*). Because of surplus killing (where a predator kills in excess of its energy and nutritional requirements; Krüuk 1972) and changeable hunting tactics, the damage experienced by livestock producers is independent of the density of wild dogs (Fig. 2) (Fleming *et al*. 2001). Surplus killing means that a few wild dogs can be responsible for many losses, and changing tactics from hunting alone to hunting in packs results in many hunters causing few losses.

The European red fox inhabits the southern half of mainland Australia (Cross 2005; Saunders *et al*.1995; West and Saunders 2003; Woolnough *et al*. 2005) and were purposely introduced into Tasmania in 2001 (Lapidge 2004). Most of the fox's mainland distribution directly overlaps with sheep grazing land (Allen and Fleming 2004; Jarman 1986). Studies detailing predation rates of lambs by foxes range from a minimum of 0.25% where foxes were regularly controlled (Greentree *et al*. 2000) to 36% of lamb deaths in areas without fox control (Lugton 1993). The cost to sheep graziers has been estimated to be AU$17.5 million per annum, excluding future lost earnings from wool and genetic improvements (McLeod 2004). Additional annual environmental costs of AU$190 million (McLeod 2004 using the valuation method by Pimental *et al*. 2000) and annual control costs of AU$16 million are also attributed to the red fox in Australia. Foxes seldom hunt other than alone, but have been implicated in surplus killing of lambs, kids and poultry (Short *et al*. 2002).

Current techniques for controlling wild canids

The erection of exclusion fences for controlling the ingression of wild dogs began in the 1880s and they became more widespread after the introduction of prefabricated wire netting at the beginning of the 20th century (Allen and Fleming 2004). Fence designs vary, but usually conventional fences are 1.8 m high and constructed of wire netting or mesh (e.g. the barrier fence along the South Australia–New South Wales northern border). Advances in electric fencing technology have resulted in the widespread use of electrified wires, either in the body of new fences or offset to existing exclusion fences (Bird 1994).

Along the State borders of New South Wales with Queensland and South Australia a government-erected exclusion fence, known as the 'dog fence' or 'barrier fence', extends 5614 km from near Dalby in south-eastern Queensland to Fowlers Bay on the Great Australian Bight in South Australia (Fig. 1) (Fleming *et al*. 2001). Before the shortening of the Queensland section of this fence in 1989, the dog fence was 8614 km long (Breckwoldt 1988). The dog fence is extended into northern New South Wales by a series of linked, privately-erected and maintained fences. Other exclusion fences in eastern New South Wales, Queensland and Western Australia were usually erected privately and are maintained by private landholders and groups of landholders. Victoria has a Land Protection and Incentives Scheme, which assists landholders to build fences on common boundaries with government lands.

From the early 1800s, when strychnine was first used for poisoning wild dogs and sometimes foxes, control programs were instigated at the property level or cooperatively. Cooperation between landholders was necessary because strychnine was expensive and could only be imported in quantities too large for individual landholders (Fleming *et al*. 2001). Ground baiting with baits containing compound 1080 (sodium fluoroacetate) is an important technology for controlling wild dogs and foxes (Allen 2005; Saunders *et al*. 1995; Thompson 1994). Since the mid-1960s, compound 1080 has largely replaced strychnine in baits.

Aerial baiting began with experimental drops of brisket-fat baits containing strychnine in Western Australia and Queensland in 1946 (Tomlinson 1954). Meat baits containing compound 1080 were first aerially distributed in the Northern Tablelands of New South Wales in 1964 and had replaced strychnine baits in aerial baiting programs in most areas by the late 1960s (Allen and Sparkes 2001; Fleming *et al*. 2001). Fixed-wing aircraft were used in eastern NSW until 1986, when helicopters became mandatory for aerial baiting in the east of New South Wales because baits could be placed with more accuracy (Thompson *et al*. 1990). Baiting from fixed wing aircraft continues for foxes in some nature reserves of western New South Wales, and for wild dogs in Queensland and Western Australia, and for fox control in the Western Shield Program in Western Australia. Aerial baiting is now generally accepted as a cost-effective method for the extensive strategic management of wild dogs (Fleming *et al*. 1996; Thomson 1986; Thompson and Fleming 1991), and is used in Queensland, New South Wales, Western Australia and the Northern Territory (Fleming *et al*. 2001).

An uncontrolled study in northern Queensland showed a reduction in calving losses and injuries caused by wild dogs in the 9 years following the introduction of an annual, broad-scale aerial baiting program (Fig. 3; Allen and Gonzalez 1998). In contrast, an increase in calf losses to wild dog predation was evident after baiting was undertaken in an experiment in central Queensland (Allen 2005; Allen and Gonzalez 1998). The wild dogs that dispersed into the sink caused by baiting were predominantly young, and may have more readily attacked calves (Allen 2005).

Thomson (1984*b*) first suggested and tested the use of dingo-free buffer zones to prevent predation of sheep in Western Australia. Buffer zones were created by aerially baiting a strip of about 2 dingo home range widths adjacent to sheep-grazing country. It took 2 years for dingoes to recolonise the buffer zone and livestock predation was effectively eliminated in the sheep-grazing country for 2 years without further baiting occurring (Thomson 1984*b*). The use of a buffer zone for managing fox predation was investigated by Thomson *et al*. (2000) and found effective, with indices within the baited core area at 26% of initial levels 2 years after baiting. The buffer zone forms the basis of wild dog control in Western Australia and a similar strategy is used in north-eastern New South Wales (Thompson and Fleming 1991). There, annual aerial baiting reduces the wild dog population in a strip 4–12 km wide adjacent to the sheep grazing lands (Fleming 1996). In eastern Victoria, the policy is to control wild dogs within 3–5 km external to a private land boundary with government land; the effectiveness of this strategy remains untested.

Shooting of foxes attracted with whistles or at night with the aid of high-powered spotlights is still a common adjunct to poisoning programs but it less effective as a control method (Coman 1988; Fleming 1997). Only rarely is shooting used as a control tool for wild dogs, and then it is usually opportunistic

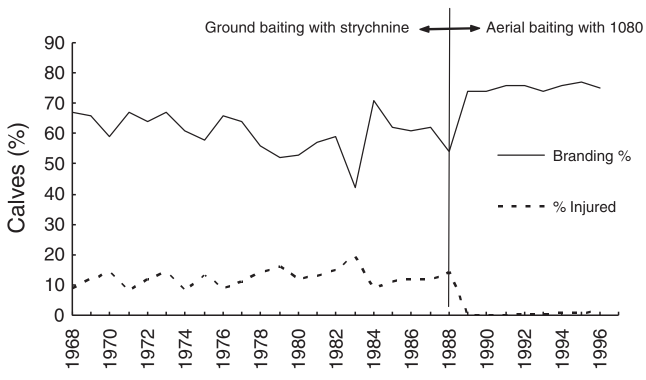

Fig. 3. Calf production losses and injuries caused by wild dogs for a north Queensland property during 20 years of single property ground baiting (1968–88) and during 9 years of coordinated aerial baiting with neighbours (1989–96) (from Allen and Gonzalez 1998).

or aided by simulated dingo calls (‘howling up a dingo’) (Harden and Robertshaw 1987).

The employment of professional trappers or doggers by government agencies, wild dog control organizations, and sometimes by groups of landholders, remains an important strategy for wild dog control. In some areas, for example, south-east New South Wales, Victoria, the Australian Capital Territory and some parts of Western Australia, doggers are still an integral part of pre-emptive reduction of wild dog populations (e.g. Brindebella and Wee Jasper Valleys Wild Dog/Fox Working Group 2002). Doggers rely primarily on trapping to reduce wild dog populations and to remove troublesome individual wild dogs. Trapping is becoming more humane with the adoption of traps with rubber-lined jaws by most States (Fleming *et al*. 1998).

Recent developments in the control of wild canids

Because of its relative specificity and the particular susceptibility to it shown by canids and felids, compound 1080 will remain an important toxin for controlling wild canids in Australia. However, there are some statutory limitations to compound 1080 usage; it has no antidote to treat accidental poisonings of domestic dogs and cats, its use has been banned in the USA and its relative humaneness has been questioned (Goh *et al*. 2005). It is, therefore, prudent to investigate alternative and new toxins to assure that baiting remains a tool for controlling wild canids. A project, which commenced in June 2003 and will continue in the new IACRC, is evaluating a novel toxin, para-aminopropiophenone (PAPP) (Savarie *et al*. 1983), which causes a relatively rapid and humane death similar to carbon monoxide poisoning (Lapidge 2004; Marks *et al*. 2004). In historical pharmaceutical trials, the toxin provided a high degree of specificity for eutherian carnivores, particularly canids, with rodents, birds and especially humans being much less sensitive than canids (Savarie *et al*. 1983).

Pen trials of the new toxin indicated that wild dogs are highly susceptible to the toxin, and show no clinical signs of emesis or physical distress (Lapidge 2004). Similar trials have since been undertaken on farmed (genetically and physically homogenous) foxes in Finland to develop an accurate dose response model (C. Marks, unpublished data). Preliminary findings indicate that both wild dogs and foxes are highly susceptible to the new toxin and that the lower dose response of foxes could be used to selectively control foxes where dingoes require conservation (Lapidge 2004).

Non-lethal testing of the new toxin on non-target carnivores and omnivores is currently being undertaken in pens and will be repeated in the field to duplicate natural exposure. Once PAPP has been shown effective, species-specific and humane for canid control, and the dose response curves calculated for foxes and wild dogs, it will be incorporated into a new canid bait medium at appropriate dosage for each species, registered and commercially released as soon as possible (Lapidge 2004).

Alternative methods of toxin delivery and improved attractants are also being investigated. Mechanical ejectors have been used in the United States of America since the 1940s for the destruction of livestock predators, principally coyotes (*Canis latrans*). One such device, the M-44 ejector, is a tube that is set into the ground with a toxin capsule mounted on a spring-driven plunger oriented vertically. A canid attractant on the capsule stimulates the dog or fox to bite and pull the capsule upwards, triggering the plunger and causing the device to eject a lethal dose of toxin (generally sodium cyanide) into its mouth, where absorption is rapid, and death is almost immediate (Connolly and Simmons 1984; Marks *et al*. 2003).

Mechanical ejectors have advantages over baits for canid control (Marks *et al*. 2003): they are more target-specific, as only the strong and slender snouts of canids are generally suited to triggering an ejector (Connolly and Simmons 1984); bait caching cannot occur, reducing the risk of accidental poisoning of working dogs and other non-target animals (Busana *et al*.1998); sodium cyanide usually produces a rapid death (but see Thompson 1994) resulting in canid carcases being found near the ejector, allowing accurate identification (Lapidge 2004) and monitoring of program effectiveness (Thompson 1994). Because multiple bait uptake and caching are not possible with M-44s, fewer placements are required than for conventional baits. M-44s can also be used to deliver other toxins, including compound 1080 (Marks *et al*. 2002). The disadvantages, when compared with conventional baits, are; the higher initial investment cost, the potentially higher occupational health and safety risks (particularly when using cyanide; Marks *et al*. 2004), the greater time for deployment in the field and the more intense training required by operators.

Sodium cyanide is highly toxic and its use is heavily regulated and restricted (Hone and Mulligan 1982), which potentially limits the use of M-44 ejectors. Marks *et al*. (1999) tested M-44 ejectors to deliver compound 1080 to foxes and found a reduced dose was required than in baits. M-44 ejectors could potentially deliver PAPP, providing a canid specific, relatively rapid and humane control option that is safer for operators than cyanide (Marks *et al*. 2004). This use of M-44 ejectors will be further investigated (Lapidge 2004).

Recent pen trials undertaken by Pestat Ltd on captive red foxes showed that synthetic fermented egg (SFE) was a useful olfactory attractant for foxes, as Saunders and Harris (2000) found. Wild dogs and foxes were attracted to SFE in field trials (D. Dall, R. Hunt, S. J. Lapidge, unpublished data) in southern NSW and similar attractiveness to wild dogs has been demonstrated in pen (Jolly and Jolly 1992) and field trials in southern Queensland (Mitchell and Kelly 1992). Pestat Ltd has developed and tested an aerosolised formulation of SFE (Feralmone) to provide consistent delivery of the volatile constituents and greater ease of use and olfactory comfort for operators. Further testing is required in other ecosystems with different suites of native predators co-occurring with wild canids (e.g. Western Australia and Northern Territory).

An alternative to lethal control of wild canids is the use of livestock guarding animals to deter predators (Jenkins 2003). The main animals used are alpacas and llamas, and guarding dogs. However, uptake of this technology has been limited, mainly because producers require scientific testing of different guarding animals before they will try them (Jenkins 2003). A pilot trial has commenced and it is hoped that future resources will be allocated from the IACRC.

Strategic management of wild canids: a holistic approach

A strategic approach to the management of vertebrate pests has been advocated by Braysher (1993). This approach involves defining the problem, developing a plan of action, undertaking the plan, monitoring everything and evaluating the plan, and encourages involvement of all major stakeholders and allows iterative improvements at local and regional scales.

The strategic approach can be dissected into 6 operational components (Fleming and Harden 2003 adapted from Braysher 1993):

(i) defining the problem quantitatively and qualitatively;
(ii) developing a plan of actions;
(iii) implementing the plan;
(iv) monitoring all aspects of the plan;
(v) evaluating the plan from the results of monitoring; and
(vi) revising the plan and progressing through another iteration.

Defining the problem includes: the identification of which stakeholders have a wild dog problem; which stakeholders are affected or potentially affected by management actions; what harm the wild dogs cause; where, when and why damage occurs; and the costs of damage and control (Fleming and Harden 2003). A management plan has set objectives including interim and long-term goals for dingo conservation, mitigation of livestock predation, strategies and actions for managing wild dog predation, tasks assigned to people or agencies, a time frame for performing actions and achieving goals and indicators for measuring performance. Monitoring occurs at different levels throughout the implementation of the plan, including costs, actions and damage responses. On completion of the evaluation process, stakeholders evaluate how the plan is working in the light of the monitoring, revise the plan accordingly and progress (Fleming and Harden 2003). This process is being applied with some success to wild dog management in New South Wales and the Australian Capital Territory (Jenkins *et al*. 2002).

The same process applies to group programs to manage red foxes (e.g. Balogh *et al*. 2001; Field *et al*. 2005; Thomson *et al*. 2000). In Victoria, the strategic approach forms the basis of adaptive experimental management of foxes on Parks Victoria estate (Robley and Wright 2003).

Wild canid management: putting it all into practice in the IACRC

Wild canids have large home ranges that often cross land tenures. In Australia, they also have different status in different tenures and ecosystems, and in those, their behaviours, and, hence, their impacts and control requirements, may differ. Therefore, a collaborative effort is needed to investigate the problem, research new technologies and applications, and to provide education and training to implement those solutions better. In the new IACRC for the first time, research, industry, environmental, and commercial agencies, and private and government land managers will work together to apply solutions to problems caused by wild canids across Australia. The IACRC provides a great opportunity for the implementation of the strategic approach to managing wild canids at local, regional and national scales.

An important goal of the IACRC is to demonstrate strategies and technologies that are successful. To that end, a number of demonstration sites have been selected in the Uptake Program. These include 2 sites that demonstrate best practice fox management, 1 in Western Australia and the other in Victoria, and a site in north eastern NSW that will encourage the use of the strategic approach to managing wild dogs for mitigation of agricultural impacts and conservation (of dingoes) in reserves.

Already, the problems of wild dog and fox predation of livestock and wildlife have been defined quantitatively in broad terms (McLeod 2004). A workshop of representatives from each State and Territory that has wild dog issues was held to prioritise IACRC expenditure. Thirty-eight projects were nominated, many of which dealt with interactions between wild dogs and foxes [and feral cats (*Felis catus*)], and showed commonality of priorities among jurisdictions. The projects that were considered to hold the greatest chance of achieving the objectives of the CRC were:

(i) to nationalise the strategic approach to managing wild dogs;
(ii) investigate and develop user-friendly and useful monitoring methods for field operators in management programs;
(iii) undertake DNA studies for estimating population abundance (e.g. Wilson *et al*. 2003), genetic constitution of wild dog populations for dingo conservation, dispersal and immigration after control (e.g. Hampton *et al*. 2004), identifying 'rogue' animals (e.g. Ernest *et al*. 2002), and identifying species responsible for predation of livestock and endangered fauna [e.g. dog predation of northern hairy-nosed wombats (*Lasiorhinus kreftii*) Banks *et al*. 2003];
(iv) investigate the movements of wild dogs for home range size, social organisation, dispersal, and corridors;
(v) investigate the ecological role(s) of wild dogs; do wild dogs have an important function in Australian ecosystems?
(vi) benchmark the socio-economics of livestock predation; and
(vii) develop models of spotted-tail quoll (*Dasyurus maculatus*) populations in the presence of wild canid management.

Importantly, these priorities provide opportunities for postgraduate students, through the Education Program of the IACRC, to participate in applied research projects in a collaborative atmosphere. The demonstration sites also integrate research, education and management, as well as providing opportunities for training of field staff and enhancing rapid uptake of products and strategies from the research. As yet, investment in fox research projects has not been determined other than those associated with demonstration sites.

The technologies that are used to control wild canids in Australia have remained largely unchanged since the middle of last century and there are many areas where management of can be improved. Improvements can be made by applying new technologies as they are developed, by better applying current technologies and by using the strategic approach to management. In the new IACRC, many such opportunities to improve the management of wild dogs and foxes in Australia will be provided through the collaborations of research, application, education and training that it will facilitate.

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References

Allen L (2005) Maximizing the effectiveness of control programs: current issues in wild dog management. In 'Proceedings of the 15th Australian sheep veterinarians conference'. (Australian Veterinary Association: Melbourne)

Allen LR, Fleming PJS (2004) Review of canid management in Australia for the protection of livestock and wildlife – potential application to coyote management. *Sheep and Goat Research Journal* **19**, 97–104.

Allen L, Gonzalez T (1998) Baiting reduces dingo numbers, changes age structures yet often increases calf losses. In 'Proceedings of the 11th Australian vertebrate pest control conference'. (Ed. G Pickles) pp. 421–428. (Vertebrate Pest Research Services, Agriculture Western Australia: Forrestfield)

Allen LR, Sparkes EC (2001) The effect of dingo control on sheep and beef cattle in Queensland. *Journal of Applied Ecology* **38**, 76–87. doi: 10.1046/j.1365-2664.2001.00569.x

Backholer JR (1986) A survey of landholders on the wild dog problem in eastern Victoria. Land Protection Service, Department of Conservation, Forests and Lands, Melbourne. Unpublished report.

Balogh S, Gentle M, Brown S (2001) 'Outfox the fox' – landholder surveys assisting with implementing best practice fox baiting. *Proceedings of the Australasian Vertebrate Pest Conference* **12**, 307–311.

Banks PB (2000) Can foxes regulate rabbit populations? *Journal of Wildlife Management* **64**, 401–406.

Banks PB, Newsome AE, Dickman CR (2000) Predation by red foxes limits recruitment in populations of eastern grey kangaroos. *Austral Ecology* **25**, 283–291. doi: 10.1046/j.1442-9993.2000.01039.x

Banks SC, Horsup A, Wilton AN, Taylor AC (2003) Genetic marker investigation of the source and impact of predation on highly endangered species. *Molecular Ecology* **12**, 1663–1667. doi: 10.1046/j.1365-294X.2003.01823.x

Biodiversity Group Environment Australia (1999) 'Threat abatement plan for predation by the European red fox'. (Department of Environment and Heritage: Canberra)

Bird P (1994) Improved electric fences and baiting techniques – a behavioural approach to integrated dingo control. Final Report to the Wool Research and Development Corporation. Animal and Plant Control Commission, Primary Industries, South Australia, Adelaide.

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

Breckwoldt R (1988) 'A very elegant animal: the dingo.' (Angus and Robertson: Australia)

Brindebella and Wee Jasper Valleys Wild Dog/Fox Working Group (2002) 'Cooperative wild dog/fox control plan, July 2002–June 2005.' (NSW National Parks and Wildlife Service: Queanbeyan)

Busana F, Gigliotti F, Marks CA (1998) Modified M-44 cyanide ejector for the baiting of red foxes (*Vulpes vulpes*). *Wildlife Research* **25**, 209–215. doi: 10.1071/WR96096

Coman BJ (1988) The age structure of a sample of red foxes (*Vulpes vulpes* L.) taken by hunters in victoria. *Australian Wildlife Research* **15**, 223–229. doi: 10.1071/WR9880223

Connolly G, Simmons GD (1984) Performance of sodium cyanide ejectors. In 'Proceedings 11th vertebrate pest conference'. (Eds DO Clark, RE Marsh, DE Beadle) pp. 114–121. (University of California: Davis)

Corbett LK (1985) Morphological comparisons of Australian and Thai dingoes: a reappraisal of dingo status, distribution and ancestry. *Proceedings of the Ecological Society of Australia* **13**, 277–291.

Corbett LK (2001) 'The dingo in Australia and Asia'. (JB Books Australia: Marleston)

Cross J (2005) 'Vertebrate pest manual: a guide to pest animal management in Queensland.' (Department of Natural resources and Mines: Brisbane)

Daniels MJ, Corbett LK (2003) Redefining introgressed protected mammals: when is a wild cat a wild cat and a dingo a wild dog? *Wildlife Research* **30**, 213–218. doi: 10.1071/WR02045

Davis E (2001) Legislative issues relating to control of dingoes and other wild dogs in New South Wales. I. Approaches to future management. In 'A symposium on the dingo'. (Eds CR Dickman, D Lunney) pp. 39–41. (Royal Zoological Society of New South Wales: Mosman)

Davis EO, Leys AR (2001) Reconciling wild dog control and dingo conservation under New South Wales legislation. In 'A symposium on the dingo'. (Eds CR Dickman, D Lunney) pp. 108–110. (Royal Zoological Society of New South Wales: Mosman)

Dickman C (2003) Species interactions: indirect effects. In 'Ecology: an Australian perspective'. (Eds P Attiwell, B Wilson) pp. 158–170. (Oxford University Press: South Melbourne)

Edwards GP, Pople AR, Saalfeld K, Caley P (2004) Introduced mammals in Australian rangelands: future threats and the role of monitoring programmes in management strategies. *Austral Ecology* **29**, 40–50. doi: 10.1111/j.1442-9993.2004.01361.x

Eldridge SR, Bryan R (1995) 'Dingo questionnaire survey June–November 1995'. (Parks and Wildlife Commission, Northern Territory: Darwin)

Ernest HB, Rubin ES, Boyce WM (2002) Fecal DNA analysis and risk assessment of mountain lion predation on bighorn sheep. *Journal of Wildlife Management* **66**, 75–85.

Field SA, Tyre AJ, Thorn KH, O'Connor PJ, Possingham HP (2005) Improving the efficiency of wildlife monitoring by estimating detectability: a case study of foxes (*Vulpes vulpes*) on the Eyre Peninsula, South Australia. *Wildlife Research* **32**, 253–258. doi: 10.1071/WR05010

Fleming PJS (1996) Aspects of the management of wild dogs (*Canis familiaris*) in north-eastern New South Wales. Master of Resource Science thesis. University of New England.

Fleming PJS (1997) Uptake of baits by red foxes (*Vulpes vulpes*): implications for rabies contingency planning in Australia. *Wildlife Research* **24**, 335–346. doi: 10.1071/WR95016

Fleming P, Harden B (2003) 'Guidelines for preparing a working plan to manage wild dogs'. (NSW Agriculture: Orange)

Fleming PJS, Korn TJ (1989) Predation of livestock by wild dogs in eastern New South Wales. *Australian Rangelands Journal* **11**, 61–66. doi: 10.1071/RJ9890061

Fleming PJS, Thompson JA, Nicol HI (1996) Indices for measuring the efficacy of aerial baiting for wild dog control in north-eastern New South Wales. *Wildlife Research* **23**, 665–674. doi: 10.1071/WR9960665

Fleming PJS, Allen LR, Berghout MJ, Meek PD, Pavlov PM, Stevens P, Strong K, Thompson JA, Thomson PC (1998) The performance of wild-canid traps in Australia: efficiency, selectivity and trap-related injuries. *Wildlife Research* **25**, 327–338. doi: 10.1071/WR95066

Fleming P, Corbett L, Harden R, Thomson P (2001) 'Managing the impacts of dingoes and other wild dogs.' (Bureau of Rural Resources: Canberra)

Glen AS, Dickman CR (2005) Complex interactions among mammalian carnivores in Australia, and their implications for wildlife management. *Biological Reviews* **80**, 387–401.

Goh CSS, Hodgson DR, Fearnside SM, Heller J, Malikides N (2005) Sodium monofluoroacetate (compound 1080) poisoning in dogs. *Australian Veterinary Journal* **83**, 474–479.

Greentree C, Saunders G, McLeod L, Hone J (2000) Lamb predation and fox control in south-eastern australia. *Journal of Applied Ecology* **37**, 935–943. doi: 10.1046/j.1365-2664.2000.00530.x

Hampton JO, Spencer PBS, Alpers DL, Twigg LE, Woolnough AP, Doust J, Higgs T, Pluske J (2004) Molecular techniques, wildlife management and the importance of genetic population structure and dispersal: a case study with feral pigs. *Journal of Applied Ecology* **41**, 735–743. doi: 10.1111/j.0021-8901.2004.00936.x

Harden RH (1985) The ecology of the dingo in north-eastern New South Wales. I. Movements and home range. *Australian Wildlife Research* **12**, 25–38. doi: 10.1071/WR9850025

Harden RH, Robertshaw JD (1987) The ecology of the dingo in north-eastern New South Wales. V. Human predation on the dingo. *Australian Zoologist* **24**, 65–72.

Hone J, Mulligan H (1982) Vertebrate pesticides. Science bulletin 89. Department of Agriculture, New South Wales, Haymarket.

Jarman PJ (1986) The red fox - an exotic, large predator. In 'The ecology of exotic animals and plants: some Australian case histories'. (Ed. RL Kitching) pp. 43–61. (Wiley: Brisbane)

Jenkins D (2003) 'Guard animals for livestock protection: existing and potential use in Australia'. (Vertebrate Pest Research Unit, NSW Agriculture: Orange)

Jenkins D, Fleming P, Cathles H (2002) South east NSW and the ACT wild dog management project. Unpublished final report to Bureau of Rural Sciences, National Feral Animal Control Program, Canberra.

Jolly SE, Jolly LM (1992) Pen and field tests of odour attractants for the dingo. *Journal of Wildlife Management* **56**, 452–456.

Krüuk H (1972) Surplus killing by carnivores. *Journal of Zoology* **166**, 233–244.

Lapidge SJ (2004) The impact of sheep predators in Australia and new control methods under development. In 'Proceedings of the Australian Sheep Veterinarians Society conference'. pp. 159–163.

Lugton I (1993) Fox predation on lambs. In 'Caring technology, proceedings of the Australian Sheep Veterinarians Society, Australian Veterinary Association conference'. (Ed. DA Hucker) pp. 17–26. (Australian Veterinary Association: Gold Coast)

McLeod R (2004) 'Counting the cost: impact of invasive animals in Australia, 2004.' (Cooperative Research Centre for Pest Animal Control: Canberra)

Marks CA, Busana F, Giglioti F (1999) Assessment of the M-44 ejector for the delivery of 1080 for red fox (*Vulpes vulpes*) control. *Wildlife Research* **26**, 101–109. doi: 10.1071/WR98014

Marks CA, Gigliotti F, Busana F (2002) Estimated 1080 dose rate for the M-44 ejector for the control of red foxes (*Vulpes vulpes*). *Wildlife Research* **29**, 291–294. doi: 10.1071/WR00115

Marks CA, Gigliotti F, Busana F (2003) Field performance of the M-44 ejector for red fox (*Vulpes vulpes*) control. *Wildlife Research* **30**, 601–609. doi: 10.1071/WR01032

Marks CA, Gigliotti F, Busana F, Johnston M (2004) Fox control using a para-aminopropiophenone formulation with the M-44 ejector. *Animal Welfare* **13**, 401–407.

Marsack P, Campbell G (1990) Feeding behaviour and diet of dingoes in the Nullarbor region, Western Australia. *Australian Wildlife Research* **17**, 349–357. doi: 10.1071/WR9900349

Meek PD (1998) 'Weed seeds and whoopsie daisies' viability of bitou bush (*Chrysanthemoides monilifera*) seeds in fox (*Vulpes vulpes*) scats. *Plant Protection Quarterly* **13**, 21–26.

Mitchell BD, Banks PB (2005) Do wild dogs exclude foxes? Evidence for competition from dietary and spatial overlaps. *Austral Ecology* **30**, 581–591. doi: 10.1111/j.1442-9993.2005.01473.x

Mitchell J, Kelly A (1992) Evaluating odour attractants for control of wild dogs. *Wildlife Research* **19**, 211–219. doi: 10.1071/WR9920211

New England Rural Development Association (undated *c*. 1963) Dingoes in New England. Community development pamphlet No. 7. University of New England, Armidale.

Newsome AE, Corbett LK, Catling PC, Burt RJ (1983) The feeding ecology of the dingo. I. Stomach contents from trapping in south-eastern Australia, and non-target wildlife also caught in dingo traps. *Australian Wildlife Research* **10**, 477–486. doi: 10.1071/WR9830477

Newsome AE, Parer I, Catling PC (1989) Prolonged prey suppression by carnivores – predator removal experiments. *Oecologia* **78**, 458–467. doi: 10.1007/BF00378734

NSW National Parks and Wildlife Service (2001) Threat abatement plan for predation by the red fox (*Vulpes vulpes*). (NSW National Parks and Wildlife Service: Hurstville)

Pech RP, Sinclair ARE, Newsome AE, Catling PC (1992) Limits to predator regulation of rabbits in Australia: evidence from predator-removal experiments. *Oecologia* **89**, 102–112. doi: 10.1007/BF00319021

Pimental D, Lach L, Zuniga R, Morrison D (2000) Environmental and economic costs of non-indigenous species in the United States. *Bioscience* **50**, 53.

Rankine G, Donaldson LE (1968) Animal behaviour and calf mortalities in a north Queensland breeding herd. *Proceedings of the Australian Society of Animal Production* **4**, 138–143.

Robertshaw JD, Harden RH (1986) Ecology of the dingo in north-eastern New South Wales. IV. Prey selection by dingoes and its effect on the major prey species, the swamp wallaby (*Wallabia bicolor* Desmarest). *Australian Wildlife Research* **13**, 141–163. doi: 10.1071/WR9860141

Robley A, Wright J (2003) 'Adaptive experimental management of foxes. Annual Report, July 2002–03: Parks Victoria technical series No. 2. (Parks Victoria: Melbourne)

Rolls EC (1984) 'They all ran wild: the animals and plants that plague Australia. (Angus and Robertson: Sydney)

Saunders G, Harris S (2000) Evaluation of attractants and bait preferences of captive red foxes (*Vulpes vulpes*). *Wildlife Research* **27**, 237–243. doi: 10.1071/WR99052

Saunders G, Coman B, Kinnear J, Braysher M (1995) 'Managing vertebrate pests: foxes.' (Australian Government Publishing Service: Canberra)

Saunders G, McIlroy J, Berghout M, Kay B, Gifford E, Perry R, van de Ven R (2002) The effects of induced sterility on the territorial behaviour and survival of foxes. *Journal of Applied Ecology* **39**, 56–66. doi: 10.1046/j.1365-2664.2002.00696.x

Savarie PJ, Ping Pan H, Hayes DJ, Roberts JD, Dasch GL, Felton R, Schafer EW Jr (1983) Comparative acute oral toxicity of para-aminopropiophenone. *Bulletin of Environmental Contamination and Toxicity* **30**, 122–126. doi: 10.1007/BF01610109

Savolainen P, Zhang Y-P, Luo J, Lundeberg J, Leitner T (2002) Genetic evidence for an East Asian origin of domestic dogs. *Science* **298**, 1610–1613. doi: 10.1126/science.1073906

Savolainen P, Leitner T, Wilton AN, Matisoo-Smith E, Lundeberg J (2004) A detailed picture of the origin of the Australian dingo, obtained from the study of mitochondrial DNA. *Proceedings of the National Academy of Sciences of the United States of America* **101**, 12387–12390. doi: 10.1073/pnas.0401814101

Schaefer MM (1981) The feral dog: economic implications for graziers operating within the Armidale Pastures Protection Board. Bachelor of Agricultural Economics thesis. University of New England, Armidale.

Short J, Kinnear JE, Robley A (2002) Surplus killing by introduced predators in Australia—evidence for ineffective anti-predator adaptations in native prey species? *Biological Conservation* **103**, 283–301. doi: 10.1016/S0006-3207(01)00139-2

Thompson JA (1994) The management of red foxes (*Vulpes vulpes*) in the Northern Tablelands of New South Wales. Master of Resource Science thesis. University of New England, Armidale.

Thompson JA, Fleming PJS (1991) The cost of aerial baiting for wild dog management in north-eastern New South Wales. *Australian Rangelands Journal* **13**, 47–56. doi: 10.1071/RJ9910047

Thompson JA, Fleming PJS, Heap EW (1990) The accuracy of aerial baiting for wild dog control in New South Wales. *Australian Wildlife Research* **17**, 209–217. doi: 10.1071/WR9900209

Thomson PC (1984*a*) Dingoes and sheep in pastoral areas. *Journal of Agriculture Western Australia* **25**, 27–31.

Thomson PC (1984*b*) The use of buffer zones in dingo control. *Journal of Agriculture, Western Australia* **25**, 32–33.

Thomson PC (1986) The effectiveness of aerial baiting for the control of dingoes in north-western Australia. *Australian Wildlife Research* **13**, 165–176. doi: 10.1071/WR9860165

Thomson PC (1992*a*) The behavioural ecology of dingoes in north-western Australia. III. Hunting and feeding behaviour, and diet. *Wildlife Research* **19**, 531–542. doi: 10.1071/WR9920531

Thomson PC (1992*b*) The behavioural ecology of dingoes in north-western Australia. IV. Social and spatial organisation, and movements. *Wildlife Research* **19**, 543–564. doi: 10.1071/WR9920543

Thomson PC, Rose K, Kok NE (1992*a*) The behavioural ecology of dingoes in north-western Australia. V. Population dynamics and variation in the social system. *Wildlife Research* **19**, 565–584. doi: 10.1071/WR9920565

Thomson PC, Rose K, Kok NE (1992*b*) The behavioural ecology of dingoes in north-western Australia. VI. Temporary extra-territorial movements and dispersal. *Wildlife Research* **19**, 585–596. doi: 10.1071/WR9920585

Thomson PC, Marlow NJ, Rose K, Kok NE (2000) The effectiveness of a large-scale baiting campaign and an evaluation of a buffer zone strategy for fox control. *Wildlife Research* **27**, 465–472. doi: 10.1071/WR99036

Tomlinson AR (1954) Aerial baiting against wild dogs and foxes in Western Australia. *Journal of Agriculture Western Australia* **3**, 37–49.

West P, Saunders G (2003) 'Pest animal survey 2002: an analysis of pest animal distribution and abundance across NSW and the ACT.' (NSW Agriculture: Orange)

Wilson GJ, Frantz AC, Pope LC, Roper TJ, Burke TA, Cheesman CL, Delahay RJ (2003) Estimation of badger abundance using faecal DNA typing. *Journal of Applied Ecology* **40**, 658–666. doi: 10.1046/j.1365-2664.2003.00835.x

Wilton AN, Steward DJ, Zafiris K (1999) Microsatellite variation in the Australian dingo. *The American Genetic Association* **90**, 108–111.

Woolnough AP, Gray GS, Lowe TJ, Kirkpatrick WE, Rose K, Martin GR (2005) 'Distribution and abundance of pest animals in Western Australia: a survey of institutional knowledge.' (Vertebrate Pest Research Section, Department of Agriculture, Western Australia: Forrestfield)

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