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Wild dog ecology, impacts and management in northern Australian cattle enterprises: a review with recommendations for RD&E investments

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Abstract

Wild dogs cause annual livestock production losses valued between $48.3m and $48.7m across Australia including annual losses of $23.4m for the beef cattle industry in northern Australia. These valuations are likely underestimates and require confirmation. Simultaneously, wild dogs may provide a benefit to individual cattle enterprises through their impacts on competitive native and feral herbivores. The dingo component of wild dog populations also has legislative protection in some jurisdictions. The effect of controlling wild dogs varies from no impact to sometimes positive and sometimes negative; the circumstances for each condition need investigation to enable best practice recommendations.

To assist in the definition of the wild dog issue for northern cattle producers, Meat and Livestock Australia (MLA) commissioned this review which outlines: the current knowledge of wild dog biology, behaviour and ecology; perceived and measured impacts on livestock, wildlife and people; legislation, regulation and policy affecting management of wild dogs across northern Australia; and current hypotheses affecting public debate and decision-making as they pertain to the cattle industry in northern Australia.

Although much is known about the biology of wild dogs, research into ecological and behavioural factors that affect predation of cattle, environmental impacts and the management of wild dogs is still wanting. Understanding of the social impacts of wild dogs, particularly in peri-urban and more intensive cattle production systems, and of societal attitudes to wild dogs is critical for implementing successful and acceptable management. Research to date, in combination with recent improvements in technology, should enable the larger and more management-focussed research questions to be successfully addressed.

Dingoes forage on a cattle carcase near a water hole in northern South Australia. Photo: Ben Allen.

Executive summary

Reported increases in the occurrence and distribution of wild dogs are associated with increased prominence of interest and concern about their impacts on cattle and other livestock enterprises. Estimates of the livestock production losses across Australia attributable to wild dogs are about $48.5 million per year and, for beef cattle in northern Australia, about $23.4 million. Simultaneously, the conservation of dingoes is rousing more public attention and their preservation, encouragement and reintroduction for biodiversity benefit have been suggested. This can influence the application of management actions by cattle producers.

The first step in dealing with contentious issues of wildlife management is to define the issue as best as possible given current knowledge, policy, and legislation. To assist in the definition of the wild dog issue for northern cattle producers, Meat and Livestock Australia (MLA) commissioned this review which outlines: the current knowledge of wild dog biology, behaviour and ecology; perceived and measured impacts on livestock, wildlife and people; legislation, regulation and policy affecting management of wild dogs across northern Australia; and current hypotheses affecting public debate and decision-making as they pertain to the cattle industry in northern Australia.

Wild dogs are middle-sized predators derived by human selection from wolves in Asia and dingoes were brought to Australia by traders about 4000 years ago. The domestic dog component of the wild dog population has been infiltrating the dingo gene pool since 1788. The proportion of “pure” dingoes increases towards the centre and northwest of the continent. Opening up of land for agriculture and the development of the cattle industry has increased the abundance and distribution of wild dogs in northern Australia over the past 100 years or so.

Wild dogs have flexible foraging strategies and a consequently varied diet, allowing them to live in most environments. Predation of livestock is the main agricultural impact of wild dogs but its occurrence is variable, and likely affected by seasonal conditions, permanent water dispersion and prey availability. Recent publications have postulated an important role for “dingoes” in retention of threatened fauna in the ecosystems where they occur. Such suggestions can affect public opinion, the development and interpretation of policy and, in turn, application of management actions by cattle producers. However, conclusive data on most aspects of wild dog interactions with their prey are lacking and require experimental investigation.

There are critical knowledge gaps that impede progress both for cattle producers and the broader community. Areas of research, development and extension that will be fruitful for Research funders and other agencies include the following, given in priority order:

1. **Cash Cow Plus: value adding to the northern Australian beef fertility project** - determining the part that wild dog predation plays in reproductive failure and enterprise profitability. Priority– High (Budget of about $1.1 M over 3 years).
2. **Yard and abattoir survey of dog bites and abattoir surveillance of hydatidosis -** determining national prevalence of bite-related losses and hydatids and associated production losses to producers and processors. Priority – High ($1.1 M over 3 years.)
3. **The roles of wild canids in agri-ecosystems -** investigating whether mesopredator (foxes & cats) release occurs where dogs are controlled, with concomitant effects on wildlife. Critical research for ensuring future capacity of livestock producers to manage wild dogs. Priority – Medium ($2.0 M over 3 years.)

4. **Facilitating the strategic management of wild dogs throughout northern Australia -** employing a national facilitator to encourage regional and local wild dog management groups. Essential for transferring RD&E outcomes to on-ground action. Priority – High ($820,000 over 5 years.)
5. **Wild dogs and beef productivity -** measuring the effect of wild dog presence on beef cattle weight gain, foraging patterns, maternal behaviour and calving success. Priority – Medium ($1.2 M over 3 years).
6. **Wild dog control and total grazing pressure -** determining the role of wild dog control in the management of total grazing pressure through changes in populations of competitors of cattle. Priority – Medium ($1.2 million over 3 years.)
7. **Prevalence and distribution of *Neospora caninum* infection in cattle herds and wild dog populations** - Field assessment determining costs to production, disease life-cycle and epidemiology, and enabling management of the disease. Priority – Medium ($1.5 million over 3 years).
8. **Limiting the source: peri-urban dog control -** determining the impacts of peri-urban wild dogs on beef cattle production and communities and devising practical strategies to solve the problem. Priority – Low ($1.4 million over 3 years).
9. **Cost-effective wild dog control by livestock guarding dogs -** evaluating efficacy, livestock production gains and costs, management requirements and economics of livestock guardian dogs. Priority – Low ($1.4 million over 3 years).
10. **Wild dog co-management and the triple bottom line -** determining the social, economic, and environmental impacts of wild dogs to identify and manage policy and legislative impediments to wild dog management. Priority – Low ($1.1 million over 3 years).

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Introduction

Issues

An adequate definition of wildlife issues and recognition of their biological, ecological and human aspects are vital for successful management. Human-wildlife interactions can result in neutral, positive or negative outcomes and, for wild dogs, all three are apparent.

The management of free-roaming dogs is a world-wide concern and not confined to northern Australia. The reasons for concern are generally associated with negative impacts on livestock production and human health and wellbeing. As there are various interpretations of the subject animals, we first define the organisms we are discussing and their interactions with the cattle industry in northern Australia. The geographic area being discussed includes Queensland, the Northern Territory, the northern half of Western Australia and the cattle zone north of the dingo barrier fence in South Australia. Historical and current perspectives of wild dogs, cattle and changes to ecosystems are also added to help define the issues involved with wild dog management today.

About this document

Objectives

The objective of this document is to provide a review of:

- biological and ecological information relevant to the management of dingoes and other wild dogs in northern Australia,
- agricultural and environmental impacts of wild dogs in northern Australia, including positive and negative economic and faunal impacts and their sources,
- human impacts and legislation and policy pertinent to managing dingoes and other wild dogs in northern Australia,
- current and potential control technologies and management strategies pertaining to northern cattle enterprises, and
- knowledge gaps and recommendations on future R, D & E investment by MLA and other interested and affected bodies.

Document structure

This review includes:

- working definitions of the subject animal,
- historical context to wild dog issues in northern Australia,
- ecological information about wild dogs pertaining to management of northern cattle enterprises,
- interactions between wild dogs and their native and livestock prey,
- published and unpublished reports on the impacts of wild dogs on cattle production,
- management strategies and control technologies for cattle enterprises,
- a review of national research planning in the past 10 years, current research projects, and
- recommendations for related future investment priorities in research, development and extension by Meat and Livestock Australia and other funding agencies.

Dingoes and other wild dogs

The wild-living dogs of Australia are derived from a number of sources and are often referred to arbitrarily as "dingoes" or "wild dogs". People have different ideas as to what constitutes a dingo, often restricting their meaning to yellow or ginger coloured wild-living dogs. Purcell [1] even suggested that all wild dogs in Australia should be called "dingoes" regardless of their colour or origin. Importantly, from a livestock impact viewpoint the type of dog causing the damage is immaterial. Therefore, we use the following definition:

> "wild dog": any dog (*Canis lupus familiaris* and other subspecies) that lives completely or partly in the wild, includes free-living dingoes (*Canis l. dingo*), free-living domestic breeds (*C. l. familiaris*) and crosses between them.

Throughout, we'll refer to them all generally as "wild dog/s" or "dog/s", but will refer to "dingoes" when dealing specifically with the *C. l. dingo* subspecies.

Historical context

Derivation of dogs through domestication

Dogs were probably the first species derived by domestication of wild animals by humans about 15,000 years before present [2, 3]. All dogs were derived by human selection and domestication from grey wolves (*Canis lupus lupus*) and, according to recent DNA evidence [3], initially from the Middle East. Ancient dog breeds, such as the dingo (*C. l. dingo*), were likely selected by people living east of the Himalayas [4, 5]. Numerous wolves were involved [4], and the process continues to this day [6, 7]. Dingoes likely were selected in east Asia (e.g. Thailand [8, 9]; southern China [4]; but see also [10]) and are still found, and indeed eaten by people, in parts of South East Asia [9].

Although dingoes are considered to be native animals in much Australian legislation (e.g. Northern Territory *Territory Parks and Wildlife Conservation Act, 2000*), they and other free-ranging dogs in Australia are all technically feral animals by definition, in that they are the wild-living descendants of a domesticated animal [9, 11, 12]. Archaeological, morphometric and genetic evidence indicates that the dingo arrived with South East Asian traders from about 4000 years ago [5, 8-10] and became feral thereafter. As trading between indigenous Australians and Asians continued in northern Australia until the 1920s [9], there was potential for introductions up until then. Alternatively, genetic studies by Savolainen *et al.* [5] suggest that the current continent-wide distribution could have originated from as few as six individuals or even the pups of one pregnant female, but the overall sample size and distribution of sampling of that study was limited. The results of a much larger and more widespread sampling effort [13] illuminates this position.

The domestic dog has been contributing to the free-ranging dog gene pool since early European settlement [14]. The dogs of northern Australia are most likely genetically closer to the original dingoes ([9, 14]; and Figure 1) while those in south eastern Australia are mostly dingo-like hybrids [13, 15].

Importantly, the dingo proportion of the wild dog population has other values. They are regarded by different sectors of the community as Australian native animals, an important part of "the Australian environment", and potential ecosystem engineers for biodiversity conservation [16, 17]. Essentially, cattle producers and other Australians hold diverse value orientations towards dogs, often expressed as various and sometimes conflicting attitudes and behaviours (e.g. [18]). Although several authors have noted that dingoes hold particular status with humans (e.g. [19-21]), the status of wild dogs is not uniform or uniformly positive. For example, Johnston and Marks [22] found that 79% of Victorians surveyed regarded wild dogs as pest animals, with 63% preferring eradication as a management option. Although mostly negative, respondents' opinions were not homogeneous and the responses might well have been different if the questions were asked about 'dingoes' rather than 'wild dogs'.

Cattle in northern Australia

Historical context

A recent review of the economics of cattle production in northern Australia is provided in McCosker *et al.* [23], but a brief look at historical development of the cattle industry is instructive in evaluating the current status and role of wild dogs. Cattle in northern Australia have come from a number of sources, the earliest being Indian cattle introduced onto Cobourg Peninsular around 1829 to support the garrison at Port Essington and other northern settlements [24], with remnants of those introductions reported as still present in 1843. Domesticated Balinese cattle (banteng, *Bos javanicus*) were also introduced to Port Essington and when these settlements closed in 1849, these cattle and water buffalo (*Bubalus bubalis*) were released. The buffalo were able to spread through much of the Top End, but the banteng were confined by natural ecological barriers or an inability to undertake broad scale movements [25]. Whether any progeny of these original cattle were still present when later explorers and pastoral pioneers arrived is not reported in the literature we have reviewed (e.g. [24, 26-28]). Of relevance to cattle production is that dingoes are known to attack and eat buffalo calves them [29], but dingo predation did not prevent buffalo surviving and expanding their distribution across northern Australia until the successful BTEC buffalo reduction program.

Pastoralism generally expanded from the south to north of Australia [24] and from south western and central Queensland to the north and west in the 1880s and 1890s [26]. Sheep and cattle were moved north from southern Western Australia, South Australia and New South Wales during the 1870s and 1880s and the sheep were often shepherded at night to avoid predation by dingoes [24, 27]. It is likely that predation by wild dogs on cattle was less when sheep were present [30]. Sheep and cattle co-occurred in the Pilbara and Kimberley regions of Western Australia at the turn of the nineteenth century. In the west Kimberleys, sheep were mostly replaced by cattle progressively from 1910, partly because of perceived competition with macropods and low returns [31] and, after the 1930s, because dingoes were becoming an increasing problem and the high price of netting required to make fences dog proof was prohibitive [27].

The northern extension of the Queensland barrier fence around the Mitchell grass plains is no longer maintained by governments [32] and sheep have proportionally declined both inside and outside the fence since 1992 after the wool reserve price scheme collapsed [33, 34]. For example, a resource study of the Condamine-Maranoa Basin, which is in southern Queensland and inside the current fence, listed predators as a serious cause of loss to the sheep industry during the 1950s through to 1972 [35]. However, wild dogs did not rate a mention among the listed predators. At that time there were 3 million sheep and 600,000 cattle in the six shires encompassed in the study. Today, sheep numbers have declined but an active campaign to reduce burgeoning dog numbers in the shires in the west of the Condamine-Maranoa Basin has removed over 2100 dogs since 2009 (Greg Mifsud, National Wild Dog Facilitator, pers. comm. June, 2011). Wild dog predation pressure on cattle in those regions outside dog barrier fences may have increased with the total removal or reduction in numbers of sheep.

During the mid to late 20th century, the introduction of bores [36], tropical grasses [37], *Bos indicus* cattle [38], and the eradication of contagious bovine pleuropneumonia in 1967 [39] changed northern Australian landscapes substantially. Permanent, artificial waters have been established in areas where continuous livestock grazing was previously impossible [40, 41] including Tanami (Mongrel) Downs in the central western Northern Territory during the 1960s [42, 43]. There are now few places in pastoral Australia that are further than 10 km from a water point [40, 44, 45]. Although relevant data from that period is scant, permanent water has undoubtedly led to increased wild dog numbers in areas where they were previously scarce [9, 14, 46].

Dingoes might have become a stable part of predator-prey interactions in Australian systems prior to European arrival [17, 47], but natural landscapes have changed dramatically since then [48, 49] and this may influence the current and future ecological role of dingoes in unexpected ways [50]. The effects of livestock grazing and artificial water point creation [45] not only change habitats (causing piospheres of disturbance centred on the water points) but can also facilitate predation by increasing the population size and ranges of water-limited predators such as dingoes [36, 40, 51]. Although their distribution has changed, wild dog numbers in northern Australia have almost certainly increased since the expansion of pastoralism [9] and outback mining (T. Newsome, G. Ballard, P. Fleming, unpublished data). Where vegetation structure has been altered through clearing and changed fire regimes associated with pastoralism, predation of cattle by wild dogs will also likely be affected. Pursuit predation by wild dogs is facilitated by more open rangelands, where large prey, like cattle, have more difficulty avoiding predators.

Current cattle industry in northern Australia

Beef production is still the predominant livestock enterprise across the north of Australia, where 72% of Australian cattle are run [52]. The majority of Australian cattle are produced in Queensland [52], which is the area where wild dogs are reported to have the greatest economic impact on cattle production [53].

There are two broad sectors of the cattle grazing industry in northern Australia: relatively intensive grazing enterprises associated with the north east and south east high rainfall zones and parts of the Queensland sub-tropics, and the extensive rangeland grazing industry associated with the wet/dry tropics and semi-arid zones. Wild dogs are likely to affect these enterprises in different ways and to different degrees. Because of logistics and seasonal accessibility problems, the more extensive holdings in the wet/ dry tropics across the north of the zone are often less-intensively managed, making it difficult to detect or quantify predation problems. More arid extensive properties in the north, south central and west of the zone do not have seasonally limited access, but retain a low labour-to-area ratio. Both restricted access and small labour forces are factors that limit detection of predation while it is occurring. Intensive properties to the east and south east have more labour per unit area and so detection of wild dogs and predation is more likely. However, given that predation by dogs is variable in timing and intensity [32, 54, 55], people are sometimes in the midst of calf losses before they detect the problem, particularly if dog problems have been absent for many years or in warmer weather when carcases rot quickly masking diagnostic signs of predation.

Small holdings are also subject to predation by peri-urban dogs, which may be free-roaming or stray domestics or wild dogs (e.g. [56]). The likelihood of detecting a wild dog problem is higher in the more intensive industries and closer settled areas in the higher density cattle zones to the east and south east of Queensland. The issue of urban and peri-urban wild dog control and human and companion animal safety has raised growing public concern [57-59]. Potential threats to public health include: direct attack on people resulting in mauling and, rarely, death; direct attack on companion animals and/or domestic livestock resulting in mauling and commonly their death and distress for the owners; a potential source of human hydatid (*Echinococcus granulosus*) infection through contamination of school grounds, municipal parks and bushland reserves with wild dog droppings; loss of public amenity and the psychological or emotional trauma caused by the loss of domestic animals and/or fear of wild dog attacks on people; and, in extreme cases, the financial loss of people relocating due to fear of wild dogs.

Management of wild dogs in urban and adjoining rural areas is complicated by a lack of knowledge on wild dog ecology by affected stakeholders, many of whom are unaware of the local presence of wild dogs until they are involved in an incident. Outside of southeast Queensland, the coastal cities (e.g. Mackay and Rockhampton) are within beef production areas and there is little if any separation between urban and rural lands. Stud stock are common there, with consequent disproportionate economic losses when predation by dogs occurs. The economics and social impacts of wild dog predation to cattle and other livestock and pets on small and peri-urban in northern Australia, particularly in eastern Queensland and near remote settlements, requires quantification [59].

The biology and ecology of wild dogs in northern Australia

General description

Australian dingoes, are typical medium-sized dogs of about 15kg [8, 9]. They usually have a ginger coat, varying from sandy-yellow to red-ginger [60]. Most dingoes have white markings on the feet, tail tip and chest, some have black muzzles and all have upright ears and bushy tails. Black-and-tan, black-and-white and white or black dingoes are less common and hybrid wild dogs have a wider range of colours, including brindle and patchy individuals [60]. Coats with a dark dorsal strip or dappling in the white areas usually indicate hybrids. The ginger colouration is dominant [9], so many hybrids are indistinguishable from pure dingoes based on coat colour alone. Recent comprehensive genetic tests have shown that pure dingoes are more frequent in northern Australian populations than in the south east, where hybrids predominate ([13]; Figure 1).

Adult wild dogs typically weigh 12.4–17.4 kg on average [9], and dingoes are smaller in Asia than in Australia. The largest reported wild dog was a 71 kg (wet weight) dog captured at Wallabadah in NSW in the 1990s (J. Williams, Tamworth RLPB, pers. comm.), but such large dogs are extremely rare and are usually escapees rather than free-ranging dogs. Most are less than 20 kg and their height and length are similarly variable. Functional differences between pure or hybrid dingoes are presently unknown [61], but expected to be negligible [1, 9].

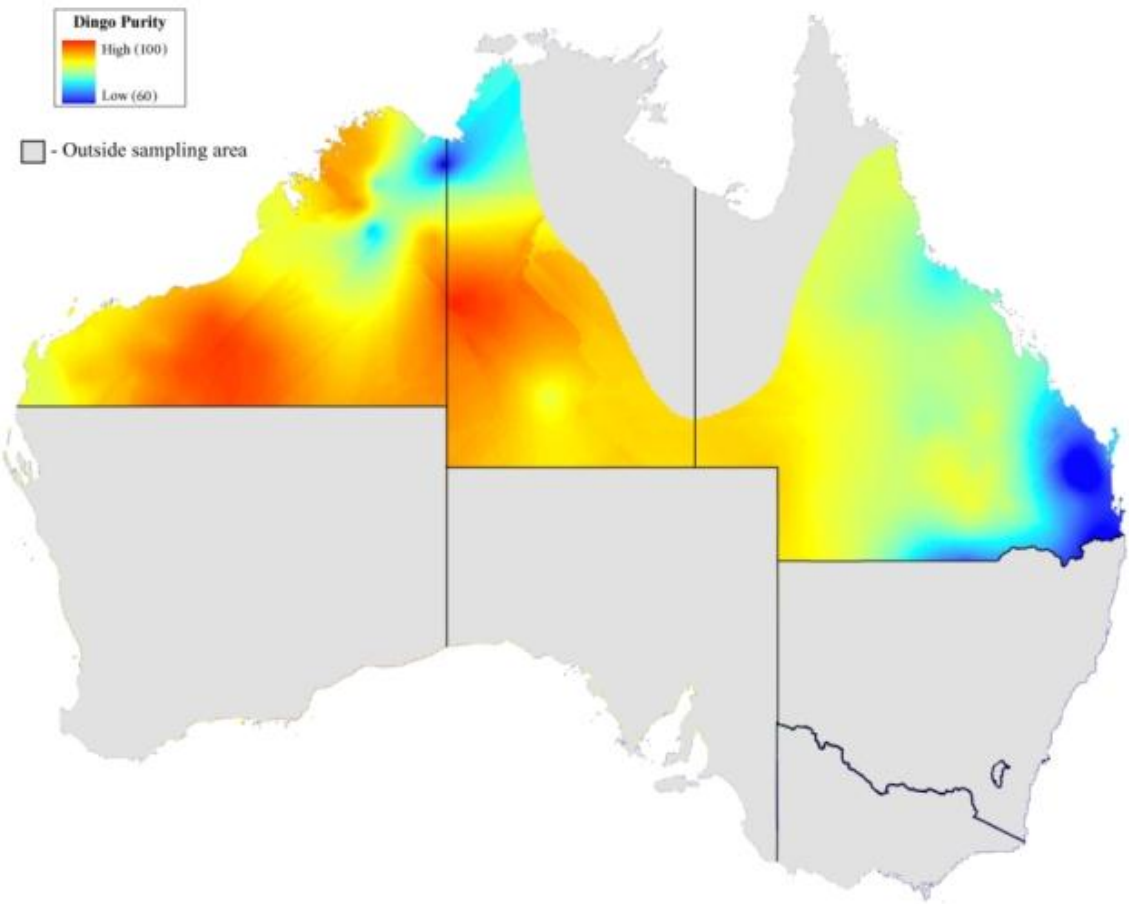

Figure 1. Distribution of relative dingo purity from DNA analysis for the northern cattle region (from [13]). Grey areas of northern Australia were unsampled.

Wild dogs are ubiquitous across all habitats in northern Australia (Figures 1 and 2). This includes rainforest, tropical savannah, ephemeral wetlands and arid areas [9, 62], though the presence and density of wild dog populations may vary in some habitats according to seasonal constraints, such as the annual flooding of monsoonal wetlands [54].

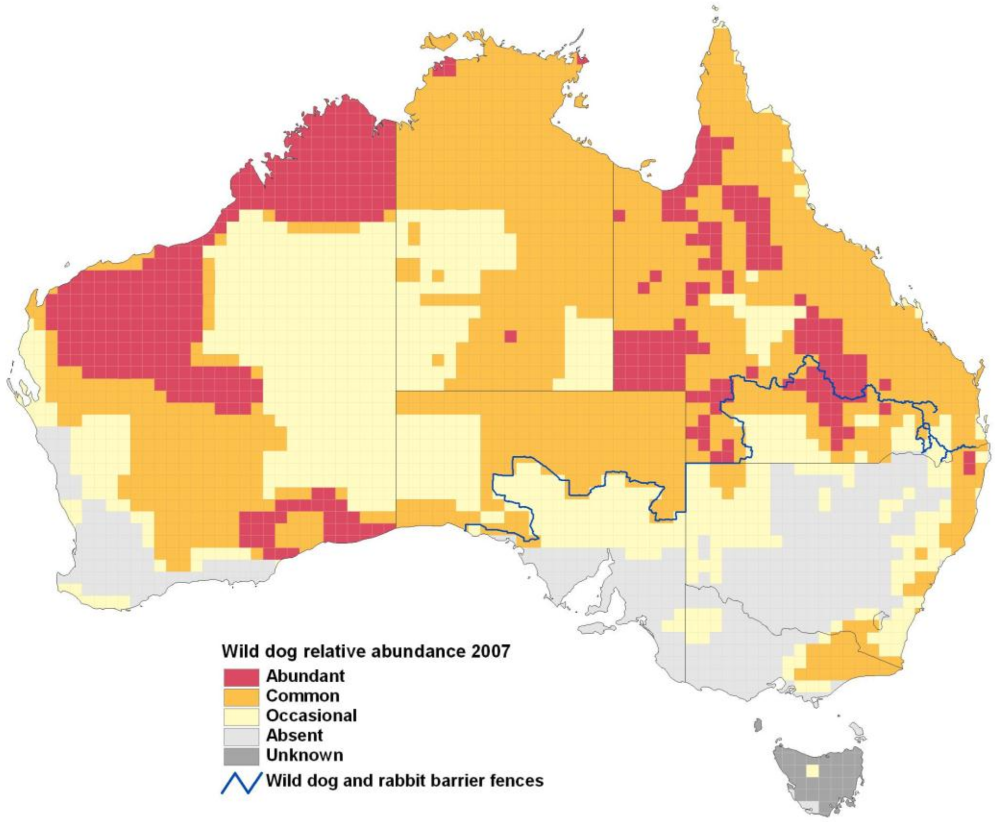

Figure 2. Distribution and relative abundance of wild dogs in 2007 compiled from various data sets by West [62]. Details of mapping methods are detailed in West [62] and the opinions of relative abundance varies between experts, resulting in artificial differences between State and Territory boundaries. The eastern end of the Queensland fence includes a rabbit-proof fence, but is effectively dog-proof. There are other private dog-proof fences in WA and eastern NSW.

Wild dogs have flexible habitat requirements and appear to be limited more by food availability than habitat restrictions, much like apex predators in other parts of the world [63-65]. Wild dogs reach their highest densities in areas where food availability is high, including areas around human settlements and places where rabbits are abundant (e.g. [66, 67]). Notable studies of wild dog ecology in pastoral areas of northern Australia have occurred in southwest Queensland and the Gulf of Carpentaria [54, 68], the Alice Springs (e.g. [69-73]) and top-end (e.g. [29, 74, 75]) regions of Northern Territory, far northern South Australia [55, 66, 76-79] and in the Fortescue River region of northwestern Western Australia [80-85]. Most of the studies occurring prior to 2001 are summarised in Corbett [9]. Current studies of wild dogs continue in similar areas.

Home range size and utilisation, dispersion and movement behaviour

Individual dogs have a home range and, like wolves, wild dogs often form social groups called packs, which defend a communal territory (a territory is a defended area within a home range) with scent and visual cues, and with sophisticated vocalisations [9]. A home range is the area over which an animal roams while undertaking the day-to-day activities of living, including foraging and watering, sheltering, communicating, mating and raising young [86]. Occasional exploratory forays and dispersion movements are not normally included in a home range estimate [87]. Like other animals with generalist foraging requirements, dog home range sizes vary with the productivity of the landscape where they occur [42, 46, 62-

64]. Therefore, we would expect dogs to have variable home range sizes across northern Australia (Table 1).

A dingo drinks from a leaking bore pipe in arid Northern Territory. Photo: Guy Ballard

Table 1. Home range sizes of resident wild dogs from some cattle producing ecosystems across northern Australia.

Ecosystem	Home range size km^2 (s.e./ range)	n	Method	Source
semi arid tropics	77.3 (22.1)	19	pooled mean 95% MCP	[83]
arid	67 (32-126)	5	not stated	[9]
monsoonal	39 (15-88)	18	not stated	[9]
arid monsoonal	25 (7-110)	24	not stated	[9]
arid monsoonal	414.9 (103.5)	9	85% Kernel	[88]
mine site	8.0 (2.4)	4	85% Kernel	[88]
arid	24 (13-32)	7	95% MCP	[66]

Dispersal, particularly in young animals, occurs in canids regardless of prey availability in the natal home range [89]. Social pressures (e.g. rejection by the pack) and local densities approaching carrying capacity may sometimes cause long distance forays to new home ranges. Recently, GPS-collared dogs have been recorded travelling greater than 1300 km in four months (150 km from point of origin), and one animal moved ~560 km from point of origin in south central Queensland to northern NSW in 30 days [90]. Overall, approximately 15% of dogs dispersed >100 km from their initial point during the study.

Such dispersals demonstrate the capacity for wild dogs to move large distances into unoccupied territories. Dispersal distances are likely to be larger in areas below carrying capacity and in areas of flatter terrain than in steeper terrain, though this requires verification. This complicates management in areas where stakeholders have different goals, i.e. positive management of wild dogs in one area will impact other areas when dispersers migrate.

All studies have shown home range use by wild dogs to be heterogeneous, often focussing around and between key resources and less arduous routes in rugged terrain (e.g. [88, 90]; G. Ballard, P. Fleming, P. Meek, L Allen and B Allen unpublished data). Associations with roads may fluctuate seasonally [90], which should influence placement of wild dog control activities. We would also expect home ranges to be focal around permanent waters where water was limiting [66, 88]. Current research using GPS technology will provide better information on use of landscape features by wild dogs.

Social behaviour and reproduction

Most of the research into the sociality of dingoes and other wild dogs is necessarily from pen trials (e.g. [9, 91]; Bob Harden, NSW NPWS, unpublished data) or physiological assessment of captured dogs [92]. From these studies and from dog studies overseas, wild dogs appear to form packs of 3–12 members, which are essentially a family group consisting of a dominant female and an alpha male with subordinate females and young beta males [9, 83, 93, 94]. However, focal resources such as remote refuse tips can support family groups A pack may be run by a dominant bitch, which attempts to take the dominant male for breeding and suppresses the breeding of subordinate bitches or kills any young they might have [9, 14, 94]. Whether or not these behaviours are widespread in wild settings is unknown, and the implications or ecological importance of these behaviours are as yet only speculated on (e.g. [54, 94]). When resources are focal, either from anthropogenic sources such as water points and rubbish tips [88] or caused by droughts [79] , dingo society has plasticity [84] which allows for members of different packs to utilise the common resource with minimal aggression [79, 88] and much larger family groups (n =55 dogs, Newsome 2011). Communication between pack members and between packs is by vocalisations (howls) and marking of objects with urine and faeces, and with scratches to the ground [9].

Females usually do not breed until their second year, especially in drier areas. Dingoes come into oestrus once annually, whereas domestic dogs of similar size cycle twice [93, 95]. Theoretically, hybrids may also be capable of cycling twice annually, but environmental and physiological constraints most likely restrict them to one successful breeding event each year [14, 93, 95]. Gestation lasts 61-69 days and they have litters of up to eleven pups (dog mean litter size 4.0–5.5, [9, 96-98], range 1–11 pups per litter [9]; G. Ballard unpublished data), which enables rapid repopulation after control or drought. Litters are typically born in winter, but can occur throughout the year. Weaning occurs at about 4 months but young of the year sometimes do not become independent of the adults until the following breeding season [9, 14].

Population dynamics

As with all widely distributed animals, the population density of wild dogs in any locality is largely dependent on the natural carrying capacity of the ecosystem (e.g. [63, 64, 99, 100]), modified by the availability of human-provided resources of water and food, and control activities [9, 14, 88]. Carrying capacities and densities are therefore subject to rapid fluctuations in many areas with or without wild dog control. To date most modelling of wild dog population dynamics (e.g. Figure 3) has been conceptual. There is a need to model populations from a low starting point, e.g. after a drought, to predict population fluctuations with and without control. Because the effectiveness of control programs in reducing dog populations varies, control effectiveness should also be factored into the calculated mortality rates.

A conceptual model of the dynamics of a population of wild dogs subject to annual reductions with effective control shows that the lowest abundance occurs immediately prior to whelping (Figure 3). While bitches are lactating, most pups survive resulting in the highest population abundance before weaning. After weaning, abundance declines as young dogs have the highest mortality [84], and this decline continues through independence and dispersal and breeding through to whelping again. Although mortality is highest among dogs in their first year, wild dogs can live for 10 years, but most die by about 5–7 years [9, 84, 95].

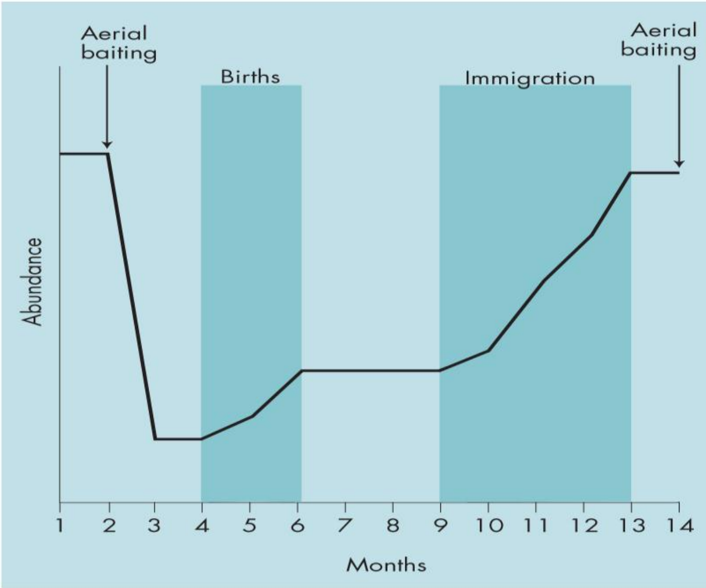

Figure 3. A conceptual model of wild dog population dynamics for a population subject to annual control of equivalent effectiveness between years (in this case by 70% reduction through aerial baiting). Month 1 is March and recruitment is through births from surviving adults and emigration from surrounding source populations (from [14]).

Diet and foraging

Foraging behaviour

Dogs also have plasticity of foraging strategies. They hunt singly, in pairs or in groups as required by prey size and will consume carrion when available or required [9, 14, 77, 82, 101]. That is, small prey like small native mammals and reptiles [102, 103], rabbits [101], feral piglets [29] and wallabies [73] can be taken by dogs hunting alone or in pairs, and larger prey like red kangaroos and feral ungulates (adult pigs, foals, buffalo and banteng) are usually taken by groups working together [9, 104], much like wolves and African wild dogs (*Lycaon pictus*) do [105]. However, single wild dogs have been observed to kill adult kangaroos [101, 106], which means that adults of no native wildlife species are outside the size range of a single wild dog. Although wild dogs are usually pursuit hunters, ambush hunting is also used for small prey like waterfowl, where some members of a group flush hidden prey towards waiting associates (e.g. [107]).

Plasticity of foraging behaviour enables wild dogs to rapidly switch prey [1, 9, 82] and is the crux of cattle predation. Small calves that are not protected by a defensive cow can be killed by individual dogs. Larger calves, weaners and even adult cattle can be hunted and killed by groups of dogs (B. Allen, G. Ballard personal observations). Those animals that are wounded, rather than killed outright, during wild dog attacks may later die from their injuries or from subsequent attacks.

Pursuit hunters, like dogs, are stimulated to attack when the prey startles and tries to escape [108]. This can result in surplus killing [109], where the number of prey killed far exceeds the nutritional requirements of the predator and much or the entire prey animal is left uneaten [110, 111]. This is particularly evident in sheep and goat predation by wild dogs [112, 113], but has also been observed for cattle (L. Allen and P. Fleming, unpublished data 1987).

Diet

Variable foraging strategies results in a broad diet. Wild dogs are generalist predators and scavengers, but with local and individual preferences. From traces in faecal deposits and stomach contents in different parts of Australia, it is evident that mammals predominate in wild dog diet (Table 2). A study of wild dogs in eastern Queensland rainforests showed their generalist diets and a preference for small to medium sized mammals [114]. In other areas of northeastern Australia, wild dogs appear to prefer medium-large sized terrestrial mammals (such as bandicoots, possums and macropods), but have the capacity to exploit populations of smaller and seemingly unsusceptible species when required [112].

The occurrence of a particular species in the stomach or scats of a predator only indicates that the animal was eaten by the predator, not that it was killed by it. Equally and conversely, the absence of a particular prey item in the scats of a predator does not mean that the predator did not (or could not) kill that prey. As discussed in [78, 112, 115], the presence or absence of prey remains in scats (including cattle) is a very unreliable indicator of wild dog predation for three reasons. First, cattle found dead from other causes are readily scavenged by wild dogs [77, 82]. Second, larger prey species (such as livestock, kangaroos or feral pigs) may be either under- or overrepresented in wild dog scats; underrepresented when proportionately more flesh and viscera are consumed and not the diagnostic hair, or overrepresented when wild dogs return to feed on a carcass on multiple occasions. Thirdly, surplus killing and injury may occur where little or none of the prey is eaten, yet there can be substantial loss without any evidence in the scats.

Table 2. The occurrence of major food groups (% of samples) in the diet of wild dogs in Australia (from Fleming *et al.* [14], adapted from Corbett [9]). f = faecal samples, s = stomach samples. Large mammals > 10 kg, medium = 750 g – 10 kg, and small < 750 g mean adult body weight. Total may be >100%.

	Wet–dry tropics	Central arid Australia	Southern arid Australia	Far western semi-arid Australia	South-east temperate Australia	Eastern temperate Australia
No. Samples (type)	6722 (f)	1480 (s)	131 (f/s)	413 (f/s)	2063 (f/s)	1993 (f)
Large mammals	12.5	36.4	39.7	100	22.9	0.4
Medium mammals	26.6	41.7	69.5	4.8	72.6	85.5
Small mammals	34.3	28.0	0	0.2	13.2	20.6
Reptiles	0.1	14.1	1.5	3.4	1.0	1.3
Birds	33.8	11.9	2.3	5.6	21.7	2.7
Insects	1.3	4.1	0.8	2.9	2.2	<0.1
Plants	7.3	0.1	0	0	1.2	0.2
Others	0.4	0.5	0.8	0.2	16.3	1.4

Cattle remains are frequently detected in wild dog scats and/or stomachs collected from pastoral areas, though the percent occurrence is highly variable between studies [9]. For example, Allen [112] and Newsome *et al*. [116] each detected cattle remains in <3% of samples, whereas others [82, 117] detected cattle in up to 30% and 64% of samples. Recently, cattle remains occurred in 12.6% of scats collected in the Tanami Desert where cattle were the predominant prey on Tanami Downs cattle station [88]. Calf predation or damage (discussed in detail below) can be either negligible (e.g. [70]) or substantial [55] in places where cattle remains consistently form relatively large components of wild dog diets. Conversely, over 30% predation of calves can occur where less than 2% of scats contain cattle remains [54, 112]. For these reasons, the incidence of cattle remains in dingo scats/stomachs should be interpreted with caution. The occurrence of cattle in wild dog scats/stomachs is, perhaps, best used as an indicator of the relative importance of different dietary items.

During predation, cattle are unaffected by the genetic lineage of their attacker. However, there has been suggestion [118] that increased genetic diversity has lead to phenotypic variability including greater body size which, in turn, could increase the likelihood of predation on cattle. This conjecture is presently unsupported by published research.

Agricultural, environmental, and human impacts of wild dogs in northern Australia

Agricultural impacts

As with any predator of livestock and co-occurring large mammalian herbivores, there are impacts of the presence of wild dogs on agricultural production. Suffice to say, wild dogs can have negative, positive or neutral impacts on agricultural values at different times and places. The impacts of wild dogs on the sheep industry are relatively clear cut – sheep and wild dogs are mutually exclusive [30, 119]. However, the relationship between wild dogs and cattle is more complex. Where predation by wild dogs is net-costly to the industry, these impacts are obviously negative. Conversely, positive impacts occur when their presence is net-beneficial to the industry. Neutrality occurs when the presence of wild dogs impacts neither positively or negatively and wild dogs are simply passengers in such agro-ecosystems. The perceived impact status of wild dogs in a particular region often determines the management actions undertaken there. As such, wild dogs may impact a range of beef production systems, including calf-producing properties, fattening properties and limited production properties (i.e. hobby farms and studs). Thus, a range of stakeholders are affected by wild dogs, including beef producers, sale-yards, processors, and ultimately consumers and investors.

In this next section, some of the impacts of wild dogs on cattle production are outlined and illustrated with three case studies.

Negative impacts on cattle production

The negative impacts of wild dogs on cattle production occur at three levels; on-farm, during selling and during processing. On-farm impacts include direct predation causing death and mauling injuries [30, 32, 110]. Predation of calves by wild dogs has long been one recognised, but largely unquantified cause of reproductive failure in cattle enterprises [32, 54, 120, 121]. The role of wild dogs in the spread of diseases affecting cattle production has also been recognised [121-124]. Secondary losses may include reduced weight gains or the delayed onset of oestrus as a result of increased vigilance and anti-predator behaviour (see below). Wild dogs are implicated in livestock disease lifecycles causing losses during production on-farm and in processing [125, 126]. Post-farm, buyers may undervalue sale lots containing individuals showing evidence of dog attack or even complete lots from “dingo country” [127].

Direct predation is typically of most concern, as calf losses in excess of 30% have been reported under certain circumstances [120]. 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 [120]. A questionnaire survey of approximately 67% of cattle graziers in the Northern Territory in 1995 estimated annual calf losses attributable to predation by wild dogs between 1.6% and 7.1% [128]. Allen [54] measured lactation failures of known-pregnant cattle on properties divided into 1080 baited and non-baited areas over several years in the mid 1990s. After excluding alternative explanations (such as disease, theft or nutritional stress), wild dog predation losses of up to 32.1% of *Bos indicus* calves occurred at a site in the Gulf of Carpentaria (Case Study 1) and up to 15.0% losses of *Bos indicus*/*Bos taurus* cross calves occurred in central and southwest Queensland [54]. In a more recent yet similar study in the arid zone of far northern South Australia, Allen [55] also recorded calf predation losses of up to 33.1% of calves at one site (Case Study 2) and 15.7% at another. Total lactation failures between confirmed pregnancy diagnosis and branding at another (non-baited) site were 53.4%, also suggestive of large predation losses, though data from a comparable baited site was not available for confirmation [55]. 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 [30, 54, 120].

While substantial losses of calves to predation by wild dogs have been demonstrated in a variety of land systems (e.g. [32, 54, 55, 70, 120]), a key finding of Allen [54], Eldridge *et al*. [70], and Allen [55] has been the absence of detectable predation losses in most years. Thus, wild dogs do not routinely impose economically significant predation losses to cattle production enterprises, yet when predation events do occur, substantial financial losses are possible. This conundrum highlights the need to better understand the environmental factors that trigger calf predation events, in order to best manage and predict their impacts. Eldridge *et al*. [70] compared branding rates and bite marks on three properties in the Alice Springs region over three years, detecting no significant calf losses or damage during this time in either baited or non-baited areas. Allen [54] similarly reported that calf losses in non-baited areas occurred in only one of seven site-years monitored in Queensland, while Allen [55] found no economic calf losses in one of four site-years monitored in South Australia. In each case, the availability of preferred wildlife prey appeared to circumvent calf predation events by wild dogs. This highlights the need to better understand the environmental factors that trigger calf predation events, in order to best manage wild dog impacts.

Dog bites affect calves, weaners and adult cattle. Physically damaged animals are valueless for the live cattle export trade from northern Australia and most such animals do not reach the boats (Glenn Edwards, NT govt., pers. comm. 2005). Although these impacts are known or expected to occur in many places, few quantitative studies have specifically addressed them. Except for small studies (e.g. [32, 70]; Ballard, Newsome and Fleming, 2010, unpublished data from NT), the frequency of dog bites is not known but could be measured in the yards on-farm and at sale-yards, feedlots and abattoirs. Such assessment of the more subtle losses to cattle enterprises is essential for a complete quantification of wild dog related losses to cattle enterprises.

Non-lethal attacks on cattle may also be a source of indirect production losses. These losses occur on- farm by reducing the weight gain of bitten animals during recovery and from chronic infection (P. Fleming, J. Thompson and K. Mercer, unpublished data 1992). Post-farm, bite marks, torn ears or other scarring results in the downgrading of stock at sale-yards [127] or removal or rejection in the boning room (costs borne by the processor). The prevalence of calf damage is not well known, but Hewitt [127] reported that Queensland beef producers observed up to 4.5% of cattle with scarring in the 2008/09 year. Ballard, Newsome and Fleming (unpublished data, 2010) found 6% of cattle at a central Northern Territory station, including weaners and calves, presented at a single muster showing bite marks from wild dogs. Eldridge *et al*. [70] reported that about 3 in every 1000 cattle exhibited scarring at three central Australian sites between 2000 and 2002. The observation of calf loss or scarring is often used by beef producers as a decision tool to initiate wild dog control. However, the occurrence of calf damage is a poor indicator of lethal calf predation, as economically significant calf losses may still occur in the absence of visible calf damage [55]. Conversely, economically significant levels of calf predation may not be occurring despite observations of some calf damage [70].

A problem affecting interpretation of wild dog impacts on the cattle industry is one of additionality (see [129]). That is, the costs of dogs to reproductive failure would need to be calculated in addition to losses from other sources [121]. The current MLA-funded Northern Australian Beef Fertility project ("Cash Cow") is investigating the reproductive output of northern cattle enterprises with the objective of identifying sources of reproductive failure. However, the questions relating to the presence and impacts of wild dogs are binary (yes/no) and inadequate to assess the relative importance of wild dog predation or relative effects of their control on either reproductive failure or net benefits or costs to reproductive output. To do that would require simultaneously acquired continuous data for wild dog densities, calf branding rates, stocking rates and control effectiveness.

Diseases

Wild dogs transmit a variety of pathogens (see Appendix in [14]), though the two primarily significant pathogens associated with cattle production in northern Australia are hydatid tapeworms *Echinicoccus granulosus* [123, 125] and the protozoan *Neospora caninum* [130, 131]. Wild dogs are the definitive host of hydatids, which are transferred from wild dogs to cattle via ingestion of worm eggs on grass and through contact with flies carrying eggs from wild dog faeces to the mouths of cattle [132]. Extraordinarily high worm burdens can be found in wild dogs in eastern Australia, where even low numbers of infected wild dogs can maintain a high transmission rate [133]. The prevalence of hydatids is maintained in the absence of an ungulate host through sylvatic predator-prey relationships primarily between wild dogs and macropods [134]. Beef cattle industries are impacted by hydatids through condemnation of infected organs, which affects offal sales and live cattle trade with southeast Asia [135]. A survey of six Queensland cattle processors indicated that nearly 6% of cattle contain hydatids [127]. Importantly, there was wide variability in the survey results, suggesting that hydatid prevalence may be attributed to the geographic location of the source cattle. In other words, higher proportions of infected cattle may originate from areas with significant wild dog and macropod populations.

Neospora caninum can cause major reproductive failures (i.e. abortion storms) in beef and dairy cattle herds [136]. An infection prevalence of 15% was reported in Queensland beef cattle, with greater incidence of infection occurring in areas of high density wild dog populations [135]. Dingoes and other wild dogs are definitive hosts of *N. caninum* [130, 131] which is prevalent wherever dogs have been tested in northern Australia (J. King and G. Brown, unpublished data). Approximately 3.75% of breeding cows in Queensland are infected with *N. caninum* by wild dogs, with 10% of these assumed to abort calves, costing over $3 million annually to Queensland cattle producers [59, 127]. Further information on *N. caninum* is not addressed here, but can be found in the reports of Landmann and Taylor [137] and King *et al*. [130].

Behaviour effects

An unknown, but potentially significant source of cattle production losses may occur through increased vigilance, anti-predator behaviour or risk effects. To the best of our knowledge, no studies have investigated these impacts on beef cattle in Australia. In North America however, a study investigating the risk effects of grey wolf predation on wild elk (*Cervus elaphus*) found that risk effects can have a major influence on elk grouping patterns, vigilance, foraging behaviour, habitat selection and diet [138]. Of the two risk-associated mechanisms thought to affect elk reproduction, the non-lethal effects of wolves on elk were better explained by changes in foraging patterns that carry nutritional costs than by increased stress hormone levels.

A similar study on beef cattle in North America [139] also showed that cattle exhibit considerably higher alertness and vigilance in the presence of wolves and mountain lions (*Puma concolor*). Vigilance was influenced by group size and vegetation density, with cattle in larger groups or more open habitats understandably displaying less vigilance. In simple terms, these studies show that in the presence of predators, wild and domestic herbivores spend less time foraging (i.e. gaining weight) and more time looking around. These behavioural responses to the presence of predators logically suggest that growth rates and possibly the onset of oestrus may be negatively affected by the mere presence or threat of predators. Similar risk effects are likely to occur between wild dogs and livestock in Australia, though the production losses associated with these are unknown. Such impacts may affect beef producers not typically affected by wild dog predation and attacks, including properties that primarily fatten cattle. New low-cost livestock location technologies fitted to cattle [140] and combined with GPS-logging collars on wild dogs and physiological/energy use monitoring of both animals, will enable investigation of these questions.

Positive impacts of wild dogs on cattle

The relationship between cattle and wild dogs is not always negative, and wild dogs may have positive impacts on beef production as well. These may include benefits derived from predation on potential competitors of cattle, such as kangaroos and wallabies (*Macropus* spp.) [141] and feral goats (*Capra hircus*), or the beneficial predation of calves during drought conditions as suggested by Corbett [9]. In theory, at some later phases of a drought cycle, predation of calves by dingoes may have net beneficial effects on cattle production by allowing dams to survive without the demands of lactation (Figure 4). In reality, cattle production practices (such as early weaning) can achieve the same result without losing the calf. Both of these potential benefits have not been tested experimentally. However, given that wild dogs may not always cause negative impacts to beef producers, balancing the negative and positive impacts of wild dogs may be critical to achieve optimal beef cattle production.

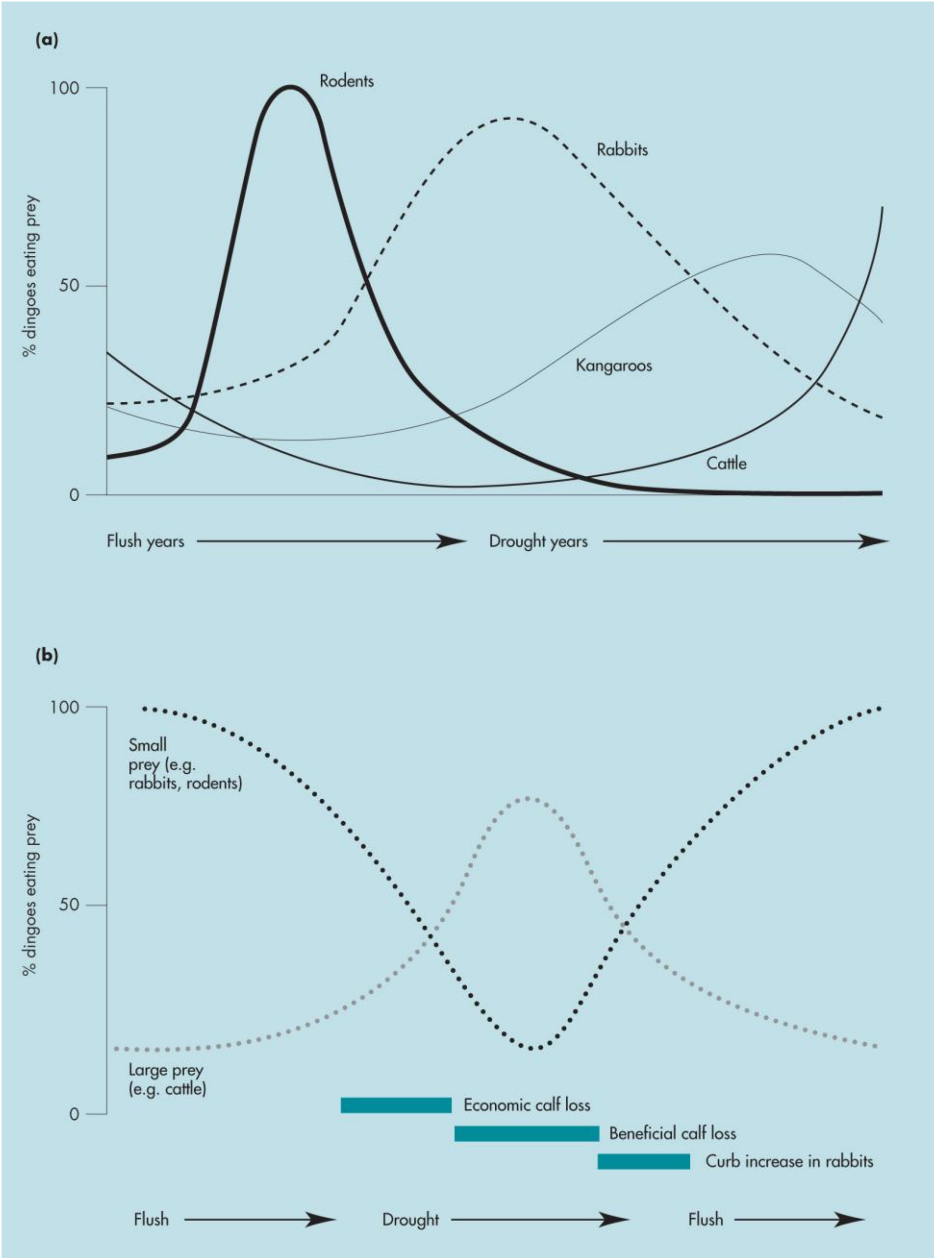

Figure 4. Conceptual models of predation by wild dogs in arid agro-ecosystems showing: a) prey-switching to prey of increasing size with decline in seasonal conditions; and b) theoretic periods of costly calf loss, beneficial calf loss and beneficial rabbit control (blue bars). From Fleming *et al.* [14], after Corbett [9].

Wild dog predation of introduced feral livestock and over-abundant native herbivores may reduce competition for forage between cattle and other species, indirectly increasing the carrying capacity of cattle (Case Study 3). For example, wild dogs are thought to regulate or suppress kangaroos in many land systems [142]. Investigating the stark differences in kangaroo abundance from one side of the dingo barrier fence to the other, Caughley *et al*. [143] proposed that wild dog predation holds kangaroo populations at very low densities in open arid country. Shepherd [144] studied kangaroo kill rates in north-western New South Wales and similarly concluded that wild dog predation can limit kangaroo densities by curtailing their rate of increase. Similar impacts on macropod populations have been observed in south-eastern Australia [145]. However, Newsome *et al*. [146] offered alternative explanations for the earlier findings of Caughley and others by demonstrating that cross-fence differences in faunal assemblages, habitats, water run-off, waterpoint densities and associated ecological processes may also explain the observed abundance of kangaroos. In contrast, the findings of Pople *et al*. [142] provide additional support for the notion that wild dogs not only limit kangaroo densities, but they also regulate them. Fillios *et al*. [147] advanced similar conclusions, but they extrapolated beyond the limitations of their experimental design [148].

Most recently, and in line with Caughley *et al*. [143], Shepherd [144], and Pople *et al*. [142], Allen [149] also reported that wild dogs can suppress kangaroo populations across large areas in the arid zone. Investigating the relationship between wild dog control, kangaroo abundance, and calf production, Allen [149] proposed that frequent and coordinated wild dog control across large arid areas affects wild dog populations to the point where they are no longer able to limit kangaroo populations, increasing herbivore competition for pasture, and ultimately reducing the carrying capacity of beef cattle. Whatever positive benefits in reduced calf predation that accrued through wild dog control were subsequently lost through increased competition for pastures [150]. While other factors may have contributed to these observations, intensive wild dog control may indirectly reduce long-term calf production through competitive effects in arid areas. This can potentially be overcome by reducing the density of competitive herbivores or restricting the frequency of wild dog control to times where the risk to calves is predicted to be excessively high.

In theory, wild dog predation of calves during below-average seasonal conditions may allow mature cows to retain energy that otherwise would have been spent suckling a calf [9] (Figure 4). Where a high proportion of calves would be expected to die from malnutrition under such conditions, calf predation events could indirectly improve the body condition of surviving cows. This may be less of an issue where beef enterprises practice early weaning and conservative stocking rates. Calf removal (either through predation or early weaning) might further improve the prospects for successful pregnancies in subsequent seasons when conditions improve. Quantification of these benefits has not occurred, and will be difficult given the highly variable seasonal conditions typical of central Australian landscapes. However, it could reasonably be expected that these benefits occur whenever calf predation occurs during unfavourable seasonal conditions (Figure 4). Although, where early weaning is practiced and cattle management practices aim to reduce stocking rates during dry times (instead of attempts to maintain them through supplementary feeding), such predation may still be undesirable and costly to beef producers. Thus, calf predation events might only be beneficial where cattle management practices aim to maintain breeders during dry times. This hypothesis, however, has not been investigated in detail. The economic benefits of this potential positive impact remain unknown and the practice is unlikely to be acceptable today given that profitability of northern cattle herds is determined primarily by reproductive output, as well as cow survival and turn-off rate of progeny [23].

Economic implications for cattle production

The economics of vertebrate pest control, particularly of predators such as wild dogs, is not simple. The underlying relationship required for determining the economics of predation and its control is the density/damage function or its inverse, the density yield function [151]. There has been only one study that investigated the relationship between damage experienced by cattle producers and an index of dog density (P. Fleming and H. Nicol unpublished data, Figure 5). The function, calculated from north eastern NSW over 12–18 months in the mid 1980s, was highly significant but had low prediction capability because of high variability between enterprises. The only reliable conclusion that can be drawn from that study is that damage will not occur when dogs are absent, which is not very insightful. Because of the logistic difficulties in undertaking studies of livestock losses and production costs across large areas, there have been no attempts to determine the density/ damage function in northern Australia and few attempts to quantify the economic implications of wild dogs on the cattle industry. This remains the major research requirement.

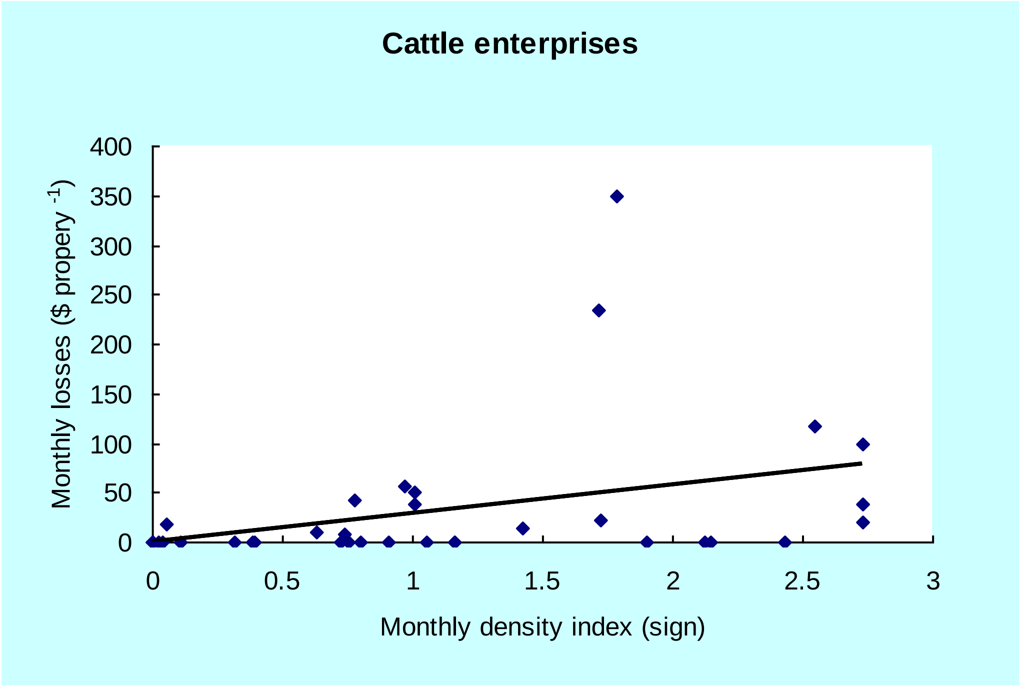

Figure 5. The relationship between the monthly damage caused to cattle producers ($ property^{-1}) in north eastern NSW by wild dogs and an index of wild dog density: Damage=28.549 x Monthly density index, r^2=0.14, *n*= 39 properties. P. Fleming and H. Nicol unpublished data.

Simplistically, if the costs of vertebrate pest damage outweigh the costs of control, then control is beneficial [151]. The instantaneous economic costs comprise the direct losses to production plus the expenditures spent on control and management [152] including administrative and research costs of vertebrate pest problems (e.g. [153, 154]). However, where predators reduce competitive effects on livestock production, economic benefits can theoretically accrue when predators are retained in the system such that net costs are equal to or greater than the direct losses. No benefit is gained by controlling the predator in such cases. When the number of potential competitors in a system is low or the amount of forage on offer is high, there is likely no competition between cattle and other herbivores [99]. In that case, there can be no economic benefit from retaining wild dogs in the system, but neither does a net cost automatically accrue. The presence of wild dogs would have neutral or negative impacts on cattle production in this case. Conversely, if the density of native and feral herbivores is high and forage on offer is limiting, then there is potential for competition with cattle. In this case, the presence of wild dogs will be beneficial only if the predation rate is sufficient to limit or regulate competitive herbivore numbers [99, 150, 151]. A neutral impact is also possible when wild dog density is insufficient to limit or regulate herbivore density. Therefore, there are likely to be a number of thresholds affecting the net cost or benefit of wild dog presence in cattle producing areas of northern Australia. Research is required about the competitive interactions between herbivores and the role of wild dogs in their population regulation before economic analysis of benefits of wild dogs on cattle production is possible.

Different economic assessments of wild dog impacts have used different methods, which makes comparisons between them difficult. However, recent broad-scale economic analyses [153, 154] have uniformly concentrated on negative impacts of vertebrate pests on livestock production. Although the sheep industry has traditionally been the primary focus of economic evaluations of wild dog predation (e.g.[14, 30, 119]), a common theme of recent analyses has been the greater overall cost to the cattle industry. In 2004, McLeod [153] estimated national losses to sheep production of $15.9 million and to cattle production of $32.4 million.

Gong *et al*. [154] determined the annual economic surplus losses by wild dogs to the national beef industry to be $26.68 million. This cost included $23.43 million to the northern beef cattle industry. The economic costs of wild dogs to the northern Australian beef industry has not been comprehensively investigated for all areas, though Hewitt [127] and Rural Management Partners [59] have undertaken detailed estimates for Queensland. In contrast to Gong *et al*. [154] who used data from historical studies and information from experts, Rural Management Partners [59] relied on personal interviews with beef producers. Respondents appeared very conservative in their quantification of wild dog predation, providing a degree of confidence in their estimates. Hewitt [127] expanded on this latter framework to quantify additional costs not fully explored in earlier assessments. Results from the more-detailed analyses of Rural Management Partners [59] and Hewitt [127] suggest that the economic costs of wild dogs to the Queensland beef industry alone are $30–$40 million annually (Table 3). More work is needed here.

Despite their apparent inconsistency, these economic assessments generally show that wild dog impacts are in the tens of millions of dollars and not the millions. They also confirm that the economic impact of wild dogs affects the entire supply chain, from beef producers through to local and international consumers. In light of their agricultural impacts, whether or not wild dogs are ‘bad’ or ‘good’ for beef producers will be a balance between the negative and positive impacts, which will have to be assessed from year to year as environmental conditions vary. This highlights the need for greater emphasis on using robust ecological data as the basis for impact mitigation strategies, in order to improve economic output.

Table 3. Estimated economic costs of wild dogs to the Queensland beef industry, after Hewitt [127] and Rural Management Partners [59].

Category	[127]	[59]
Calf livestock losses	$22,840,000	$9,531,000
Product loss due to dog-bitten cattle (sale-yards)	$1,036,914	Not estimated
Product loss due to dog-bitten cattle (processors)	$1,031,441	Not estimated
Neosporosis	$3,143,536	$3,400,000
Hydatids	$2,057,685	$6,000,000
Wild dog management and control costs	$11,460,498	$18,393,000

Case studies of wild dog predation and beef cattle

Case study 1 – Wild dog predation of beef cattle in central Australia

(from [155])

A project investigating the production costs of wild dogs was initiated in response to growing concerns from beef producers that wild dogs were killing unsustainable numbers of calves. On-ground monitoring of wild dog populations began in 2008 on four representative properties, where wildlife and calf monitoring was also undertaken. The monitoring project was designed to measure calf losses in baited and non-baited areas, while simultaneously monitoring the activity of wild dogs and the wildlife prey they were likely to eat.

At one site in northern South Australia (where 1080 baiting had not occurred since 1991), calf losses were monitored over the 2009–2010 calving season during a time of deteriorating environmental conditions (i.e. hot, dry, and windy weather when surface water resources were rapidly drying up). Calf loss, as determined by monitoring lactation failures from known-pregnant cows, showed that a total of 45.1% of calves (55 of 122 known-pregnant cows) were lost in areas where no wild dog control was conducted, while 20.8% (16 of 77 known-pregnant cows) of calves were lost in areas where wild dogs had been baited with manufactured 1080 baits in spring and autumn since October 2008. Previous work in rangeland environments has shown that approximately 12% of calves die of other causes, such as abortions, stillbirths, or mismothering [156]. So, assuming similar levels of losses from these other causes between baited and unbaited areas, wild dog predation losses were in the vicinity of 33% in non-baited areas and 9% in baited areas that year, with 1080 baiting reducing wild dog predation by nearly 73%. Dead calves, bite marks, torn ears, and other forms of visible calf damage were not observed in either the baited or non-baited areas (because attacked calves did not survive until branding, and were probably eaten or scavenged), and the body condition scores showed that all cows were in excellent physical condition, despite the seasonal conditions.

Examination of prey remains in wild dog scats showed that their diets contained a large proportion of small and medium sized mammals, including mice, rabbits, and dunnarts. The activity of these species appeared to decline as seasonal conditions deteriorated. Baiting should have reduced wild dog numbers in line with the declining prey sources, while the higher numbers of wild dogs in the non-baited area (in the absence of kangaroos or other prey resources) apparently compensated for the declining prey by killing calves. Cattle hair was found in 24% (311 of 1303) of wild dog scats from the site [78]. Nearly 500 feral donkeys and horses were culled on the property during this time, suggesting that their presence did not prevent significant calf losses.

Based on branding rates only, the managers of this property had observed similar differences between baited and non-baited areas but had assumed a lower bull-to-cow ratio in the non-baited area. This might normally be a plausible explanation for low branding rates in the absence of data on lactation failures, but this example highlights how significant calf predation can occur yet go unnoticed by managers. The cost of baiting was estimated to be <$5,000, including bait costs and labour and fuel to distribute bait . Had baiting not occurred across the entire station that season, the conservative estimated value of the calves killed by wild dogs was about $262,000–$332,000 (i.e. 1,000 *Bos indicus* cross calves <200 kg @ $262–332 [157]).

Case study 2 – Wild dog predation of beef cattle in the Gulf of Carpentaria

Ironhurst Station (from [158])

Ironhurst Station is a 520km² beef property northwest of Georgetown in the Gulf of Carpentaria. Between 1965 and 1997 it was owned and managed by the same producer. Initially, from 1968–1987, 1000–1500 strychnine baits were laid annually by vehicle around waters. But beginning in 1988, and until 1997, Ironhurst, together with a group of adjoining cattle stations, commenced an annual aerial 1080 baiting program over a large contiguous area of approximately 50,000 km² (as opposed to *ad hoc*, localised programs). Subsequent to the change in baiting practices, the percentage of calves bitten by dingoes, which had ranged 8–19% from 1968–88, declined to zero for two years (Figure 6). Eleven bitten calves (1.2 %) were found in 1996, the highest number since aerial baiting commenced. Following 1988, the branding rate immediately rose and averaged 75.3% (SE 0.4, 1989–96), 18% higher than the previous ten year average of 57.3% (SE 2.5). The average branding rates and sales after the introduction of baiting were better than the best ever achieved in the preceding 20 years (Figure 6). Better seasonal conditions did not explain improved branding because mean rainfall generally declined in the years subsequent to the introduction of annual large scale aerial1080 baiting program.

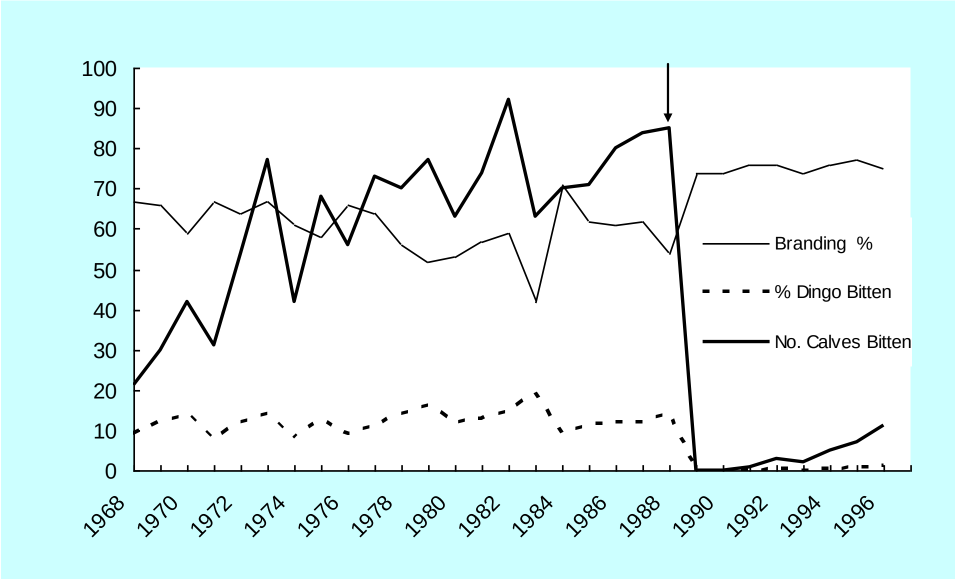

Figure 6 Calf production (branding %), and numbers and percentage of calves presenting with bites from wild dogs, before and after the introduction of broadscale aerial baiting (down arrow) with 1080. From Allen and Gonzalez [158].

Over the late 1960s and early 1970s, Ironhurst was increasing stock numbers following the destruction of several thousand brumbies. Despite heavy culling of brumbies, no change in reproductive success was evident until the new baiting strategy was implemented. Assuming that predation losses were negligible subsequent to 1080 baiting in 1988, dingo predation appeared to account for a mean annual calf loss of 32%. Excluding a variety of other potential factors, the greater regional distribution and access to remote areas afforded by aerial baiting reduced dingo densities at a regional scale and reduced predation. Re-colonisation of baited areas by wild dogs consequently took longer, and the effectiveness of baiting was sustained as these immigrant and internally recruited wild dogs were controlled by the broad scale annual baiting.

Strathmore Station (from [54])

Reproductive performance of beef cattle was examined in detail for three consecutive years at Strathmore Station, northwest of Georgetown from 1995–1998, using a similar approach described to that in Case Study 1. As in case study 1 above, assessments of calf loss were based on monitoring lactation failures in known-pregnant, Brahman (*Bos indicus*) cows depastured in baited or un-baited areas separated by a buffer. While no lactation failures were detected in the un-baited area beyond previously observed normal background loss (i.e. <12%, [156]), on an identical herd, pastured just 30km away in the baited area, predation losses did occur. While predation losses were not detected every year in the baited areas, calf losses of 5.5% and 30% were detected in two out of the three years studied. Overall, in the three years examined, there were 129 lactation failures from 546 known pregnant cows in the baited area (annual mean of 23.6%) compared to 44 lactation failures from 534 pregnant cows in the non-baited area (annual mean of 8.2%). Incidents of predation loss were associated with years when annual rainfall was below-average, preferred prey populations were low or declining, or where baiting had occurred but wild dog activity had recovered soon afterwards [54]. The higher predation losses in baited areas were thought to be caused primarily by reinvading juvenile dingoes unable to cooperatively capture enough large macropods, killing calves instead.

The study found that wild dog predation is highly variable and not directly related to seasonal conditions. Hence, although wild dogs have the capacity to cause serious economic impacts to beef producers, their impact can be negligible in some years or under certain conditions. As seen in the previous case studies, control of wild dogs control can reduce and even eliminate predation losses for cattle producers. However, at other times, when wild dog control is not or cannot be conducted at sufficient scale or efficacy it can exacerbate losses to the point that baiting may be counter-productive in the long-term.

Case study 3 – Balancing the effects of wild dog control and kangaroo competition in the arid zone

(from [149])

The cattle production zone of northern South Australia (NSA) is divided into the Northeast (NE) and Northwest (NW) regions. Wild dog control historically occurred (and still occurs) infrequently in the NE region, as it did in the NW region prior to 1990. However, the frequency and intensity of 1080 baiting in the NW region increased significantly in 1990 and remained at relatively high levels until 2005. Within a few years of the increased baiting, beef producers began to report marked increases in the abundance of kangaroos in the NW region. This led to the establishment of a kangaroo harvesting industry in the mid 1990s, when annual kangaroo abundance estimates began to be collected in order to inform sustainable kangaroo harvesting quotas. Records of calf production, 1080 usage, and rainfall were also being collected during the period, allowing an examination of the relationships between wild dog control, kangaroos, calf production and environmental variables.

Property-specific calf production and 1080 usage records were compared with regional rainfall totals and kangaroo abundance estimates. Kangaroo numbers were converted to cattle numbers through the use of standardised Dry Sheep Equivalent values (1 kangaroo = 0.35 DSE, and 1 cow = 22 DSE, based on a 400kg *Bos taurus* beef cow feeding a 7-10 month old calf; [159-161]).These data showed that regional calf production did not increase any faster in the NW region (where intensive wild dog baiting occurred) than it did in the NE region (where very little wild dog control occurred), though individual properties varied significantly. Kangaroo densities correlated well with both rainfall patterns and 1080 baiting (with a 4yr lag). Converting kangaroos to cattle showed that kangaroos consume enough pasture to support the regional production of 7,000–19,000 additional calves in any season, or 1.26 calves km^{-2}. Kangaroos contributed 20–40% to the combined kangaroo/cattle grazing pressure at all times. Assuming kangaroos compete with cattle only 50% of the time, kangaroo competition accounted for cattle production losses between \$9 km^{-2} and \$38 km^{-1} in any given year, or between \$1.1 million and \$4.7 million for the NW region. For an average sized property in the NW region, this equates to an average loss of >\$112,000 annually.

There were other factors that could have explained the results, which warrant caution in these interpretations. Regardless, wild dog predation of calves and kangaroo competition are two processes known to impact upon beef producers. Because wild dogs are likely able to limit kangaroo densities in open country [142, 143, 146], wild dog control programs must balance the positive and negative impacts of wild dog predation in order to optimise cattle production. While trying to protect calves from wild dog predation through baiting, spatiotemporally extensive wild dog control probably frees kangaroo populations from suppression by wild dogs, and the resulting competition costs may ultimately be more economically important than wild dog predation losses. Beef producers need to compare their losses to wild dog predation with their losses to kangaroo competition and determine which is worse. An appropriate balance might be achieved by restricting wild dog control to the times and locations when substantial wild dog predation events are likely to occur, rather than coordinated routine control programs that reduce wild dog numbers across large areas. Using wild dogs to manage total grazing pressure may allow sustainable calf production increases over the longer term. Alternatively, control of kangaroos could be required to achieve economic gains from wild dog control.

Environmental impacts of wild dogs and wild dog control

Wild dogs have positive, negative or neutral environmental impacts [162]. Wild dogs directly prey upon native wildlife, including threatened species [8, 131, 132], but they might also exclude other invasive predators through competitive interactions [16, 163]. As such, the beneficial effects of wild dogs on biodiversity will depend on the strength of interactions between wild dogs, mesopredators (such as foxes *Vulpes vulpes* and feral cats *Felis catus*), and the prey these three predators share.

There is a growing body of literature supporting the hypothesis that wild dogs limit, regulate or suppress smaller mesopredator populations (the mesopredator release hypothesis, MRH [164]) and enhance biodiversity through trophic cascade effects (e.g. [47, 165]). Multiple studies (e.g. [47, 165-167]) have reported inverse numerical relationships between foxes and wild dogs or corresponding positive correlations between some threatened species and wild dogs. On that basis, it is claimed that wild dog control led to the continental collapse of native species (e.g. [136, 138]). This has led to the proposition that the general reintroduction of wild dogs and/or cessation of wild dog control programs will enhance biodiversity (e.g. [137, 139, 140]). While most of the studies supporting this concept cannot be used to make conclusions about regulation of mesopredators by dogs (e.g. [122, 131, 141]) and their interpretations and conclusions are not universally accepted [148, 168], popular opinion has nevertheless been generally swayed to this line of thinking. This had led to proposed [169] and accepted [170] legislation changes in the absence of evidence demonstrating negative impacts of wild dog control to biodiversity [171] and while disregarding conclusive evidence to the contrary (e.g. [46, 48, 147-149]). The functional basis of these recent claims need critical evaluation focussing on both positive and negative impacts of wild dogs [172]. How wild dogs might be managed to capture any positive impacts on biodiversity without negatively impacting on beef production values and wildlife is an important focus for research and management in the future.

Impacts on sympatric introduced predators

As indicated above, the impacts of wild dogs on populations of co-occurring (sympatric) predators is a topic currently attracting significant interest from conservation agencies around the country. This is because wild dogs may reduce the impacts of mesopredators on threatened prey species [173], thereby providing overall net benefits to biodiversity conservation efforts [16, 174]. Although too often studies claiming to provide evidence for the biodiversity benefits of wild dogs extrapolate beyond the limitations of the methods and data [148, 175], wild dogs may have net benefits to biodiversity through their impacts on some prey species. Being larger in size, wild dogs sometimes kill foxes and cats and they may also suppress them through competitive interactions. Hence, a reduction of mesopredators may yield greater biodiversity benefits than an increase in wild dog impacts. It has also been claimed that wild dog control influences the ability of wild dogs to suppress mesopredators [165] but how this would happen remains unclear [50, 176]. However, given the complex nature of predator-prey interactions in a dynamic environment, these processes would need to be thoroughly investigated before management actions promote any predator, especially one known to cause livestock losses.

Impacts on sympatric native predators

The spotted-tailed quoll (*Dasyurus maculatus*) occurs in southeast Queensland and there is a smaller subspecies (*D. maculatus gracilis*), which is restricted to the Atherton Tablelands region and north on the east side of Cape York. Both these subspecies are threatened, but, given research findings from north eastern NSW (e.g. [177, 178]), it is unlikely that wild dog control is a threatening process for them [171]. Perhaps coincidentally, recent searches for south east Queensland research sites suitable to assess the effects on quoll populations of ground baiting for dogs with 1080, failed to find quoll populations except where dogs and foxes had been controlled (P. Cremasco and S. Myer-Gleaves, unpublished data). Further work is required to determine positive and negative effects of wild dogs and control, and other factors on quoll persistence in north eastern Queensland.

Across northern Australia there were another two species of quoll that were smaller than the spotted-tailed quoll, the western quoll (*D. geoffroii*), which is now extinct in northern Australia, and the northern quoll (*D. hallucatus*), which has suffered recent range contraction [179]. It is likely that habitat reduction and changed fire regimes [180], and competition and predation by introduced predators (e.g. [155, 156]) caused these declines and the mainland extinction of the eastern quoll (*D. viverrinus*, [17]) and, with cane toads (*Bufo marinus,* syn. *Rhinella marina* [157, 158]), are threatening processes for the two small quolls. Given the widespread losses of northern and eastern quolls and the limited control of dogs at a landscape level [76], it is unlikely that these species have been adversely affected by dog control at a population level. In fact, although not adequately addressed as a possibility by Glen *et al.* [160, 161], quolls may benefit from targeted control of wild dogs through reduced competition [181]. This possible effect of wild dog control has not been scientifically appraised.

Impacts on prey and other species

Wild dog impacts on prey species are often considered to be a "natural" process, and have usually only been investigated as a factor influencing livestock predation. However, wild dog predation on some prey species can be unsustainably excessive where alternative food sources bolster wild dog densities. For example, the presence of rabbits may sustain wild dog populations at higher-than-normal levels, and the resulting predation pressure on alternative species can be severe [78, 182, 183]. Additionally, waste food and other anthropogenic food [88], cattle, or carrion may sustain wild dog populations at higher abundance than where these food supplements are absent, maintaining predation on native wildlife, particularly in drought [8, 66, 93]. Wild dogs have been implicated in the declines of multiple threatened species both historically [9, 175] and in the recent past [184], with predation impacts expected to be greater in heavily grazed areas due to lack of vegetation cover and forage. Wild dogs are a known or potential threat in no less than 14 different national threatened species recovery plans listed by the federal government in the *Environmental Protection and Biodiversity Conservation Act 1999* (see www.environment.gov.au for details). More species may be at risk of wild dog predation, but the recovery plans of other potentially susceptible species, such as dibblers *Parantechinus apicalis*, eastern barred bandicoots *Perameles gunnii*, or Gilbert's potoroo *Potorous gilbertii*, do not currently identify wild dogs as a threat because wild dogs are largely absent from the area where the species persists. Predation and hybridisation by feral dogs is a listed Key Threatening Process for threatened species, populations, and communities in New South Wales [185] where their predation impacts may threaten multiple mammal, bird and reptile species [115, 186].

Human impacts

Although not everybody living in areas where wild dogs occur are adversely affected by them, the impacts of wild dog predation of livestock affects people at the individual, family and community scale [187]. These impacts are largely unmeasured, but recent pilot investigations by Australian Bureau of Agricultural and Resources Economics indicated that the trauma experienced by individual graziers experiencing attacks by wild dogs on their livestock were similar in magnitude to post traumatic stress sufferers (P. Please, unpublished data). Reductions in this social impact are sometimes incorporated in management planning processes as a direct measurable aim (e.g. the Brindebella- Wee Jasper Wild dog and Fox management plan [188])

Wild dog management for northern Australia

Relevant legislation and policy

Wild dog management occurs within the bounds of legal and policy constraints. Legislation and policy vary between the three States included in this review and between them and the Northern Territory. Overriding Commonwealth laws also affect wild dog management. There are also generic Acts with similar function between States, which affect the practice of wild dog control, e.g. dealing with prevention of cruelty to animals, pesticides and indigenous land management. Where the dog fence forms the State boundary between New South Wales and South Australia and Queensland (i.e. part of the southern boundary of the northern cattle zone), the *NSW Wild Dog Destruction Act 1921* also comes into effect.

Commonwealth

The Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999* includes dingoes in its definition of “native”: i.e. a species that was present in Australia or an external territory before 1400 AD. The objectives of this act are to protect biodiversity and remove threatening processes. Under this Act, controlled actions (Section 67) that might be seen to endanger fauna listed in Schedule 1 associated with the Act, require referral to the Minister. In the early 2000s, such a referral was made under this section to enable aerial baiting of wild dogs in areas of NSW where spotted-tailed quolls were extant. Changes to wild dog control technologies in northern cattle regions could potentially require such referral (e.g. if a new wild dog control technology was perceived to be a potential threat to northern quolls).

Queensland

In Queensland, all wild dogs are declared Class 2 pest animals under the *Land Protection (Pest and Stock Route Management) Act* 2002. Landholders, including government agencies responsible for State lands, are obliged to take reasonable steps to control declared pest animals on their land. Under the Act, local governments must have pest management plans to manage pest animal impacts in their local government area. The dingo is defined as both ‘wildlife’ and ‘native wildlife’ under the *Nature Conservation Act* 1992, and is a natural resource within protected areas such as National Parks. Protected areas have prescribed management principles, which refer to protecting and conserving the natural resource and the natural condition. Policy is enabled through a State wild dog strategy [189], which outlines how these apparent paradoxes are addressed. Bounties are offered by some Shires, but with varying justification and evidence required by claimants.

Northern Territory

In the Northern Territory, dingoes are listed as indigenous to Australia and legally protected across all land tenures under the *Territory Parks and Wildlife Conservation Act* 2000. However, this Act allows for the control of animals that cause impacts on human values such as livestock production under approved management plans (e.g. within the Parks and Wildlife Service, Department of Natural Resources, Environment and the Arts 2005). A Territory-wide strategic plan facilitates control of wild dogs for protection of livestock and other values [190].

South Australia

Under the *Natural Resources Management Act 2004* and associated Policy [191] on the management of dingo populations in South Australia, dingoes are a declared pest (to be controlled by all landholders) in the 40 percent of the state south of the dog fence (where sheep are present). Of the 60 percent of the State north of the fence, about 25 percent is pastoral cattle zone. No baiting is done in the other desert areas which make up the 35 percent of the state. Aerial baiting is prohibited north of the fence and there are no bounties offered in SA. North of the dog fence in the pastoral zone, dingoes are not protected but are regarded as a legitimate wildlife species and, other than in a 35 km buffer zone extending north of the fence where they are subjected to routine ongoing control, are offered the following *de facto* protections. Cattle producers wanting to bait north of the dog fence must apply to the Natural Resource Management Board, and a risk assessment is done to determine the relative risk to calves based on rainfall history, seasonal conditions, prey abundance, dingo abundance and reported calf damage. Baits are supplied dependent on the risk, and trapping is not permitted.

Western Australia

In Western Australia the dingo is categorised as A7 in the list of Declared Animals under the *Agriculture and Related Resources Protection* Act (ARRPA) 1976. This means there is a management program relevant to their control in situations where required, but are elsewhere not controlled. Any control of dingoes is facilitated by subsidiary legislation to the *Wildlife Conservation Act* 1950 declaring the dingo as unprotected fauna throughout Western Australia. The Department of Agriculture and Food Western Australia (DAFWA) considers dingoes, feral dogs and their hybrids collectively as 'wild dogs' in pastoral and agricultural areas of the State. Under ARRPA wild dogs are declared A5 requiring that numbers are reduced or controlled.

The Department of Environment and Conservation (DEC) considers dingoes to be native fauna and is more concerned to distinguish dingoes from other wild dogs (feral dogs and dingo-dog hybrids). Fauna, including unprotected fauna, cannot be taken on land managed by DEC without their approval (*Conservation and Land Management Act* 1984). DAFWA and DEC both support the principles set out in the Western Australian Wild Dog Management Strategy 2005 [192]. This Strategy emphasises that stock protection only requires wild dog (including dingo) control on and adjacent to holdings running stock.

ARRPA places the responsibility for wild dog control on the owner or occupier of any land, private or public. It also provides for owners and occupiers to lay poison and set traps for the control of declared animals. Though the *Animal Welfare Act* 2002 prohibits cruelty to animals, it considers killing pests in a 'usual and reasonable manner' a defence to charges of cruelty. Jawed traps are currently listed as inhumane devices but are allowed if used by prescribed persons responsible for wild dog control in a prescribed manner including the use of a strychnine cloth on the trap jaws. The *Poisons Act* 1964 administered by the Department of Health WA controls the use of 1080 and strychnine.

Control technologies

In principle, the technologies available for controlling wild dogs are exclusion or culling with poisoning, trapping and shooting and these have remained unchanged since the invention of guns and steel-fabricated leg and foothold traps [14]. Exclusion techniques fall into physical barriers, such as fences and natural features, and livestock guarding animals, which aim to prevent livestock attacks [14, 111]. The effectiveness of the application of these tools, where studied, has been found to be variable [32, 54, 76, 193]. For the vast majority of rangeland grazing enterprises in northern Australia, the distribution of poisoned baits is the only practical broad-scale wild dog management tool. Other tools are supplementary in rangelands, but primary in closer settled areas.

Destructive methods

To ensure ongoing availability and humane application of the various methods of control a series of Codes of Practice and Standard Operating Procedures have been developed for all vertebrate pest control methods including those for wild dogs [194-196].

Poisoning
Poisoning can be done with ground-laid or aerially distributed baits. Depending on jurisdiction (see above), compound 1080 (sodium fluoroacetate) and strychnine [197] are the toxins presently permitted for killing wild dogs. Compound 1080 is the most widely used toxin and is highly toxic to dogs and foxes, resulting in target specificity at the dosages used for dogs [198]. The toxin is odourless, colourless, biodegradable, and occurs naturally in some native plants in the northern cattle zone. Although its humaneness is sometimes queried, e.g. [199], death is believed to be relatively humane, but observing intoxicated dogs is distressing[200]. There is no antidote for 1080 poisoning [198].

Although still used in some jurisdictions for particular situations, strychnine is considered inhumane because the affected animals remain conscious after onset of clinical signs, which include violent muscle contractions and breathing difficulties. Strychnine is also used on traps when daily checking is not possible or desired [201].

Where studied [54, 111, 158, 197, 202-205], control effectiveness as measured by dog population reduction or index reduction has been variable. However, in most cases (exceptions [203, 204]) there was no attempt to determine the density of wild dogs over which the known density of baits was distributed. Regardless of toxin used, effectiveness of control should be measured both by reduction in target animal density and production responses [76, 149].

In National Parks in NSW, the M-44 ejector [200] is permitted to be used to deliver 1080 poison to wild dogs and foxes, but this technology is not yet available to northern cattle producers. This target-specific device is spring-loaded and placed in the ground so that the baited trigger is on the surface. A dog or fox pulls up on the bait and a single measured dose is delivered into its mouth. The device can be used to deliver other toxins and the Invasive Animals CRC is developing a package for approval by the Agricultural Pesticides and Veterinary Medicines Authority (APVMA). The invasive animals CRC is also presenting APVMA with an approval package for the new toxin, Para-amino propiophenone (PAPP). PAPP has the advantage of an effective antidote for people to use on accidentally poisoned working dogs and pets while being particularly toxic to dogs, foxes and cats and having a humane mode of action.

Trapping
The traps available for capturing wild dogs are leg/foot hold traps [206] and cage traps. The latter are totally unsuitable for wild dogs but may have application for peri-urban, semi-tame dogs. The use of foot and leg hold traps is a specialist activity and is usually targeted at

individual dogs or localities where dogs require removal. Although the function of traps has been reported [206], there has been little attempt to quantify the effectiveness of trapping as a dog population control method. Where scalp records have been kept in Western Australia [197], Queensland [207], and northern New South Wales [181], trapping (particularly in association with bounties) at best provides sustained yield harvesting and at worst has no effect [208, 209]. However, trapping still remains an important adjunct to poisoning programs and is often used to remove troublesome individual dogs or where poisoning is problematic [158].

Shooting
Shooting of wild dogs by skilled marksmen results in almost instantaneous death with minimal suffering and pain, and is therefore the most humane control method and is favoured over poisoning by the RSPCA [14]. However, shooting is neither a strategic method of control nor a means of dog population reduction and is best used to target troublesome individual dogs. It is usually opportunistic, although dog-drives, where a line of beaters push through the bush frightening the dogs towards a waiting line of shooters (a battue), and ambushes, where the shooter simulates dog howls to attract dogs to within range for shooting (howling-up) or lies in wait at watering points or carcases, are sometimes used. Being labour-intensive, shooting is not a cost-effective option for reducing populations of wild dogs in northern Australia.

Non-destructive methods

Private and public fencing
The dominant features of the landscape across the bottom of the northern cattle zone are the public dog barrier fences (Figure 2). The majority of costs of construction and maintenance of these fences are borne by State authorities such as the Wild Dog Barrier Fence Panel (Queensland)[189], the South Australian Dog Fence Board and the Wild Dog Destruction Board of NSW. The fence in Queensland has been shown to be cost beneficial in a number of reviews [210, 211]. However, increases in reported losses to wild dogs and numbers of wild dogs captured inside the fence in the past 10 years have caused the functional effectiveness of the fence to be questioned again [212].

Private dog-proof fencing is uncommon, mainly because of the additional expense required for building a new fence or upgrading existing stock fences to make them dog-proof. Graziers in central Queensland who have parts of the old extended dog barrier fence on their property could potentially upgrade or repair the fence to keep dogs out but that would require co-investment by neighbours with the fence and considerable effort to remove dogs from any areas encompassed by the fence. The reliability of both private and public fencing is dependent on maintenance and considerable effort is assigned annually to the public fences.

Livestock guarding animals
Livestock guarding animals have been commonplace in central Europe and the Mediterranean for centuries and are used there and in North America primarily to protect sheep from large native predators [213, 214]. Guarding dogs are the most frequently used animal, but llamas, alpacas and donkeys have also been used [213, 215]. There is a general paucity of scientific assessment of effectiveness of livestock guarding animals under Australian conditions and this has been identified as a major limiter of the uptake of livestock guardians by producers [213]. Livestock guarding dogs are being used in central Queensland to protect cattle and sheep from predation by wild dogs [215], resulting in a reduction of sheep losses to predation from 2% to zero since their introduction. No assessment of changes in calving rates is mentioned [215]. Investment in research to assess the economics, effectiveness, mode of action and grazing responses of livestock when livestock guarding dogs are used is needed to assist producers in decision making.

Management strategies

It doesn't matter how good available management tools are if they aren't used properly and most effectively. As with any agricultural enterprise or land management issue, strategic planning provides a framework to apply, measure and evaluate management actions. Strategic plans can be effective tools for improving management outcomes in those situations where multiple groups have stakes in a management system. In Australia, a classic example of strategic planning would be a group of farmers and several Government agencies coming together to cooperatively manage wild dogs for the purpose of reducing livestock predation or conserving dogs for herbivore control, or a combination of both.

To get the best possible outcomes from the strategic planning process it is important that all participants have a clear understanding of what the process entails. It is also important that groups working together to develop or review plans are supported by a facilitator (see below) who is familiar with the process. Facilitation by experts, particularly those with detailed and broad scale knowledge of wild dog issues, can expedite planning in a comprehensive and non-confrontational way.

What is a strategic management plan?

At its most simple, a strategic management plan is a record of agreed actions for addressing a particular management problem or problems. It should record the who, how, what, where, when and why of managing the issue/s that stakeholders are interested in. Furthermore, it should do this in such a way that if the planning group were suddenly replaced in its entirety, their replacements could, within reason, understand the intent of the plan and continue to implement its actions.

Limitations: The things the strategic planning process CANNOT do
It is vital from the outset that all prospective participants understand that the strategic planning process has limitations. In particular, there are two key issues that simply 'turning up to a meeting' will not overcome. Firstly, a plan, on its own, cannot achieve effective management. Success only comes from working together to develop, implement, monitor and refine agreed management actions. Secondly, the process cannot turn attendees into genuine participants. Every person involved in the planning process has to decide for themselves that they would rather be part of a solution than create difficulties. To this end, taking time to empathise with the other participants can make a vast difference; the difference between attending pointless meetings and participating in a worthwhile process.

Principles in strategic management planning

Strategic planning brings together several key principles to achieve improved management outcomes. It's important that all participants understand these principles.

Cooperative management
Cooperative management is about sharing the burden of management to achieve a common goal. Although this seems relatively straightforward, many people struggle with it in practice. It does not mean an individual or group giving away all management responsibilities to other stakeholders. It does, however, mean working with other stakeholders to achieve positive outcomes. Since the issues dealt with in strategic management plans typically involve multiple tenures (see the cross-tenure strategy below) it is vital that the people responsible for those tenures work together in management.

The cross-tenure strategy
In this situation the word 'tenure' refers to the status of land, particularly with regard to how and by whom it is managed. The cross-tenure approach (see also "nil-tenure" [110, 188]) is a tool used during strategic planning to select a management unit that is of appropriate scale

to the problem, without regard to who owns or manages the land. In extensive cattle properties in northern Australia, the tenure in question may be a number of large paddocks, a couple of adjoining properties (e.g. Case study 2 above) or perhaps land under different State and Territory jurisdiction.

In the early stages of planning, mapping where management issues occur and how they should be addressed without referring to boundaries between different land tenures (e.g. private, indigenous and public lands [188]), is useful because these boundaries are often artificial in the natural world. Wild dogs and/or other wildlife we seek to manage rarely respect lines on maps so when planning to manage these species in the best possible way participants should not fixate on those lines. That said, it is important to remember that boundaries do have real impacts on people and how we can operate in particular areas (i.e. due to legislation or regulation) so they cannot be ignored completely. At a later point in the planning process it is important to re-consider tenure boundaries because of different jurisdictional constraints they can place on the proposed actions.

Planning review

In the real world, systems (including aspects of legislation, policy and regulations) change over time, locations of problems shift in the landscape and new technologies are developed. In light of such changes, initial management strategies may no longer be ideal or may have been flawed in the first place. Unless management actions are reviewed and adapted to account for changes and further information they cannot be considered optimal. Adaptive management is essentially an ongoing process of implementing, reviewing what's been done/ achieved and then using what has been learned to refine future management efforts.

A national strategic approach [53, 110] is the best way to tackle the complex issues relating to wild dog management across northern Australia. The movements of wild dogs are not inhibited by paddock, property, regional or State boundaries, and consequently their management requires a broad scale approach to address the oft conflicting requirements of different managers. In other words, wild dog management in one place will eventually affect others some distance away. The cross-tenure strategy enables managers to view the landscape from the wild dog population perspective and plan accordingly. To undertake this change in paradigm, the Invasive Animals Cooperative Research Centre and Australian Wool Innovation have invested in a National Wild Dog Facilitator, who encourages groups of stakeholders at the levels indicated above to work together to reach commonly-agreed management targets. A preliminary economic assessment [53] has shown that the facilitator has yielded an expected return on investment of 5.1:1 when contrasted with a scenario without a facilitator. It is imperative that the good work undertaken since 2006 is supported into the future and that the investment made is not wasted. The National Wild Dog Facilitator has concentrated on areas with immediate sheep predation losses, but the position could well service cattle properties in the peri-urban and extensive environments of northern Australia.

Research, development, and extension projects and knowledge gaps

Review of national research planning undertaken since 2001

Throughout mainland Australia, there are many stakeholders in the diverse wild dog issue. Priorities vary between jurisdictions, reflecting different predation problems, different objectives (conservation and control), different topographies and environments and different legislative structures. Over the past 10 years, there have been six major exercises planning research into dingoes and other wild dogs. A number of consistent and common themes are evident, and work has been undertaken to address some priorities.

The first documentation of research needs, in 2001, listed the relationship between wild dog abundance and predation of cattle as the first of 18 deficiencies in knowledge and practice relating to wild dogs in Australia [14]. These were to assess:

- The relationship between wild dog abundance and predation of cattle
- The relative effectiveness and efficacy of baiting strategies
- The potential effect of reduced rabbit abundance in response to Rabbit Calicivirus Disease on wild dog predation of livestock,
- The feasibility of compensation schemes for wild dog predation
- Improve public awareness of agricultural production, conservation and animal welfare issues for wild dog control
- Develop species-specific and more humane control techniques for wild dogs
- The economic importance of hydatids in wild dogs
- The role of disease-induced mortality in wild dogs
- The role of wild dogs if rabies were introduced and investigate why is there no rabies in Australia
- The risks to non-target species of 1080 poisoning
- The ecological effects of wild dog control on feral cat and fox populations
- The interactions of wild dogs and native carnivore populations
- The economic and social values of dingo conservation
- Develop methods to identify genetically pure dingoes, and improve knowledge of the current taxonomic status of wild dogs
- The ecological role of dingo hybrids.

Progress has been made with some of these topics including genetic analyses, development of standard operating procedures and codes of practice for use of wild dog control methods, Invasive Animals CRC development of new toxins and methods for canid control, and risks to non-target animals of 1080 (see below). The National Wild Dog Management Advisory Group (NWDMAG) was formed in December 2008 and has spent a lot of effort raising public awareness of wild dog issues. Some topics remain controversial, including public awareness of animal welfare issues and ecological roles of wild dogs. Training for vertebrate pest control operators and managers was also seen as a priority and some progress has been made through State agencies and the Invasive Animals CRC.

In May 2004, Australian Wool Innovation conducted a workshop in Sydney to identify research needs with particular emphasis on the wool industry [216]. The workshop raised many of the same topics as the [14](2001) document. The outcome was a call for an integrated research development and capacity-building strategy to address the following themes:

- Social and economic impacts of wild dog predation,
- Control technologies, their best application and non-target responses,
- Biology, behaviour and ecology of wild dogs in relation to improved control,
- The role of wild dogs in their environments around Australia,
- Conservation of dingoes, and
- Education and training for better adoption of a strategic approach to management.

Specifically, a list of research priorities to improve management and incorporate the different objectives of major stakeholders and to ensure reduced impacts of wild dogs on livestock was developed. The most pressing priority at the time related to non-target impacts of current control methods in sheep grazing lands of southern Australia. Adverse publicity about 1080 baiting effects on spotted-tailed quoll [217, 218] was likely to limit the extent of control that livestock producers in south east Queensland, eastern NSW and north eastern Victoria could apply. Subsequent research (e.g. [178, 219]) showed that public concerns for spotted-tail quoll populations in areas baited for wild dogs were unfounded.

In October 2005, two workshops were held to provide direction for future research on dogs, the first planning a national approach to managing wild dogs in the Invasive Animals CRC[110], and the second [220] identifying scientific procedures for investigations into the benefits of dingoes to biodiversity, assuming the mesopredator release hypothesis applied to Australian ecosystems. The former listed 35 research topics from around Australia and identified 8 national priorities for IACRC partners (Table 4). Although many of the projects have or are being brought to fruition (Table 4), there still remain many unanswered questions and few researchers to undertake the work.

The second Adelaide workshop in October 2005 [220] had a different objective, which was to plan experimental investigations of the role that dingoes (the term ‘wild dog’ was not used in the workshop proceedings [163, 220]) play in maintaining ecosystem function through top-down trophic regulation. However, more research into the direct effect of the dingo on cattle and livestock production and the interaction between the dingo, feral pigs, cattle and vegetation in northern ecosystems were also suggested [221]. The upshot of this workshop was a second workshop in Perth in 2007 [139, 175, 176], in which attendees divided the Australian continent into four broad bioclimatic zones to investigate the trophic roles of the dingo. These projects were seen as long-term and the need for experimental manipulation of dingoes and prey were recognised. Agricultural production was very much a secondary consideration in these workshops.

Table 4. Research and management priorities for the Invasive Animals CRC, 2006-2012, decided by a national working group, Adelaide, October 2005.

Priority	Topic	Achieved/ Pending/ Outstanding
1	Nationalise Strategic Approach to Management of wild dogs	A
2	Development of better monitoring methods	P
3	DNA studies (conservation/ mark-recapture estimates)	A/ P
4	Movement studies. Conduct a workshop to benchmark and facilitate collaboration	A/ P
5	Ecological role of Wild dogs.	O
6	Socio-economics of livestock predation	O
7	Models of spotted-tail quoll populations & wild dog management in eastern Australia.	P
8	Central Western Australian dog fence feasibility study	A

The NWDMAG was formed to provide a formal advisory role for the best-practice management of wild dogs across Australia. Representatives from multiple federal and state governments, NRM agencies, industry bodies, and conservation agencies are present on the NWDMAG, which has scope to encompass a wide variety of issues and address the needs of a variety of stakeholders. Led by an independent Chairperson, the NWDMAG aligns with the federal Vertebrate Pest Committee and is formally acknowledged as an advisory group to that Committee. In 2009, the NWDMAG developed a priority list of R, D&E needs to address wild dog management issues across Australia (Table 5).

Table 5 – Priority R, D,& E topics and their status as identified by the National Wild Dog Management Advisory Group in 2009 (*projects ranked equal third; # projects ranked equal fourth).

Priority	Topic	Achieved/ Pending/ Outstanding
1	Investigate the functional role of wild dogs in Australian ecosystems, including interactions with foxes, cats, and threatened species	O
2	Determine effective aerial baiting regimes for southeastern Australia	P
3*	Obtain more detailed information on basic wild dog ecology, such as: dispersal and movements, the demographics of dogs responsible for killing livestock, wild dog impacts in various systems	O
3*	Economic costs of wild dogs	A/P
4#	Relative efficacies of bait types and presentation methods, including the efficacy of livestock guarding dogs	A/P
4#	Social barriers to wild dog management and control	A/P
4#	Animal welfare impacts of control techniques, including the testing of Lethal Trap Devices (LTDs)	A/P
n/a	Determining the level of dingo purity in various regions Developing improved analytical techniques (e.g. more accurate calculation of home ranges) Investigating the impacts and management of peri-urban wild dogs	A P O

Key knowledge gaps in the management of wild dogs in northern Australia

Some of the research issues of interest to northern cattle producers have been listed in the national priorities listed above and some work has been undertaken with limited investment from industry. These prior studies have demonstrated that wild dogs can have significant impacts on calf production in some circumstances, leading to unacceptable economic losses to beef producers.

The most glaring and fundamental knowledge gap is that we really don't know the true extent of wild dog predation on beef cattle anywhere in Australia. We don't know the magnitude or cost of the problem, its frequency, its distribution or what causes it. Calf predation by wild dogs is likely linked most closely with the local unavailability of preferred prey species (i.e. macropods, rabbits, possums, piglets, etc), but we don't confidently understand the environmental triggers that conspire to produce calf predation events, nor are we able to reliably predict calf predation events. Although the sequence of studies on beef reproductive performance have attributed a large proportion of calf losses to 'unknown' causes (e.g. , where the calf remains were never found), we also do not know what proportion of these unknown neo-natal and post-natal losses are attributable to wild dog predation. In some circumstances, predation of calves has also been shown to be higher and occur more frequently in areas where wild dogs are controlled (compared to adjacent areas where they are not controlled), but it is not known if this is a universal phenomenon, a product of inadequate local wild dog population reduction or insufficient scale of the control program, or what the factors are that produce it. We do not know the extent and cost of diseases of cattle and zoonoses where wild canids are the intermediate host

Underlying these knowledge gaps are uncertainties surrounding the ecology and behaviour of wild dogs and the breed and behavioural characteristics of cattle that affect relative susceptibility to predation in different parts of the northern cattle zone. Some questions (in no particular order) are: Is predation of cattle in the northern cattle zone dependent on the density of wild dogs? Are all calves equally susceptible to predation? Are some breeds or mothers better protectors of their calves? Are there particular cow or calf behaviours that predispose them to predation? Do all wild dogs kill calves or only those of a certain age or social status? Are calves only at risk in places where wild dogs have already learned to kill calves? How effective are wild dog control programs at reducing populations? What scale of control is necessary to achieve improved branding percentages and sales returns? Are controlled wild dog populations a greater/lesser predation risk than un-controlled wild dog populations? Are livestock guardian animals a suitable control method for cattle enterprises? While we know that increased predation can be associated with poor seasonal conditions, that baiting can be less successful when prey numbers are good, and that wild dogs can reduce the impacts of cattle competitors (such as kangaroos), we do not know at what point wild dog control is essential, unnecessary or counterproductive. In other words, we don't know when wild dog control indirectly increases competition between cattle and other herbivores, or when the low-risk periods are when baiting need not occur.

From the review and latest input from cattle producers and NWDMAG, below is a list of projects that are of immediate interest to or impact upon northern cattle enterprises (Table 6). A

Table 6. Wild dog research, development and extension projects of immediate interest to or impact upon northern Australian cattle enterprises. Relative priority is for MLA investment. (MLA= Meat & Livestock Australia, AWI= Australian Wool Innovation, ADC= Australian Dairy Corporation, LG= Local Government, SG= State Government, AG= Australian Government, U= Universities.)

Relative Priority	Topic	Recommended Investors
H	Cash Cow Plus: value adding to the northern Australian beef fertility project	MLA, SG, U
H	Yard & abattoir survey of damage	MLA, SG, LG, U
H	Wild canids in agro-ecosystems	MLA, AWI, AG, SG, U
H	Facilitating the strategic management of wild dogs throughout Australia	AWI,MLA, AG, SG, LG
M	Wild dogs presence and beef productivity	MLA, SG, U
M	The role of wild dog control in the management of total grazing pressure	SG, MLA, AG, U
M	Prevalence of Neospora caninum in wild dogs & cattle herds	MLA, ADC, U
L	Limiting the source: peri-urban dog control	LG, SG, AG, MLA, ADC
L	Cost-effective wild dog control by livestock guarding dogs	SG, AWI, MLA, U
L	Wild dog co-management and the triple bottom line: social, economic, and environmental impacts of wild dogs	AWI, MLA, ADC,SG, AG, LG, U

Basic project descriptions of each of the projects listed in table 6 are given below with indicative budgets representing the total investment including in-kind contributions from collaborators. Relative priority ratings are for the northern beef industry.

The list is comprehensive but not complete. Other topics of interest that have not been costed are:

- An evaluation of alternative types of livestock guarding animals for preventing wild dog predation of calves. Donkeys, and llamas have been suggested by stakeholders, but it is unknown whether these animals just add to the prey of wild dogs.
- Economic assessments of upgrading private fencing to exclude wild dogs on a property or small regional basis.
- Evaluation of wild dog impacts and management strategies for mixed wool and meat sheep and beef enterprises in the Mitchell grass belt and southern Queensland,

especially within and adjacent to the dog barrier fence, would best be addressed with co-investment from AWI.

- Modelling of rabies epidemiology and its likely effects on the management of extensive beef herds in northern Australia. Rabies is exotic to Australia but is only 300knm from our poorly patrolled northern coastline. Some measure of likelihood of introduction and progress of the disease front is necessary because, judging from the North American experience, its introduction will severely impact upon cattle producers and their veterinarians

Details of wild dog projects for northern Australian cattle industry

1 Cash Cow Plus: value adding to the northern Australian beef fertility project

Lead organisations: Biosecurity Queensland, University of Queensland, NSW Department of Primary Industries, WA Department of Agriculture

Expected budget and timeframe: $1.1 million over 3 years

Location/s: North Queensland, north of Northern Territory, Kimberleys, northern South Australia

Expected methods:

- Monitor lactation failures from known-pregnant cows
- Wild dog activity/abundance surveys
- Wildlife (wild dog prey) activity/abundance surveys
- Wild dog diet surveys
- Hydatid prevalence surveys (from dog faeces)
- Yard surveys of cattle damage (e.g. bite marks, torn ears etc) surveys

Expected findings:

- A density/ damage function for the costs of wild dog damage to northern cattle producers
- Variable relationships between wild dog abundance and calf losses/damage
- Variable efficacies of wild dog control programs
- Prey availability determines calf predation risk
- Hydatids are more prevalent in areas with higher wild dog and macropod (especially wallaby) densities

Expected outcomes:

- Greater understanding of wild dog impacts on cattle reproductive performance
- Greater understanding of environmental triggers for calf predation events
- Greater understanding of factors contributing to the efficacy of baiting programs
- Improved cost-effective wild dog management strategies

Links with other project(s):

- Yard and abattoir survey
- Wild dogs and beef production systems
- Wild canids in agro-ecosystems

Priority rating: Higher

2 Yard and abattoir survey of dog bites and abattoir surveillance of hydatidosis and other wild dog-related causes of downgrading during processing-

Lead organisations: Biosecurity Queensland, Biosecurity NSW, Meat & Livestock Australia Invasive Animals CRC

Expected budget and timeframe: $1.1 million over 3 years

Location/s: Northern Australian saleyards and abattoirs, including far northern South Australia and northeast New South Wales

Expected methods:

- Use MLA processor lists, and NLIS and PIC databases
- Randomised and targeted surveillance of saleyard lots and $ paid for bitten and bite-free lots.
- Traceback of bitten lots and follow-up surveys to determine
- Animal health reports from abattoirs on disease prevalence and costs
- GIS analysis

Expected findings:

- Distribution, prevalence and cost of dog bites to cattle producers and processors
- Distribution and prevalence of hydatidosis among cattle production regions and processing centres
- Quantification of the extent and costs to producers, exporters and processors of wild dog bites, hydatidosis and other wild dog-related causes of downgrading during processing-

Expected outcomes:

- Better models of economic s of wild dogs for northern cattle production
- Accurate figures of total costs of wild dog presence on cattle sales

Links with project(s):

- Cash Cow Plus: value adding to the northern Australian beef fertility project
- Triple bottom line co-management solutions
- Facilitating the strategic management of wild dogs throughout Australia

Priority rating: High

3 The roles of wild canids in agro-ecosystems

Lead organisations: NSW Department of Primary Industries, Biosecurity Queensland, WA Department of Agriculture, University of Queensland, University of New England, Australian Wildlife Conservancy, Invasive Animals CRC, Australian Wool Innovation

Expected budget and timeframe: $2 million over 3 years

Location/s: Gulf of Carpentaria, central (Tanami) and north of Northern Territory, Kimberleys, far northern South Australia, northeast New South Wales

Expected methods:

- Wild dog activity/abundance surveys
- Wildlife activity/abundance surveys
- Scat collection of wild dogs, foxes, cats, quolls, and raptors (where appropriate)

Expected findings:

- Only wild dog and fox populations are temporarily affected by wild dog control programs, all other wildlife species fluctuate independent of wild dog control
- Threatened species populations are not negatively affected by wild dog control

Expected outcomes:

- The demonstrated ecologically conservative use of wild dog control
- Recommendations for the continued use of wild dog control to protect both livestock and threatened species

Links with project(s):

- Cash Cow Plus: value adding to the northern Australian beef fertility project
- The role of wild dog control in the management of total grazing pressure
- Facilitating the strategic management of wild dogs throughout Australia

Priority rating: Higher

4 Facilitating the strategic management of wild dogs throughout Australia: a national facilitator

Lead organisations: Invasive Animals CRC, NWDMAG, Australian Wool Innovation

Expected budget and timeframe: $820,000 over 5 years

Location/s: Various (as required)

Expected methods:

- Facilitation and coordination of wild dog management planning in livestock production areas (i.e. workshops, field days, planning training, establishing cooperatives etc)

Expected findings:

- Data for social component of triple bottom line assessment.

Expected outcomes:

- Development of cooperative wild dog management plans in beef, sheep, and mixed grazing livestock production areas
- Extension of best practice management to wider community of cattle producers

Links with project(s):

- This project benefits from all other projects and provides a conduit for extension of all the other research to the cattle producers and other endusers
- Most important component of the E part of RD&E

Priority rating: Higher

5 Wild dogs and beef productivity: the effect of wild dog presence on beef cattle weight gain, foraging patterns, and maternal behaviour

Lead organisations: Biosecurity Queensland, Central Queensland University

Expected budget and timeframe: $1.2 million over 3 years

Location/s: North Queensland (Fitzroy and Burdekin NRM regions)

Expected methods:

- Wild dog activity surveys
- GPS collaring and tracking of wild dogs and cows
- In-utero tagging of calves (taggle technology)
- Weighing calves at regular intervals until weaning

Expected findings:

- Spatial separation between wild dogs and calving cows
- Predation of calves by wild dogs
- Reduced weight gain of calves in dog-affected areas
- Increased vigilance of cows in dog-affected areas
- Identification of culprit dogs, including demographic characteristics
- Unique cow behaviours associated with wild dog predation

Expected outcomes:

- Greater understanding of the timing of calf predation events
- Greater understanding of non-lethal effects of wild dogs on cows and calves
- Greater understanding of behavioural factors associated with calving success
- Recommendations for improved co-management of wild dogs and breeding cows

Links with project(s):

- Limiting the source: peri-urban dog control
- Cash Cow Plus: value adding to the northern Australian beef fertility project
- Cost-effective wild dog control by livestock guarding dogs

Priority rating: Higher

6 Wild dog control and total grazing pressure: the role of wild dog control in the management of total grazing pressure and the effects of reduced dog populations on competitors of cattle

Lead organisations: Biosecurity Queensland, NSW Department of Primary Industries, Rangelands NRM Board (Western Australia)

Expected budget and timeframe: $1.2 million over 3 years

Location/s: Gulf of Carpentaria, far northern South Australia, Pilbara

Expected methods:

- Wild dog activity/abundance surveys
- Cattle-competitor (e.g. kangaroos, goats, rabbit, and large feral herbivores) activity/abundance surveys
- Stocking rate surveys/cattle grazing pressure estimates
- Plant biomass and diversity surveys

Expected findings:

- Competition between cattle and other herbivores occurs irregularly
- Populations of some herbivores (e.g. goats and kangaroos) increase faster and are in greater abundance in areas where wild dogs are intensively controlled
- Conservative wild dog management practices can optimise both predation and competition effects
- Stocking maximums can be increased where wild dogs are controlled less-frequently

Expected outcomes:

- Greater understanding of interactions between wild dogs and cattle-competitors
- Greater understanding of the positive effects of wild dogs on cattle production
- Recommendations for optimal timing of wild dog control

Links with project(s):

- Wild canids in agro-ecosystems
- Cash Cow Plus: value adding to the northern Australian beef fertility project

Priority rating: Moderate

7 Prevalence and distribution of *Neospora caninum* infection in cattle herds and wild dog populations.

Lead organisations: North Queensland, north of Northern Territory, Kimberleys, northern South Australia

Expected budget and timeframe: $1.5million over 3 years

Expected methods:

- Correspond sites with Cash Cow project
- Monitor abortion rates from known-pregnant cows and other results
- Wild dog activity/abundance surveys
- Coproantigen and other tests of Neospora prevalence surveys from dog faeces
- GIS

Expected findings:

- A density/ damage function for the prevalence of Neospora for northern cattle producers
- Variable relationships between wild dog abundance and Neospora prevalence
- Neosporosis is a significant cause of reproductive failure in clusters across the northern Australian beef herd

Expected outcomes:

- Greater understanding of wild dog impacts on cattle reproductive performance
- Costing of Neospora to northern beef producers
- Understanding of Neospora epidemiology
- Improved cost-effective wild dog management strategies

Links with other project(s):

- The role of wild dog control in the management of total grazing pressure
- Wild canids in agro-ecosystems

Priority rating: Medium

8 Limiting the source: peri-urban dog control

Lead organisations: Biosecurity Queensland, NSW Department of Primary Industries, QLD and NSW Departments of Health, various local governments, mining companies, and indigenous community organisations, Invasive Animals CRC, Animal Management in Rural and Remote Indigenous Communities (AMRRIC)

Expected budget and timeframe: $1.4 million over 3 years

Location/s: Cities, towns and semi-rural areas of coastal Queensland and New South Wales

Expected methods:

- DNA, blood, scat, and stomach samples from wild dogs
- Document impacts of wild dogs in peri-urban areas
- GPS collaring and tracking of wild dogs
- Test various management alternatives (e.g. PAPP, ejectors etc)
- GIS

Expected findings:

- Peri-urban wild dogs harbour multiple parasites and pathogens important to humans, pets, and livestock
- Wild dogs inhabit urban settlements and move between urban and rural areas
- New control tools can be successfully used in peri-urban areas and around intensive livestock production enterprises (e.g. feedlots, cattle studs etc)

Expected outcomes:

- Greater understanding of wild dog impacts on cattle industries in peri-urban areas
- Greater understanding of disease transmission between wild dogs and cattle and potential disease risk to humans
- Improved ability to minimise wild dog impacts to cattle industries in peri-urban areas
- Greater understanding of human impacts of wild dogs
- Recommendations for improved management of wild dogs in peri-urban areas

Links with project(s):

- Triple bottom line of wild dog co-management
- The effect of wild dog presence on beef cattle weight gain, foraging patterns, and calving success
- Neospora prevalence
- Saleyards and abattoir surveys of wild dog damage
- Facilitating the strategic management of wild dogs throughout Australia

Priority rating: Moderate

9 Cost-effective wild dog control by livestock guarding dogs

Lead organisations: Biosecurity Queensland, NSW Department of Primary Industries, VIC Department of Sustainability and Environment, University of New England, Invasive Animals CRC, Australian Wool Innovation.

Expected budget and timeframe: $2.3 million over 3 years

Location/s: Central Queensland, northeast New South Wales, and Victoria

Expected methods:

- GPS collaring and tracking of wild dogs
- GPS collaring and tracking of guarding dogs
- Assessments of paddock-usage by cattle and sheep

Expected findings:

- Livestock guarding dogs prevent livestock predation and attacks
- Livestock guarding dogs have variable efficacy for cattle and sheep producers
- Livestock guarding dogs have negative impacts on macropod abundance

Expected outcomes:

- Greater understanding of the usefulness of guarding dogs for protecting cattle and sheep
- Recommendations for guard dog use in mixed sheep/cattle areas

Links with project(s):

- Facilitating the strategic management of wild dogs throughout Australia
- The effect of wild dog presence on beef cattle weight gain, foraging patterns, and calving success

Priority rating: Lower

10 Wild dog co-management and the triple bottom line: social, economic, and environmental impacts of wild dogs in northeast NSW and south east Queensland

Lead organisations: NSW Department of Primary Industries**,** Invasive Animals CRC, Australian Wool Innovation

Expected budget and timeframe: $1.1 million over 3 years

Location/s: Mixed locations affected by wild dog predation and environmental issues

Expected methods:

- Quantitative and qualitative social research to determine and measure the attitudes of various communities to dingoes and other wild dogs, their impacts and control.
- Economic assessments of wild dog impacts and co-management projects from previous work in the Invasive Animals CRC wild canid demonstration site and other data sources including AWI, Queensland shires, South Australian cattle stations.
- Use work from environmental experiments to obtain the environmental costs and benefits of wild dogs in ecosystems.
- Drawing on the results of previous and proposed projects, collate knowledge on the social, economic, and environmental costs/benefits of wild dogs

Expected findings:

- A description of attitudes amongst the communities of interest.
- A range of economic assessments of wild dog predation and management programs across industries and regions.
- Better information for planning control and assessing its effectiveness

Expected outcomes:

- A range of strategies to better target wild dog management messages across sectors of the community.
- Development of desktop tools and recommendations to improve the co-management of wild dogs across Australia

Links with project(s):

- This project benefits from all other projects and provides benefit to them.
- Although primarily targeted at sheep production areas, cattle production areas in coastal NSW will provide information useable in the peri-urban dog project.
- Cash cow plus.
- National facilitation of wild dog management

Priority rating: Lower

Conclusions

Many of the national issues about wild dogs also affect cattle production in northern Australia. While much of the biology of wild dogs is known, little is known about the factors that influence the predation of cattle, the cascading ecological and environmental impacts wild dogs might have on biodiversity and how best to manage them. Because of logistical constraints, much of the previous work lacks adequate replication or is correlative or observational in nature. Manipulative experiments are needed to obtain conclusive evidence for many ecological and livestock predation processes. The subtle impacts of wild dogs on the economics of cattle production and native fauna populations, for example through dog-borne disease effects, also require investigation. Understanding of the social impacts of wild dogs, particularly in peri-urban and more intensive cattle production systems, and of societal attitudes to wild dogs and their management strategies and tools is critical for implementing successful management. Research undertaken in the past 15 years and the new research technologies, such as GPS collars, place researchers in a strong position to examine the issues raised in this review and develop and improve management as a result. Investment from RDCs and governments at all levels is warranted.

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A group of dingoes herds cows and calves in arid Northern Australia: are they a net cost or a net benefit? Photo Guy Ballard