


Pets and pests: a review of the contrasting economics and fortunes of dingoes and domestic dogs in Australia, and a proposed new funding scheme for non-lethal dingo management

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Abstract

Carnivore conservation and management is complex and expensive, and significant ongoing management costs may inhibit the development of new tools and any subsequent transition away from lethal control. We review and compare the economic costs and benefits of dingoes and domestic dogs in Australia and suggest that public affinity for domestic dogs may be co-opted into yielding more positive management outcomes for dingoes. Whereas Australians spend over AU\$10 billion annually on purchasing and maintaining 4.2 million domestic dogs, landowners and government spend at least AU\$30 million attempting to limit the density and distribution of dingoes, feral dogs, and their hybrids. These contrasting investments highlight the dual response of society towards domestic and wild members of the *Canis* genus. We suggest that a modest conservation levy on the sale of pet dogs or dog food, or both, could secure long-term funding to support efficacious non-lethal management of dingo impacts. A modest levy could generate AU\$30 million annually, funding the development of non-lethal dingo-management tools without compromising existing management practices while new tools are investigated. Ultimately, a transition away from controlling dingoes through culling or exclusion fencing, to managing the negative impacts of dingoes could result in both more successful and sustainable management outcomes of dingoes and support the ecological, cultural and economic benefits they confer as Australia's apex predator.

Additional keywords: carnivore, conservation, human–wildlife conflict.

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Introduction

Humans have a long history of association with wild and domestic canids, and these relationships can be contradictory, politically complex and emotionally charged (Treves and Bonacic 2016). This is particularly the case in Australia, a country where native dingoes (variously *Canis dingo*, *C. familiaris*, *C. familiaris dingo* or *C. lupus dingo*) are subject to a range of control measures, including large-scale exclusion fencing and lethal control (Fleming *et al.* 2014). This fate contrasts with the lives of the 4.2 million Australian domestic dogs (*Canis lupus familiaris* or *C. familiaris*) that are housed,

provisioned and, in some cases, given the status of honorary family members. Arguably, the emotional, cultural and political backdrop of these relationships often has an impact on wild-canid management decisions (Smith 2015).

Dingoes have been recognised as performing important ecological roles (Purcell 2010) in preying on non-native pest species such as foxes (*Vulpes vulpes*), pigs (*Sus scrofa*) and feral cats (*Felis catus*; Wallach *et al.* 2015; Feit *et al.* 2019) and through top–down regulation of native fauna (e.g. wallabies and kangaroos; Shepherd 1981; Robertshaw and Harden 1986;

Letnic and Crowther 2013; Allen 2015). Although there are suggestions that feral dogs and hybrids (often collectively ‘wild dogs’) do not have the same ecological roles or effect on prey species as do dingoes (Corbett 2001), this assertion is not yet supported by empirical data (Purcell 2008). Certainly, there appear to be measurable trophic cascade effects in tropical-savanna, forest and desert biomes (Leo *et al.* 2019), including both in areas where we could expect ‘pure’ dingoes to occur (e.g. arid zone; Letnic *et al.* 2009) and in areas where we may expect populations to be hybridised (e.g. south-eastern forests; Purcell 2008, 2010; Colman *et al.* 2014). However, current management largely defines all possible dingoes as ‘wild dogs’ rather than distinguishing among individuals by their appearance, genetic status (Allen *et al.* 2011b) or ecological function (Purcell 2010).

As the diversity in common and scientific names suggests, the taxonomic identity and status of the Australian dingo has been unsettled and controversial since its initial description in 1792 (Jackson *et al.* 2017; Smith *et al.* 2019), and the name(s) selected by authors can act as a reliable indicator of the subject matter (e.g. ‘wild dogs’ in reference to livestock management and ‘dingoes’ in reference to ecological roles and conservation) and even the employment and funding sources of authors (Kreplins *et al.* 2018). Although a lack of scientific consensus persists on what makes a dingo a dingo, and, indeed, whether it matters, here, for simplicity, we consider all wild-living dogs as a single group in Australia (including dingoes, feral dogs and their hybrids), and refer to them hereafter as dingoes, unless stated otherwise.

The control and management of dingoes, as well as our understanding of their effects on society and the environment, are further complicated because dingoes are recognised as both a native animal and a pest, with this being largely dependent on their location (e.g. inside or outside National Parks). In turn, this means that some people believe that dingoes should be conserved and protected in parts of their range, whereas others hold the opinion that dingoes should be subjected to various pest-control mandates (Fleming *et al.* 2001; Hytten 2009). The various legislation pertaining to dingo management in the various states and territories has been reviewed elsewhere (e.g. see: Smith and Appleby 2015; Pest Smart 2018), and is summarised in Table 1.

By estimating the cost of controlling dingoes in Australia and comparing this figure with investments made to maintain domestic dogs, we broadly summarise the economic relationships among humans, dingoes and domestic dogs in Australia. Current knowledge is reviewed to highlight important gaps, and the occasionally contradictory relationship that Australians have with domestic dogs and dingoes is exposed. Through this process, we hope to stimulate discussion on the economics, motives and emotions of dingo management, while suggesting some pragmatic solutions. Overall, the purpose of the present review is to quantify the economic costs and benefits of dogs, wild-living and domestic, in Australia, and explore novel methods to manage dingoes as a creature that both provides ecosystem services and, in some cases, disservices to agriculture.

As the duality of humanity’s response to wild and domestic carnivores is widespread, our suggested solutions may be effectively adopted internationally. From wolves (*Canis lupus*) in Europe and North America, to lions (*Panthera leo*) in Africa and India, similar issues arise with (1) how to manage

livestock depredation by wild carnivores, and (2) how to fund carnivore conservation and management. Specifically, we suggest how to harness our affinity for domestic dogs for the benefit of Australia’s dingo; however, although our focus is on dingoes in Australia, the issues addressed are applicable to carnivore management and conservation worldwide.

Defining dogs in Australia

Dingoes

For 200 years, debate has raged over the taxonomic classification of the dingo (Jackson and Groves 2015), with recent studies referring to the dingo as a distinct taxonomic or evolutionary unit (*Canis dingo*; Crowther *et al.* 2014; Smith *et al.* 2019) or, alternatively, as an ancient breed of dog (*Canis familiaris*; Jackson *et al.* 2017), and so the controversy continues (see also Allen *et al.* 2017a and Jackson *et al.* 2019, for further discussion on how dingoes should be classified). In light of this ongoing debate, we have taken the pragmatic approach here of defining all wild-living *Canis* spp. in Australia as one, and referring to them as dingoes, unless otherwise stated.

Although it may be useful in terms of management to treat readily identifiable feral dogs differently from dingoes and their hybrids, in practice differentiation often appears highly challenging if not impossible. This is highlighted by the conflicting legislation presented in Table 1. Some have suggested that the main conservation threat to dingoes is hybridisation with other dogs (Elledge *et al.* 2006; Corbett 2008; Stephens *et al.* 2015; Allen *et al.* 2017a), and ‘pure’ dingo populations are, thus, commonly considered to be of special conservation value and may be viewed as warranting active conservation. However, even on K’gari (Fraser Island), a World Heritage National Park renowned for the ‘pureness’ of its dingo population (but see Woodall *et al.* 1996), lethal control of dingoes remains a component of management as a result of human–dingo conflict (O’Neill *et al.* 2017).

In this context, defining a ‘pure’ dingo has assumed importance, but is particularly challenging because phenotype is not diagnostic (Crowther *et al.* 2014), and such classification may be irrelevant anyway, depending on what the management or conservation objectives are. One suggestion is to use ‘93% purity’ as a minimum standard for categorising an animal as an Australian dingo (Allen *et al.* 2017a); however, this does not necessarily assist managers in making practical decisions in the field, unless ‘purity’ is used at a population level. Thus, the way forward may be to manage the negative impacts of dingoes rather than their numbers (e.g. through lethal control), thereby removing the need to distinguish pure dingoes from hybrids in the field.

Domestic dogs (guardian dogs, working dogs and companion dogs)

Domestic dogs are usually kept and fed by someone and include companion animals (pets), guardian dogs, and other working dogs (such as sheep dogs and police dogs). There is some overlap among these three subcategories. For example, a guardian dog could certainly be argued to be a working dog, and some companion dogs are also trained to perform certain tasks.

Table 1. Summary of legislation pertaining to dingo/wild dog management in Australia

Table has been adapted from National Wild Dog Action Plan – May 2014 (revised June 2018) (see https://www.pestsmart.org.au/wp-content/uploads/2018/10/NWDAP_FINAL_Revision-Aug-2018-1.pdf, accessed 14 November 2018)

State/territory	Legislation protecting dingoes	Legislation <i>not</i> protecting dingoes/wild dogs or legislation relevant to the management of wild dogs
Australian Capital Territory	Protected under the <i>Nature Conservation Act 1980</i> ; however, the dingo can be culled on private land subject to a permit.	Wild dogs (including dingoes) are a declared pest under <i>Pest and Plants Act 2005</i> .
Northern Territory	Protected under the <i>Territory Parks and Wildlife Conservation Act 2000</i> as a native species, making it an offence to possess, interfere with, or kill dingoes unless authorised to do so.	Wild dogs a declared animal under the <i>Territory Parks and Wildlife Conservation Act 2006</i> for feral animal management.
New South Wales	Protected as a native species under the <i>National Parks and Wildlife Act 1974</i> , the <i>Threatened Species Conservation Act 1995</i> , and the <i>Forest Act 2012</i> .	Under the <i>Rural Lands Protection Act 1998</i> and the <i>Wildlife Dog Destruction Act 1921</i> the dingo is classified as a wild dog, a pest, and land owners are required to cull them. Under the <i>Biosecurity Act 2015</i> public and private land owners are required to take all practical measures to minimise the risk of any negative impacts of wild dogs on their land or neighbouring lands.
Queensland	Protected under the <i>Nature Conservation Act 1992</i> in conservation areas such as K'gari (Fraser Island). The dingo is defined as both 'wildlife' and 'native wildlife' under the Act and only protected within defined protected areas.	The dingo is a declared pest under the <i>Rural Lands Protection Act 1985</i> . The <i>Biosecurity Act 2014</i> requires land owners to manage the negative impacts of invasive animals such as dingoes and wild dogs.
South Australia	—	Dingo is a declared pest south of the Dingo Fence under the <i>Natural Resources Management Act 2004</i> . The <i>National Parks and Wildlife Act 1972</i> lists dingoes as unprotected. Although not protected in the 60% of the state north of the Dog Fence, there are restrictions on the amount of baiting to ensure the survival of the dingo as a wildlife species.
Tasmania	—	Dingoes have never colonised Tasmania and importing dingoes is prohibited under the <i>Nature Conservation Act 2002</i> . The <i>Dog Control Act 2000</i> legislates for the control and management of feral dogs.
Victoria	The dingo is listed as a threatened species under the <i>Flora and Fauna Guarantee Act 1988</i> and is protected under the <i>Wildlife Act 1975</i> . However, the dingo is unprotected on all private land and within a 3-km buffer zone on the public land bordering private land in some areas of the state to protect livestock.	Feral or wild dog are a declared pest under <i>Catchment and Land Protection Act 1994</i> . Land owners have a duty to take reasonable steps to prevent the spread or, if possible, eradicate declared pests.
Western Australia	—	Dingoes must be controlled in livestock areas under the <i>Biosecurity and Agriculture Management Act 2007</i> . Under <i>Wildlife Conservation Act 1950</i> dingo listed as 'unprotected fauna'.

However, maintaining the broad distinctions is valuable for quantifying their differing costs.

Companion dogs or pets are, as the name suggests, important for the companionship they provide and not the specific tasks they might perform (Wilson and Turner 1997). Any dog can be a companion dog, and many working-dog breeds are now more important as family pets because of their 'friendly' natures (e.g. Retrievers).

Guardian dogs have been used for centuries to protect livestock from predators and thieves and have been systematically and successfully trialled in Australia (van Bommel and Johnson 2012, 2014; Allen *et al.* 2017b). Livestock-guardian dogs are generally large breeds (e.g. Maremma sheepdogs) that are trained to live with livestock, which they appear to treat as their social companions. Maremma sheepdogs are being tested as guardians of native fauna as well (see Guardian Dogs as Bandicoot Bodyguards; Zoos Victoria

2016). In general, guardian dogs remain with their charges, but are provisioned, and, in sufficient numbers, may be as effective when ranging freely on large properties as they are in small-scale farming systems (van Bommel and Johnson 2012).

Finally, a *working dog* is one that is owned and cared for primarily to perform a specific task other than guarding livestock. Our use of the term working dog here includes herding dogs, service or assistance dogs, rescue dogs, hunting dogs, guard dogs, police and military dogs, and detection dogs used to find an almost unlimited number of substances (e.g. from termites to illegal drugs).

The costs of dogs in Australia

We explore the economic costs and benefits of both dingoes and domestic dogs in Australia. Unsurprisingly, there are various, and sometimes contradictory, estimates, and we provide the range where possible.

Dingoes

Dingoes can have devastating impacts on livestock production (Allen and West 2013; Allen and West 2015), causing significant economic loss and stress for producers (Fleming *et al.* 2001; Ecker *et al.* 2017). Although there are numerous studies on factors and management interventions that may have an impact on livestock reproductive success (see McGowan *et al.* 2014, for a review), ascertaining the success of any given management intervention can be challenging, especially in the context of dingo depredation (Appleby 2015a). Although the financial obligation of dingo management is borne by the state and private landowners, the financial burden of stock losses and damage attributed to dingoes is largely borne by livestock farmers (Allen and Fleming 2004).

To attempt to quantify the economic costs and benefits of canids in Australia, we initially conducted a broad literature search on Web of Science of the terms dog* or dingo* or canid* and Australia. Within these papers, any reviews or studies with relevant costs and benefits were determined, and subsequent reference lists mined for useful sources. Further online searches were conducted of feral-dog and pest management in Australia and a general search of the costs and benefits of dogs was also conducted (e.g. Google Scholar; within specific journals and databases such as CSIRO Publishing). We also contacted dingo-management practitioners at the state level for up-to-date and detailed figures, and asked the following questions:

- (1) how much does the state/territory spend on dingo control/management;
- (2) how much do land owners spend on managing dingoes on their land in your state/territory?

Our results considered only the direct and tangible economic costs and benefits of dingoes and domestic dogs. Management and control of dingoes in Australia is planned and managed at the local, state or territory, and national levels, with each having a unique plan. We quantified the economic costs and benefits at the national, state and individual (or household or business) level, but scale up to the national level wherever possible to provide an overview. Although undoubtedly important, the more variable and less tangible social, cultural and ecological costs and benefits of dogs are only afforded limited discussion here.

The direct economic costs of dingoes in Australia are difficult to quantify precisely, with there being various estimates in circulation. Estimates, including efforts to control dingo impacts, range from AU\$175 million per annum (on the basis of figures in Table 2), to AU\$250 million nationally. This wide range is partly due to the lack of estimates by State Governments concerning the cost of predation by dingoes on livestock in New South Wales, or any figures on what local landowners are spending in New South Wales, Victoria, South Australia and the Northern Territory.

An Invasive Animals Cooperative Research Centre report estimated that dingoes, referred to as 'wild dogs' in the report, cost Australia at least AU\$48.5 million per year in livestock losses, disease spread and control efforts (Gong *et al.* 2009). This estimate differs substantially from that provided by an Agforce report that estimated the cost of dingoes (again 'wild dogs' in the report) on the Queensland grazing industry alone in 2008–09 at AU\$67 016 575 (Hewitt 2009). Because the Agforce study was conducted in 2009, more recent estimates put the annual cost in Queensland alone at no less than AU\$100 million (Locke 2015).

Table 2. Estimated minimum annual costs of dingoes and domestic dogs in Australia

How these values were obtained is often not clear or substantiated in the reports. Dog pet care (AU\$) values are 2007 figures from http://acac.org.au/pdf/PetFactBook_June-6.pdf, accessed 2 February 2016

State	Dog pet care (AU\$)	(%)	Control of dingoes state government (AU\$)	Control of dingoes local owners (AU\$)	Costs of predation/injury to livestock (AU\$)
NSW/ACT	902 000 000	32.8	3 000 000 ^A	??	??
Vic.	676 000 000	24.5	??	??	13 000 000 ^B
Qld	592 000 000	21.5	6 247 859 ^C	13 709 140 ^C	47 059 576 ^C
SA/NT	266 000 000	9.7	475 000 ^D	??	40 000 000 ^E
WA	240 000 000	8.7	3 460 250 ^F	~5 000 000 ^F	45 000 000 ^G
Tas.	78 000 000	2.8	0 ^H	Low	Low
Total	2 754 000 000	100			

^A2015: all pests and weeds in New South Wales (Agricultural White Paper delivers AU\$3 million to combat pest animals and weeds in drought-affected areas of NSW 2016; <http://minister.agriculture.gov.au/joyce/Pages/Media-Releases/agwp-3m-for-pest-animals-weeds-NSW.aspx>, accessed March 2017). Reduced to AU\$1 million for the cost of dingo in the overall analysis.

^BLightfoot (2011).

^CHewitt (2009).

^D2016 – replies from government agencies of Northern Territory and South Australia.

^E2012 – media release by (Northern Territory Cattleman's Association 2012) claim loss of 60 000 cattle from 2011–12, costing AU\$80 million. This does not include any estimate of loss from South Australia.

^F2013–14 investment mapping, Stakeholder Consultative Group, dingoes.

^GGong *et al.* (2009).

^HTasmania has very little dingo activity and, therefore, has very low costs. Most reports of dog impacts seem to stem from wandering (pet) dogs.

Although dated, a 2002 report (Pimentel 2002, p. 36) is useful insofar as it showed the spread of costs of dingoes (again referred to as ‘wild dogs’) in Australia. It stated annual losses:

‘in agricultural production, mainly in the ranching industry, to wild dogs is at least AU\$20 million. The Australian Federal and State/Territory Governments spend an estimated AU\$4 million or more annually on wild dog control, and land-owners are thought to spend about AU\$2.5 million in direct control. Wild dog control research costs AU\$1.5 million.’

The cost of the national dingo-barrier fence currently approaches at least AU\$10 million annually to maintain (Bradshaw and Ritchie 2012), but protects a sheep-farming industry on the other side that was reported to be worth AU \$4.66 billion annually in 2008–09 (East and Foreman 2011). This industry has been in decline over the past 20 years because of world economic factors (Forsyth *et al.* 2014; van Eeden *et al.* 2018), but some authors argue that dingoes have played an important role in this decline in the Australian context (Allen and West 2013, 2015). More recently, the 2014 National Wild Dog Action Plan stated that ‘estimates of the impacts on the Australian economy from production losses due to predation on livestock, disease transmission in livestock, and the costs associated with control conservatively range from AU\$48 million to AU\$60 million annually’ (Pest Smart 2016, p. 5).

Pest Smart (2016) reported on the results of a national survey in 2014–15 on the cost of dingoes at the farm level, detailing that average stock losses and control costs for a small property were claimed at AU\$22 900 per annum, midrange properties AU \$166 000 per annum, and large (pastoral) properties AU \$1 940 000 per annum. Such figures provide a range of costs but would be more useful if given as an AU\$ value per unit area (e.g. per km²). The same report, additionally, estimated the combined State agency annual expenditure on dingo-management (control) activities at more than AU\$27 million per annum.

Dingoes are also known to attack people, albeit very rarely. For example, on K’gari, an average of 10.7 (range: 3–22) serious (highest management category, E) incidents are reported annually (Appleby *et al.* 2018), some of which require medical treatment for the people involved (Allen *et al.* 2012). Male dingoes, particularly subadults, feature heavily in these incidents, with unsupervised children being most at risk (Appleby *et al.* 2017, 2018); however, detailed costs of these attacks are highly variable and not readily estimable. Incidents involving dingoes may also occur elsewhere but attempts to estimate frequency and associated costs were not attempted here.

Clearly, there is great variation in the estimated costs associated with dingoes and their management in Australia, and great variability in the methods used to quantify costs, including here, with little certain, except that dingoes and dingo management have significant costs (see Table 2).

Domestic dogs

In contrast to dingoes, the economic costs of domestic dogs are more easily estimated (see Table 3), although some uncertainty remains regarding the total costs because not all dog owners

Table 3. Breakdown of companion dog costs

Source: Love That PetTM (2016)

Item per dog	Cost per year
Dog purchase	AU\$200–1500 (average AU\$592.70)
Preventative health care	AU\$70–105
Equipment (bed, brush, bowls, collars)	AU\$20–300
Grooming	AU\$30–600
Basic food	AU\$1213
Treats, bones, dental chews	AU\$200
Toys	AU\$10–50
Training, boarding, day care	AU\$10–500
Veterinary	Average AU\$450

register their pets, and so reported costs are likely to represent a minimum estimate.

The average annual cost to owners per companion dog has been estimated at approximately AU\$2452 (Love That PetTM 2016). Extrapolating these values to the ± 4.2 million domestic dogs registered nationally (RSPCA 2016) indicates that Australians spend approximately A\$10.3 billion on pet dogs annually.

There are also costs associated with attacks on people by domestic dogs. In the most recent council report of dog attacks in New South Wales (NSW Government 2013), there were 3329 attacks in this state alone in 2011–12, 28% of which resulted in some degree of injury, including 146 people that were hospitalised. Treatments were not specified, nor whether private or state health funds were used, and, therefore, the costs of these attacks are not readily estimable here. In addition, between 2000 and 2010, domestic dogs were directly linked to the deaths of 27 people in Australia (<https://www.ncis.org.au/wp-content/uploads/2017/11/Animal-Related-Deaths.pdf>, accessed 29 May 2019).

For livestock-guardian dogs, the average purchase cost is AU\$600 (van Bommel and Johnson 2012). Initial additional costs for neutering and vet checks and vaccinations of approximately AU\$340, and yearly running costs added up to AU\$467 for dog food and health care (van Bommel and Johnson 2012). Emergency veterinary treatment, as with all domestic dogs, may also be necessary, the cost of which would be variable but may be high.

The median cost involved in owning a herding dog was estimated to be a total of AU\$7763 over the period of its working life (Arnott *et al.* 2014). For police dogs, net costs depend on the level of training it (and its handler) has received, and a well-trained dog can cost AU\$15 000 or more. Untrained dogs are similarly priced to companion dogs and require intensive training for up to 6 months, thereby increasing their value. In 2016, the New South Wales detection dog unit, the largest in the country, cost more than AU\$9 million a year, not including staff salaries (Triple J 2016). Guide dogs to help partially sighted or blind people are estimated to cost AU\$30 000 to train (see <https://www.givenow.com.au/guidedogswa>, accessed 29 May 2019), and then have upkeep costs similar to those of other domestic dogs (see Table 2).

Domestic dogs may have significant effects on the ecosystems they either inhabit or visit repeatedly. For example, domestic

dogs can harass or kill native wildlife (Young *et al.* 2011; Doherty *et al.* 2017), and dog walking can displace native birds from areas (Banks and Bryant 2007). Domestic dogs can also have an impact on native carnivores through disease transmission (e.g. African wild dogs (*Lycaon pictus*) Woodroffe *et al.* 2012; Ethiopian wolves (*Canis simensis*) Laurenson *et al.* 1998). Although their ecological effects are not easily quantifiable, given that dogs may be the most abundant carnivore in some areas (Feldmann 1974; WHO-WSPA 1990; Gompfer 2014), the ecological impacts of their presence may be profound.

Further important ecological costs to dog ownership include the 'carbon pawprint' of pet-food production (see Rushforth and Moreau 2013), and the impacts of using agricultural land to generate dog food rather than to produce human food or support natural ecosystems.

The benefits of dingoes and dogs in Australia

Dingoes

Economically, the benefit of the dingo to biodiversity conservation centres on its role in ecosystems as an apex predator (Ritchie *et al.* 2012) and, in some areas, its contribution to eco-tourism. As such, dingoes are recognised as the iconic top-predator in most terrestrial Australian ecosystems.

Focusing on economics, K'gari dingoes are an important attraction for international tourists and locals alike. K'gari tourism was worth an estimated AU\$277 million in 2002 (Kleinhart-FGI 2002); however, it is difficult to quantify the value of the contribution that dingoes make to this figure, considering K'gari is itself an attraction. Indeed, whereas some people may be motivated to visit the island and other locations where dingoes are present to see them, others may be deterred because of safety concerns.

More recently, attempts have been made to quantify the dingo's potential benefits to the cattle industry by modelling the apex-predator role that dingoes perform in controlling kangaroo populations and, therefore, improving the grazing rangelands for cattle (Fleming *et al.* 2012; Prowse *et al.* 2015). Without top-down predator regulation, populations of herbivorous native wildlife, such as kangaroos in Australia, can increase to very high densities (Letnic and Crowther 2013), and these may then compete with livestock through foraging and water competition, especially in periods of drought (Grigg and Pople 2001). Predation of potential competitors for pasture, such as kangaroos, has, therefore, been recognised as a potential economic benefit of dingoes to livestock producers (Allen 2015, 2017).

Indeed, in typical stocking densities for semiarid rangelands, it was estimated 'that kangaroo control by an unbaited dingo population would increase pasture biomass by 53 kg ha⁻¹, improve gross margins by AU\$0.83 ha⁻¹ and reduce inter-annual variability' (Prowse *et al.* 2015, p. 455). This improvement was even more marked at low stocking densities, where high kangaroo abundance had previously been permitted in the absence of predation.

Another study used 40 years of data covering 250 000 km² of arid South Australia, so as to highlight the benefit of dingoes

controlling kangaroo numbers and, subsequently, reducing the kangaroos' competition with cattle (Allen 2015), with cost-savings for cattle producers ranging from AU\$60 000 to AU\$5.65 million annually, depending on the level of kangaroo competition and the net value of their cattle.

Domestic dogs

The idea that pets are 'good for us' is not a new one, but it is only in the past few decades that it has been subject to formal scientific scrutiny (Wells 2009). A 1999 study based on a survey of 1011 people in America, Australia and Britain showed that pet dogs and cats confer quantifiable health benefits to their owners (Headey 1999). The survey showed that dog and cat owners make fewer annual visits to medical doctors and are less likely to be on medication for heart problems and sleeping difficulties than are non-owners. By linking these sample survey results to data on health expenditure, the paper proposed a preliminary savings estimate of AU\$988 million for Australia for the financial year 1994–95 (Headey 1999).

On the basis of the assumption that pets (dogs and cats) confer a 2.7% saving to overall health expenditure (Headey 1999), this would equal AU\$4.2 billion in health savings for the financial year 2013–14 alone (total expenditure on health in 2013–14 in Australia was AU\$154.6 billion; Australian Institute of Health and Welfare 2015). Given our previously estimated costs of acquiring and caring for a domestic dog (AU\$10.3 billion), this reduces the net financial cost of companion-dog ownership to approximately AU\$6.1 billion. And it is, of course, impossible to estimate the non-economic benefits of the companionship provided by dogs.

We can generate more easily quantifiable economic benefits when we consider livestock-guarding dogs. In a recent survey, 66% of 150 participants indicated that predation on their livestock ceased completely after obtaining guardian dogs, and a further 30% indicated that predation decreased (van Bommel and Johnson 2012). Furthermore, the same study stated that 95% of respondents thought that their dogs were a cost-effective way of protecting their livestock and that costs of purchasing and maintaining the guardian dogs was fully off-set by the value of stock saved within 1–3 years. Guardian dogs were especially effective for lamb and sheep protection (dog's value returned in 1 year), but less so for cattle, poultry and goats, where it took up to 3 years for the cost of the dog to be recouped (van Bommel and Johnson 2012). The benefits of these dogs are highly context-specific, relating to local risk level, herd size and the efficacy of the protection they provide. However, on one 47 000-ha sheep farm near Hughenden in Queensland, guardian dogs were estimated to be worth AU\$14 000 per annum in terms of sheep saved from predation by dingoes and other predators after the initial year (van Bommel 2010; van Bommel and Johnson 2012).

A separate study aimed to estimate the value of the typical Australian herding dog in terms of predicted return on investment (Arnott *et al.* 2014). This required an assessment of the costs associated with owning herding dogs and a valuation of the work they typically perform. Data on a total of 4027 dogs were acquired through The Farm Dog Survey, which gathered information from 812 herding-dog owners around Australia.

The median cost involved in owning a herding dog was estimated to be AU\$7763 over the period of its working life, whereas the work performed by the dog throughout this time was estimated to have a median value of AU\$40 000 (on the basis of the number of hours worked herding stock at the rate of AU\$20 per hour), such that herding dogs typically provided their owners with a 5.2-fold return on their investment.

The benefits of other working dogs are much less clear cut. Dunn and Degenhardt (2009) studied the efficacy of drug-detection dogs in Sydney and suggested that dogs did not make a significant impact in deterring drug-taking behaviour, and a recent press report suggested that drug-detection dogs cost AU\$9 million annually in New South Wales in 2016 (Triple J 2016). Other examples of detection dogs, for example, assisting in the detection of rare native fauna such as the spotted-tailed quoll (*Dasyurus maculatus*; Leigh and Dominick 2015) and the koala (*Phascolarctos cinereus*; Cristescu *et al.* 2015) represent innovative solutions to conservation problems; however, it is difficult to quantify the cost-effectiveness of such approaches or stipulate exactly what is achieved (in purely economic terms) by detecting those fauna.

Similarly, the use of dogs has been shown to have some positive impacts on treating children with autism spectrum disorder (O'Haire *et al.* 2014; Hall *et al.* 2016); however, it is still at an early stage of study. In contrast, the use of guide dogs to help vision-impaired people has been in use since at least the 1930s, and may be of benefit to some 1.4% of the Australian population (or some 357 000 people) that are partially sighted or blind (Australian Network on Disability 2018).

The contrasting economics of dingoes and domestic dogs

Although some of the costs of both domestic dogs and dingoes are difficult to establish definitively, it is clear that the amount Australians spend on domestic dogs dwarfs the amount spent to manage the negative impacts of their wild counterparts. Annually, Australia may spend over AU\$10 billion on its domestic dogs, and these dogs are thought to confer health benefits on their owners that equal at least AU\$4 billion. In contrast, dingoes cost the livestock industry at least AU\$145 million, and land owners and the government collectively spend more than AU\$30 million to manage and control dingoes across Australia.

The benefits of dingoes are harder to quantify; nevertheless available figures highlight humanity's dichotomous response to these closely related canids, lavishing affection on domestic dogs, while demonising and persecuting their wild relatives; a duality that has previously been remarked on with respect to wolves and domestic dogs (Treves and Bonacic 2016). Beside any intrinsic value, the economic benefits of dingoes in Australia derive largely from their ecological function as apex predators and the attraction of dingoes for ecotourism. Although benefits derived from dingo-driven ecotourism are hard to separate from overall touristic appeal, the value demonstrated by reintroducing apex predators elsewhere suggests that it may be significant (Molloy 2011). Meanwhile, the economic benefits that dingoes provide for cattle producers by controlling numbers of wild herbivores that compete with livestock for food appear to be

considerable (Wicks and Allen 2012; Allen 2015; Prowse *et al.* 2015).

Current dingo-management practices in Australia

Australia's approach to dingo management highlights the paradox posed by an animal viewed both as a valuable native predator that should be conserved, and as a pest to be destroyed. 'Pure' dingoes are sometimes advanced as being the worthiest of conservation from an ecological perspective; however, there is continued debate on whether dingoes do indeed perform an important ecological role benefiting Australia's native biodiversity (Allen *et al.* 2011a, 2013, 2017c; Letnic *et al.* 2011; Hayward *et al.* 2015; Nimmo *et al.* 2015), and importantly a lack of robust empirical evidence that dingo purity has an influence in terms of impacts on ecosystems.

The lack of scientific consensus on how to classify the dingo or identify dingoes in the field, and whether it matters, has implications for dingo-management plans and strategies. Despite their probable beneficial role in top-down regulation of ecosystems, free-ranging wild-living *Canis* spp. (including feral domestic dogs and hybrids) are subject to lethal and non-lethal control measures, including exclusion fencing, whereas potentially phenotypically indistinguishable, but assumed 'pure', dingoes are viewed as native fauna to be conserved. For example, Queensland's Wild Dog Management Strategy 2011–16 (Queensland Government 2011) seeks to show zero tolerance for 'wild dogs' within the barrier fence, control numbers elsewhere and, yet, simultaneously conserve dingoes within the state, without a clear plan of how to achieve these seemingly contradictory aims. In contrast, New South Wales Wild Dog Management Plan 2012–15 (NSW DPI 2012) addresses the issue by focusing on managing the negative impacts of wild dogs regardless of the genetic make-up of the dogs in question. Importantly, much of this plan looks at ways to resource and audit the effectiveness of the plan and recognises that innovative solutions to funding management are needed.

Harnessing humanity's affinity for domestic dogs to conserve their wild counterparts

If large carnivores are to be effectively conserved outside of isolated fortress-style reserves, their negative impacts must be effectively mitigated. It has been suggested that 'management' is sometimes a 'euphemism' for killing carnivores (e.g. Thirgood *et al.* 2000), and whether a predator is conserved or killed often depends on where that predator is encountered. Essentially, this sets up the equivalent of a predator 'postcode lottery', with the treatment of dingoes being heavily reliant on their location rather than their behaviour or the specific threat they pose. This is likely true for other species and, from a wider conservation perspective, such intolerance is increasingly problematic because few countries contain sufficiently large reserves to sustain large carnivore populations in the medium to long term. If we are to avoid the extirpation of large carnivores, effective means for coexistence on land shared with livestock must, therefore, be found.

Whether inside costly-to-run reserves or across the broader landscape where expensive mitigation measures may be needed, large carnivore conservation is expensive (Packer *et al.* 2013),

which has often resulted in a disjointed approach to carnivore management because of a lack of secure long-term funds. Effective control of the impact of dingoes in Australia has long suffered from being fragmented, uncoordinated and non-strategic, although some of these problems are now being addressed in some states by adopting a coordinated approach across all land tenures (e.g. NSW Wild Dog Management Plan 2012–2015, NSW Department of Primary Industries 2012). However, even these coordinated approaches generally focus on lethal control and, where possible, exclusion fencing, including in and around national parks and reserves, where dingoes are notionally protected. How might innovative, non-lethal approaches that might be better-suited to striking a balance between dingo conservation and management be explored and, importantly, paid for?

We suggest that one possible funding stream would be to apply a dingo-conservation levy on domestic dog owners, either through a one-off animal-sales levy ($\leq 1.2\%$ of the dog cost) or through a levy on domestic dog food ($\leq 0.6\%$). Either levy could raise AU\$30 million or more annually, at least matching the estimated AU\$27 million currently spent on dingo management by state agencies (see Pest Smart 2016). Such a levy would harness humanity's affinity for dogs to fund both management of the negative impacts of dingoes and their conservation, allowing wider enjoyment of the positive impacts that dingoes appear to be able to bestow (e.g. suppressing invasive species, Letnic *et al.* 2009; Newsome *et al.* 2015; controlling native prey numbers and promoting biodiversity, Ritchie *et al.* 2012).

In the same way that third-party insurance is mandatory even for careful drivers, applying a levy to all dog owners may also be justified on the basis that at least some 'wild dogs' are, to some extent, domestic dogs gone wild (Stephens *et al.* 2015). Perhaps more importantly, dog owners may already be inclined to support such a scheme. Research has shown that pet owners tend to view wild animals (including wild canids) more positively (e.g. Prokop and Tunncliffe 2010), with pet ownership apparently correlated with subsequent concern about the welfare of wild animals (Paul and Serpell 1993). Norwegian farmers with household pets also expressed fewer negative attitudes towards large carnivores, than did their non-pet-owning counterparts (Vittersø *et al.* 1998).

As we have shown, managing *Canis* spp. is expensive in all contexts, regardless of whether they are domestic or wild-living. Currently, our proposed levy represents only $\sim 0.3\%$ of the amount that pet owners spend on obtaining and maintaining their dogs in Australia, or AU\$7.36 per domestic dog annually. Although this value seems modest, especially given the potentially considerable conservation-management benefits it could provide, the results of a recent Choice-modelling survey suggested that our proposed levy is higher than households might be happy to contribute, if it were optional. The survey looked at how much respondents (randomly selected residents of Victoria, Queensland and South Australia) were willing to pay individually for the management of 'wild dogs' to reduce their social and environmental impact (Wicks *et al.* 2014). Respondents reported being willing to pay between AU\$0 and AU\$5.67 annually to reduce the adverse impacts of 'wild dogs' in various contexts. This value of AU\$5.67 would equate to $<1\%$ of the average cost of buying a dog or $\leq 0.5\%$ of the dog owners'

average annual spend on dog food, but would generate just under AU\$24 million annually.

Furthermore, a dingo conservation levy may be more acceptable if it were clear that the funds would be channelled towards research into the application of *non-lethal* management techniques in particular. In a community in the United States, objections were raised when taxes were used to remove wildlife; however, it was suggested that this was because lethal control was perceived as a political response to industrial interests (Fox 2001). Although lethal control is likely to be retained as a dingo-management tool, such a levy (even at more modest levels) could contribute significantly to the development and integration of non-lethal techniques into dingo-management strategies.

Currently, dingo-management budgets are allocated almost entirely to exclusion or removal techniques, principally through large (landscape)-scale fencing, and lethal-control programs (e.g. see South Australian Wild Dog Strategic Plan 2016–2020, SAWDAG 2016). Yet, lethal control appears to be largely ineffective at resolving conflict over long periods, because management interventions are often cyclical and reactive (Appleby 2015b; Smith and Appleby 2018). Fencing, which can be very effective at excluding dingoes from conflict areas (Allen and West 2013, 2015), can also be expensive to erect and maintain. It may also form a barrier to other species. Fencing is likely to always play an important role in alleviating conflict, but where it cannot be cost-effectively applied, non-lethal alternatives are required.

Any re-focus of efforts from controlling dingoes to controlling dingo impacts will not occur overnight, so additional revenues above the existing management budgets will be required to develop and test alternative or supplementary non-lethal management tools. Our suggested levy could fill that void.

Clearly, the future uptake of alternative management tools will require evidence that these approaches are effective across a range of relevant circumstances, and this evidence can be provided only through a process of focussed, independent, experimental research. Therefore, we advocate that such a shift requires an initial phase of parallel investment in evaluating potential non-lethal alternatives, before promoting techniques of proven efficacy. A modest dingo-conservation levy could facilitate this transition, which would result both in more publicly acceptable and sustainable management of dingoes and the retention or even expansion of the conservation benefits they appear to confer on ecosystems. During this transition phase, it may also be appropriate and beneficial to seek research and development funding from the eventual financial beneficiaries of increased non-lethal management. Although these ultimate beneficiaries (e.g. guardian-dog breeders and manufacturers of aversive equipment) may fund small-scale trials, we suggest, however, that a domestic dog levy would be better placed to produce the level of funding required to catalyse a widespread transition away from current practices.

Spending the levy

Potential alternative or supplementary tools that could be evaluated using these levy funds would almost certainly include those already shown to work in some contexts, but

which may require more broad-scale testing across a wider range of situations to convince end-users of their potential benefits. Guardian animals are a good example here, with some research showing that they are effective across a range of farm and flock sizes (van Bommel and Johnson 2012, 2014). However, although evidence that they work effectively on small-scale holdings is generally accepted, there remains some scepticism from end-users regarding the utility of guardian animals on large (>4000 km²) pastoral properties in the Australian rangelands. Should their efficacy prove limited, help in determining these limitations and the need for supplementary or complementary approaches could then be usefully determined.

Additional techniques that could be tested with funds from a dingo-conservation levy include the use of localised deterrents that utilise the dingo's natural territorial signals and responses to them (i.e. biofences, see Robley *et al.* 2015). Such biologically relevant deterrents have shown promise in managing other canids internationally (e.g. grey wolf, Ausband *et al.* 2013; African wild dog, Jackson *et al.* 2012) and we believe they deserve wider empirical investigation in Australia.

Preliminary results from shock collars also suggest that they could modify dingo behaviour appropriately (see Appleby 2015b; Appleby *et al.* 2017), justifying further investigation, and smaller-scale and even temporary fencing, including electric fencing, specifically aimed at alleviating acute or seasonal conflict (e.g. attacks during lambing) also warrants additional investigation.

In comparison to large-scale exclusion, more localised repulsion has the benefit of retaining the ecological, cultural and economic benefits of dingoes over larger areas. Although it is beyond the scope of this paper to prescribe specific non-lethal solutions, we are broadly in favour of any techniques designed to reduce the negative impacts of dingoes on livestock, while retaining and enabling the positive effects that dingoes have on ecosystems. This is most likely to be achieved through the strategic use of a mix of techniques.

The case for considering novel funding routes is clear, because raising sufficient funds to expand the dingo-management tool kit beyond exclusion fencing and lethal control is a challenge under existing funding structures, where the lion's share of budgets is allocated to just these approaches. If domestic-dog ownership alone were used to compensate farmers for their losses, while also paying for current dingo management (the latter alone costing AU\$7.36 per domestic dog per annum), the levy would need to be raised to at least AU\$42 per domestic dog, or $\leq 7\%$ of the dog sale value, or $\leq 3.5\%$ of the dog food cost. This is clearly a great deal larger than the AU\$5.67 that the respondents stated that they were willing to pay and would not even provide for increased investments in developing and testing new and alternative techniques.

With the efficacy of compensation payments increasingly being questioned (Bulte and Rondeau 2005), long-term funding of compensation schemes would likely be a poor use of any conservation levy. However, short-term compensation schemes may relieve some farmers during the transition to non-lethal approaches, or help cover losses from the use of experimental controls, which might otherwise be difficult to justify to participating producers.

Our proposed dingo-conservation levy could be administered through veterinary clinics and pet stores (Twardek *et al.* 2017) or through a tax to pet-food manufacturers, but would benefit from overall government oversight and coordination. Pet-food manufacturers could also be approached to discuss their voluntary involvement in such a scheme, perhaps as part of a trial. Livestock producers should also be an integral part of decisions regarding which non-lethal methods to explore and how their interests may be properly acknowledged and protected. We believe that if producers felt that conservationists were willing to listen to and work with them more, and that conservationists were actively looking at solutions to help producers, this would foster a great deal more collaboration and mutual understanding.

Conclusions

We highlight the two-sided nature of Australia's relationship to dogs, which can very generally be summarised as an affinity for domestic dogs alongside an aversion to wild-living counterparts (see Fitzgerald 2009). The dingo is a wild canid that provokes especially mixed sentiments. As Australia's terrestrial apex predator, the dingo performs an important ecological role and probably contributes to ecotourism revenue in some national parks and reserves. Dingoes also exert top-down regulation of wild competitors of livestock and other agricultural pests, thus increasing available forage and water and reducing livestock management costs.

At the same time, dingoes cause considerable economic losses and even psychological harm to farmers and their families through livestock depredation. Precise figures on the overall costs and benefits of all these canids are lacking and estimates vary wildly, prohibiting objective assessments of management interventions and their outcomes. We suggest that the ecological and other benefits of dingoes may be best conserved through a holistic approach to management, including increased investment in innovative combinations of non-lethal conflict-management tools and strategies. To fund such work, we propose a modest dingo-conservation levy on the sale of domestic dogs or their food as a way to harness humanity's affinity for domestic dogs for the benefit of their wild cousins, with concomitant benefits for ecosystem conservation and livestock management in general.

Conflicts of interest

This paper suggests a hypothetical levy that we argue could be used to fund research and development of non-lethal management tools. Some authors may stand to benefit from such a levy in the event that it or similar was introduced. The authors declare no further conflicts of interest.

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