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Animal welfare considerations for using large carnivores and guardian dogs as vertebrate biocontrol tools against other animals

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ABSTRACT

Introducing consumptive and non-consumptive effects into food webs can have profound effects on individuals, populations and communities. This knowledge has led to the deliberate use of predation and/or fear of predation as an emerging technique for controlling wildlife. Many now advocate for the intentional use of large carnivores and livestock guardian dogs as more desirable alternatives to traditional wildlife control approaches like fencing, shooting, trapping, or poisoning. However, there has been very little consideration of the animal welfare implications of deliberately using predation as a wildlife management tool. We assess the animal welfare impacts of using dingoes, leopards and guardian dogs as biocontrol tools against wildlife in Australia and South Africa following the 'Five Domains' model commonly used to assess other wildlife management tools. Application of this model indicates that large carnivores and guardian dogs cause considerable lethal and non-lethal animal welfare impacts to the individual animals they are intended to control. These impacts are likely similar across different predator-prey systems, but are dependent on specific predator-prey combinations; combinations that result in short chases and quick kills will be rated as less harmful than those that result in long chases and protracted kills. Moreover, these impacts are typically rated greater than those caused by traditional wildlife control techniques. The intentional lethal and non-lethal harms caused by large carnivores and guardian dogs should not be ignored or dismissively assumed to be negligible. A greater understanding of the impacts they impose would benefit from empirical studies of the animal welfare outcomes arising from their use in different contexts.

1. Introduction

Large carnivores influence ecosystems through consumptive and non-consumptive effects. They frighten, displace, harass, chase, attack and kill other animals (e.g. van Bommel, 2010; Thorn et al., 2012; Potgieter et al., 2013; Fleming et al., 2014). Adding predators to multi-predator multi-prey systems can produce a variety of outcomes (Hairston et al., 1960; Holt and Lawton, 1994), including profound welfare effects on other species (Fleming et al., 2012). Both the non-lethal and lethal impacts of predators cause distress and/or death to

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individual prey (Fox, 1969; Power and Compion, 2009; Behrendorff et al., 2018), which can lead to population declines and local extinction of some species (Kruuk, 1971; Sinclair et al., 1998; Woinarski et al., 2015) and population increases and recoveries of others (Terborgh and Estes, 2010; Estes et al., 2013; Ripple et al., 2014). Besides killing prey, predators also wound prey and act as vectors for pathogens debilitating to prey, such as *Echinococcus granulosus* or *Neospora caninum* (e.g. Barnes et al., 2008; King et al., 2011). Predators can also alter space use and foraging patterns of individual prey and prey populations (Ripple and Beschta, 2004; Atwood et al., 2009; Moll et al., 2017; Palmer et al., 2017), causing local extinctions in places where these effects are strong. The direct effects of predation can be a driver of ecosystem structure (Hairston et al., 1960; Mech, 1966; Barbosa and Castellanos, 2005; Eisenberg, 2011; Linnell, 2011; Peterson et al., 2014), as can indirect effects (Brown et al., 1999; Creel and Christianson, 2008; Clinchy et al., 2013; Bleicher, 2017). Thus, consumptive and non-consumptive mechanisms are expected to be present and strongly influence species abundance, distribution and behaviour in multi-predator multi-prey systems. These direct and indirect effects make predators attractive as potential biocontrol tools for use against susceptible wildlife species that humans wish to control.

Human conflict with wildlife is a global issue, and a wide variety of wildlife control tools and techniques are used to reduce the distribution, abundance and impacts of the animals involved (e.g. Fleming et al., 2014; du Plessis et al., 2018). Lethal techniques include shooting, trapping and poisoning (e.g. Bothma, 1971; Saunders and McLeod, 2007), and aim to maximise mortality. Non-lethal techniques include aversive conditioning or deterrents (e.g. Breck et al., 2017; Smith and Appleby, 2018), and aim to scare or displace animals. Other techniques, such as exclusion fencing (de Tores and Marlow, 2011; Allen and West, 2013) and guardian animals (Potgieter et al., 2013; Linnell and Lescureux, 2015; Allen et al., 2016), operate in both lethal and non-lethal ways. All wildlife control tools are typically applied against a select number of target species within multi-predator multi-prey systems, sometimes producing variable and uncertain outcomes (Treves et al., 2016; Lennox et al., 2018; van Eeden et al., 2018; Campbell et al., 2019).

Encouraged by the positive ecological changes reported following the reintroduction of grey wolves (*Canis lupus*) to Yellowstone National Park in North America (e.g. Ripple and Beschta, 2012) and many success stories of using livestock guardian dogs (*Canis familiaris*, such as Maremmas) to protect livestock (e.g. van Bommel, 2010; Potgieter et al., 2013; Linnell and Lescureux, 2015), many now advocate for the intentional use of large carnivores and/or guardian dogs as more desirable 'natural' alternatives to traditional approaches to wildlife control like fencing, shooting, trapping, or poisoning (e.g. Ritchie et al., 2012; van Bommel and Johnson, 2012; Letnic, 2014; Wallach, 2014; Minnie et al., 2015; Newsome et al., 2015; Atkins et al., 2017). But while such traditional tools have often been subject to intense and repeated formal assessment of their efficacy (e.g. Eldridge et al., 2002; Allen et al., 2014; Campbell et al., 2019) and welfare impacts (e.g. Fleming et al., 1998; Marks et al., 2004; Meek et al., 2019; Allen et al., In press), to date there has been very little consideration of the animal welfare implications of deliberately using predation and/or fear of predation as a wildlife management tool (Allen et al., 2017). This is symptomatic of the disproportionate animal welfare scrutiny that is applied to different conservation practices, with human-caused predation representing an under-addressed issue (Hampton and Hyndman, In press).

Predation is not usually considered an animal welfare issue given that the behaviour is not usually considered to be anthropogenic, but rather natural. Nearly all ethical viewpoints applied to animal welfare require consideration of only those processes that humans impose on animals (Palmer, 2010; Fraser and MacRae, 2011), though this rule is complicated and is not universal (Torres, 2015; Horta, 2017). When predation occurs between wild animals living independent of humans, few (if any) ethicists would consider humans to have a moral responsibility to consider the welfare of prey (Palmer, 2010). However, when predators are deliberately introduced (or reintroduced) into an ecosystem by humans, a process sometimes referred to as rewilding (Soulé and Noss, 1998), predator effects on prey could be considered to be anthropogenic and therefore warrant ethical scrutiny. Some authors have considered the implications of knowingly exposing prey to predation when prey are introduced or reintroduced (e.g. Swaisgood, 2010; Harrington et al., 2013), but few authors have considered the implications of intentionally causing predation when predators are introduced or reintroduced (Allen et al., 2017). Here we refer to the deliberate release, reintroduction or deployment of predators or use of predation or fear of predation as anthropogenic predation. Alternative viewpoints may not consider such predation events to be anthropogenic or may view the level of human responsibility for them to attenuate over time. This question is complex, but important, because it determines whether humans are responsible for the animal welfare impacts arising from introducing predators or not. We assume that humans are responsible for the purposes of this assessment, but we revisit this issue later.

Most (if not all) methods for managing wildlife are controversial (e.g. Fitzgerald, 2009; Suryawanshi et al., 2014; Linnell et al., 2017; Mormile and Hill, 2017; Slagle et al., 2017). A prominent source of contention is the animal welfare impacts imposed on target and non-target species, and the ethical issues these raise (Dubois et al., 2017). For example, poisoning is commonly used to control dingoes (*Canis familiaris*), coyotes (*Canis latrans*) and black-backed jackals (*Canis mesomelas*; hereafter jackals) in attempts to reduce their impacts on sheep (*Ovis aries*) and goats (*Capra hircus*; e.g. Fleming et al., 2014; Minnie et al., 2016a; du Plessis et al., 2018). However, poisoning (like all other approaches) is often undertaken without first demonstrating that the target individuals or species are actually impacting livestock, without measuring the efficacy of poisoning at reducing these livestock impacts, and without assessing potential impacts of poisoning on non-target species. These 'shots in the dark' (sensu Treves et al., 2016) have raised ethical concerns about the justification for implementation of predator control (e.g. Marks et al., 2000; Berger, 2006; Reddiex et al., 2006; Allen et al., 2014; Doherty and Ritchie, 2017). Related to, but distinct from ethical concerns, critics have also highlighted the many animal welfare impacts associated with common wildlife control tools (Sherley, 2007; Twigg and Parker, 2010; Littin et al., 2014; Mallick et al., 2016; RSPCA, 2016), calling for their replacement with techniques claimed to be less-harmful or for the cessation of wildlife control altogether (e.g. Letnic, 2014; McManus et al., 2014; AJP, 2015; Smith and Appleby, 2018). Recognition of these concerns and the ongoing desire to improve wildlife control methods have contributed to the refinement of wildlife management tools and techniques. This includes, for example, the development and adoption of less-harmful traps and similar devices, less-harmful poisons, and more-effective strategies for their use (e.g. Marks et al., 2004; Anon, 2014; Eason et al., 2014; Meek et al., 2018; Meek et al., 2019; Allen et al., In press). Great progress has also been made in assessing the relative welfare impacts of wildlife management tools and techniques in some regions of the world (e.g. Sharp and Saunders, 2011; Littin et al., 2014; Baker et al., 2016; Hampton et al., 2016). These assessments have included examination of both direct and intentional impacts (e.g. those that arise from poisoning), and also indirect and unintentional impacts (e.g. those that arise from fencing), which are collectively referred to as 'harms' (sensu Fraser and MacRae, 2011).

Here, we assess the animal welfare impacts of deploying large carnivores and guardian dogs as biocontrol tools against a variety of wildlife known or suspected to be in conflict with humans. Our goal is to provide an assessment of the animal welfare impacts associated with this control technique to assist wildlife managers and decision makers in identifying the most appropriate wildlife control technique for a given situation. We hope to highlight knowledge gaps and stimulate discussion on the advantages and disadvantages of introducing large carnivores and guardian dogs to multi-predator multi-prey systems, and whether or not their use truly can be considered to represent an animal welfare improvement over the traditional tools commonly used by wildlife managers worldwide.

2. Methods

2.1. Study systems

We assessed the animal welfare impacts of large carnivores and guardian dogs as biocontrol tools in two different ecological systems: Australia and South Africa.

In Australia, dingoes have been proposed as biocontrol tools for use against European red foxes (*Vulpes vulpes*), feral cats (*Felis catus*), European rabbits (*Oryctolagus cuniculus*), feral pigs (*Sus scrofa*), feral goats, exotic small mammals such as house mice (*Mus musculus*) and black rats (*Rattus rattus*), and overabundant native macropods such as red kangaroos (*Osphranter rufus*; e.g. Letnic et al., 2012; Ritchie et al., 2012; Wallach, 2014). In some parts of Australia (such as the sheep farming zone in the south-east), all of these species co-occur, interact with each other, and cause considerable social, economic and environmental impacts (West, 2008; McLeod, 2016). Dingoes are absent from or occur in low densities across much of this zone given their historical extirpation to enable sheep and goat production (Yelland, 2001; Allen and West, 2013, 2015). Dingoes are Australia's largest non-human terrestrial predator and kill, consume and elicit fear in these prey species (Glen and Dickman, 2005; Letnic et al., 2012; Allen and Leung, 2014; Allen et al., 2018). As such, some have proposed the intentional reintroduction and active restoration of the extant dingo populations within this zone as a means of suppressing target wildlife species (e.g. Wallach, 2014; Newsome et al., 2015). Opposition has arisen from livestock producers and other stakeholders about the potential impacts of dingoes on livestock and threatened native fauna (e.g. Allen and Fleming, 2012). In response, proponents further advocate for the broad-scale deployment of livestock guardian dogs to protect the tens of millions of livestock from the recovering dingo population (van Bommel and Johnson, 2012; Smith and Appleby, 2018). The proponents envisage a scenario where dingoes will control target wildlife, guardian dogs will protect livestock from dingoes, and consequently humans will not need to engage in lethal wildlife control. This approach has been described by proponents as a “humane”, “virtuous”, “predator-friendly”, “efficient”, “compassionate, cost-effective, sustainable and ethical approach” to problematic wildlife control (e.g. Ritchie et al., 2012; van Bommel and Johnson, 2012; Wallach, 2014; Wallach et al., 2015; Johnson and Wallach, 2016).

In South Africa, leopards (*Panthera pardus*) have been proposed as biocontrol tools for use against black-backed jackals and caracals (*Caracal caracal*) on sheep and goat farms (Minnie et al., 2015; du Plessis et al., 2018), and also for managing chacma baboons (*Papio ursinus*), warthogs (*Phacochoerus africanus*), Himalayan tahr (*Hemitragus jemlahicus*) and other species in other areas. In some parts of South Africa, jackals and caracals occupy the trophic position of apex predator given that larger predators, such as lions (*Panthera leo*) and leopards, have been locally extirpated to enable sheep and goat production (Van Sittert, 1998; Skead, 2007, 2011). Both jackals and caracals cause substantial impacts to small livestock species and are subject to widespread poisoning, trapping and shooting (Bergman et al., 2013; Minnie et al., 2016b; Drouilly et al., 2018a; du Plessis et al., 2018; Minnie et al., 2018). Warthogs damage fencing infrastructure (facilitating the dispersal of jackals; Minnie et al., 2018), exhibit other nuisance behaviours (Mason, 1982), and have been introduced to many areas outside their historical range (Somers, 1992; Skead, 2007, 2011). Baboons are frequently implicated in livestock predation, crop-raiding activities, and also perform a variety of other nuisance behaviours (Minnie, 2009; Hoffman and O'Riain, 2012; Drouilly et al., 2018b; Somers et al., 2018). Big cats, such as leopards, are known to kill, consume and illicit fear in these wildlife species (Hayward et al., 2012; Clements et al., 2014). Leopards present on livestock farms might therefore be expected to act as biocontrol tools to reduce predation losses experienced by livestock producers (Minnie et al., 2015). Permitting large predators to reside on livestock farms is opposed by many livestock producers who seek to prevent or mitigate all sources of livestock predation. Some have proposed that livestock guardian dogs (such as Anatolian shepherd or Kangal dogs) be deployed to protect livestock from predators (Potgieter et al., 2013; du Plessis et al., 2018); they envisage a similar scenario where large carnivores can control smaller predators, guardian dogs protect livestock from large carnivores, and humans do not need to engage in lethal wildlife control. This approach has been described by proponents as an “effective”, “non-lethal”, “cost-effective”, “selective”, “useful, practical, and economically feasible” way to achieve “improved animal welfare and reduced non-target casualties” (Marker et al., 2005; Potgieter et al., 2013; Rust et al., 2013; McManus et al., 2014).

The Australian and South African systems we describe are similar, in that they both reflect multi-predator and multi-prey systems where predators are expected to negatively influence prey through consumptive (direct, kill) and non-consumptive (indirect, fear) mechanisms (e.g. Glen and Dickman, 2005; Letnic et al., 2012; Valeix et al., 2012; Riginos, 2015). The two systems we describe are also different, in that the Australian predator-prey guild is largely comprised of a depauperate assemblage of relatively small-sized, invasive and exotic species introduced since the European settlement of Australia in the late 1700s, whereas, the South African predator-prey guild is largely comprised of co-evolved native species of all sizes. We assess these two systems to explore the welfare impacts that arise for different potential applications of vertebrate biocontrols in different multi-predator multi-prey systems. Our assessment provides insights into the welfare outcomes of using large carnivores as biocontrol tools; we do not assess their efficacy, cost-effectiveness, sustainability or utility.

2.2. Animal welfare assessment

We assessed the animal welfare impacts of using dingoes, leopards and guardian dogs as biocontrol tools using the ‘Five Domains’ approach developed by Mellor and Reid (1994). This approach has since been widely utilised to assess animal welfare impacts imposed by different wildlife control tools in a variety of contexts, including European rabbit control in the United Kingdom (Baker et al., 2016) and brushtail possum (*Trichosurus vulpecula*) poisons in New Zealand (Beausoleil et al., 2016). It has also been adopted in Australia for assessing the control tools used against multiple invasive carnivore and herbivore species (RSPCA, 2010; Sharp and Saunders, 2011), where codes of practice and standard operating procedures have been further developed for a wide variety of particular applications (available at www.pestsmart.org.au). Using this approach, both lethal and non-lethal animal control tools are given an overall ‘humaneness score’ that enables their animal welfare impacts to be compared to other potential tools. As a result, for example, ground-shooting a feral goat in the head (rating = 3A) is considered to produce superior welfare outcomes to aerial-shooting (rating = 4C), which are both superior to mustering, holding, drafting, transporting, and eventually slaughtering the goat in an abattoir (e.g. Fig. 1; Sharp and Saunders, 2011). This welfare assessment approach does not intend to prescribe which tool should be used by wildlife managers or declare a given tool ‘humane’ or ‘inhumane’, but rather makes the animal welfare impacts associated with each tool quantifiable and explicit. This allows comparison of different tools and techniques so that inferred animal welfare impacts can be ranked and considered along with efficacy, efficiency and other practical criteria when determining the most appropriate animal control tool for a given situation.

The full assessment approach has been described in detail previously (e.g. Mellor and Reid, 1994; Sharp and Saunders, 2011;

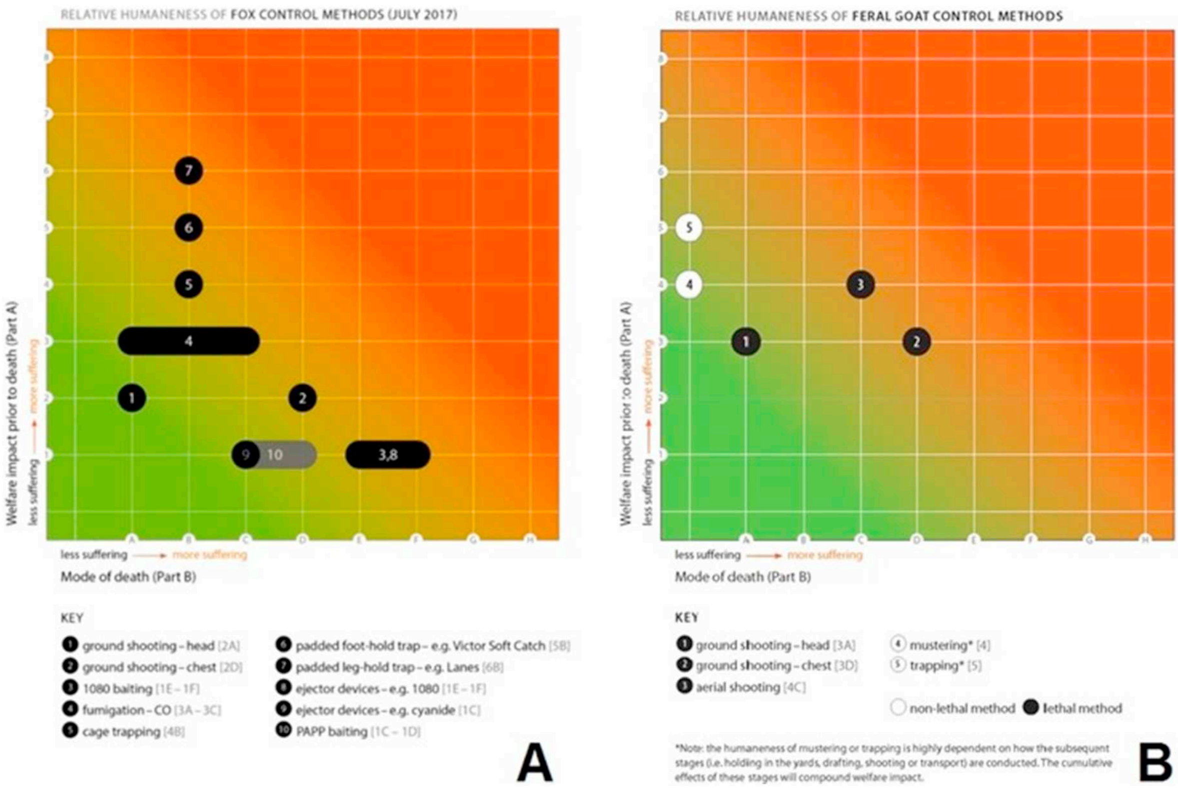

Fig. 1. The relative humaneness of a variety of control tools used against (A) European red foxes and (B) feral goats in Australia. Adapted from Appendix 12 in Sharp and Saunders, 2011, and used here to illustrate the outcomes of the five domains animal welfare impact assessment process.

Part A Overall impact on welfare	Duration of impact <60 seconds	1–60 minutes	1–24 hours	1–7 days	>7 days
Extreme	5	6	7	8	8
Severe	4	5	6	7	8
Moderate	3	4	5	6	7
Mild	2	3	4	5	6
No impact	1	1	1	1	1

Part B Level of suffering	Time to insensibility <60 seconds	1–60 minutes	1–24 hours	1–7 days	>7 days
Extreme	E	F	G	H	H
Severe	D	E	F	G	H
Moderate	C	D	E	F	G
Mild	B	C	D	E	F
No impact	A	A	A	A	A

Fig. 2. The overall humaneness scoring matrices for (A) Part A, the welfare impact associated with 'the chase' or the period preceding death, and (B) Part B, the welfare impact associated with 'the kill' or mode of death (adapted from Sharp and Saunders, 2011, where detailed definitions can be found explaining the mild, moderate, severe and extreme categories).

Beausoleil and Mellor, 2015; Mellor and Beausoleil, 2015; Baker et al., 2016). In summary, the assessment consists of two parts (A and B) that are collectively rated on a scale of 1–8, with another two welfare-related factors considered for each part (duration of suffering, and level of suffering) and collectively rated A–H (Fig. 2). Part A assesses the welfare of the controlled, individual animal before death. Part B assesses the mode of death. For each part, impacts are assessed within five domains used to determine an overall score: domain 1 is food or water deprivation, domain 2 is environmental challenge, domain 3 is disease/injury/functional impairment, domain 4 is behavioural restriction, and domain 5 is anxiety/fear/distress. The duration of suffering is assessed in categories such as immediate to seconds, minutes, hours, days, or longer. The level or intensity of suffering (which considers pain or discomfort, fear and distress) is assessed in categories such as mild, moderate, severe, or extreme. In other words, Part A assesses pre-death welfare and is scored 1–8 (with 1 indicating least and 8 indicating most suffering), Part B assesses the mode of death and is scored A–H (with A indicating least and H indicating most suffering), and judgments of suffering account for both the duration (in units of time) and the level of suffering (along a gradient of severity). This assessment approach produces overall scores such as 2B, 4D, 6F, and so on (Fig. 1), with a score of 2A reflecting a tool that produces superior welfare outcomes to a tool with a score of 3C, for example.

The scores should ideally be derived by an experienced and diverse panel of participants considered to be expert in their subject-matter (Sharp and Saunders, 2011). Baker et al. (2016) used only one author to perform the assessment and Beausoleil et al. (2016) used a panel of six scientists with various levels of expertise in animal welfare science, pest control and veterinary toxicology. In our assessment, we used a large, relevantly experienced and diverse author group who have collectively contributed to 784 published articles during our combined 263 years of experience (Table 1) at the time of writing. When performing our assessment, all 13 authors thoroughly discussed all overall scores before arriving at a unanimous consensus, which we report below. Despite our efforts, we acknowledge that because the five domains approach uses expert panels to make the assessment, it suffers from the problems of subjectivity inherent to the use of expert opinion, including how panel members are chosen. We attempted to minimise this issue by engaging

Table 1
Overview of the subject-matter experience of the expert panel (author group) performing the humaneness assessment.

Author / assessor	Years of experience	Dingo ecology	Leopard ecology	Guardian dog ecology	Use of traditional wildlife control tools	Vertebrate biocontrol / predator introductions
Benjamin L. Allen	14	x		x	x	x
Lee R. Allen	38	x		x	x	x
Guy Ballard	12	x		x	x	x
Marine Drouilly	8		x	x	x	
Peter J.S. Fleming	35	x		x	x	x
Jordan O. Hampton	16				x	
Matthew W. Hayward	15	x	x		x	x
Graham I.H. Kerley	38		x	x	x	x
Paul D. Meek	30	x			x	x
Liaan Minnie	10		x		x	
M. Justin O'Riain	15		x	x	x	
Daniel M. Parker	11		x	x	x	x
Michael J. Somers	21		x			x

Author / assessor	Welfare assessments of wildlife control tools*	Policy planning, review & implementation	Conservation research & management	Animal welfare research & management	Pest animal research & management	Publications in Scopus	Link to Scopus author profile
Benjamin L. Allen	x	x	x	x	x	48	https://www.scopus.com/authid/detail.uri?authorId=36493877100
Lee R. Allen	x	x	x	x	x	30	https://www.scopus.com/authid/detail.uri?authorId=7401631337
Guy Ballard	x	x	x	x	x	38	https://www.scopus.com/authid/detail.uri?authorId=25937120200
Marine Drouilly		x	x		x	6	https://www.scopus.com/authid/detail.uri?authorId=56465117900
Peter J.S. Fleming	x	x	x	x	x	75	https://www.scopus.com/authid/detail.uri?authorId=24447931200
Jordan O. Hampton	x	x	x	x	x	34	https://www.scopus.com/authid/detail.uri?authorId=7202738924
Matthew W. Hayward			x		x	94	https://www.scopus.com/authid/detail.uri?authorId=7102577443
Graham I.H. Kerley		x	x		x	198	https://www.scopus.com/authid/detail.uri?authorId=7004771979
Paul D. Meek	x	x	x	x	x	47	https://www.scopus.com/authid/detail.uri?authorId=7004594243
Liaan Minnie			x		x	7	https://www.scopus.com/authid/detail.uri?authorId=55897377500
M. Justin O'Riain	x	x	x	x	x	63	https://www.scopus.com/authid/detail.uri?authorId=7003884206
Daniel M. Parker	x	x	x			52	https://www.scopus.com/authid/detail.uri?authorId=56321903700
Michael J. Somers		x	x			92	https://www.scopus.com/authid/detail.uri?authorId=7101619676

* *Not including the current assessment.*

participants with diverse backgrounds, but the conclusions we reach through use of this model are ultimately qualitative in nature (Mellor and Beausoleil, 2015).

Dingoes, leopards and guardian dogs have not previously been assessed as control tools of wildlife (Allen et al., 2017). Hence, we assessed dingoes and guardian dogs as control tools of European red foxes, feral cats, feral goats, small mammals (such as house mice and black rats), kangaroos, feral pigs, and rabbits in Australia. We also assessed leopards and guardian dogs as control tools of jackals, caracals, cheetahs (*Acinonyx jubatus*), baboons, warthogs, fallow deer (*Dama dama*), Himalayan tahr, feral pigs and Cape foxes (*Vulpes chama*) in South Africa. The choice of prey species assessed for each predator was intended to reflect those that some people have argued need to be controlled (because of conflict with humans) and are potentially controllable by these predators. For convenience, in the text we collectively refer to all animals attacked or killed as 'prey', regardless of their functional role (carnivore or herbivore etc.) or whether or not they are consumed. We also refer to all those animals that do the attacking or killing as 'predators', regardless of their trophic position (top-predator, mesopredator, etc.) and whether or not their attacks successfully deter or kill prey.

3. Results

3.1. Performing the assessment

Though prey might technically be deprived of food or have their behaviour restricted during a predation event, we considered there to be 'no impact' in Domains 1, 2 and 4, and we do not discuss these further. We considered Domains 3 (e.g. injury, functional impairment) and 5 (e.g. anxiety, fear, pain and distress) to be most applicable to the mode of action (predation or fear of predation) in our case. We discussed and scored each predator against each prey over a period of several weeks using the assessment approach described above. During this process, the general paucity of empirical studies measuring the animal welfare impacts experienced during predation led to some personal variation in initial scores, with different values being attributed to the level of suffering authors perceived for individual prey species. In other words, some authors initially considered a given prey to be experiencing only mild suffering, whereas others felt that same prey might be experiencing extreme suffering. After considering these initial individual views, group discussion led to unanimous agreement that once a prey animal becomes aware that a predator is about to kill it, that prey animal can reasonably be assumed to be experiencing extreme suffering in those moments preceding capture; and that once the predator captures and proceeds to kill the prey, that prey animal can reasonably be assumed to be experiencing extreme suffering in those moments prior to insensibility or death. Thus, scores for Domain 3 and Domain 5 were considered to be extreme in all cases.

3.2. Dingoes in Australia

The minimum time taken by dingoes to chase prey may be < 60 seconds, and the minimum time taken to kill prey may also be < 60 seconds. Assuming that prey experience extreme harm during both the chase and kill components of the process, the minimum score that any prey species can receive is 5E. This was the case only for small mammals, such as mice and rats (Fig. 3). Given that chases may last minutes (but unlikely hours) and time-to-death may also last minutes (but unlikely hours; e.g. Behrendorff, 2018), scores for all other animals produce ranges, from 5E–6E for feral cats and European rabbits, from 5E–6F for red foxes and kangaroos, and 5E–6H for feral goats and feral pigs (Fig. 3). The higher maximum scores for these prey reflect the longer chasing and handling times that might be expected for larger individuals of these prey species.

3.3. Guardian dogs in Australia

The minimum time taken by guardian dogs to chase Australian prey may also be < 60 seconds, and the minimum time taken to kill prey may also be < 60 seconds. Assuming that prey experience extreme harm during both the chase and kill components of the assessment, the minimum score that any prey species can receive is also 5E. Given the way guardian dogs function in relation to prey species (Allen et al., 2016), scores for all animals produce ranges, from 5E–6F for feral cats and red foxes, from 5E–6H for kangaroos, from 5F–6H for feral goats and feral pigs, and 5F–7H for dingoes (Fig. 3). The higher maximum scores for dingoes reflect the longer time it would normally take for guardian dogs to chase, subdue and kill dingoes.

3.4. Leopards in South Africa

The minimum time taken by leopards to chase prey may be < 60 seconds, and the minimum time taken to kill prey may also be < 60 seconds. Assuming that prey experience extreme harm during both the chase and kill components of the process, the minimum score that any prey species can receive is still 5E. Given the way leopards ambush and kill their prey (Hubel et al., 2018), scores for all animals produce ranges, from 5E–5F for Cape foxes, jackals, warthogs, fallow deer, Himalayan tahr, and feral pigs, and from 5E–6F for baboons and caracals (Fig. 3). The higher maximum scores for baboons and caracals reflect the longer time it might take for leopards to chase, subdue and kill these prey given their similar morphology (caracals) or use of group defence strategies (baboons).

3.5. Guardian dogs in South Africa

Like guardian dogs in Australia, the minimum time taken by guardian dogs to chase South African prey may also be < 60 seconds, and the minimum time taken to kill prey may also be < 60 seconds. Assuming that prey experience extreme harm during both the chase and kill components of the assessment, the minimum score that any prey species can receive is also 5E. Guardian dogs in South Africa produce ranges of scores from 5E–6F for Cape foxes, jackals, warthogs and caracals, and from 5F–6H for cheetahs and baboons (Fig. 3). The higher maximum scores for these two species reflect the longer expected time it might take for guardian dogs to chase, subdue and kill these dangerous prey. As an aside, deployment of guardian dogs is not without risk to the guardian dogs, which are also killed by dingoes and other wild predators (e.g. Allen et al., 2016), producing similar harms to the guardian dog.

4. Discussion

Large carnivores and guardian dogs are increasingly being recognised for the ecosystem services they can provide (e.g. Linnell and Lescureux, 2015; van Bommel and Johnson, 2016; Gilbert et al., 2017; O'Bryan et al., 2018), including their ability to act as vertebrate biocontrol tools through consumptive and non-consumptive mechanisms (e.g. Allen, 2015; Potgieter et al., 2016; Williams et al., 2018; Thinley et al., 2018). Accordingly, predators are now being deliberately used or recommended as management tools for reducing the distribution, abundance and impacts of a variety of prey species, including both carnivores and herbivores (e.g. Allen et al., 1998; Minnie et al., 2015; Atkins et al., 2017). While much attention has been given to the animal welfare impacts associated with the use of traditional tools and techniques like poisoning, trapping or shooting (Sharp and Saunders, 2011; Littin et al., 2014), almost no attention has been given to the animal welfare impacts associated with 'natural tools', such as infectious biocontrols (Hampton and Hyndman, In press) or the intentional use of large carnivores and guardian dogs as vertebrate biocontrol tools (Allen et al., 2017). Stakeholders have polarized views regarding such use of

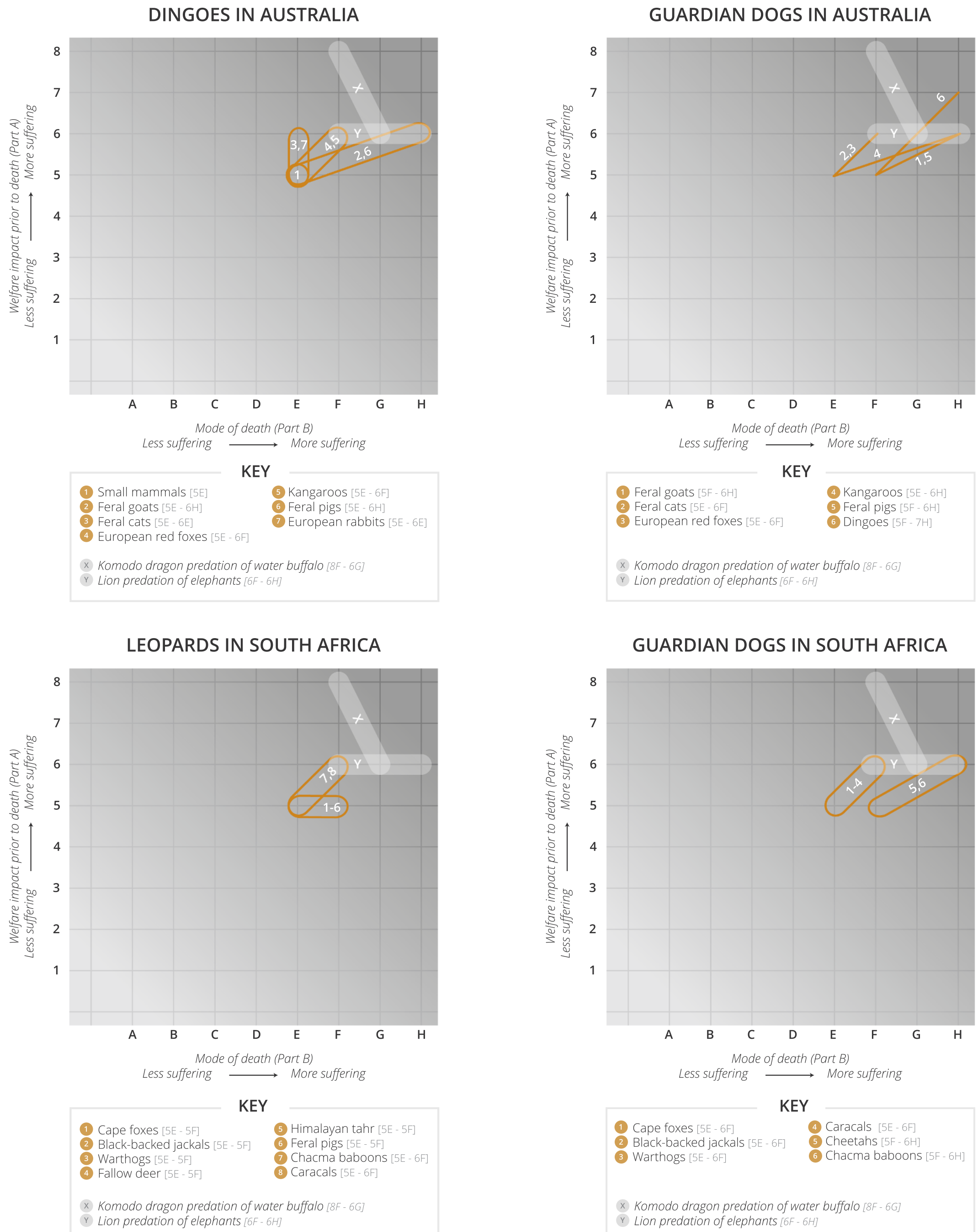

Fig. 3. The relative humaneness of using dingoes in Australia (top left), guardian dogs in Australia (top right; lines used instead of circles for clarity), leopards in South Africa (bottom left), and guardian dogs in South Africa (bottom right) as vertebrate biocontrol tools against a variety of wildlife species that come into conflict with humans. Humaneness scores for applications shown in the bottom-left of each panel are considered less harmful than scores in the top-right of each panel.

large carnivores. Some claim that deployment of large carnivores represents an "ethical", "humane" and "virtuous" approach (e.g. Wallach, 2014; Johnson and Wallach, 2016), while others claim that it represents a "cruel", "wrong", "immoral" and non-compassionate approach (e.g. Schwartz, 2016; Wallach et al., 2018). This becomes particularly confusing when individuals draw opposite ethical conclusions depending on the predator-prey combination being discussed (e.g. Wallach, 2014 advocates using dingoes to control foxes and feral cats, but later denigrates others' use of dingoes to control feral goats; Wallach et al., 2018). With few empirical studies to draw from, the results of our formal assessment of using large carnivores and guardian dogs as biocontrol tools indicates that their animal welfare impacts vary depending on the large carnivore involved, the prey species they are intended to control, and the way in which the carnivores interact with those animals (Fig. 3). In general, the consumptive and non-consumptive mechanisms used by large carnivores and guardian dogs cause considerable animal welfare impacts to the individual animals they are intended to control, and this harm is typically rated greater than those harms caused by most traditional techniques (see Sharp and Saunders, 2011 for details).

Using dingoes to control red foxes, for example, rates as the most harmful tool of all those that are currently in use or proposed for use against red foxes. Trapping red foxes with padded leg-hold traps is rated at 6B, or the most harmful of all current red fox control tools (Fig. 1; Sharp and Saunders, 2011). This score conservatively accounts for the worst instances in which foxes remain in traps for up to 24 hours and chew their own toes or feet (Meek et al., 1995; Fleming et al., 1998). Dingoes are cursorial predators that 'bite and shake' their prey to death (Corbett, 2001; Behrendorff et al., 2018). Using dingoes to chase, attack and kill red foxes was conservatively scored as 5E–6F depending on how long red foxes are chased and how long it takes dingoes to kill them (Fig. 3). Even at best – 5E, which represents extreme harm being experienced in a chase that lasts < 60 seconds, and extreme harm being experienced in a kill that lasts < 60 seconds – using dingoes against red foxes is rated as being more harmful to the red fox than using padded leg-hold traps (compare Fig. 1 with Fig. 3). At worst – 6F, which represents extreme harm being experienced in a chase that lasts > 60 seconds, and extreme harm being experienced in a kill that lasts > 60 seconds – using dingoes against red foxes substantially exceeds the suffering experienced by using firearms, traps, poisons (both sodium fluoroacetate or 'Compound 1080' and para-aminopropiophenone or 'PAPP'), or any other red fox control tool. This is similarly the case for using dingoes against feral cats (Fig. 3).

Using leopards to control various wildlife in South Africa is rated as 5E–6F depending on the target species and the time taken by leopards to catch and kill the prey (Fig. 3). Leopards are ambush predators that stalk and approach prey unseen prior to initiating a short chase or a single pounce (Hubel et al., 2018), and as such, leopard prey are likely to experience extreme harm in a chase that lasts < 60 seconds. Furthermore, leopards employ a skull bite to kill smaller prey and a throat or nape bite for larger prey (Brain, 1981), which will result in prey experiencing extreme harm in a kill that lasts < 60 seconds. This type of 'stalk and pounce' predatory behaviour produces lower humaneness scores (such as 5E; Fig. 3) than 'chase and catch' types of predatory behaviour. However, baboons and caracals are formidable prey with teeth and claws which can be used in defence against leopard attack (Brain, 1981; Jooste et al., 2012). This is likely to increase capture and handling time and thus a time-to-death of > 60 seconds, resulting in a rating closer to 6F (Fig. 3). No comparative data exists to evaluate our results against other commonly used wildlife control tools in South Africa, such as ground shooting, cage trapping, leg-hold traps (or gin traps) and poisoning (Minnie, 2009; du Plessis et al., 2018). However, one may assume that the animal welfare impacts of similar management tools for similar species (i.e. jackals and red foxes, and caracal and feral cats) would be comparable between South Africa and Australia. Thus, we can assume that the animal welfare impacts of a jackal caught in a leg-hold trap in South Africa would be similar to that of a red fox caught in a leg-hold trap in Australia, which was rated at 6B (Fig. 1). Similarly, we can assume that the animal welfare impacts of shooting a caracal in a cage in South Africa would be similar to that of a feral cat shot in a cage in Australia, which was rated at 4B–5B (Sharp and Saunders, 2011). Thus, even in a best-case scenario (rating = 5E; Fig. 3), using leopards against jackals, caracals, and other prey species would be rated as being more harmful to jackals and caracals than using leg-hold traps, ground shooting, or poisoning.

Guardian dogs have been used as biocontrol tools for centuries, and can be very effective at reducing livestock predation in some contexts (Coppinger and Coppinger, 1993; van Bommel, 2010; Potgieter et al., 2013; Linnell and Lescureux, 2015). They typically work by defensively guarding livestock, frightening potential predators away and seldom seeking-out or hunting-down predators and other wildlife (e.g. Allen et al., 2016). They are usually thought of as a non-lethal tool, intended to non-consumptively instil fear and repel predators (van Bommel and Johnson, 2014). However, guardian dogs are known to consumptively kill target and non-target animals (van Bommel, 2010; Potgieter et al., 2016), and should thus be classified as both a non-lethal (intentional harm) and lethal (unintentional harm) tool. When such lethal effects occur, the associated harms to the prey are relatively straightforward to assess and are rated similarly to other large carnivores (Fig. 3). An exception to this occurs when a guardian dog is involved in a fight that is not immediately fatal to the target animal, but where death is delayed and the animal dies as a consequence of its injuries (e.g. by secondary infection or starvation) sometime later. This scenario produced the higher limits of the range of some humanness scores for dingoes and guardian dogs (Fig. 3), where extreme harm can be experienced over a time-to-death that can last longer than 24 hours. Though extreme, at their worst these outcomes are still similar to other natural predation behaviours exhibited by other wild-living large carnivores. For example, the restraining and killing of elephants (*Loxodonta africana*) by lions (*Panthera leo*), which can last longer than 24 hours (Power and Compion, 2009), would be scored at a maximum rating of 6H were it to be considered anthropogenic predation worthy of scrutiny. Likewise, the intentional biting, envenomation and eventual (days later) death of water buffalo (*Bubalus bubalis*) by Komodo dragons (*Varanus komodoensis*; Auffenberg, 1981; Fry et al., 2009; Bull et al., 2010) would be rated at 8F–6H, depending on when the chase is considered to stop and the kill is considered to start. Deploying large carnivores as biocontrol tools essentially represents a management decision to introduce considerable consumptive and non-consumptive effects into food webs as a means of mitigating the undesirable impacts of target wildlife. In almost all cases, however, these 'natural' biocontrols will impose greater animal welfare impacts to target animals than any other anthropogenic tool used by managers, which typically have no chase period (e.g. poisoning), an immediate or very short kill period (e.g. aerial shooting), or both (e.g. ground shooting, cyanide poisoning; Sharp and Saunders, 2011).

Essential for assessing the animal welfare impacts of using large carnivores and guardian dogs as biocontrol tools using the five domains approach is an understanding of how carnivores hunt and catch their prey, or their fine-scale interactions with other predator and prey species. Despite a rich body of such literature (e.g. Barbosa and Castellanos, 2005; Schmitz, 2008; Thaker et al., 2011; Belgrad and Griffen, 2016; Moll et al., 2016; Allen et al., 2018), patterns of predation behaviour are rarely simple (MacNulty et al., 2007) and relatively few studies quantify the animal welfare outcomes experienced by prey during predation (but see Creel and Christianson, 2008; Kluever et al., 2008; Creel et al., 2009; Behrendorff et al., 2018). Thus, in making assessments such as ours (Fig. 3), we are reliant on expert opinion and will almost certainly be working with few relevant empirical data. Moreover, all qualitative index approaches for assessing animal welfare impacts, such as the one we have used, have limitations in predicting the actual welfare outcomes for animals (Beausoleil and Mellor, 2015). "Because of the dearth of objective data relating to welfare in this particular field, some judgements will have to be made subjectively" (Sharp and Saunders, 2011; pg. 40). Making assumptions is unavoidable. Quantifying welfare impacts requires physiological measurements of stress and injury responses over time for both the chase (Part A) and the kill (Part B) phases. These data must then be compared with similar measurements for the other methods (e.g. traditional tools) that form the basis of the comparisons of animal welfare impacts. Given this, our assessment (1) represents testable predictions based on current (lack of) literature and expert opinion, (2) represents a valuable starting point which stimulates discussion on the animal welfare implications of using large carnivores and guardian dogs to control other species, and (3) highlights the type of empirical information required to repeat our assessment and advance our understanding of the harms associated with these biocontrol tools.

In our assessment we assumed that in most (if not all) individual predator-prey altercations the prey experiences an extreme level of suffering during both the chase and kill components considered in the assessment process. We also assumed that prey are aware of their impending predation. For example, when a jackal becomes aware that a leopard is chasing it with intent to kill it, the jackal is probably experiencing some of the following criteria from Domain 5, described by Sharp and Saunders (2011; pg. 48) viz., "extreme inescapable or unrelieved anxiety, fear, pain, sickness, breathlessness, nausea, lethargy/weakness, dizziness, unsatisfied thirst and/or hunger or [some] other negative affective experience causing distress which is judged to be at or beyond the limits of reasonable endurance and results in the death of the animal". Any re-assessment of our results (Fig. 3) – by any other assessment panel, either with or without empirical data – cannot yield lower animal welfare scores than what we report unless (A) it is assumed or can be shown that prey are unaware they are being chased or killed or (B) prey experience less-than-extreme welfare harms when they are knowingly being chased and killed. It might reasonably be argued that in some individual predation events (particularly of leopards against smaller prey), prey may be unaware of their impending predation and/or may experience a relatively instantaneous death. If, when or where this is true, then the humaneness scores we report will be overestimated. We considered assuming prey unawareness or less-than-extreme suffering as a minimum in Domains 3 and 5, but felt more confident in assuming that such events would be the exception rather than the rule. If prey are aware and the intensity of suffering is conservatively assumed to be extreme (as we have done), then the outcomes of assessing large carnivores as biocontrol tools largely depend on the duration of harm, which will vary in different predator-prey combinations. For example, the animal welfare impacts of guardian dogs on jackals (5E–6F) are relatively more harmful than those of leopards on jackals (5E–5F) given that guardian dogs would typically rely on a prolonged chase to subdue prey while leopards are ambush predators which either pounce or engage in a very brief chase. Furthermore, canids typically kill their prey with a bite-and-shake movement (e.g. Behrendorff et al., 2018) rather than the swift and crushing skull or neck bite used by leopards (e.g. Brain, 1981). Regardless of the particular predator-prey combination, short chases and quick kills will be rated less harmful than long chases and protracted kills.

In contrast to the lethal, consumptive outcomes of interactions between large carnivore biocontrol tools and prey (discussed above), their non-lethal, non-consumptive harms are much more difficult to assess reliably. If large carnivore and guardian dog biocontrol tools are successful in establishing a landscape of fear (sensu Brown et al., 1999) and animals suffer as a result of that fear, then harm is caused. Large carnivores and guardian dogs are obviously intended to work in this way (e.g. Linnell and Lescureux, 2015; van Bommel and Johnson, 2015); the challenge lies in determining just how harmful these effects are for the target and non-target wildlife they are deployed against, and how these harms compare to other wildlife management tools.

The duration of harm component of the assessment process is relatively easy to complete given knowledge of large carnivore contact times with other species or the time they spend in close proximity to each other. This will typically fall in the range of seconds to minutes (e.g. Behrendorff, 2018), but may sometimes extend to hours (Barbosa and Castellanos, 2005; Allen et al., 2016). However, these interactions are repeated over time and may represent 'cumulative effects' or 'compounded welfare impacts' (Sharp and Saunders, 2011), the magnitude of which is determined in large part by their frequency. What is difficult to assess is how harmful these cumulative welfare effects are to prey and whether these are more or less harmful than those of other tools. Several difficult questions arise. For example, is dying from poison over several hours a better welfare outcome than being repeatedly chased by a predator over many months or years, or being displaced and forced into starvation or conflict with conspecifics? Or, should the harm be assumed less for co-evolved predators and prey (e.g. leopards and jackals) than those species that have only come into contact through anthropogenic activities (e.g. leopards and guardian dogs)? Prey species frequently come in close proximity to their predators in multi-predator multi-prey systems. Some species (e.g. kleptoparasitic scavengers) even follow their dominant predators around, hoping to scavenge a meal from them (Iyengar, 2008; Cusack et al., 2017). Species that coexist in this way likely evolved behavioural and physiological adaptations that allow them to tolerate – to some degree – these non-consumptive, cumulative harms without debilitating physiological effects. On the other hand, prey can suffer greatly from non-lethal interactions, with the landscape of fear affecting their movement patterns, sociality, foraging, reproduction, fitness and survival (Kluever et al., 2008; Creel et al., 2009; Clinchy et al., 2013). Proactive anti-predator behaviours typically carry food-mediated costs, reactive anti-predator behaviours typically carry stress-mediated costs, and both of these costs can be manifest as reduced fitness, fecundity and survival (Creel, 2018). Thus, there is likely to be a strong positive relationship between the strength of a landscape of fear and harmful animal welfare impacts experienced by the prey (Fig. 4), and one cannot argue that a strong landscape of fear exists while at the same time arguing that the prey are not experiencing any harm from that fear. The cumulative welfare impacts that arise from repeated non-consumptive predator-prey interactions will always last longer than the effects of any lethal anthropogenic wildlife control tool. Thus, 'non-lethal' does not necessarily equate to 'least harmful'. Though challenging to quantify and rank, the potential for large carnivores and guardian dogs to cause substantial cumulative harms to both target and non-target animals cannot be disregarded and requires further inquiry.

5. Conclusion and recommendations

Large carnivore and guardian dog biocontrol tools act through both lethal (consumptive) and non-lethal (non-consumptive) mechanisms. When intentionally deployed by humans for wildlife management purposes, the harms they impose on other animals could be considered anthropogenic in origin and require ethical scrutiny. The passive or active use of such anthropogenic predation may offer important benefits to wildlife management and conservation, but, like all other tools, they cause harm to target and non-target animals. The animal welfare impacts of large carnivores and guardian dogs as biocontrol tools appear similar across different predator-prey systems, but are highly dependent on specific predator-prey combinations. In most cases where they can be compared to other tools, our results indicate that predation and/or fear of predation produces more harm to target animals than most other alternative 'human tools' assessed. The intentional lethal and non-lethal harms caused by introducing somewhat uncontrollable consumptive and non-consumptive mechanisms into food webs should not be ignored or dismissively assumed to be negligible. These findings complement knowledge of the harm caused by traditional wildlife management tools and have important implications for those considering rewilding programs or the use of large carnivores or guardian dogs as biocontrols of wildlife within multi-predator multi-prey systems.

Some have argued that common control techniques, such as the poisoning of red foxes with Compound 1080 or PAPP in Australian sheep production zones, should be prohibited or abandoned ostensibly on animal welfare grounds, and instead be replaced with the deployment of dingoes as biocontrol tools against red foxes and deployment of guardian dogs to protect sheep from dingoes (e.g. Johnson and Wallach, 2016; Smith and Appleby, 2018). However, deliberately deploying carnivores for this purpose is undeniably anthropogenic and assessment of their animal welfare impacts suggests that this course of action represents abandonment of less-harmful tools in favour of more-harmful ones. Some have also argued that traditional forms of jackal control (such as ground shooting at night) should be discouraged because they impose greater animal welfare impacts than the deployment of guardian dogs (du Plessis, 2013; McManus et al., 2014). However, guardian dogs kill jackals directly and may also create a landscape of fear that displaces jackals, which together have been rated here as causing greater animal welfare impacts than ground shooting. How these harms compare to other tools is presently unclear given that formal animal welfare assessments have not been completed for other wildlife control tools used in South Africa. Once completed, such assessments may enable more informed discussion about the animal welfare impacts associated with different wildlife control tools used there (see du Plessis et al., 2018), but it should be noted that the five domains assessment

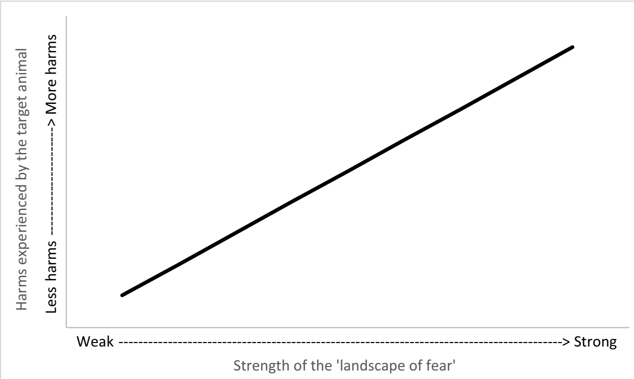

Fig. 4. The predicted relationship between the strength of the landscape of fear and the welfare harms experienced by individual animals.

approach does not generally consider indirect or unintentional harms (Beausoleil and Mellor, 2015), which are also important (Fraser and MacRae, 2011).

We predict that large carnivores and guardian dogs can be effective vertebrate biocontrol tools in some contexts (e.g. Allen et al., 1998), both despite and because of the consumptive and non-consumptive harms they cause to prey animals. A greater understanding of their utility as wildlife management tools would benefit from further demonstrations of their efficacy, advantages and disadvantages in different contexts, including explicit empirical assessment of their animal welfare impacts on prey. This information will play an increasingly important role in the future social license of using guardian animals specifically and rewilding with large carnivores more generally (Hampton and Teh-White, 2019).

Framing our assessment was the view that when predators are introduced to an environment by humans, the impacts predators exert in that environment constitute anthropogenic effects in perpetuity. This logic is an extension of the ethic applied to the ecological impacts incurred by invasive species and the generally accepted moral responsibility of humans to mitigate these impacts in the field of conservation (Russell et al., 2016). However, we acknowledge that an alternative view may be that when humans reintroduce predation (less so for novel introductions) it restores certain previously occurring processes such that an ecological system can henceforth function autonomously (although, determining an acceptable historical benchmark creates its own problems; Hayward, 2012). Under this premise, subsequent predation events would not be considered anthropogenic and would not be morally equivalent to other wildlife management tools used by humans. This complex question is further complicated by variation in what might be regarded as the naturalness of the predator and the environment (Torres, 2015). For example, reintroducing wolves to Yellowstone may be argued to be highly natural given that wolves previously occurred there, were extirpated by anthropogenic processes, and were absent for a period of only decades. On the other end of the spectrum, the introduction, training and maintenance of domestic guardian dogs in an environment that never supported natural wild populations of dogs could only tenuously be considered natural.

The ethical consequences of this issue are profound for conservation and invasive species disciplines. If it is asserted that the harm imposed by all introduced and reintroduced predators deserve equal animal welfare consideration as other wildlife management tools, then predation and fear of predation are likely to be seen as an unappealing option for managers. Under this ethical interpretation, whereby anthropogenic predation constitutes an 'immoral' approach, the social license of rewilding programs and all predator reintroductions would be extremely fragile (Allen et al., 2017). Even the widely celebrated reintroduction of grey wolves to Yellowstone National Park could be argued to constitute an unacceptable anthropogenic harm imposed on the naïve prey animals of that ecosystem. In contrast, should anthropogenic predation not be considered anthropogenic at all (i.e. if humans are deemed to not be responsible for the predation, fear and distress arising from introducing predators), then concerns about the welfare effects of using large carnivores as vertebrate biocontrols are void, and managers may begin to deploy vertebrate biocontrols more frequently. In any event, we assert that the animal welfare impacts arising from deliberate use of large carnivores and guardian dogs requires more critical examination, and we invite discussion.

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Author contributions

BA initiated the concept of using the five domains approach to assess the animal welfare impacts of dingoes as a biocontrol tool against other species. GB and PF expanded the concept to include guardian dogs, and LM and DP expanded it further to include leopards. BA led the writing, all authors participated in the assessment and contributed to the results, and all authors contributed to the writing and editing of the manuscript.

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