Yes, killing is sometimes essential for conservation.

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ABSTRACT

Animal invasions threaten native biodiversity globally and are the most important threat to Australian faunal biodiversity. Lethal control predominates efforts to manage invasive animal impacts upon agricultural and ecological values, but increasingly there are calls for its substitution by non-lethal methods. Here we ask whether killing of invasive animals is essential for wildlife conservation. Firstly, we define wildlife conservation and its population ecology requirements. Secondly, we discuss ethical considerations and then we answer our question using the scientific method, proposing that killing is not essential (the null hypothesis) and offering two working alternatives. The hypotheses are addressed with three conservation case studies of increasing likelihood that killing is essential. Examining spotted-tailed quoll, rabbit-affected ecosystems and New Zealand bird recovery efforts, we conclude that killing invasive animals is sometimes essential to achieve conservation outcomes.

Key words: canid, *Dasyurus maculatus*, fauna, lethal control, *Oryctolagus cuniculus*, population dynamics, rate of increase

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Introduction

We like animals - all sorts of animals. That is why we are members of the Royal Zoological Society of NSW (RZS). However, that is irrelevant to the conversation about whether or not people need to kill animals to achieve conservation outcomes, and we should not let our personal predilections and felt preferences unduly influence our objectivity and considered preferences (*sensu* Norton 1984).

Invasive species are the second most important cause of biodiversity loss globally (human population growth and associated landuse changes are first: Pimentel *et al.* 2005) and likely the most important threat in Australasia (Allek *et al.* 2018). There are human dimensions to invasive species issues: humans are responsible for the introduction and establishment of invasive animals and plants, things humans value (e.g. livestock, wildlife, wilderness, amenity) are often impinged upon by them, and humans can be the victims of negative consequences of invasion (e.g. predation, zoonoses).

Indigenous biodiversity is often negatively affected by invasive animals and faunal biodiversity conservation is commonly dependent upon substantial reductions or total removals of invasive animals by killing with poisoning and trapping (e.g. black rats-*Rattus rattus*-on Anacapa Island, California, Howald *et al.* 2007; and see Glen *et al.*2013). Indeed, population reduction through killing of invasive animals is the foundation of many conservation programs where invasive animals are the key threat to persistence of a species, population, community or ecosystem (e.g. Lindenmayer *et al.* 2013; Marlow *et al.* 2015; Radford 2014).

However, some question the effectiveness and effects of lethal control (e.g. Allen 2016; Wallach *et al.* 2010; Wallach *et al.* 2015) and suggest that there are alternative non-lethal techniques, such as fladry, hazing devices, shepherds, translocation and guardian animals (dogs, llamas and donkeys) that can be used to mitigate negative impacts of invasive predators (e.g. Glen *et al.* 2014; van Eeden *et al.* 2018; Musiani *et al.* 2003; van Bommel and Johnson 2017). The need to kill for conservation is being questioned more (e.g. Ramp 2013; Ramp and Bekoff 2015) and reversal of trophic cascades through promoting predators is proposed as a means of conserving endangered Australian fauna (Johnson and Ritchie 2013; Ritchie and Johnson 2009; Wallach *et al.* 2017). This poses the question of the RZS Symposium title, “Is killing essential for conservation?” and an additional question, “Should we kill *in the name of* conservation?” (Bekoff

2013, our italics). There is a subtle difference in meaning between these two questions: the first can be addressed scientifically, but the second is more philosophical.

Objectives & format

In this paper, we define wildlife conservation and explain the conditions under which it is achieved. We answer the question about the necessity to kill for conservation by proposing a null hypothesis and two working alternatives. Australasia has an especially poor record of conservation, with the rates of mammal extinction in Australia and bird extinctions in New Zealand being extreme (Holdaway 1999; Johnston 2006; Duncan and Blackman 2004). Hence, we use three case studies of conservation efforts for threatened animals from Australasia to address the null hypothesis and briefly discuss the ethics and philosophy underlying our conclusions.

What is conservation?

There are two components to conservation, the process and the underlying philosophy that motivates people undertaking the process. Conservation is the retention and /or recovery of things that are valued by people (e.g. cultural artefacts, language and art), and in this context, it applies to wildlife and other natural values. Biological conservation is the scientific management of nature to protect species, their habitats and ecosystems from decline and extinction (Frith 1973). Conservation biology is the science that examines the biological processes that underlie the retention, restoration and recovery of species, populations, communities and ecosystems (Soulé 1985). Wildlife conservation is reliant on soil, plant and animal ecology, particularly animal population and community ecology. Restoration ecology is similar except that it pertains to returning species and rebuilding degraded systems rather than retaining extant biodiversity and ecosystems (Fleming *et al.* 2017; Young 2000).

Underlying the activities and studies of biological conservation (hereafter "conservation") is "a philosophy of managing the environment in a manner that does not despoil, exhaust or extinguish" (Jordan 1995). It is an ethic of proper use of natural resources to maintain the health of the globe and retain biodiversity (Jordan 1995 and see Norton 1984).

How is conservation achieved?

As Frith (1973) commented in his seminal book, *Wildlife Conservation*, "Conservation is the one big task". Conservation is achieved when three things occur: the biological and physiological requirements of the organism to be conserved are sufficient; the habitat constraints are not limiting; and human behaviour promotes the persistence of populations of the organism. Here, we assume that the abiotic and biotic components of the environment are sufficient for the organism and the societal environment is conducive to conserving fauna. Subsequently, it is the reproductive biology and the interactions with other species that determine persistence of an animal species.

Invasive animals have adverse impacts on native and desirable fauna when they kill it, out-compete it for food or shelter, degrade its environment so that key habitat elements are missing or by adding novel pathogens (Allek *et al.* 2018). The adverse impacts only threaten persistence when they affect the population dynamics such that the rate of removal or loss exceeds the rate of recruitment.

At its simplest, population change can be described by:

$$N_{t+1} = N_t + births + immigrants - deaths - emigrants$$

where N_t = number of individuals in the population at time t (i.e. the starting population), and N_{t+1}= the number of individuals in the population at the next time, $t+1$. If births plus immigration is greater than or equal to mortality plus emigration, the population grows or persists: if they don't, then the population declines and eventually goes extinct (for more detailed discussion of population dynamics theory, see Caughley and Birch 1971; Fryxell *et al.* 2014; Krebs 2014).

Another way of encapsulating this concept is through the realised *per capita* rate of increase of a population, r (Krebs 2014). That is, when r=0, the population is stable, when r>0, the population is growing and when r<0, the population is declining.

The aim of conservation is to make or maintain $r \geq 0$ for the species or communities at risk. For $r \geq 0$, then $N_{t+1} \geq N_t$, i.e. the population size tomorrow is greater than or equal to the population size today, and so on. If a threatening process, whatever it happens to be, pushes the rate of increase below zero, then the population will go extinct unless the threat is removed or the population is removed from the threat (i.e. translocation).

Conversely, to reduce populations of invasive species that threaten the persistence of valued native species, the objective must be to make the population decline to a level where the negative impact on the threatened population's growth rate or size is nil and its population can recover (Fleming *et al.* 2017; Hone 1994; 2007). To achieve this, the invasive population must be reduced to such an extent that it stops growing and then declines (Caughley 1980; Hone 1999; Hone *et al.* 2010). The maximum proportion of a population that must be annually removed to stop a population growing is termed p and is given by,

$$p = 1 - \left(\frac{1}{e^{r_m}}\right)$$

where r_m is the maximum annual growth rate that occurs with unlimited resources (Caughley 1980; Hone et al. 2010). For example, the average proportional reduction required for rabbits in Australia, which have a mean annual rate of increase of 2.06 (Hone 1999), is ~0.87. That means, to reduce a population of rabbits so that their population declines substantially over time requires enough effort to remove >~87% of them each year, and every year.

In most instances in Australasia, removal of invasive animals must be through killing rather than relocation (including rehoming). This is because the effort required to achieve $r<0$ of invasive animals by non-lethal means is logistically or financially prohibitive and often just relocates the problem. For example, removing eastern grey kangaroos (*Macropus giganteus*) from an area of high abundance near Bathurst to other areas failed to prevent their subsequent deaths (i.e. postponed lethality) and did not account for the densities or sociality of kangaroos at the relocation sites (Kerle 2018).

Ethics, morals and other topics of contention

Essentially, the underlying question of the whole Symposium/Theme Edition is, "is it ethical to kill animals to conserve other animals?". But what is an ethic? An ethic is a philosophy or principle guiding an individual's thoughts, words and actions. Ethics is a set of moral principles generally accepted by or governing the conduct of a particular group. Those are culturally and personally modulated and driven, and are not universal. Conservation scientists, like all of society, are ethically diverse. It is the differential prioritisation of ethics that leads to agitated discourse about the rightness of killing of invasive animals to achieve conservation objectives and leads to conflict among conservationists.

One's morals are what one thinks is right and wrong. There are a lot of morals that are ingrained from childhood from both the society and family: we grow up with them. Morals and ethics are entwined; what is considered right or wrong rests in part on an individual's set of ethics.

Values are things and ideas that we place value on, whether because of their intrinsic value, their existence value, their environmental value, their ecosystem service value or their economic value. We might never have seen a lot of New Zealand's unique birds in the wild but we can still value them for their existence.

Our attitudes are more flexible. Attitudes are how we feel about and towards things, including invasive animals, livestock, domestic pets, threatened fauna and "the environment". Attitudes can be moved a bit by education and experience, and on the basis of ethics, values and beliefs.

Beliefs are convictions or ideas that individuals hold as true regardless of evidence, and these can be shared, i.e. "common beliefs". Our behaviours are our actions in response to a complex mix of our values, beliefs, ethics and attitudes. So, for example, our decisions to implement lethal or non-lethal control of invasive animals for conservation benefit, or, indeed, to take no action, are driven by these motivations. Therefore, both the decisions to kill or not to kill for conservation can be perceived as "ethical" when the decision conforms with the ethics of the individual or their group.

Methods

Using the principle of multiple working hypotheses (Platt 1964; Underwood 1990), we tested our titular statement against a null hypothesis:

H_0: *Killing is not essential for conservation*

There are two alternative hypotheses:

H_1: *Killing is essential for conservation*

H_2: *Killing is sometimes essential for conservation*

We addressed the null with three case studies from the field of conservation biology where killing is possibly essential for conservation, is probably essential and is essential for conservation.

Results

Case study 1: Killing is possibly essential for conserving spotted-tailed quolls

The spotted-tail quoll (*Dasyurus maculatus maculatus*) is a vulnerable species in New South Wales and endangered across its mainland Australian distribution (Burnett and Dickman 2008; Long *et al.* 2016). We propose that predator control is possibly essential for its survival and persistence. As evidence, we give a study undertaken to investigate the possible negative impacts of wild dog control on spotted-tailed quolls in South-east Queensland and contiguous north- east New South Wales (data from Cremasco and Selles 2008).

Cage trapping for spotted-tail quolls was conducted at twelve sites were within their historic range and most were on the Great Dividing Range between Goomburra (-28.043725º S: 152.109047º E) and Wallangarra(-28.922137º S: 151.928755º E) (exception Beeron National Park, near Munduberra, Queensland). These sites are at the northern extent of their current known range. Sites had anecdotal reports of the presence of spotted tailed quolls (n= 10) or had known populations (n=2), and most were within the New England Tableland Bioregion with similar geology, climate, elevation, topography and vegetation (n=9). Study landscapes were a mosaic of grasslands, and sclerophyllic woodland and forests that were dominated by Eucalypts and most trapping was conducted between March and September.

This was a natural experimental manipulation, which was represented as a bimodal treatment and control with multiple replications (e.g. Pople *et al.* 2000), rather than a true experimental manipulation (*sensu* Underwood 1990; 1996). The inference is therefore midrange (Allen *et al.* 2013; Hone 2007).

Few extant quolls were found except at sites where regular control of dogs and foxes with baiting programs had occurred (Table 1). The capture rate was approximately 100-fold greater at sites with canid control effort, despite the capture effort being almost double in the areas without canid control (~4,000 trap nights *cf* 2,000 trap nights).

Körtner (2007) has evidence that introduced predators kill spotted tailed quolls and Glen and Dickman (2008) also suggested that killing of foxes is beneficial for spotted-tailed quoll populations. At the canid control sites, both wild dogs and foxes were targeted and killed because baiting for wild dogs also kills foxes, and fox population indices decline more than wild dogs following baiting targeting wild dogs (Fleming 1996). No attempts were made to estimate population size or to control co-occurring feral cats (*Felis catus*). Hence, we conclude, because of limited inference, that it is possible that conservation of spotted-tailed quolls is reliant on the killing of competing canids.

Case study 2: Killing is probably essential for ecosystem restoration

Although a threatened keystone species in their native Mediterranean range, rabbits (*Oryctolagus cuniculus*) are highly invasive vertebrates that have become widely established in Australia and New Zealand. In Australia, they threaten at least 73 species of fauna (44 birds, 20 mammals, 6 reptiles, 1 invertebrate, 1 fish and 1 amphibian), 260 plant species, and nine ecological communities (Commonwealth of Australia Department of the Environment and Energy 2016) and their grazing, competition and land degradation are formally recognised as a key threatening process under Australian (*Environmental Protection and Biodiversity Conservation Act, 1999*) and State legislation (e.g. *NSW Biodiversity Conservation Act, 2016*). Rabbit grazing can even adversely affect populations of red kangaroos, *Osphranter rufus* (Cooke and Mutze 2018). The indirect impacts of rabbits on ecological values, e.g. as a supplementary food source facilitating hyperpredation on endangered small mammals and birds (e.g. Norbury and Mcglinchy 1996), is also recognised as a threat.

The control of rabbit populations is mandated or encouraged under New Zealand (e.g. *NZ Biosecurity Act, 1993*) and Australian Commonwealth and State Acts (*Commonwealth of Australia Biosecurity Act, 2015*; *Queensland Biosecurity Act, 2014*). Most control is lethal through biocontrol (Di Giallonardo and Holmes 2015), poisoning, trapping, shooting, den fumigation and habitat destruction, e.g. through warren ripping (Fleming *et al.* 2013).

But, how much control is enough to remove adverse impacts and facilitate conservation (Mutze 2016)? Rabbits can be managed to low densities, but only lethally at the moment (Cooke *et al.* 2013; Cooke 2012). However, densities of rabbits that are ≤0.5 rabbit ha^{-1} prevent recruitment of *Allocasuarina* and associated *Acacia* species in the Coorong, South Australia (Bird *et al.* 2012). These trees and shrubs are the structural backbone of the fragile, coastal ecosystem in which they occur, supporting the faunal communities in the ecosystem. Without recruitment, no regeneration is possible and the ecosystem changes, likely affecting all the animals that are part of that system. Unless rabbits in the Coorong are controlled to below that threshold, there will be massive structural change to the ecosystem as the extant trees senesce and die. This is ecosystem engineering on a broad scale that will likely affect the persistence of all the things that live there.

Can we leave it to the mammalian predators, which are mostly introduced, to control those pesky rabbits (e.g. Wallach *et al.* 2015)? For introduced predators to push the rate of increase below zero requires an annual rabbit population reduction of >~87% (see above), and that hasn't been demonstrated anywhere in Australia (Cooke and Soriguer 2017). Some plants and some ecosystems will probably become locally extinct unless we lethally control the rabbits. That is a catastrophe, not a conservation outcome.

Case study 3: Killing is essential for conserving New Zealand's endemic birds

In New Zealand most animals are predator-naïve, and many have become extinct on the main islands outside of fenced reserves (Innes *et al.* 2010). European and Maori people have introduced a suite of eutherian and marsupial mammals to a landscape that had no experience of mammalian predators (Holdaway 1999). To preserve birds like the New Zealand robin (*Petroica australis*) and Kiwi species (*Apteryx* spp., McLennan *et al.* 1996) it is necessary to either translocate them to or encourage their populations on predator-free

Table 1. The effect of canid control on relative population size (capture rate) of spotted –tailed quolls at 12 sites in south east Queensland and north-east New South Wales (After Cremasco and Selles 2008)

Treatment	Area	Trap nights	Effort	Capture rate	$F_{8,2}$	P
	(ha)	(n)	(nights/ha)	(s.e.)		
No canid baiting	14,049	3923	0.28	0.07%	0.013	<0.001
(9 sites)				(-0.05)		
≥Annual canid baiting	13,777	2281	0.17	6.70%		
(3 sites)				(-0.75)		

islands (Armstong and McLean 1995; Russell *et al.* 2016) (e.g. Kapiti Island, Wellington), or build predator-proof fences (Innes *et al.* 2012; Scofield *et al.* 2011) and systematically eradicate introduced invasive species, i.e. mice (*Mus musculus*) black rats, stoats (*Mustela erminea*), feral ferrets (*M. putorius furo*), feral cats and brush-tailed possums (*Trichosurus vulpecula*), from within the fence (e.g. Bushy Park Sanctuary, near Whanganui, North Island New Zealand). The fencing facilitates the imposition of the lethal control required to achieve negative *r* for the damaging invasive animals. Removal of the invasive animals for relocation, assuming it were feasible, would simply put more predation pressure on fauna outside the fences. Rates of increase for many New Zealand birds can only become positive when invasive animals are eradicated, leading to the quest for a "predator-free New Zealand" (Russell *et al.* 2015). In this case study, killing of invasive predators is essential for conservation of endangered bird species and not to do so ensures their extinction.

Conclusions

We have demonstrated that the null hypothesis is contradicted and that H_2 is supported: we sometimes need to kill for conservation to occur. The additional question, "Should we kill *in the name of* conservation?" (Bekoff 2013), can be answered simply, "yes": we have shown that sometimes killing is essential, so we should. The question could also be considered distractive. An alternative, nuanced reading implies that the killing is done on the *pretext* of conservation; conservation being the justification for killing of animals that is really undertaken for other reasons, such as recreation. We do not pass judgement on such reasons but acknowledge this is a topic for further philosophical discourse.

Whenever conservation of one species requires the suppression of another there will be decisions based on ethical trade-offs. Sometimes it is ethical to kill invasive animals to preserve other values. In killing animals then, an animal right or animal welfare value for an individual animal is sacrificed for a perceived or agreed greater value- the conservation value of individuals of other species and their populations. If killing is the only way to suppress the rate of increase of a harmful invasive animal below zero, some people might consider it unethical to refrain from killing enough individuals to ensure $N_{t+1}<N_t$. Killing is then essential for adherence to the conservation ethic.

The conservation ethic of many farming families is to leave the farm better than it was, or at least as good as it was, when it was acquired. This is a good ethic to follow for conservationists more generally. A second ethic that pertains to conservation is to take responsibility for, and make amends for, disruption, downgrading and degradation of ecosystems and loss of biodiversity; "If you make a mess, clean it up." If we want to clean up the mess that humans have made by introducing invasive animals in Australasia, a substantial proportion of them must be killed annually if their rates of increase are to be suppressed below zero and that of the threatened species is to be equal to or greater than zero. For adherence to the greater conservation ethic some animals must be killed so that we can leave the place better than (or at least as good as) when we came by it.

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