NRC Research Press

REVIEW

Fido, Fluffy, and wildlife conservation: The environmental consequences of domesticated animals

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Abstract: Humans have created a strong relationship with cats and dogs by domesticating them. Whether owned by a human or living feral, modern domestic cats and dogs interact extensively with people and the environment. The negative interactions between these domesticated animals and wildlife have been discussed in several reviews, but few reports have provided an overview of both the positive and negative impacts these domesticated animals have on wildlife conservation. Here, we describe the diverse issues associated with domestic cats and dogs and wildlife including predation, competition, pathogen transmission, hybridization, behavioural modification, harvest of wild animals for pet food, and creation of human–wildlife conflict. We then discuss their role in supporting conservation efforts (e.g., use in species identification and tracking, biological control), and shaping our social values towards animals and appreciation for nature. Finally, we suggest necessary steps to harmonize our relationship with cats and dogs and the conservation of wildlife. For owned animals, there is potential for pet owners to support conservation efforts through a 'pet tax' adopted by veterinary clinics and pet stores to be used for wildlife conservation. Moreover, information regarding the impacts of these animals on wildlife and potential solutions (e.g., voluntarily keeping cats and dogs inside or use of "pet curfews", use of bells to alert wildlife to cats) should be made available to owners who are most likely to have an influence on the behaviour of their companion animal.

Key words: domesticated, animals, environment, wildlife, conservation, pets.

Résumé : Les humains ont établi une solide relation avec les chats et les chiens en les domestiquant. Qu'ils appartiennent à une personne, ou qu'ils soient féraux, les chats et les chiens modernes interagissent beaucoup avec les gens et l'environnement. Les interactions négatives entre ces animaux domestiqués et la faune ont été analysées dans plusieurs revues, mais peu de rapports ont donné une vue d'ensemble des impacts tant positifs que négatifs que ces deux animaux domestiqués ont sur la conservation de la faune. Ici, nous décrivons les diverses questions associées aux chats et aux chiens domestiques et la faune y compris la prédation, la compétition, la transmission de pathogènes, l'hybridation, la modification du comportement, la récolte d'animaux sauvages pour des aliments pour animaux de compagnie et la création de conflits entre la faune et les humains. Nous analysons ensuite leur rôle dans le soutien d'efforts de conservation (p. ex., l'utilisation dans l'identification d'espèce et le dépistage, le contrôle biologique) et le façonnement de nos valeurs sociales par rapport aux animaux et à l'appréciation de la nature. Finalement, nous suggérons des étapes nécessaires afin d'harmoniser notre relation avec les chats et les chiens et la conservation de la faune. Pour des animaux appartenant à quelqu'un, il y a la possibilité que les propriétaires d'animaux de compagnie soutiennent des efforts de conservation par une taxe sur les animaux de compagnie adoptée par les cliniques vétérinaires et les animaleries, et qui servirait à la conservation de la faune. De plus, les informations quant aux impacts de ces animaux sur la faune et aux solutions possibles (p. ex., volontairement garder les chats et les chiens à l'intérieur ou l'utilisation « de couvre-feux pour les animaux de compagnie », l'utilisation de cloches pour alerter la faune de la présence de chat) devraient être mise à la disposition des propriétaires et seraient les plus probables d'avoir une influence sur le comportement de leur animal domestique. [Traduit par la Rédaction]

Mots-clés : domestiqué, animaux, environnement, faune, conservation, animaux de compagnie.

Introduction

Domestic relationships among humans and wild animals date back to the last Ice Age (Nobis 1979), with the gray wolf (*Canis lupus*) and wildcat (*Felis silvestris*) among the earliest animals domesticated. Our relationship with dogs and cats has permeated our culture for thousands of years, with current estimates suggesting that the dog was domesticated over 15 000 years ago (Driscoll and Macdonald 2010) and the cat 9500 years ago (Vigne et al. 2004). Historically, these animals were revered as hunters, companions, and religious figures (Morris 1996; Clutton-Brock 1995) and have now taken on roles as diverse as aiding those with disorders (Berry et al. 2013) to assisting in conservation (Kerley and Salkina 2007). Given their close association with humans, it is not uncommon for companion animals to be treated like family members (Hart 1995).

The prevalence of these domestic animals worldwide is estimated to be between 500 and 987 million for dogs (Wandeler et al. 1993; Hughes and Macdonald 2013; Gompper 2013) and between 448 and 752 million for cats (Dauphiné and Cooper 2009), suggesting

Received 30 November 2016. Accepted 16 May 2017.

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A correction was made to the e-First version of this paper on 21 August 2017 prior to the final issue publication.

Table 1. Beyond Fido and Fluffy–other companion animal issues.

Issues	Description	Cases	References
Ornamental fish			
Exotic species introduction	Ornamental fish have been released into inland waters and established breeding populations	Breeding populations of ornamental fishes in Indian, South African, and Mexican waterbodies	Sandilyan 2016; Ellender et al. 2014; Mejia-mojica et al. 2012
Fish removal	Ornamental fish removal can reduce population productivity and reproduction of symbionts	Conservation threat in the Amazon	Frisch et al. 2016; Moreau and Coomes 2007
Destructive fishing methods	Ornamental fisheries may use blast fishing and chemical capture to collect ornamental fish, also resulting in by-catch	Destructive fishing has reduced coral cover in the Philippines	Feitosa et al. 2008; McManus et al. 1997
Amphibians			
Exotic species introduction	Amphibians represent a small proportion of pet trade but have the potential to establish invasive populations	African clawed frog establishment in southern South America	Kopecky et al. 2016; Lobos et al. 2013
Pathogen spread	Amphibians transported around the world can be vectors for pathogens to wild populations	Chytrid fungus transferred from Asian to European salamanders	Martel et al. 2014; Ip et al. 2016; Richgels et al. 2016
Harvest of protected species	Populations of amphibians have declined due to the pet trade	Over exploitation of the critically endangered Chinese giant salamander (*Andrias davidianu*)	Wang et al. 2004; Natusch and Lyons 2012
Reptiles			
Population decline	Reptiles such as turtles are typically sourced from the wild	The Asian Turtle Crisis or steep population declines from the Asian pet trade	Nijman et al. 2015; Lyons et al. 2013; Lyons and Natusch 2011
Invasive collection	Collection of reptiles can damage moist microhabitats	Low abundance of lizards in heavily disturbed areas in the United States	Goode et al. 2005; Webb et al. 2002
Birds			
Exotic species introduction	Bird escapees are common and can result in established populations	Introduced bird species into Taiwan from the bird trade	Su et al. 2016; Carrete et al. 2008
Harvest of threatened species	Many bird species harvested from tropical areas are listed by the IUCN	Illegal trade of IUCN-listed birds in Brazil	Alves et al. 2013; Herrera and Hennessey 2008
Mammals			
Trade of threatened species	Trade of primates that are threatened	The black-headed spider monkey and the Buff-headed capuchin are both critically endangered and traded	Da Silva et al. 2016; Ortiz-Martínez and Rico-Gray 2007
Pathogen spread	Rodents carry considerable levels of pathogens and disease that can affect humans and wildlife	Rodents imported from Latin America to the United States carry numerous zoonotic pathogens	Bueno et al. 2016; Lescano et al. 2015
Invertebrates			
Exotic species introduction	Introduction into waterbodies where they can infect and outcompete native fauna	Snails and crayfish have established or have the potential to do so where kept as pets	Karatayev et al. 2009; Patoka et al. 2014

there is approximately 1 domestic cat or dog for every 5–8 people on earth. The sheer abundance of these animals creates the potential to have a large influence on both humans and also the environment with which they interact. The domestic dog evolved from an efficient hunter, the gray wolf, and still engages in pack hunting behaviour (MacNulty et al. 2014). Domestic dogs often target larger prey and scavenge more often than cats (Campos et al. 2007). The domestic cat functions as a mesopredator and has remained extremely efficient at hunting (Woods et al. 2003). Domestic cats usually kill prey < 2 kg in size (reviewed in Bonnaud et al. 2011) but have been recorded killing mammals up to 4 kg (Fancourt 2015) and may kill without a metabolic purpose (as per Dickman and Newsome 2015). However, the impacts of cats and dogs go beyond predation. A growing number studies are acknowledging the diverse and widespread impacts these animals have on the environment (Hughes and MacDonald 2013; Gompper 2013; Marra and Santella 2016; Medina et al. 2014; Young et al. 2011; Takahashi 2004; Vanak and Gompper 2009). As a result, cats have been listed in the top 100 of the world's most invasive species (Lowe et al. 2000), whereas dogs are the most numerous carnivore in the world (Vanak and Gompper 2009; Gompper 2013) and are considered a global threat to biodiversity (Silva-Rodriguez and Sieving 2012; Young et al. 2011).

The impact that cats and dogs have on the environment largely depends on the extent to which they are allowed outdoors. While virtually all owned dogs go outside in a yard or on a leash to relieve themselves, many cats are restricted entirely to the indoors. Both taxa experience varying degrees of time outdoors, from limited outdoor access (fenced-in yards/parks or on a leash), to being allowed to freely roam (free-ranging outdoors, which includes strays and barn cats), to fully feral (less human reliance). In the United States alone the number of feral cats has been estimated to be 60–100 million (Jessup 2004). Here, we provide a concise overview of the environmental issues associated with cats and dogs and point out the roles they play in wildlife conservation. We then provide suggestions for owners and managers to minimize the impacts these animals have on wildlife. In this review, 'domestic animals' include all dogs and cats within *Canis familiaris* and *Felis catus*, respectively (as per the naming convention suggested by Gentry et al. 2004), whereas 'companion animals' refer to a subset of all 'domestic animals' that have owners. We acknowledge that there are issues associated with other types of pets (some of which have been domesticated while others have not) but the literature base is too small to warrant a narrative review (see Table 1 for a summary).

Environmental issues

Direct consequences on biodiversity (predation/competition)

One of the most widely documented impacts of domestic cats and dogs on wildlife is predation, which is caused by both free-ranging and feral individuals (Dauphiné and Cooper 2009; Bonnaud et al. 2011). Estimates of total numbers of wild animals predated by cats has numerous known issues, and while no numbers exist for dog predation, cat predation on birds has been estimated in several countries. Direct predation of birds by free-ranging and feral cats is estimated at 1.3–4 billion annually in the United States (Loss et al. 2013), 100–350 million annually in Canada (Blancher 2013), 5.4 million per month during the spring and summer in Great Britain (Woods et al. 2003), 0.1–0.3 million per month during spring in Switzerland (Tschanz et al. 2011), and 144 000 per month in Finland (Kauhala et al. 2015). This suggests that in some areas cats are the largest source of anthropogenic mortality for birds. Cat predation on mammals is estimated at 6.3–22.3 billion annually in the United States (Loss et al. 2013), whereas for all native animals in Australia the estimate is 2.8–4.9 million per year (Fougere 2000), and in Finland the estimate is 1 million per month (Kauhala et al. 2015). The taxa most impacted vary by location, season, and habitat; most studies report the largest effects on birds and mammals/marsupials (Risbey et al. 2000; Catling 1988; Dickman 2009; Coman and Brunner 1972; Tschanz et al. 2011; Brickner-Braun et al. 2007; Yip et al. 2014; Barratt 1997), but others report more consumption of reptiles (Loyd et al. 2013; Paltridge 2002) or invertebrates (Campos et al. 2007). Worldwide, cats on islands have been recorded to consume 248 animal species (Bonnaud et al. 2011), and they have directly caused the drastic reduction (e.g., the kakapo (*Strigops habroptilus*)) and ultimately extinction of 33 species on islands, comprising 14% of modern global mammal, bird, and reptile extinctions and have contributed to the decline of an additional 38 threatened island species (Medina et al. 2011; Nogales et al. 2013). In Australia cats have preyed on 400 vertebrate species, of which 28 are red-listed (Doherty et al. 2015). Though less studied, free-ranging dogs can have similar effects: they were strongly implicated in the extirpation of rock iguanas (*Cyclura carinata*) on the Caicos Islands (Iverson 1978), the Conga hutia in Cuba (Borroto-Paez 2009), and marine iguanas (*Amblyrhynchus cristatus*) in the Galapagos (Kruuk and Snell 1981).

Most studies report intraspecific variation in prey preference and predation rates, with some individuals not capturing any prey and a few individuals with high consumption rates of uncommon prey (Dickman 2009; Tschanz et al. 2011; Yip et al. 2014; Kauhala et al. 2015). This suggests that the behavioural composition of the local domestic animal assemblage will affect the abundance and diversity of prey taxa consumed and that this should be considered in management programs (Moseby et al. 2015; Dickman and Newsome 2015). In fact, even though cat densities were low, targeted hunting by individual cats was likely responsible for the reintroduction failure of hare-wallabies (*Lagostrophus fasciatus fasciatus* and *L. hirsutus*) (Hardman et al. 2016) and the western barred bandicoot (*Perameles bougainville*; Short 2016), whereas a single dog was estimated to have killed 500 individuals (over 50%) of a kiwi (*Apteryx australis mantell*) population (Taborsky 1988) in New Zealand.

Most studies of predation only account for actual deaths and not for partial or missed predation attempts. Studies using recording devices on cats found that 43%–68% of predation attempts were unsuccessful (Loyd et al. 2013; McGregor et al. 2015), whereas behavioural observations on cats noted a kill rate of only 13% (Kays and DeWan 2004). Cats are especially notorious for playing with prey, and dogs can harass more than they kill (Silva-Rodriguez and Sieving 2011; Holderness-Roddam and McQuillan 2014). Injured prey may escape or be left behind and die later, and likely few are brought in to veterinarians or rehabilitation centers. A single rehabilitation facility in California received 1015 animals with cat-caused injuries (30% of their total intake) of 36 species over 9 months (Jessup 2004), and cats accounted for 28.7% (98/341) of adult bats admitted to four rehabilitation centers in Italy over 3 years (Ancillotto et al. 2013). Bluetongue lizards (*Tiliqua scincoides*) brought in to rescue groups in Sydney, Australia, were less likely to survive dog-related than cat-related injuries (25% vs 50%; Koenig et al. 2002), whereas dogs were responsible for more injured wildlife in Tasmania than were cats (Holderness-Roddam and McQuillan 2014). The sublethal effects of being chased by predators even when the prey escape direct injury are well known and include prey behavioural changes and physiological stress (Lima 1998; Clinchy et al. 2013); however, these effects are rarely quantified or considered.

The different effects on abundance and diversity between cats and dogs likely reflects their evolutionary diet preferences. Dogs are social and typically take a few large meals, whereas cats are solitary and take many small meals (Bradshaw 2006). Thus, cats are more likely to impact both abundance and diversity: they take more prey, and small-bodied prey are comprised of more taxa. While most studies focus on the numbers of prey species consumed (Hawkins et al. 2004; Grayson and Calver 2004), cats have also been shown to reduce diversity (Dickman 2009). Several studies mention that rare or endangered taxa were consumed, but because they were consumed at lower rates than numerically dominant species, these effects often become buried in the data. Cats consume rare birds within state and globally important bird areas (Winter and Wallace 2006) and can cause the extirpation of local prey populations (Frank et al. 2014; Bamford and Calver 2012). When high predator density is maintained through human-supplemented food or abundant exotic prey (Courchamp et al. 2000; Bonnaud et al. 2011), predators can have disproportionately strong effects on low-abundance prey (Spiller and Schoener 1998; Spencer et al. 2014) especially if prey suffer from Allee effects (Courchamp et al. 2008). Conservation efforts will be improved when the effects on prey with large populations are separated from the effects on sensitive prey (Loss et al. 2013).

The spatial habitat use and dietary preferences of domestic and wild species often overlap, resulting in the potential for competitive interactions between them (Vanak et al. 2013). However, the interaction between cats, dogs, and other canids and felids is complex, and current diet and habitat use may be a cause or consequence of interactions that include exploitative competition, interference competition, and predation. Dogs are believed to have the stronger direct effect (interference and predation) due to their active nature, pack formation, loud barks, and conspicuous scent marks (reviewed in Krauze-Gryz et al. 2012). For example, free-ranging dogs kill foxes (*Vulpes vulpes*), and foxes avoid dogs at small and large spatial scales (Vanak and Gompper 2010; Vanak et al. 2009), even though dogs show little diet overlap with foxes (Vanak and Gompper 2009). Dogs show higher dietary overlap with wolves, but wolves kill dogs and few studies exist on their spatial competition (Lescureux and Linnell 2014). Feral dogs and cats overlap spatially and reduce the presence of several small-bodied native carnivores in Madagascar, possibly because both feral species prey on the native carnivores, and the sheer abundance of these animals relative to wild individuals (Farris et al. 2015; Farris et al. 2016). Feral dogs are so similar to dingoes (*Canis lupus dingo*) in Australia that the two are often combined as 'wild dogs' in studies of dietary and spatial overlap (Glen and Dickman 2008; Mitchell and Banks 2005), reducing our ability to partition species-specific effects. These wild dogs and feral cats show high dietary overlap with each other and non-native foxes (spotted-tailed quolls, *Dasyurus maculatus*, a marsupial carnivore), but also show various types of resource and spatial partitioning; additionally, dogs predate quolls and feral cats, whereas feral cats predate quolls (Glen and Dickman 2008). Free-ranging dogs and cats showed spatial and temporal differences in habitat use between themselves and native red foxes, presumably driven by avoidance of dogs by the other two species (Krauze-Gryz et al. 2012). Similarly, coyotes (*Canis latrans*) kill cats and therefore cause spatial habitat partitioning (Gehrt et al. 2013).

There is less evidence that dogs and cats are significant exploitative competitors with wild animals, and interference behaviors may reduce exploitation when they result in habitat partitioning. A study placing experimental carcasses on the periphery of an African wildlife reserve found that dogs were better scavengers than leopards (*Panthera pardus*), lions (*Panthera leo*), and spotted hyenas (*Crocuta crocuta*) but were outcompeted during direct interactions (Butler and du Toit 2002). In fact, dogs may have a larger effect on other scavengers, as dogs chased vultures away from carcasses (Butler and du Toit 2002). Free-ranging dogs had low diet overlap with the endangered Ethiopian wolf (*Canis simensis*), but dogs harassed wolves (Atickem et al. 2010). Feral cats have high diet overlap with European wild cats but showed spatial and size-based resource partitioning (Biró et al. 2004), reducing exploitative competition. Cats have high diet overlap with dingoes (Paltridge 2002), but there is little evidence that the presence of dingoes reduces the abundance of cats, suggesting competition is not strong (reviewed in Allen et al. 2015). Given that domestic cats exist at hyper-abundant levels (Dauphiné and Cooper 2009) and that rodents are often a common prey item (Woods et al. 2003), it is conceivable that cats engage in exploitative competition for prey with the plethora of species that also consume rodents, such as birds of prey (George 1974), weasels, foxes (Catling 1988), raccoons, and snakes. However, population-level effects on these other predators are rarely documented. Thus, most evidence suggests domestic and wild felids and canids interact more through predation than competition, and predation is theorized to have the stronger effect on community structure (Davis 2003; Ritchie et al. 2014). However, these studies rarely compare habitat use and diet before and after cat or dog invasion or compare locations with and without cats or dogs, making it hard to tease apart local environmental effects from actual preferred habitat use, innate behaviours from learned avoidance, and plasticity from evolutionary responses. Competition and predation may also occur simultaneously, resulting in complex feedback mechanisms that make identifying relationships among taxa difficult.

Pathogen transmission

Due to their wide prevalence, domestic dogs and cats may act as a reservoir for numerous pathogens (Fitzwater 1994; Stone et al. 2016). Pathogens of domesticated cats and dogs are primarily (90%) multihost (Cleaveland et al. 2001) and therefore have the potential to spill over to wild animals when outbreaks occur in domestic pets (Bryan et al. 2011; Woodroffe and Donnelly 2012; Viana et al. 2015; Acosta-Jamett et al. 2015; Prager et al. 2012; Orozco et al. 2014). Transmission may occur directly during predation attempts and interbreeding as well as indirectly through feces and body fluids spread through the air or on nonliving objects. Pathogens may also be transmitted through vector borne modes (e.g., parasites; Rizzo et al. 2015; del Amo et al. 1999; Otranto et al. 2015). For example, pet travel appears to be introducing exotic species of ticks from the United States and Africa to the United Kingdom (Jameson and Medlock 2011), which could potentially result in pathogen outbreaks amongst humans and wildlife (Millán et al. 2016). There can be many complexities surrounding successful pathogen transmission, including social structure (Carver et al. 2016; Ghil et al. 2009; Conrad et al. 2005; Millán et al. 2016) and overall health of the host populations (Fung et al. 2014). Higher densities of domestic dogs within an area also facilitate the maintenance of pathogens (e.g., rabies virus) compared with low-density dog groups (Cleaveland and Dye 1995). In lower density groups, the virus can be maintained depending on the state of the virus in the infected individuals (e.g., infectious carriers vs slow incubators; Cleaveland and Dye 1995). Transmission is also dependent on the life histories of the pathogen (Galvani 2003). In Africa, rabies from domestic dogs has a relatively low basic reproductive rate, supporting the notion of eliminating rabies via mass vaccination efforts (Hampson et al. 2009).

The supposition that transmission occurs between domestic and wild animals is typically based off the identification of a pathogen in both domestic and wild individuals in an area where they co-exist, as it is often difficult to definitively identify the source of pathogens in wildlife. Interactions between domestic and wild carnivores can be frequent (e.g., villages surrounding the Serengeti National Park) creating the possibility for pathogen transmission to wildlife (Craft et al. 2016). Multihost pathogens such as canine distemper virus (CDV), rabies virus, canine parvovirus (CPV), and canine adenoviruses (CAV) can be transmitted from domestic dogs to wild species. CDV is a lethal and highly contagious virus transmitted by domestic dogs through bodily fluids either directly, indirectly in food or waste products in the environment, or through aerosol droplets (Shen and Gorham, 1980). Domestic dogs have been implicated in the spread of CDV to foxes, badgers (*Meles meles*), lesser grisons (*Galictis cuja*), and Iberian wolves (*Canis lupus signatus;* Acosta-Jamett et al. 2015; Di Sabatino et al. 2016; Megid et al. 2013; Mueller et al. 2011). Additionally, long-term research on lions (*Panthera leo*) in the Serengeti suggests that major CDV outbreaks in domestic dogs were initially responsible for infections in lions, but other wildlife species became hosts that then maintained the pathogen's prevalence in the long term (Viana et al. 2015). Domestic dogs and cats may also be a source of rabies to wildlife. Rabies is spread through the saliva of an infected dog or cat when it bites another individual. Dogs, for example, are suggested to have transmitted rabies to at least 10 species of wild carnivores including the endangered African wild dog (*Lycaon pictus*; reviewed in Hughes and Macdonald 2013; Prager et al. 2012; Woodroffe et al. 2012). Rabies transmission to wildlife via cats has not been documented to the same extent as domestic dogs, although the frequency of rabies virus in stray cats can be moderate (14%) in some regions (Roseveare et al. 2009). Wild species are particularly susceptible to pathogens with high environmental stability such as CPV. Contact with domestic dogs is associated with greater CPV exposure in endangered species such as the African Wild Dog (Woodroffe et al. 2012) and can be fatal in gray wolf pups (Johnson et al. 1994). CPV can maintain prevalence greater than 50% in domestic dogs and cats with similarly high levels in wild species that co-exist spatially (Minakshi et al. 2016; Furtado et al. 2016; Suzán and Ceballos 2005). In addition to CPV, CAV is a highly stable virus that is spread both direct and indirectly via bodily substances leading to canine hepatitis and potential death (Greene 2006). CAV from domestic dogs has been documented in pampas foxes (*Lycalopex gymnocercus*) and crab-eating foxes (*Cerdocyon thous*) in wildlife reserves of Brazil (Monteiro et al. 2015).

The transmission of pathogens to wildlife is not restricted to dogs; it is also an issue for domestic cats. Outdoor fecal excretion is estimated at 10.7 kg per free-roaming owned cat per year (Dabritz et al. 2006), creating a high potential for pathogen exposure to wild animals. Indeed domestic cat feces facilitates the transmission of the multihost parasite *Toxoplasma gondii* (Innes 2010). *T. gondii* has a number of impacts on infected species such as causing mortality in endangered Hawaiian geese (*Branta sandvicensis*; Work et al. 2002, 2016), reducing fertility in alpine red deer (*Cervus elaphus*; Formenti et al. 2015; Millán et al. 2016), and facilitating behavioural changes in rats (the intermediate host) that increases their susceptibility to predation by cats (Webster 2007). *T. gondii* also has the potential to transmit to both aquatic and terrestrial animals. For example, the pathogen was found in 52% of dead southern sea otters (*Enhydra lutris nereis*) with the highest levels found in urban centres with freshwater runoff (Conrad et al. 2005). Moreover, cats were deemed responsible for the transmission of *T. gondii* to elk (*Cervus* Canadensis) in the central Appalachians (Cox et al. 2017). The transmission of *T. gondii* by domestic animals has impacted a number of species and has even hindered reintroduction attempts of endangered species (Work et al. 2002).

Despite the importance of *T. gondii*, many other pathogens of domestic cats exist that are also being transmitted to wild animals such as feline parvovirus (FPV). FPV-infected cats have been found on the periphery of protected areas creating a reservoir for the pathogen (Fiorello et al. 2004). FPV has caused mortality in both Eurasian lynx (*Lynx lynx*) and wildcats with the source suggested to be domestic cats (Wasieri et al. 2009). The opportunity for spillover of FPV is high given that it is transmitted indirectly through bodily fluids and is stable in the environment. Thus, all domestic cats and dogs can potentially transmit parasites and pathogens to wild animals, as even the waste material from indoor-only pets can be a source of infection, and any pet with access outside can also be involved in direct or indirect transmission (Suzán and Ceballos 2005).

Due to the social connection between humans and domesticated animals, we administer antibiotics to our pets when illnesses occur (Pleydell et al. 2012). These antibiotics are increasing the disease resistance of pathogens (Guardabassi et al. 2004) raising concerns over their spread into the environment (Soulsby 2007; Geunther et al. 2011). It is suggested that the use of antibiotics in pets may already be spreading resistant bacteria (*Escherichia coli* and other *Enterococci* spp.) to small wild mammals (Geunther et al. 2010).

Pathogen transmission between domestic and wild animals is an important consideration and its reduction should be a top priority when endangered species become at risk of infection. Many of the previously mentioned pathogens have been detected in at-risk species including the American badger (*Taxidea taxus jacksoni*), Iberian lynx (*Lynx pardinus*), African wild dogs, and Ethiopian wolf (Ethier et al. 2017; Millán and Casanova 2007; Laurenson et al. 1998; Woodroffe et al. 2012). Research aimed at understanding and reducing the spillover of these pathogens will be important to protect the health of humans, wild animals, and domestic pets (Child 2007).

Feeding Fido and Fluffy

Millions of tonnes of pet food are imported and exported globally each year (FAO 2007). In developed countries, there is a growing demand for high-quality pet food (Combelles 2004) that often includes a protein source in the form of raw or processed fish (Tacon and Metian 2009), creating pressure on targeted fish stocks. High-end pet food options are now becoming increasingly popular in US-based markets, offering human-grade quality meats and organic ingredients at a premium price (Authors, direct observation). Pet food products that contain raw fish or fishmeal are typically made up of small pelagic forage fish including anchovies, herring, mackerel, and sardines (Tacon and Metian 2009). It is estimated that 13.7 kg of forage fish are consumed per cat per year, equating to 2.48 million tonnes per year globally (Euromonitor 2007; Gooley et al. 2006; De Silva and Turchini 2008). This does not include the estimated 2.9 million tonnes of fishmeal used in dog, fur animal, and ornamental fish feed worldwide (De Silva and Turchini 2008; RSBP 2004). Pet food may also contain various products from highly threatened large marine fishes such as tuna (Armani et al. 2015) and sharks (Sakai et al. 2007), and many pet food websites claim to use Pacific salmon (*Oncorhynchus* spp.) as an ingredient even though some of these species are threatened (COSEWIC 2011). Aside from these direct effects on wildlife, the fossil fuel emissions, habitat loss and fragmentation, and noise associated with pet food production and distribution also indirectly impact wildlife, although their quantification remains nebulous.

Hybridization

Mating between distinct species has occurred across numerous taxa within the animal kingdom (Bullini 1994). Although interspecific mating is relatively uncommon, the likelihood of an interspecific mating event occurring is greater when stable mating pairs are disrupted (e.g., hunting mortality) and for individuals with minimal breeding experience (Bohling and Waits 2015). Interspecific mating can reduce the reproductive potential and thus fitness of the hybridizing individuals, interfere with genetic integrity of the populations, and facilitate disease transfer (reviewed in Leonard et al. 2013). The loss of intraspecific mating opportunities with genetically pure individuals is particularly important in small populations including those that are threatened such as the Ethiopian wolf (Gottelli et al. 2013).

Interspecific mating can lead to viable hybrids, as chromosome number is shared between wild and domestic species of cats and dogs. In most cases, strong selection against these hybrids prevents their introgression into the population (Randi 2011). However, successful cases of introgression exist. For example, following a severe bottleneck in a Bulgarian wolf population, nearly 11% of individuals showed evidence of introgression with feral dogs (Moura et al. 2014). Introgression also threatens endangered wildcats in Scotland, as they mate with both feral cats and their hybrid offspring (Kilshaw et al. 2016). In these small populations, maladaptive genes introduced through hybridization with domestic animals can be maintained due to genetic drift and infrequent mating opportunities (Crow and Morton 1955).

Hybridization between dogs and both gray wolves and coyotes has persisted throughout the dog's domestication, particularly in North America (Tsuda et al. 1997; Gompper 2002; Way et al. 2010). Dogs have also hybridized with the Iranian wolf (*Canis lupus pallipes*; Khosravi et al. 2013), Iberian wolf (*Canis lupus signatus*; Torres and Fonseca 2016), dingo (Newsome and Corbett 1985), and the golden jackal (*Canis aureus*) (Galov et al. 2015). Hybridization has occurred in all dingo populations across Australia (Newsome and Corbett 1985), and in some areas only 17% of the population can be classified as a true dingo based on skull morphology (Jones 1990). Domestic cat hybridization has affected fewer wild species than domestic dogs, though hybridization with wildcats has threatened populations around the world (Nowell and Jackson 1996) and has made genetic tools necessary to determine the lineage of wild individuals (Daniels et al. 1998). Domestic cats also have low levels of hybridization with African wildcats (*Felis silvestris lybica*; Le Roux et al. 2015).

Hybridization with domestic animals has complicated the management of wild felids and canids. In Scotland, difficulty distinguishing pure wildcats from domestic cat hybrids has affected the captive breeding program and conservation of wildcats (Fredriksen 2016). In Australia, introgression with domestic dogs has made the designation of a wild dingo difficult, rendering protective legislation ineffective (Daniels and Corbett 2003; Glen and Dickman 2008). Hybridization also raises ecological and ethical questions over the conservation of hybrids (Jackiw et al. 2015).

Agents of human–wildlife conflict

Human–wildlife conflict occurs when the presence of wildlife disrupts human well-being or livelihoods. Small pets are suitable prey for their larger, wild counterparts (e.g., cougars or pumas (*Puma concolor*), bobcats (*Lynx rufus*), wolves, and coyotes) as well as other apex predators, and even pet food can attract wildlife to human civilizations (Rowley 1974; Timm et al. 2004). For example, pumas consume more domestic cats in areas of greater housing density, and cats make up 19% of puma diet in suburban areas (Smith et al. 2016). High frequencies of attacks on pets have also been reported for American alligators (*Alligator mississippiensis*) in the southern United States (Harding and Wolf 2006), with other common companion animal predators including coyotes (Poessel et al. 2013; Grubbs and Krausman 2009), red foxes (Plumer et al. 2014), and to a lesser extent crowned eagles (*Stephanoaetus coronatus*; McPherson et al. 2016). In some cases, predators may not need to be attracted to human areas to attack domesticated animals. In Wisconsin, wolf attacks on hunting dogs are the second most common type of wolf damage in the state (Treves et al. 2009). Free-ranging domestic animals have also been the source of conflict as they have been reported killing substantial numbers of game species. Domestic dogs on Polish hunting grounds were responsible for the death of 33 000 wild animals annually (Wierzbowska et al. 2016). In some extreme cases of human–wildlife conflict, persecution may be organized and encouraged such as mass annual wolf and fox hunts (Baker and Harris 2006; Sjölander-Lindqvist 2015), although threats to domesticated animals may not serve as the basis for these activities.

Behavioural changes

The behaviour of wild animals is largely dependent on the risk of predation (Dwyer 2004; Støen et al. 2015; Møller and Ibanez-Alamo 2012). For wildlife, the mere presence of predatory domestic animals may result in behavioural changes, resulting in lowered reproductive success (Vitousek et al. 2014; Travers et al. 2010). For example, alarm calling in birds in response to the presence of cats can reduce their fecundity by attracting other nest predators such as corvids (Bonnington et al. 2013). Models reflecting the density of cats in the U.K. suggest even small reductions in fecundity caused by 'fear' can lead to substantial population declines in birds (Beckerman et al. 2007). The sound of dogs barking—which occurs even when dogs are leashed—led to an increase in the time devoted to nest vigilance in coots (*Fulica atra*; Randler 2006). Harassment by dogs changed the spatial distribution of pudu (*Pudu puda*), a threatened species of deer (Silva-Rodríguez and Sieving 2012). Cats have increased the refuge-seeking behaviour and wariness of lava lizards (*Tropidarus* spp.) in the Galapagos (Stone et al. 1994) and wall lizards (*Podaris erhardii*) in Greece (Li et al. 2014), and they have even been the source of selection for smaller body sizes which may affect fecundity (Stone et al. 1994).

Wildlife may also respond to the presence of domestic animal excretion. In response to cat urine and feces, both mountain beavers (*Aplodontia rufa*) and house finches (*Haemorhous mexicanus*) decreased feeding behaviour (Epple et al. 1993; Roth et al. 2008) and rodents exhibited signs of anxiety (Brachetta et al. 2015), yet stoats (*Mustela erminea*) were attracted to the scent (Garvey et al. 2016). Two native small mammals did not change behaviour in response to dog feces (Banks et al. 2002), but bandicoots (*Perameles nasuta*) avoided backyards of houses with dogs even when dogs were inside (Carthey and Banks 2012). Although the consequences of these sublethal behavioral effects may seem comparatively minor relative to the immense predation by pets on wildlife (Dauphiné and Cooper 2009), perceived predation risk among vertebrate prey can have pronounced impacts at the population level (Boonstra et al. 1998; Beckerman et al. 2007). Furthermore, a woodland community experienced a 35% decrease in bird diversity and a 41% decrease in bird abundance when exposed to dogs being walked (Banks and Bryant 2007), though three mammal species avoided dogs temporally but not spatially, suggesting little impact on larger species (Parsons et al. 2016).

Social dimensions

It is well known that the relationship between an owner and their companion animal can take on a deep emotional connection, to the extent that the animal is treated like family (Hart 1995). This strong human–animal relationship influences people's attitudes and beliefs towards wildlife, as the ownership of a pet is positively associated with a person's appreciation, understanding, and connectedness towards nature (Nisbet et al. 2009). Further, children with pets show greater knowledge of and positive attitudes towards both 'popular' and 'unpopular' animals than children without pets (Prokop and Tunnicliffe 2010). Ownership of a pet can increase the time spent in nature, which is related to a decreased fear of commonly feared animals (Prokop et al. 2011). Overall, positive attitudes towards nature increases the likelihood that pet owners will engage in environmentally respectful behaviours and be concerned about environmental issues (Schultz 2000). However, the attitudes of pet owners towards domestic animal-induced environmental issues often differ from those of nonpet owners. For example, predation of wildlife by cats is a well-documented issue; however, cat owners are less likely to agree that this is a problem (Hall et al. 2016*a*). Pet owners also tend to downplay the role of free-roaming cat feces on water quality compared with nonowners (Dabritz et al. 2006). In addition, Hall et al. (2016*a*) showed that owners were less likely to support cat legislation such as roaming and limits to ownership, although this was suggested as necessary to protect wildlife. Nonetheless, 80% of cat owners in Australia contain their cats at night with wildlife protection as one of their primary concerns (Toukhsati et al. 2012). The impacts of pets on the environment can be intensified if owners believe their domesticated animal has a strong physical or emotional need to be outside (McLeod et al. 2015), because outside access increases the likelihood of depredation, disease transmission, and behavioural changes on wildlife. Additionally, many aspects of owning pets (i.e., purchasing high-quality pet food, toys, and clothing) may result in an increased carbon footprint.

In many cases the negative impacts on wildlife may be the purpose for having the domestic animal (Sepúlveda et al. 2014). For example, farmers protecting their chickens with guard dogs reported the highest levels of dog–wildlife interactions in rural Chile (Sepúlveda et al. 2014), and rodents foraged less when cats and dogs were used to protect agricultural fields (Mahlaba et al. 2017). Owned domestic dogs may be trained to protect livestock but free-roaming and feral dogs can do the opposite and predate upon farm animals. For example, feral dogs are efficient predators of various deer species and exhibit hunting efficiencies similar to that of wolves (Duarte et al. 2016). In areas where dogs and wild carnivores coexist, there is potential for the depredation of valued wild animals (livestock and game species) to be wrongfully attributed to the wild carnivore, resulting in unnecessary efforts at increased wildlife control. Humans have often taken advantage of dogs' proficient hunting behaviour. In Canada, long-term records indicate higher deer harvest when hunting with dogs (Godwin et al. 2013). In developing countries such as Nicaragua hunting dogs are an important asset to subsistence hunters (Koster, 2008). Though both livestock protection and hunting are detrimental to wild animals, these activities may improve the attitude of dog owners towards wildlife and the environment. A survey of farmers in South Africa indicated that tolerance towards cheetahs (*Acinonyx jubatus*) increased when livestock was protected by a guard dog (Rust et al. 2013). In addition, wildlife recreationists (e.g., hunters) are 4–5 times more likely to support local conservation efforts, enhance wildlife habitat, and participate in local environmental groups than nonrecreationists (Cooper et al. 2015), although the extent that hunting dogs contribute to hunting and this conservation ethic is unknown.

Management of feral cats has been the source of ongoing debate with diverging preferences amongst conservationists, animal activists, and the public. The public's response to proposed management strategies appears to vary with their socioeconomic background. For example, respondents in Georgia, USA, had almost equal support for cat sanctuaries (shelters), trap–neuter–release (TNR), and euthanizing feral cats (Loyd et al. 2013). Animal rights groups such as Alley Cat Allies and Best Friends Animal Society support the continued existence of feral cats through TNR programs and object to management of feral cat populations by euthanasia (Alley Cat Allies 2017). The cat colony caretakers believe feral cats should be treated as protected wildlife and disagree that cats harm wild birds or carry diseases (Peterson et al. 2012). Cat owners have similar attitudes and generally disagree that cats are harmful to wildlife and so tend to only support TNR as a mitigation strategy (McDonald et al. 2015). TNR is even preferred by the Audubon Society, a group that is motivated to conserve bird populations (Wald et al. 2013), though other bird conservation professionals support euthanasia rather than TNR

Table 2. Potential conservation benefits of domesticated cats and dogs.

Benefit	Description	Advantages	Example
Biological control agents	The use of cats and dogs to manage invasive or pest species abundance	This method can be highly effective at eradicating the pest species	Cats removed rabbits from 11% of islands where rabbits were introduced (Flux 1993)
Wildlife detection	Dogs can be trained to identify evidence of rare or at-risk species	Detection can be very efficient and accurate	Identified scats of endangered kit foxes in San Joaquin (Smith et al. 2003)
Attitudes towards nature	Pet ownership can have an important role in developing human relationships with nature	Pet ownership can foster greater understanding, appreciation, and connectedness towards nature	People with pets had a greater 'nature-relatedness' score (Nisbet et al. 2009)
Education and exposure to animals	Interactions with pets can shape a child's understanding of animals	Children with pets have earlier learning of biological concepts	Pre-school aged children with pets attributed biological properties to animals (Geerdts et al. 2015)
Environmental stewardship	Pet ownership is linked to positive attitudes towards nature (Prokop et al. 2011)	Positive attitudes towards nature will increase the likelihood a person acts respectfully towards the environment (Schultz 2000)	Pet owners may be more likely to pick up litter, for example

(Peterson et al. 2012). In Hawaii where the impacts of feral cats are severe, 78% of stakeholders and public respondents support the permanent removal of feral cats from the environment (Lohr and Lepczyk 2014). TNR is often considered a more humane management approach, which contributes to its popularity, despite returning cats back to the dangerous and unsanitary conditions they lived in prior to capture (Jessup 2004). Euthanasia is considered a more humane alternative when feral cats are viewed as suffering and struggling to survive (Jessup 2004) and is typically the most effective means of reducing feral cat population sizes (Lohr et al. 2013). Alternative management strategies include the use of poisonous baits, which have been successful at controlling dingo–dog hybrids, although continuous baiting was needed to be effective (Allen 2015). Feral cats are less likely to consume poison baits and it is suggested releasing typical cat prey with poisonous collars and injections may be better suited for their management (Read et al. 2016). Management strategies using poison baits are controversial as poison may also be ingested directly by many nontarget wildlife species such as the threatened Tasmanian devil (*Sarcophilus harrisii*; Buckmaster et al. 2014) or indirectly when predators feed on poisoned prey (Vyas et al. 2017).

Any disagreement amongst stakeholder groups complicates management decisions, leading to ineffective control of feral cats and hindering conservation efforts for the wild species that they impact. Using decision analysis that incorporates the preferences of multiple stakeholder groups, it was suggested that TNR be implemented in small populations of cats (<50 cats) while euthanasia would be optimal in larger populations (Loyd and DeVore 2010). Feral dogs are less of an issue in the United States, but are of growing concern in Australia. However, their management is well established and has not been subjected to the same debate as management of feral cats in the United States (Department of Primary Industries 2012).

Domestic animals and conservation

The potential role of domestic animals in conservation should not be overlooked despite the many negative impacts their populations pose to wildlife. Indeed, domestic animals are used by humans in a variety of ways that contribute to conservation initiatives. Trained dogs can detect wildlife more effectively than humans can (Woollett et al. 2013; Long et al. 20). Detection typically involves the identification of scat or feces (Oliviera et al. 2012) and has been used on a variety of species including threatened mammals, reptiles, birds, and even insects (Smith et al. 2003; Cablk and Heaton 2006; Wasser et al. 2012; Zahid et al. 2012). These techniques are particularly valuable for the detection of large carnivores that have vast home ranges and low population numbers (Long et al. 2007). The identification of scat or feces and subsequent genetic analyses has been used to identify the presence of endangered (Arandjelovic et al. 2015) and invasive species (Savidge et al. 2011; Suma et al. 2014), ultimately contributing value and efficiency to conservation and management strategies.

Historically, domestic animals were used as a means of biological control for invasive or pest species (Flux 1993; Wodzicki 1973). Cats and dogs have effectively removed small rodents and rabbits from islands (Wodzicki 1973; Parkes et al. 2014; Flux 1993) and cats can increase nest success of some birds by consuming invasive rats, which are egg predators (the 'mesopredator release effect'; Dickman 2009; Courchamp et al. 1999). The release of cats and dogs has associated ecological risks, and there may be a subsequent need for the eradication of the introduced domestic animals (Veitch 2000). To minimize long-lasting consequences, domestic animals used for biological control could be sterilized prior to release (Hood et al. 2000). Somewhat ironically, detection dogs are being used to detect feral cats as part of cat management strategies (Glen et al. 2016).

Seeking harmony

Though it is challenging to weigh the indirect benefits of improved environmental values stemming from pet ownership (see Table 2) against the direct impacts of domestic animals on the environment, it is clear that the environment would be better off without free-ranging or feral domestic animals. As the species responsible, we need to understand and manage this impact. The largest impact of domestic animals occurs when they are outdoors, and it will vary depending on where and for how long this is allowed. Populations of free-roaming domestic animals have most easily expanded in areas where native species evolved without strong competitors and predators and where domestic animals lack a natural predator (e.g., islands, human communities; Courchamp et al. 2003; Woods et al. 2003). Free-roaming domestic animals have the added advantage of access to human-provisioned food that can allow them to increase in abundance compared with native wildlife (Newsome et al. 2014; Morters et al. 2014). Additionally, free-ranging unowned cats engage in predation at a rate three times higher than owned cats (Loss et al. 2013). Roaming behaviour is at least partially affected by habitat, as free-roaming dogs tend to stay within 200 m of human households and move further in pasture versus forest habitat (Sepúlveda et al. 2015), and domestic cats roam less in areas of high housing density and roam further when they are younger (Hall et al. 2016*b*). Increased abundance, time spent outdoors, and use of natural habitats will result in more direct and indirect interactions with wildlife and the greater potential for predation, competition, behavioural modification, pathogen transmission, and hybridization between domestic and wild animals. Many of these interactions can occur simultaneously, such as domestic cats spreading disease and hybridizing with wildcats (Sarmento et al. 2009), likely limiting the ability of wildcats to re-establish. Other factors such as the life-histories of pathogens and wild species affected will also influence the degree of damage imposed by domesticated animals (Galvani 2003; McKinney 1997). We as humans must understand the drivers of domestic animal impacts so we can minimize their damage to wildlife.

There are two main areas where the impacts of domestic animals can be improved by human management. The first lies with pet owners who can choose to engage in several strategies that will reduce associated environmental consequences. The most obvious is to keep cats and dogs strictly indoors. This is unlikely to ever happen for dogs, and so keeping control of the dog on a leash, allowing off-leash time only in designated areas, and being mindful of wildlife will all reduce the direct impact of dogs. Dogs and cats that have access to the outdoors should be kept well fed so they will be less likely to consume prey (Silva- Rodríguez et al. 2011), though this strategy may not be as effective for cats as hunting can continue even when food is provided (Adamec 1976). Pet owners may also consider clipping their animal's nails to reduce their hunting ability. If cats are allowed outside, bells or sonar devices on their collar can reduce predation rates on birds and mammals, though these are less effective in deterring herpetofauna and invertebrate predation (Ruxton et al. 2002; Nelson et al. 2005; Gordon et al. 2010). Newer devices, such as CatBibs, are more effective at reducing free-ranging predation by cats on most vertebrate groups (birds 81%, mammals 45%, herpetofauna 33%) (Calver et al. 2007), whereas other devices, such as Birdsbesafe, reduced predation of prey with colour vision (birds and herpetofauna) by 47% (Hall et al. 2015). Pets should be contained indoors overnight to reduce the time they can interact with wildlife, and although this reduces the number of mammals caught, it increases the number of herpetofauna caught (Woods et al. 2003). Sterilization will also help reduce the sheer number of pets (Algar et al. 2011). Finally, ensuring timely vaccination and removal of outdoor pet feces will reduce the chance of disease transmission to wild animals. Proper adherence to these recommendations (Fig. 1) would provide owners with the social benefits of having a pet while minimizing the social costs and environmental issues.

The local government and wildlife protection agencies can also assist in reducing the impacts of pet ownership. Devices such as ultrasonic deterrents can be used to restrict the access of cats to ecologically sensitive areas (Nelson et al. 2006). The location of off-leash areas should be chosen to protect sensitive wildlife from the visual, chemical, and auditory stress of domestic animal presence, and dogs can be restricted in areas with sensitive animals (Miller et al. 2001; Langston et al. 2007), which can be very effective (Parsons et al. 2016). Legislation may also be necessary, such as a mandatory "pet curfew" overnight (Grayson and Calver 2004), limits on the number of pets owned, or bans on ownership near ecologically sensitive areas (Thomas et al. 2012). Owners could be provided information on pet–environment interactions and recommendations on minimizing impacts distributed though vet clinics and pet stores. Pet food could be accompanied by printed material outlining recommendations to reduce their pet's harm on the environment, or a small pet tax to support conservation initiatives could be applied each time you register or adopt a pet, visit the veterinarian, or buy pet food. Adherence to and support for these recommendations will depend on many factors (Lilith et al. 2006). For example, the majority of cat owners in Victoria, Australia, contained their cats to a property at night, but not during the day (Toukhsati et al. 2012). Containment of cats was motivated by both protection of wildlife and cats from injury, suggesting that further education highlighting the advantages of containment on cat welfare could increase adherence. Australian

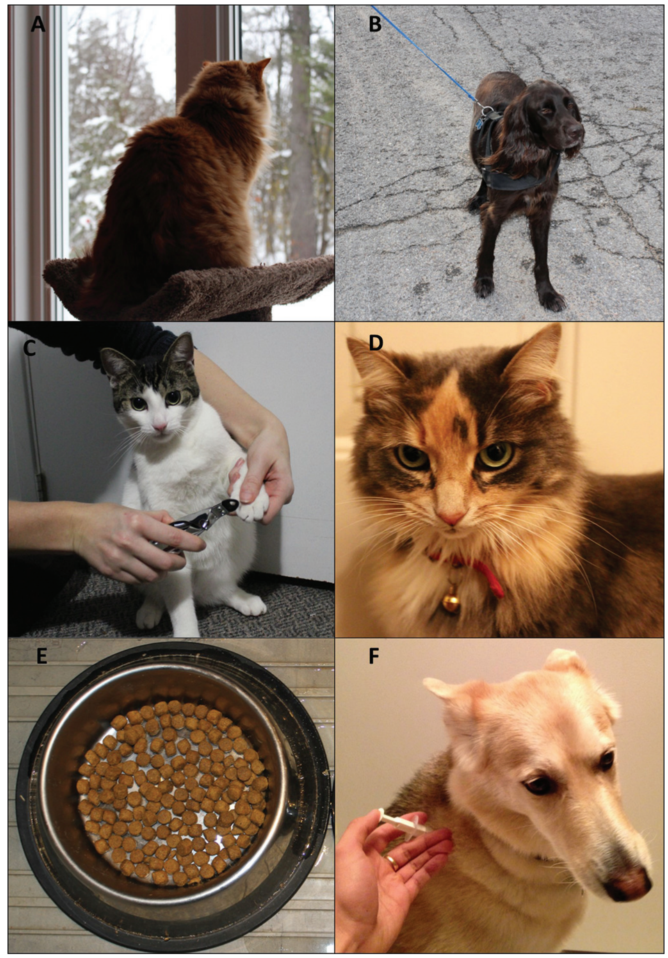

Fig. 1. Pictorial examples of some of the ways in which it may be possible to achieve greater harmony between domesticated cats and dogs and wildlife conservation. (A) Voluntarily keeping pets inside or abiding by "pet curfews" (at night) can reduce the potential for domesticated animals to interact with wildlife. (B) Keeping pets on a leash when taken outdoors can minimize the amount they disturb wildlife. (C) Clipping a pet's nails can make them less effective at hunting. (D) Wearing a bell can alert potential prey to the presence of the animal. (E) Feeding pets properly can reduce hunger-driven hunting. (F) Vaccinating pets at the veterinarian can decrease the likelihood of infections and subsequent transfer of disease to wildlife. Photos taken by W. Twardek.

cat owners also recognize the need for compulsory sterilization, cat registration, containment, and a maximum number of cats per property (Grayson et al. 2002). Even in areas where free-ranging cats are kept to control pests (e.g., farms), owners agreed they would support population control if they perceived threats to native wildlife (Coleman and Temple 1993).

The second area where the impacts of domestic animals can be improved by human management is the control of feral populations. This is undoubtedly necessary in some locations, and criteria exist for determining the most at-risk areas (Dickman et al. 2010). Island eradications have been attempted at least 87 times and are largely successful, but sometimes have unintended consequences (Campbell et al. 2011). Sound science will aid in the management of feral populations (Doherty et al. 2015; Doherty et al. 2016; Doherty and Ritchie 2016; Stoskopf and Nutter 2004), as sometimes well-intentioned efforts to help wildlife in the presence of domestic animal interactions have unforeseen results (e.g., Alterio et al. 1998). This is complicated when highly abundant non-native prey is present, as removal of cats may increase those populations causing more intense competition or predation on the native fauna (Medina and Nogales 2009). TNR or euthanize programs (Lohr et al. 2013) and poisonous prey or baits (Fleming 1996; Read et al. 2015) may be necessary to prevent growth of feral populations.

Though domestic pets have many negative effects on individuals of other species as outlined here, it is less clear whether these translate into population-level declines (Thomas et al. 2012; Risbey et al. 2000). However, a view that only population-level impacts are important means that cats are valued as individuals, whereas wildlife is only valued as a population (Longcore et al. 2009). In either case, it may be wise to adopt the precautionary principle (Calver et al. 2011) due to the large effects already documented and the numerous other effects that are beginning to emerge. It is interesting that many species of wildlife, while protected from illegal harvest from humans, receive no such protection when human's pets are responsible (Jessup 2004).

Many wild felids and canids are at considerable risk across the world (MacDonald and Sillero-Zubrini 2005; Loveridge et al. 2010). In contrast, domestic dogs and cats are numerous and widespread due to their association with humans. Pet owners have a deep compassion towards dogs and cats (Hart 1995), which could be directed into conservation effort for their wild counterparts. It is important that interactions with companion animals are encouraged to enhance people's appreciation for animals, while attempting to minimize the impacts of these companion animals on wildlife.

Conclusions

As we are now in the Anthropocene, there is a strong impetus to reduce the global human footprint on our natural ecosystems. As a society, we commonly target obvious things like diet, transport, and energy use, but there are many overlooked aspects of our daily lives that have real-world environmental impacts. Here we focused on domesticated cats and dogs but acknowledge that there are also many issues associated with other types of pets (some of which have been domesticated while others are simply kept in captivity; Table 1). Moving forward, domesticated animals of all types (but especially dogs and cats) should be a greater part of that conversation, considering these animals are equipped to prey on and compete with wildlife, spread disease, hybridize with wild animals, modify prey behaviour, and trigger human–wildlife conflict. These same domesticated animals can benefit conservation through an increased awareness of and appreciation for nature and wildlife, be used in species identification and tracking, and be used as biological control agents. Considering that 2.6 million cats and dogs are euthanized at shelters in the United States every year (e.g., ASPCA), pet stores should be encouraged to only advertise dogs or cats that are from a shelter or rescue organization. Indeed, this is now legally mandated in over 80 jurisdictions across North America (e.g., Best Friends.org), and should help shelters have the space to take more abandoned and feral pets off the streets. Information regarding the impacts of these animals on wildlife and potential solutions should be made available to owners who are most likely to have an influence on the behaviour of their companion animal. We encourage those who want more information on various topics covered here to seek out more detailed reviews and books (e.g., Gompper 2013; Hughes and MacDonald 2013; Marra and Santella, 2016; Medina et al. 2014; Young et al. 2011; Vanak and Gompper 2009).

Acknowledgements

Funding was provided by NSERC (CGS-M to W. Twardek and DG to S. Cooke) and the Canada Research Chairs Program. Thanks to the pets (Misa, Saucy, Ginger, Calli, and Charlie) and their owners for providing the photographs used in this manuscript.

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