

The movement patterns of free-roaming dogs inhabiting an offshore island of Singapore

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1 Overview

Establishing or restoring ecosystem health is a critical goal for conservation biologists and ecologists, and one of the major causes for concern is the introduction of non-native species into an ecological community (Macdonald, King, and Strachan 2008). Unfortunately, the migration and distribution of human populations across the globe gave rise to the purposeful or incidental introduction of many species (including domestic commensals) into a vast range of habitats and consequently, ecosystems. This phenomenon can be problematic for biodiversity conservation as the introduction of non-native species can further ‘weaken’ an ecosystem that is already affected by habitat fragmentation and degradation. As such, introduced species may assume the role of a convenient scapegoat aimed at misdirecting attention from more fundamental systemic issues such as habitat loss. For example, Gurevitch and Padilla (2004) argues that the rapid rate of extirpation in unionid mussels was caused by poor habitat management (e.g., degradation, pollution) and not due to the (commonly assumed) introduction of the invasive Zebra mussels (*Dreissena polymorpha*).

Domestic commensals living with strong associations with human communities can be problematic for biodiversity conservation especially when these animals are intricately tied to the economic, social, and political values and views of the human community(Simberloff

2001). For example, Medina et al. (2011) reviewed that the domestic free-roaming cat (*Felis silvestris catus*) are the primary drivers for at least 14% of the global bird, mammal, and reptile extinctions and are a prominent threat to almost 8% of critically endangered birds, mammals, and reptiles. This is, in part, due to a myriad of reasons: 1) cats were displaced globally, including many remote islands, alongside human migration (Medina et al. 2011), 2) cats are dietary generalists and will consume a large variety of prey (Campos et al. 2007; Forsyth et al. 2014), 3) most native island species have naive defences against mammalian predators [Kier et al. 2009], hence the extinctions of insular endemic and local island species populations were largely driven by the introduced free-roaming cat.

Despite being the one of the most abundant carnivores in the world (Young et al. 2011), the domestic dog (*Canis familiaris*) has received far lesser notice despite being a major problem in many urban and natural landscapes, and potential predators of or competitors with a wider variety of native species in comparison to the domestic cat (Feldmann 1974). Unfortunately, the scarcity of information on the environmental and ecological effects of the free-roaming dog (FRD) stems from lack of scientific examination on the domestic dogs' potential population-level impacts (Hughes and Macdonald 2013), anecdotally reports on canid-wildlife conflicts (Mitchell and Banks 2005) or poorly studied roles within an ecosystem (Fleming et al. 2017). As such, there is a need to study and understand the roles and impacts of these animals so as to enhance the efficacy and progress of biodiversity conservation initiatives in dog-present landscapes and facilitate the recovery and maintenance of global and/or local wildlife populations.

2 The origin of the domestic dog

The global estimate for the domestic dog population is seldom reported and such estimates are typically derived from unclear methodologies (Matthew E. Gompper 2013). For example, large-scale estimates are often derived through dog:human ratios which are the result of diverse survey methods and density estimations produced by pet product manufacturers, veterinary

associations and establishments, and animal welfare shelters or organisations (Matthew E. Gompper 2013). That being said, the most recent global-level estimate for dog numbers within the present literature was cited at 700 million dogs by Hughes and Macdonald (2013), and this estimate is expected to increase in tandem with the growth and expansion of human populations.

Unfortunately, the estimates obtained from the dog:human ratio are typically derived from a single point in time; multiple estimates rarely exist especially for countries without a national unified system for dog population management (Matthew E. Gompper 2013). In addition, there will be difficulties in accounting for dog numbers derived from different degrees of dog ownership between regions, and the unaccountable presence of free-roaming dogs. For example, differences in regional estimates of dog numbers may be influenced by the societal norms of local dog ownership as well as local dog management strategies. More importantly, dogs are often dependent on resources supplemented by humans and the fluctuations in dog numbers can arise from differences in waste disposal practices and management, and the availability of human-derived resources (e.g., medicine, shelters) in urban, rural and natural areas. As such, the dog:human ratios can differ greatly between urban and rural landscapes, and between countries and regions (Matthew E. Gompper 2013). For example, the owned domestic dog population in the United States increased by 3 to 4% annually while an inverse pattern was observed in Australia, where the owned domestic dog populations declined by 15% between 1998 to 2009 (Matthew E. Gompper 2013).

From a taxonomic perspective, the term ‘dog’ can be ambiguous and confusing. Having evolved from the gray wolf (*Canis lupus*), the domestic dog (*C. familiaris*) is still regarded as a subspecies of the wolf despite being phenotypically distinct (Matthew E Gompper 2013). In addition, subsequent evolution of the introduced domestic dog, the dingo (*C. lupus dingo*), in the Australian landscape further confounds the contentious delineation between the domestic dog, their wild and feral counterparts (e.g., coyote (*C. latrans*), jackals (*C. mesomelas*)), and their hybrids (e.g., coydog (*C. latrans* \times *C. lupus familiaris*), wolfdog). For all intents and purposes, I refer to the term ‘dog’ specifically to address the domestic dogs while terms

pertaining to their wild or hybrid counterparts (e.g., dingoes, coyotes) will be specifically mentioned. In addition, owing to the general lack of domestic dog-related studies in the present state of canid literature, references to the domestic dogs' wild counterparts may be used to exemplify (dis)-similarities of the ecological role within the members of the Canidae family.

A genomic study into the evolutionary origins of the dog suggests that the domestication relationship between humans and *Canis* occurred after the origin of domestic plants and agriculture where the shift away from a more carnivorous diet catalyzed the domestication of the dog (Larson and Bradley 2014). As such, the association with humans (e.g., food dependency) appears to be the stimulus for the close relationship between primitive *Canis* and humans, which is still being presently observed in modern times. For example, today's domestic dogs take on complex and diverse roles (e.g., as pets, working or protection animals) with varying levels of integration into different types of human communities. Even when not owned, the direct and indirect dependency on human-derived materials (e.g., food, shelter, protection) has mirrored the dogs' tremendous growth and distribution with the growth and expansion of human population and settlements across the globe.

Outside of roles defined by human ownership (e.g., pets, working dogs), there have been many efforts made to define and describe the categories of 'unowned' dogs (Matthew E. Gompper 2013). For example, Banks and Bryant (2007) differentiates the domestic dog plainly between owned and unowned, while other nomenclatures includes rural, village, feral, wild and free-roaming (Boitani and Ciucci 1995; Butler and du Toit 2002; Fleming et al. 2001; Manor and Saltz 2004; Ruiz-Izaguirre 2013, respectively) were used contextually to ecologically characterise the domestic dog. However, most authors would agree that these categories are flexible and non-restrictive as dogs are likely to switch or fall into more than one category (Vanak and Gompper 2009). Therefore, to reduce the confounding terms and complexity of categorising dogs, it could be more meaningful to examine the dogs' ecological impact and function through the spatial and circumstantial context of their ownership (or lack of).

3 The ecological impact of the free-roaming dog

Regardless of ownership, the domestic dog is dependent on the provision human-derived supplementary resources (e.g., commercially prepared pet food) or foods that were scavenged (e.g., foraging for human refuse). In a natural landscape, the provision of supplementary resources, regardless of intent, are often an ecological subsidy and will facilitate the population growth of animals that subsists on them. For example, Webb, Boarman, and Rotenberry (2004) reported that anthropogenic subsidies (e.g., human refuse and waste) have significantly contributed to the dramatic increase in the abundance of the Common ravens (*Corvus corax*) and Burger et al. (2007) noted similar findings with the glaucous gulls (*Larus hyperboreaus*) and shorebirds in a migratory stopover. In addition to population density increases, the provision of supplementary resources can lead to behavioural pattern shifts as observed in wild Slovenian red deers (*Cervus elaphus*) developing smaller home range sizes (e.g., reduced extent and/or frequency of roaming patterns) after being supplementally fed by hunters to increase their value (Jerina 2012).

Being an adaptable generalist has provided dog populations the capacity to attain higher densities in comparison to their wilder counterparts, particularly in landscapes where dogs are viewed upon commensally. This is true in urban or semi-rural landscapes where the free-roaming domestic dog have been reported to opportunistically capitalize (i.e., reduced territoriality, increased foraging distances) on the availability of food and shelter (e.g., garbage sites Tiwari et al. (2019)) in human communities or climatic events (e.g., religious feasts, stormy weather; Tiwari et al. (2018)), especially when they are not the intentional recipient of said resources (Butler, Brown, and du Toit 2018). For example, dog population densities have been found to range from 468 dogs per km² in semi-urban Philippines (Childs et al. 1998) to 6 – 21 dogs per km² in rural Kenya (Kitala et al. 2001) in comparison to coyote populations ranging from 0.2 to 0.44 per km² and wolf populations from 0.005 to 0.4 per km² (Carbone and Gittleman 2002).

With the capacity to loosely form yet highly territorial groups (Matthew E. Gompper

2013), the artificially enhanced free-roaming dog population may result in the increase in predation pressure on prey species where their rate of predation can exceed the rate of consumption and the energetic requirements of said predator (i.e., surplus killing). Surplus killing is a commonly seen predatory behaviour in canid species for two primary reasons: (1) ineffective prey response due to novel interactions with introduced dogs and (2) large packs of dogs are capable of defending kills and continue hunting despite having acquired sufficient food (see Kruuk 1972). An Australian study reported 83 red kangaroos (*Macropus rufus*) were preyed upon by a pack of five dingoes over a period of seven weeks and the dogs were only consuming portions from half of the killed kangaroos (Shepherd 1981). Similarly, Bayarbaatar, Young, and Fine (2009) noted that free-roaming dogs may be a threat to Saigas during harsh winter condition when saigas are in poor health, as well as in stages of neonate birthing and rearing where dogs have reportedly consumed more than 10,000 calves annually.

Apart from affecting prey numbers, artificially enhanced populations not only provides the free-roaming dogs with the numerical advantage to outcompete other predator species in acquiring resources, it also provides the dogs the capacity to compete with a wider range of top predators (e.g., wolves; *C. lupus*), mesopredators (e.g., jackals; *C. mesomelas*), as well as non-mammalian carnivores (e.g., monitor lizards *Varanus spp.*) in semi-rural or urban landscapes (Vanak et al. 2013). In Zimbabwe, Butler and du Toit (2002) reported that free-roaming dogs monopolized the supply of domestic animal carrion and outcompeted the principal competitors (e.g., vultures, lions (*Panthera leo*) and spotted hyaenes (*Crocuta crocuta*)) on the peripheries of reserves owing to their high densities (6.5% growth per annum), physical and numerical dominance and greater tolerance to anthropogenic disturbances.

However, not all forms of ecological subsidy gave rise to negative interaction effects. Even though occurring in large densities (10 dogs km⁻²), (Atickem, Bekele, and Williams 2009) reported that fecal analysis showed no overlap in the diet as well as home ranges between the Ethiopian wolf (*C. simensis*) and the free-roaming dogs. This is because the dogs were found to depend almost entirely on human-derived foods (> 70%) while the wolves had a diet consisting primarily of rodents. Similarly, Athreya et al. (2016) found that leopards

(*Panthera pardus*) subsisted almost completely on domestic livestock (e.g., goats, cows) but dogs played the most important food resource (39% of entire diet). Yet, despite the selection pressure for domestic dogs and cats (hence the reduced economic pressure of depredation), the human-leopard conflict is still exacerbated by the sentimental value of the dog (to humans) and the encroachment into the close proximity to household with dogs.

As a relatively large-bodied predator, dogs can assume the role of an apex predator in a natural system free from a larger mammalian predator or a landscape where larger-bodied carnivores are persecuted. For example, the dogs abandoned on Galapagos islands fulfilled the role of a missing apex predator and preyed on many native species (e.g., marine iguanas, nesting marine birds) that were naive to dogs as potential predators (Barnett and Rudd 1983). On a similar note, the dingo (and their domestic and hybridised counterparts) in mainland Australia dominated over most subordinate native mammalian predators during direct encounters (Doherty et al. 2019; Short, Kinnear, and Robley 2002) due to their advantageous body size as well as their ability to hunt in packs. For example, Mitchell and Banks (2005) found a high degree of overlap in the diet composition between dingoes (and wild dogs) and foxes which possibly resulted in temporal avoidance or localized habitat shifts in the two species. Therefore, it is not unlikely that the introduction of the dingo into Australia played a significant role in the extinction of the thylacine (*Thylacinus cynocephalus*) and the Tasmanian devil (*Sarcophilus harrisii*) (Vanak et al. 2013).

Asides from the lethal effects of predation, the mere presence of a predator can also affect prey species in subtle yet apparently harmful ways. For example, dogs may be able to suppress prey populations through non-consumptive means (e.g., harassment) which can cause disruption of normal activities or states where anti-predatory behaviours such as increased vigilance, flight, refuge seeking and/or freezing would occur. This has been found in Israel where Manor and Saltz (2004) concluded that the presence of free-roaming dogs were a threat to the mountain gazelles (*Gazella gazella gazella*) recruitment, and their direct acts of harassment (e.g., chasing of adult and kid) were contributory to the gazelle's reduced reproductive success and survival. Similarly, native bandicoots (*Paremales nasuta*; (Carthey

and Banks 2012)) and Indian foxes (*Vulpes bengalensis*; (Vanak and Gompper 2010)) were less likely to forage and/or traverse through dog-dominated landscapes even when these areas were potentially higher in human-derived resources.

Another growing concern in the interaction between free-roaming dogs and wildlife lies in dog's potential role as disease vectors towards wildlife (Hughes and Macdonald 2013). Previously, a series of well publicized and large-scale die-offs of wild carnivore populations occurred following the introduction of pathogenic viruses originating from free-roaming dog populations (Knobel et al. 2013). As a result, this critical issue of addressing dog-transmissible diseases was quickly recognized as important drivers of wildlife population dynamics and demanded a multi-disciplinary approach despite the long-standing recognition in the importance of disease and health in wildlife conservation.

At present, dogs are the primary cause for 99% of the rabies-induced human fatalities reported worldwide (Tenzin et al. 2015) and are hosts to more than 60 other transmissible zoonoses. Viruses that are particularly infectious towards carnivores such as canine distemper, parvovirus, rabies and rotavirus which can be found in the feces of un-vaccinated dogs (Yan et al. 2020), and reports citing cross-species infections have been reviewed extensively by (Knobel et al. 2013). A local example noted by (Mendenhall et al. 2016) reported that two common palm civet cats (*Paradoxurus musangus*) tested PCR-positive for parvovirus infection, and the tested strain bears similarities to the Canine Parovirus (CPV) clade that have infected dogs in China and Uruguay.

In spite of all the aforementioned interactions between dogs and wildlife, dogs can potentially assume a beneficial role and exert a positive impact through an ecosystem. In Australia, the presence of dingoes benefitted the native dusky hopping mice (*Notomys fuscus*) through the suppression of smaller mesopredators (e.g., feral cats and foxes; (Letnic, Ritchie, and Dickman 2012)), and this form of control over introduced species is a welcomed interaction. This is because the introduction of invasive species (such as cats and foxes) into the Australian ecosystem has been damaging; Woinarski et al. (2017) reviewed that feral cats in Australia killed $35.6 \text{ birds km}^{-2} \text{ yr}^{-2}$ and 99% of these mortalities were native bird species.

Amidst the obvious risks (e.g., surplus killing, harassment) imposed by dogs (and their wild counterparts) in an ecosystem, the value of introducing or conserving the dog in natural landscapes and ecosystems is worth debating. Canid researchers, particularly dingoe conservationists in Australia, proposes re-introducing the dingoe into degraded rangelands for wildlife conservation and ecosystem restoration Newsome et al. (2015)]. As aforementioned in an example by Letnic, Ritchie, and Dickman (2012), the idea of dingoe re-introduction is based on theories and results of studies suggesting that the presence of the dingoe can suppress mesopredators such as red foxes and feral cats, in turn benefiting small prey by reducing overall predation pressure. In addition, the suppressive effects of the dingoe may extend towards medium-sized grazers (e.g., feral goats and kangaroos), when in high densities, can contribute significantly to vegetation degradation in most natural landscapes (Letnic, Ritchie, and Dickman 2012). Therefore, the question lies as to whether the free-roaming domestic dog, with its similarities to its wilder counterparts (e.g., dingoes and their hybrids), may exert similar predation pressures through an ecosystem and yet contribute to native biodiversity conservation (e.g., mesopredator and prey suppression) in a similar fragmented landscape (i.e., lack of an apex terrestrial predator).

4 Introduce ME concept

To examine the (free-roaming) dogs capacity to interact with wildlife, Vanak and Gompper (2009) suggests that the ranging behaviour and location of the studied dog are critical in determining their diet (hence interaction). This is because the type of landscape in which the dog is located and their capacity for movement has direct implications on the likelihood and frequency of any probable wildlife interaction. For example, dogs with constrained movements within urban landscapes (e.g., pet dogs) are less likely to interact with wildlife in comparison to unconstrained dogs (freely roaming) in natural landscapes. However, I counter-propose examining the interaction between dog and wildlife through a framework that also considers the dogs' direct and indirect access to non-wild resources (e.g., human-derived

food) in addition to their ranging behaviour and location.

With the proposed framework, one could examine the type of dog-wildlife interaction based on the dogs' access to varying degrees of supplementary resources as well as movement patterns. For example, Atickem, Bekele, and Williams (2009) and Bayarbaatar, Young, and Fine (2009) reported that free-roaming dogs had small home ranges with close proximity to human settlements when heavily reliant on human-derived resources, and thus less likely to be significant threats to wildlife (Ethiopian wolf; *C. siamensis*, Mongolian saiga; *Saiga tatarica mongolica*). Conversely, Sepúlveda et al. (2014) reported that dog interactions with prey species in the temperate forests of Chile seemed driven by hunger and inadequate diet while Ruiz-Izaguirre (2013) reported that 'feral dogs' independent of humans were found further away from households, had larger mean activity range and scavenged more turtle nests. Unfortunately, the aforementioned studies were conducted through interviews and focal surveys, and more could be done to quantify the dogs' relative impact on wildlife.

5 Finsih with thesis layout

One approach to understanding dog-wildlife interaction comes through the study of an animal's movement ecology. This field of inquiry (see Fig ??) in animal movement examines fundamental questions regarding the movement of an organism and the mechanistic explanations as to how their movements are influenced and linked to external, environmental factors (???). This form of acquired knowledge allows researchers to examine and understand the spatial distribution of an organism, which is crucial for forecasting the organism's impacts in the ecosystems they inhabit, and on the members within their ecological community. This is particularly prevalent in modern movement-based research where the advancement and miniaturisation of electronics and technology allows for the examination of the animal's movement patterns through smaller and more varied biologging tools and systems (???).

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