Ehrlichia canis and wild dingoes in Australia

Disease Risk Assessment

Undertaken by Wildlife Health Australia

and submitted to Animal Health Committee

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Contents

1. EXECUTIVE SUMMARY

Ehrlichia canis is a bacterium transmitted by tick bites and causes serious, often fatal, disease in dogs. The pathogen was first detected in Australia in May 2020. It is now considered established in the Northern Territory and is present in the north of Western Australia and the far north of South Australia. The pathogen is spreading geographically, and eradication is not considered feasible. Dingoes are closely related to domestic dogs and are widely present in the areas of Australia where *E. canis* has been detected. Information on the impacts of *E. canis* infection in dingoes is not currently available. It is assumed that dingoes do not differ fundamentally from domestic dogs in their susceptibility to *E. canis* infection.

Many gaps in knowledge exist, including the amount of mingling that occurs between wild dingoes and domestic dogs, the susceptibility of dingoes to parasitisation by brown dog ticks and the susceptibility of dingoes to disease following infection with *E. canis*.

Ehrlichia canis has had a devastating impact on dogs in remote Indigenous communities, with estimated prevalence as high as 100% and mortalities estimated as high as 30% in some locations. Community dogs[1] roam freely and may have direct and indirect contact with wild dingoes. Other owned dogs may also have contact with wild dingoes or move through areas where dingoes live.

The brown dog tick, the vector for *E. canis*, is less likely to thrive on wild dingoes than within human settlements and built environments. Nevertheless, following the process undertaken in this risk assessment, we determined the likelihood of *E. canis* entering, establishing and spreading in wild dingo populations to be LOW and the consequences of such an event to be MAJOR. The overall risk of *E. canis* to wild dingo populations in Australia is considered to be MODERATE. This includes impacts to individual dingoes, populations and on the species at large. It also includes flow-on impacts to the environment, to ecological cascades and to both Indigenous and non-Indigenous people in Australia.

Continued movement of domestic dogs around the country will result in the ongoing expansion of the geographic spread of *E. canis* in Australia. The wider the geographic spread and the higher the prevalence of *E. canis* in domestic dogs, the greater is the likelihood of this pathogen moving into the wild dingo population.

The best way to control the risk to dingoes is to apply regular effective tick control to all domestic dogs in at-risk areas, with a particular focus on dogs in remote Indigenous communities. Logistical and resourcing challenges may prevent this from being a practical solution under the current circumstances.

This risk assessment suggests that in order to manage the risk posed by *E. canis* to wild dingoes, the following actions could be considered:

- deployment of resources to effectively manage brown dog ticks in remote communities and other areas where there is a transmission risk to wild dingoes.
- active and passive surveillance of health and disease in wild dingoes wherever possible, along with surveillance to determine presence and prevalence *E. canis* in domestic dogs and ticks throughout Australia.
- management of movement of dogs into and out of risk areas, and communication of risks to dog owners, to minimise the further geographic spread of *E. canis* in Australia.
- identification of factors which encourage the spatial overlap of domestic dogs and wild dingoes, such as availability of food sources near communities (e.g. rubbish dumps and hunting carcasses), with actions taken to minimise transmission risk associated with these factors.

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[1] See definition of "community dog" under section 8.2

PART A: RISK ASSESSMENT PROCESS

2. Background and context

Ehrlichia canis was first reported in Australia in May 2020 in domestic dogs. *Ehrlichia canis* may have been present in northern Australia for some years at low levels. Alternatively, it may be a more recent occurrence. There are no reports of the infection in wild dingoes. Wildlife Health Australia (www.wildlifehealthaustralia.com.au) was asked by Australia's Animal Health Committee (AHC) to examine the risk of *E. canis* in wild dingoes in Australia.

3. Process, limitations and restrictions

This modified wildlife disease risk assessment was undertaken as a simple "desktop" exercise by one WHA officer, with a time allocation of approximately 0.5 days a week over approximately 25 weeks. A qualitative risk assessment method was used. Expert advice was sought from three subject matter experts: one veterinary infectious disease expert and two dingo ecology experts. The document was prepared by WHA as a draft and circulated to AHC for review before finalisation.

Additional consultation and/or validation is currently outside the capacity of WHA, given the limited resources available.

This document examines the risk of *E. canis* to wild dingoes only (as defined in Section 8). It does not address the risk to feral dogs, domestic dogs, foxes or other canids in Australia (although these groups are mentioned throughout the document). Much of the information relevant to both domestic dogs and dingoes will be relevant to feral dogs and other canids in Australia.

This assessment considers the transmission of *E. canis* to a dingo as part of the current outbreak. New introductions of *E. canis* from outside Australia (including new strains with possible differing pathogenicity) are not addressed in this risk assessment.

This document aims to give a perspective on the actions that are most likely to result in a reduced risk to wild dingoes. It is acknowledged that it may be logistically, socially and economically challenging to meet these recommendations, for a wide number of reasons.

4. Assumptions

- Dingoes are closely related to domestic dogs
- Dingoes do not fundamentally differ from domestic dogs in their susceptibility to disease as a result of *E. canis* infection
- Brown dog tick (*Rhipicephalus sanguineus)* distribution is wider than previously recorded by Roberts (1970) and at least as wide as hypothesized by Chandra et al. (2020)
- *Ehrlichia canis* infection is not currently present in wild dingoes or feral dogs in Australia.

5. Risk questions to be addressed

1. What is the likelihood that *E. canis* could enter, establish and spread in wild dingo populations in Australia?

2. What are the possible consequences if *E. canis* enters, establishes and spreads in wild dingo populations in Australia?

3. What is the overall risk of *E. canis* to wild dingo populations?

4. What are the possible mitigation measures to reduce the risk of *E. canis* to wild dingoes in Australia?

PART B: INFORMATION ON *E. CANIS*, BROWN DOG TICKS, DINGOES AND DOGS IN AUSTRALIA

6. Introduction

Ehrlichia canis is a bacterium transmitted by tick bites. It causes serious disease (called canine monocytic ehrlichiosis), which can lead to death, in dogs. Australia was previously believed to be free of *E. canis*. During 2020, the organism was detected in Australian dogs for the first time. Infection with *E. canis* is a notifiable disease in Australia. Pathogens from the genus *Ehrlichia*, collectively, are considered to be emerging infectious diseases (Walker and Dumler 1996; Davidson et al. 2008). Dingoes are widely present in the areas of Australia where *E. canis* has been detected in dogs. Information on the impacts of *E. canis* infection in dingoes is not currently available.

7. Detections of *E. canis* in Australia

Ehrlichia canis was first detected in a small number of domesticated dogs in the Kimberly region of Western Australia (WA) in May 2020. Previous studies had found no conclusive evidence of *E. canis* in dogs in Australia (Mason et al. 2001; Barker et al. 2012; Hii et al. 2012) and the national animal surveillance system had not detected any evidence of the pathogen in Australia. The detections in Kununurra in 2020 were soon followed by reports in dogs in various areas of the Northern Territory (NT): in Katherine and in a remote settlement west of Alice Springs in June 2020 (DPIR 2020; AMRRIC 2021). The pathogen is now considered widespread in remote Indigenous communities throughout a vast geographic area of the NT and in WA, north of the 26th S parallel, and has been reported in the far north of South Australia (SA). Further details of known distribution are available on state, territory and Commonwealth government websites (e.g. www.outbreak.gov.au/current-responses-to-outbreaks/ehrlichiosis-dogs). There are currently no peer-reviewed publications detailing the Australian *E. canis* outbreak. (See also Occurrences in Australia, below).

8. Canids in Australia

Within Australia, there are three loose groupings of potential *Canis familiaris* hosts for *E. canis*. These are:

i) wild dogs (un-owned with limited or no interaction with humans and always free to roam; includes feral dogs, dog-dingo crosses and dingoes) (see Appendix 1; Figure 1)

ii) free-roaming domestic dogs (owned but allowed to roam freely at some point; includes dogs in Indigenous communities[2])

iii) restrained domestic dogs (owned, with their movement restricted) (Sparkes et al. 2016).

Both dogs and dingoes have strong cultural and spiritual importance to Indigenous people (Brookes et al. 2020).

Wild dogs (including dingoes), unrestrained owned dogs and restrained owned dogs may all interact with each other to a degree. The type and amount of interaction is often unquantified or assumed, although studies are

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[2] See definition of "community dog" under section 8.2

providing increased understanding of this area (e.g. Sparkes et al. 2016; Bombara et al. 2017; Smout et al. 2018; Gabriele-Rivet et al. 2021). Genetic, telemetry and camera trap data indicate regular or potential interactions, in particular between dingoes/feral dogs and community dogs (Smout et al. 2018; Gabriele-Rivet et al. ; Gabriele-Rivet et al. 2021). Interactions may vary significantly by location, season or other circumstance. It is difficult to make accurate, generic statements about the amount and type of interaction between dingoes and domestic dogs. Domestic dogs that are typically restrained may be taken on hunting trips by owners and may have increased opportunities for interaction with wild dogs and dingoes during these times, while off-leash and roaming freely.

Introduced feral red foxes (*Vulpes vulpes*) are potential, but unlikely, hosts for *E. canis* in the Australian setting, and are outside the scope of this disease risk assessment.

8.1 Dingoes and wild dogs in Australia

Australia's sizeable wild dog population is made up of dingoes, feral dogs and feral dog/dingo crosses. Dingoes are a uniquely Australian ancient dog breed and are considered a distinct lineage of wild-living canid. The taxonomy of dingoes is under dispute; dingoes and domestic dogs are able to interbreed, and it has been suggested that dingoes may be a subspecies of domestic dog (*Canis familiaris dingo*) or a separate species (*C. dingo*). Importantly, dingoes are considered native Australian wildlife and are of conservation concern, whereas feral dogs originate from domesticated stock and are considered pests. The conservation status of dingoes may vary according to jurisdiction, for example, in South Australia, under the National Parks and Wildlife Act (1972) wild dogs (dingoes) are not a protected species, which applies north of the dog fence. South of the SA dog fence, dingoes and wild dogs are classed as a pest species, and landholders are required to control them under the Landscape South Australia Act 2019. The variable conservation status of dingos may have an impact on management decisions regarding *E. canis*.

Individual wild dogs may be a genetic mix of both dingo and domestic dog lineage. It is not possible to determine the status of dogs (i.e. feral dog or dingo) by appearance alone (Tatler et al. 2021). Recent studies indicate that the majority of free-living dogs in Australia, particularly in the north and west of the country, are genetically pure or close-to-pure dingo (Cairns 2021).

Wild dingoes are apex predators and play an important role in keeping natural ecosystems in balance. Dingoes have been shown to have a positive conservation effect, supporting numbers of small to medium sized prey species, by suppressing the impacts of invasive mesopredators (e.g. feral cats and foxes) (Nimmo et al. 2015).

Both dogs and dingoes have strong cultural and spiritual importance to Indigenous people (Brookes et al. 2020). Dingoes hold a significant and privileged place in the spiritual and cultural practices of many Australian Indigenous communities, featuring in traditional stories and ceremonies, on cave paintings and rock carvings. Dingoes may be a totem animal for some Indigenous people (Smith and Litchfield 2009; Bush Heritage 2021).

8.2 Dogs in remote communities

Dogs in remote Indigenous communities (referred to in this document as community dogs) are abundant and usually allowed to free-roam. Community dogs are highly valued and live in close proximity to people. Almost all community dogs are owned and are considered intrinsic members of the family. They are companions, protectors (both physical and spiritual) and hunters (Brookes et al. 2020). Movement controls that include domestic dogs in remote communities may have a negative impact on communities' ability to hunt and obtain food.

Community dogs may roam widely (e.g. 10-20 km) (Dürr and Ward 2014; Smout et al. 2018; Ward 2021) and may also travel over wide areas when involved in hunting events with their owners. Hunting dogs may go out of sight of owners and may go “missing” on a hunt, or while roaming. The distribution of dingoes/feral dogs overlaps spatially with free-roaming domestic dog populations, particularly in remote communities. The degree and type of interaction between these populations is not precisely defined although there are ample verbal reports of interactions. Human-provided sources of food (e.g. rubbish dumps, hunting carcasses) and other areas close to remote human settlements may be focus points for dingo/domestic dog interaction or overlap (Newsome et al. 2013; Gabriele-Rivet et al. 2021a).

There is limited and sporadic access to veterinary services in remote Indigenous communities and health issues in community dogs are likely to be under-reported or under-detected compared to dogs in more urbanised areas (Gabriele-Rivet et al. 2019). Costs of parasite control treatments for dogs are higher in remote regions than in urban areas and residents may not be able to afford these products, even when available (Brookes et al. 2020; AMRRIC 2021). There are other challenges in diagnosis and treatment of health issues in dogs in remote communities, such as delays between sampling, testing and notification of results (e.g. vets are no longer in the community by the time results are available) and communicating results to animal owners is also challenging. There may be limited access to medications, including parasite control products, as well as issues with cost and compliance with long courses of antibiotics.

9. Epidemiology of *E. canis*

9.1 Aetiologic agent

Ehrlichia are gram-negative, small coccoid to ellipsoidal bacteria that reside within cytoplasmic vacuoles of the host cells, frequently in compact inclusions called morulae.

Ehrlichia canis was originally reported from Algeria in 1935 and during the Vietnam War the disease resulted in significant mortality among the military dogs (many of them German Shepherds) of the US forces and their allies (Kelch 1984).

9.2 Global distribution

Ehrlichia canis occurs worldwide, particularly in tropical and subtropical regions and is endemic throughout Southeast Asia.

9.3 Occurrences in Australia

Ehrlichia canis was, until recently, considered to be absent from Australia. It is now considered to be established in the NT and in WA, north of the 26 S parallel. The first reports of ehrlichiosis in dogs in the far north of SA occurred in March 2021 (DPIR 2021b). The most current information on known distribution of the pathogen in Australia can be found on the relevant state and territory government departments of agriculture websites. In some remote communities in the NT, the estimated prevalence in community dogs is as high as 100%, with mortalities in dogs estimated as high as 30% in some locations (Cumming 2021a).

It is not known how or when *E. canis* entered Australia. The widespread prevalence of the organism on surveillance during 2020 indicated the organism may have been present, undetected, for some years. A syndrome in dogs similar to *E. canis* infection has been reported by vets in northern Australia for several years (Irwin 2020). *Ehrlichia canis* may have been present in northern Australia for some years at low levels, alternatively, it may be a more recent occurrence (within the last 24 months). The scale of infection and observable signs that have been reported during the northern wet season of 2020-21 is unprecedented. This was most likely assisted by the favourable climatic conditions for tick reproduction during that season (as opposed to relatively ‘dry’ wet seasons for the previous few years) (Cumming 2021b).

It appears likely that *E. canis* will continue to spread geographically in Australia throughout all regions where the brown dog tick is endemic. It is possible that *E. canis* in domestic dogs may eventually exist sporadically over the whole of mainland Australia, given the ability of the vector, the brown dog tick, to reside in houses [which means that climatic limiters of distribution may be over-ridden] (Irwin 2021a).

9.4 Affected species

Some *Ehrlichia* spp. appear to be host-specific but other species are known to infect hosts that are taxonomically distant (Davidson et al. 2008). Dogs are the principal vertebrate reservoir of *E. canis* (Ewing 1969). Some breeds of dog, for example German Shepherds, appear to be particularly susceptible to disease. Prevalence of infection in some dog populations globally has been reported to be over 70% (Diniz et al. 2007).

There are reports of infection in other canid species globally (Santoro et al. 2016), see below and Appendix 2. On rare occasions, humans or cats can become infected from a tick bite although this has not been reported in Australia (Stich et al. 2008; Day 2011).

9.5 *Ehrlichia canis* infections in non-domestic carnivore species

Ehrlichia canis infection has been reported in a range of carnivore species in endemic regions of the world (Davidson et al. 2008) (see Appendix 2). Both naturally occurring and experimental infections have been reported. Evidence of infection has been reported in both captive (e.g. zoo) and free-ranging settings in endemic areas. Many reports are derived from serological studies, where cross-reactivity with other species of *Ehrlichia*, or even other closely-related bacteria, may be a confounding issue. André (2018) provides a recent summary of molecular evidence of *E. canis* infection in non-domestic species.

Relatively little is known about the impacts of *E. canis* infection in non-domestic carnivore species. Most studies have focused on the potential of non-domestic carnivores to act as reservoirs or as hosts for *E. canis* infection passing to domestic animals. The epidemiological importance of infection in hosts other than dogs is still not understood (Davidson et al. 2008). There is little evidence to suggest that hosts other than the domestic dog play an important epidemiological role in this disease and it is likely that they are incidental hosts. Although there is relatively little information on the possible pathogenic effects of infection in non-domestic carnivores, clinical signs have been reported. In general, infected animals show few or no clinical signs, and signs, when seen, are similar to those seen in domestic dogs. Some earlier reports speculated that non-domestic carnivore hosts such as the red fox, jackal and others may play a role as reservoirs of *E. canis* however there is little contemporary evidence to support this (Davidson et al. 2008).

9.6 *Ehrlichia canis* and dingoes

There are no reports of *E. canis* infection in wild dingoes and no available information on the clinical expression of disease due to *E. canis* in this canid. As dingoes are closely related to the domestic dog, it is assumed that dingoes may also become infected with *E. canis* and may be susceptible to similar disease as a result.

Given that there appear to be differences in the susceptibility of domestic dog breeds to *E. canis* infection, it is possible that dingoes may also differ as a taxonomic group in their susceptibility to *E. canis*, compared with domestic dogs. Likewise, there will probably be differences in susceptibility to disease between individual dingoes, influenced in part by host genetics, as is the case in domestic dogs. As dingoes would be a naïve host, they would almost certainly be severely affected by *E. canis* infection, as has been seen in community dogs in Australia in 2020-21.

9.7 *Ehrlichia canis* transmission and the brown dog tick

Ehrlichia canis is transmitted by the brown dog tick (*Rhipicephalus sanguineus*; BDT), which is the most widespread tick globally (Dantas-Torres 2010)[3]. The BDT is widely present in Australia, predominantly in the north (Greay et al. 2016; Chandra et al. 2020) (see Appendix 1; Figure 2). This tick is not native to Australia and is thought to have been introduced to Australia with European migration and domestic dogs (Greay et al. 2016). The exact distribution of the BDT in Australia is unknown, and recent publications and discussion have suggested a wider distribution than previously reported (Greay et al. 2016; Chandra et al. 2020). Greay et al. (2016) suggested the BDT would be distributed into the northern parts of SA, in climatic and biogeographic zones similar to where it is found in central NT. In February 2021, the BDT was reported in the state of South Australia for the first time, in the Anangu Pitjantjatjara Yankunytjatjara (APY) lands (DPIR 2021a).

Although dogs are the natural host of the BDT, the ticks may occasionally parasitise other mammalian hosts, including humans (Dantas-Torres 2010). The BDT is a vector of many other dog pathogens (Dantas-Torres 2008).

Dogs acquire *E. canis* infection within a short time (<3-6 hours) after being bitten by an infected tick, and the bacteria passes into the dog's bloodstream. The disease is maintained by a cycle of transmission between ticks and dogs. Dogs cannot transmit the disease directly to each other.

The BDT is a three-host tick. Immature stage ticks (larvae and nymph) become infected after feeding on infected dogs and are able to maintain the infection between life stages. Ticks in both nymphal and adult stages can infect the host (Dantas-Torres 2010), however transovarial transmission (from female tick to eggs) does not occur. Each female tick life-stage feeds only once. Male BDT, which are highly mobile (often between dogs) and 'graze' (i.e. imbibe small amounts of blood), may act as mechanical vectors with even shorter transmission times (Bremer et al. 2005; Fourie et al. 2013). The organism can be transmitted by the tick less than three hours after attachment (Stanneck and Fourie 2013; Jongejan et al. 2016; Irwin 2021b). Ticks can remain infectious for up to 5 months. The organism can also be transmitted through blood transfusions. Under optimal conditions, ticks can complete four life cycles in a year and can survive for many months in the environment. Desiccation is a major limiter of BDT survival, and BDT numbers typically increase during humid seasons.

The BDT may be active throughout the year, not only in tropical and subtropical regions, but also in some temperate areas. Transmission of *E. canis* occurs mainly during warmer months, when the tick vector is most active (Dantas-Torres 2010). This tick species can complete its entire lifecycle indoors, thereby potentially allowing it to survive in colder climates. In the tropical north of Australia, communities with dogs typically see a significant increase in BDT numbers during the wet season (generally November to March) (Cumming 2021b).

The BDT is highly adapted to living inside human dwellings (endophilic), and this is where they are predominantly found, but they are also able to survive in outdoor environments, if suitable refuges (e.g. walls with nooks and crannies) and humidity are available. The BDT primarily employs host-seeking behaviour, although it can also adopt ambush behaviours. It is likely that the behavioural traits of the BDT evolved from

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[3] *Ehrlichia canis* DNA has been detected in *R. turanicus* in Israel, where prevalence of *E. canis* in dogs and other canids is high (Harrus et al. 2011); and in *R. bursa, Haemaphysalis sulcata* and *Dermentor marginatus* in Sardinia (Satta et al. 2011; Masala et al. 2012). Experimental transmission of *E. canis* in dogs has been accomplished by *D. variabilis*, the American dog tick, which is not present in Australia (Johnson et al. 1998). There is no evidence to suggest these, or any other ticks play an epidemiological role in transmission of *E. canis*.

its relationship with the domestic dog and their shared environment, over evolutionary time (Dantas-Torres 2010).

Globally, there is little detailed information about the prevalence of *E. canis* in BDT in endemic areas. A Turkish study looking primarily for molecular evidence of trans-stadial transmission of *E. canis* in BDT under field conditions reported a 35% infection rate in ticks derived from infected dogs (Ipek and Aktas 2018). However the dogs in the Turkish study displayed no clinical signs and the authors speculated that the low detected prevalence of *E. canis* in ticks may have been due to insufficient concentrations of circulating pathogens in the clinically healthy dogs to allow detection. This is likely to be in contrast with the situation in Australia where naive dogs are becoming infected and showing severe signs of disease. We assume in the Australian situation that levels of bacteraemia would be considerably higher, and therefore prevalence of infected ticks would be considerably higher than that seen in endemic areas globally.

9.8 Brown dog ticks and wild dingoes

There are no known published reports of BDT on wild dingoes, although the available data on ectoparasitism in wild dingoes in general are limited. The BDT is not considered to be a "bush tick" and is less likely to thrive in an unmodified environment away from human settlements. As such, there may be limited opportunities for BDT to parasitise wild dingoes. Subject matter experts, including veterinarians working in remote Indigenous communities, report that ticks in general are rarely seen on wild dogs and BDT have not been seen on wild dingoes. Wild dingoes have no visible signs of tick presence on camera trap images, even in areas and during seasons when ticks are abundant on nearby domestic dogs (Allen 2021; Ward 2021); and wild dingoes (e.g. pups) brought into communities are rarely observed with tick infestations (AMRRIC 2021). This most likely reflects the ecological preferences of BDT for shelters and dwellings, the much lower densities of dingoes in the wild, compared with dogs in communities, and the frequency with which wild dingoes move around in their environment.

Dingoes are likely to congregate in relatively small groups, move often between resting sites, groom each other and actively groom themselves, perhaps more so than domestic dogs. It is thought that dingoes may be more agile and flexible, and may be able to groom themselves more thoroughly than a domestic dog is able to (Cutter 2020). All these factors are likely to reduce the likelihood of BDT parasitising dingoes.

There is no evidence to suggest that dingoes are biologically more resistant to parasitism by BDT than domestic dogs, although this is possible. Any differences in ectoparasite prevalence between dogs and dingoes would most likely reflect differences in ecology, such that dingoes living in conditions similar to domestic dogs would have equal likelihood of BDT parasitism as dogs in the same environment. Wild dogs living in close proximity to human settlement (e.g. near rubbish dumps and other sources of food) may be more likely to carry ticks that wild dogs in other areas (Allen 2021).

10. Clinical signs and pathology

Canine ehrlichiosis has an incubation period of 8–20 days following exposure of a dog to an infective tick. The severity of disease in dogs may range from subclinical to life-threatening. There may be variations in the immune response in individual dogs or breeds, and there may be differences in the strain of pathogen transmitted (Little 2010; Rawangchue and Sungpradit 2020). Young and old animals seem to be more susceptible to disease effects. Mortality is highest in naïve dogs and in certain breeds, for example, German Shepherd (Irwin 2001).

Infection may be acute (non-myelosuppressive), subclinical or chronic (myelosuppressive) and may progress through each phase (Harrus and Waner 2011). Clinical pathology changes in affected dogs include thrombocytopenia and anaemia. Reports of clinical disease in domestic dogs in Australia are consistent with reports of severe disease from other parts of the world.

There is limited information available on *E. canis* disease expression in non-domestic canids (Davidson et al. 2008). Naturally and experimentally infected wolves, foxes, jackals and African wild dogs either showed few or no clinical signs, or displayed signs similar to those seen in domestic dogs with *E. canis* infection (Amyx and Huxsoll 1973; Harvey et al. 1979; Van Heerden 1979).

There is no available information on *E. canis* disease expression in dingoes.

11. Diagnosis

Definitive diagnosis of ehrlichiosis requires collection and testing of blood samples via serological and/or molecular techniques. The diagnosis is supported by clinical signs, haematological and serum biochemistry abnormalities, and response to treatment. A range of in-clinic diagnostic test kits are available worldwide (but not in Australia) and they vary in their sensitivity and specificity (Irwin 2020).

The immunofluorescence assay (IFA) detects IgG antibodies against *E. canis.* Antibodies may not be detectable early in disease, and titres can persist for many months to years after the infection is resolved. PCR assays detect organism-specific DNA in the blood. PCR can be positive before seroconversion occurs and can detect an active infection. Due to the pathophysiology of the disease, detection of *E. canis* by PCR on whole blood is most reliable in the early stages of infection. Later in the course of chronic infection, sensitivity of PCR may decline as the organism sequesters in peripheral tissues (Harrus et al. 1998). An *E. canis* ELISA has been verified as 'fit for purpose' for surveillance of *E. canis* in the Australian dog population, and a number of state veterinary laboratories are routinely using the ELISA as a screening serological assay, rather than the IFA. For the diagnosis of *E. canis* infection in dogs with acute clinical disease, PCR testing on EDTA blood samples, in addition to serological testing, is currently recommended in Australia(CSIRO ACDP 2021). Definitive serological diagnosis of acute *E. canis* infections may require detection of an active *E. canis*-specific antibody response, as demonstrated by a rising titre of greater than or equal to 4-fold in magnitude when testing paired blood samples by IFA. Ideally, paired samples should be collected at least 2 weeks apart.

Because diagnosis requires collection and testing of blood samples, and sometimes repeated blood collection and testing, infection would be difficult to confirm in individual wild dingoes, due to logistical requirements. There is no validation data available for dingo samples in any serological or molecular assay for *E. canis* and the diagnostic characteristics of theses assays in this population is unknown. Whilst this significantly complicates the interpretation of any diagnostic results, for the purposes of this risk assessment, we assumed that the diagnostic testing methods used in domestic dogs would also be valid for dingoes. PCR on whole blood samples from dingoes could be used for the detection of active *E. canis* infection. Positive results may be informative. However, negative results must be interpreted in light of the unknown sensitivity of this assay in the dingo host. Any serological results from dingoes should be interpreted with caution, due to the unknown diagnostic sensitivity and specificity in this population (CSIRO ACDP 2021). It is also noted that interpretation of *Ehrlichia* spp.-reactive antibody titres detected in IFA surveys among wild mammalian hosts can be complicated by serological cross-reactions to other pathogens (André 2018).

Differential diagnoses may include anaplasmosis, babesiosis, lymphoma, multiple myeloma and other immune-mediated diseases.

Australia is developing a national case definition for *E. canis* infection in canids, which will discuss methods of diagnosing infection and disease in domestic dogs.

12. Treatment

Early treatment of infected dogs is important for full clinical resolution. If treated early, antibiotics and supportive care may assist in curing the disease. Tetracycline, doxycycline and minocycline have been shown to be moderately effective treatments for all forms of canine ehrlichiosis, with rifampicin also recommended in cases of tetracycline failure (Mylonakis et al. 2019). Antibiotic treatment is required daily for at least four weeks in infected dogs.

There is currently no information on the likely effectiveness of these treatments in dingoes, if they were to become infected with *E. canis.* Due to their close taxonomic relationship to dogs, it is assumed that treatments used in dogs would be equally effective in infected dingoes. Logistically, treatment of wild dingoes would not be possible.

13. Prevention and control

There is no vaccine against *E. canis.* Once ehrlichiosis is present in the tick population, it is very difficult, if not impossible to control, particularly in tropical and subtropical regions. Tick control is the main preventative measure against the disease (Little 2010). Regular treatment of dogs with an effective acaricide (in accordance with the manufacturer's recommendations) to prevent tick attachment is of primary importance to protect individual dogs. A combination of tick control methods may be required e.g. a treatment that is strongly repellent to ticks (to prevent tick attachment), in combination with an acaricide (which kills ticks), in order to achieve optimum control of the disease in both the individual and the dog population at a given location. Treatment of the environment for ticks may also be required when tick burdens are high (Stanneck and Fourie 2013; Jongejan et al. 2016).

A study found that the speed of kill of two systemic acaricides (afoxolaner NexGuard® and fluralaner Bravecto®) against the BDT was not sufficiently fast to prevent transmission of *E. canis* in dogs and resulted in only partial protection capacity. A product combining imidacloprid and permethrin (Advantix®) effectively blocked transmission of *E. canis* to dogs in the challenge period (Jongejan and Uilenberg 2004). Seresto® collars (imidacloprid 10%/flumethrin 4.5%) were also found to be effective in long-term prevention of transmission of *E. canis* in dogs in experimental conditions (Stanneck and Fourie 2013). These products are up to ten times more expensive to purchase than other tick control treatments currently used in most remote communities, and there may be concerns in the use of collars in community dogs (Cumming 2021a).

14. Surveillance, control and management protocols for *E. canis* in Australia

For many years, Australia has had stringent quarantine protocols to prevent entry of *E. canis* into Australia from overseas importation (Department of Agriculture 2013). *Ehrlichia canis* is a nationally notifiable animal disease (DAWR 2016). Prior to detection, there were no formal surveillance programs in place in Australia for *E. canis*, although research had been undertaken to look for evidence of *E. canis* infection in dogs in northern Australia (Mason et al. 2001) and the national animal surveillance system had not detected any evidence of the pathogen in Australia.

After the initial detections of *E. canis* in northern Australia in 2020, both the WA and NT governments advised against movement of dogs. WA placed controls on dog movement from the shires of Broome, Derby-West Kimberley, Halls Creek and Wyndham-East Kimberley to other regions (www.agric.wa.gov.au/biosecurity/kimberley-dog-controlled-area-%E2%80%93-dog-movement-conditions). In the NT, advisory notices against dog movement (rather than regulatory controls) were put in place[4] (https://nt.gov.au/industry/agriculture/livestock/animal-health-and-diseases/ehrlichiosis-disease-dogs). Tasmania has enacted a requirement that dogs entering the state be declared tick-free on arrival, in order to reduce the risk of entry of the brown dog tick (Biosecurity Tasmania 2021).

Wildlife Health Australia provided interim advice to CCEAD to consider movement controls on dingoes where allowable (i.e. if researchers or wildlife managers were planning to move wild dingoes).

State and territory departments instituted surveillance efforts (of both real time and archived samples) soon after detection of the pathogen in Australia (National Pest & Disease Outbreaks 2021). Animal Management in Remote and indigenous Communities (AMRRIC; www.amrric.org), along with relevant state and territory departments developed community advisory programs for *E. canis* and domestic dogs (e.g. www.amrric.org/resources/view/tick-prevention-for-dogs-and-cats).

A working group of Australia's Animal Health Committee (AHC; www.agriculture.gov.au/animal/health/committees/ahc) developed a document outlining a proposal for nationally-agreed controls for *E. canis*.

Educational materials and tick control programs continue to be developed and circulated through both affected and unaffected areas (AHC 2021).

PART C: ASSESSING THE RISK OF *E. CANIS* TO WILD DINGOES IN AUSTRALIA

15. What is the likelihood that *E. canis* could enter, establish and spread in wild dingo populations in Australia?

15.1 What is the likelihood that *E. canis* could enter wild dingo populations?

There are no reports of *E. canis* in wild dingoes in Australia. For wild dingoes, the most likely entry source of *E. canis* would be via BDT from infected domestic dogs. Other possible sources (e.g. ticks from infected feral dogs and foxes, iatrogenic spread) are considered highly unlikely and are not addressed in this document. Further new introductions of *E. canis* from outside Australia (including new strains with possible differing pathogenicity) are not addressed in this risk assessment.

15.1.1 What are the possible transmission pathways for pathogen from domestic dogs into wild dingoes?

Transmission of *E. canis* from one host to the next requires a BDT to feed on the first (infected) host, acquire the pathogen, drop off the first host, and then feed on the second host. For female BDT, a change in life-stage needs to occur before she feeds on the new host. Male BDT can feed multiple times during one life-stage ('grazing'). Trans-ovarial transmission does not occur.

Interactions between dingoes and dogs are pivotal to the risk posed to wild dingoes by *E. canis*. Published studies have examined the interactions and spatial overlap of wild dingoes and domestic dogs, with a view to assessing risks associated with disease transmission, in particular rabies (Sparkes et al. 2015; Bombara et al. 2017; Gabriele-Rivet et al. 2021b). However in contrast to rabies, the transmission of *E. canis* does not require direct contact between hosts, only the ability for infected ticks to spread from one host to another.
Dogs in remote communities arguably pose the highest transmission risk to wild dingoes because of their location in areas of Australia with recognised BDT presence, their largely free-roaming nature and proximity to

[4] In the NT there was no existing legislation to support a mandated movement control of dogs.

wild dingoes, along with reduced access to veterinary services, disease investigation and treatment options, and tick prevention products and programs.

Restrained domestic dogs are less likely to provide a transmission pathway for *E. canis* to dingoes, however hunting activities with owners, for example, may bring these dogs into areas where wild dingoes also live.

Therefore the likelihood of *E. canis* spilling over from domestic dogs to wild dingoes in Australia is intimately linked to the prevalence of both *E. canis* infection and BDT in remote Indigenous communities.

The possible transmission pathways for *E. canis* to move between domestic dogs and dingoes include:

1. **Close contact between dogs and dingoes, allowing for easy transmission of infected ticks**. There are numerous anecdotal reports of dingo pups being brought into, and raised in, remote communities as pets. In these cases it is typical that around the age of sexual maturity the dingo pups "take off back to the bush" and presumably reunite with other wild dingoes (AMRRIC 2021; Cumming 2021a; Ward 2021). If individual dingos returning to the wild have become infected with *E. canis* during their time in the community, or are infested with BDT-carrying *E. canis*, a clear potential transmission pathway exists.

   Genetic studies also show mixing of domestic dog and dingo lineages, indicating ongoing interactions between dingoes and dogs, although when or how this has occurred is not always clear (Bombara et al. 2017). Some community dog owners actively promote mating between community dogs and dingoes, to "bring dingo genes" into their owned dogs (favoured particularly for hunting) (Phelan 2021).

   The free-roaming behaviour of community dogs and the practice of hunting with dogs in remote areas of Australia may also bring domestic dogs into closer contact with dingoes. However, it is considered unlikely that free-roaming or hunting domestic dogs would have close physical contact with wild dingoes, in most instances, due to the reserved nature of wild dingoes (Ward 2021).

2. **Presence of** infected **ticks in the shared environment**. There is ample opportunity for free-roaming or human-accompanied domestic dogs to shed ticks into the environment. Infected ticks may then subsequently parasitise dingoes in the area. However, as the BDT is endophilic, it is unlikely that many of these ticks would be present outside of human settlements.

15.1.2 What is the likelihood of an *E. canis*-infected brown dog tick parasitising a wild dingo in Australia?

Due to the endophilic nature of the brown dog tick, it is considerably less likely that wild dingoes would be parasitised by this tick species, than domestic dogs (see Section 9.8 Brown dog ticks and wild dingoes, above). Available information supports the assumption that wild dingoes are infrequently, if ever, parasitised by the BDT, even in regions and climates where the tick is commonly found in other (domestic) settings. Dingoes living in conditions similar to domestic dogs would have equal likelihood of BDT parasitism as dogs in the same environment.

Wild dogs (including dingoes) that are in close proximity to human settlements are more likely to be parasitised by BDT than those living in more remote locations. In this risk assessment we consider wild dingoes that frequent areas such as refuse dumps and other areas where human-sourced food is available, to be at greatest likelihood of acquiring BDT. In addition, wild dingoes have none of the benefits of parasite control programs.

The likelihood that a BDT will be carrying *E. canis* will vary depending, in part, on the prevalence of *E. canis* in domestic dogs in the vicinity and the type and extent of tick management program that is in place in these domestic dogs. Assuming a near-100% prevalence of *E. canis* in domestic dogs, as reported in some remote communities, and assuming that little to no effective tick control may be undertaken in some communities, the likelihood of BDT being infected with *E. canis* may be as high as 100%.

For the purposes of this risk assessment, we adopt the scenario of a wild dingo frequenting areas close to human habitation, which infers the highest likelihood of a wild dingo being parasitised by a BDT, and also the highest likelihood that BDT will be infected with *E. canis*. We apply this likelihood to the risk assessment from this point onwards. There is some information on ectoparasitism in wild dingoes, and relatively detailed information on the prevalence of *E. canis* in some remote communities, so we are moderately certain of this prediction.

Therefore, the likelihood of wild dingoes being parasitised by BDT is considered to be LOW (see Appendix 3; Table 1). The degree of certainty of this prediction is MEDIUM (See Appendix 3; Table 2).

Ongoing spillover of *E. canis* infection from domestic dogs to wild dingoes (via infected ticks) could occur, facilitating establishment and spread of infection within dingo populations.

15.1.3 What is the likelihood of wild dingoes becoming infected with *E. canis* once parasitised by an infected brown dog tick?

For the purposes of this risk assessment, we have assumed that dingoes are as susceptible to infection with *E. canis* as domestic dogs. It is known that naïve dog populations are highly susceptible to infection from *E. canis*, if exposed (Kelch 1984).

Therefore, the likelihood of a wild dingo becoming infected with *E. canis* if parasitised by an infected BDT is considered HIGH. The degree of certainty of this prediction is HIGH.

15.1.4 What is the overall likelihood of *E. canis* entering a wild dingo population?

In summary, the likelihood of wild dingoes being parasitised by BDT is LOW and the likelihood of a wild dingo becoming infected with *E. canis* if parasitised by an infected BDT is HIGH.

Overall, the likelihood of *E. canis* entering a wild dingo population is considered to be LOW. The degree of certainty of this prediction is MEDIUM.

15.2 What is the likelihood that *E. canis* could establish within a wild dingo population?

Establishment of *E. canis* within a wild dingo population is defined in this document as persistence and transfer of *E. canis* infection within a wild dingo population, without the requirement for ongoing spillover from domestic dogs to maintain the infection cycle.

In order for *E. canis* to establish within a dingo population, in the absence of ongoing spillover from domestic dogs, dingoes would need to be competent hosts of *E. canis*. Given their close taxonomic relationship to dogs, we assume that dingoes would be competent hosts for *E. canis*.

The establishment of *E. canis* infection within a wild dingo population is considered less likely than establishment in community dog populations, due to the differences in the ecology, behaviour, and housing of dingoes compared to community dogs with respect to likely exposure to BDT. The endophilic nature of the BDT also means that wild dingoes are much less likely to be exposed to the vector than community and other owned dogs.

Therefore the likelihood of *E. canis* establishing within wild dingo populations is considered LOW. The degree of certainty of this prediction is MEDIUM.

15.3 What is the likelihood that *E. canis* could spread between dingo populations?

In this document, spread is defined as the movement of a pathogen beyond the originally infected host population to new geographic areas or populations.

If wild dingoes become infected, and suffer ongoing parasitism from brown dog ticks, we assume this pathogen could continue to spread to other dingoes (and other domestic dogs) which come into contact with infected ticks. There would be no need for hosts to have direct contact with each other, and different life-stages of an infected tick may transfer the pathogen to a new host in their vicinity. The pathogen could spread between dingo populations by:

- the movement of infected dingoes between populations (if BDT are also present) or
- the movement of infected ticks between susceptible hosts or populations, if, for example, different dingo groups share the same resting sites.

The factors influencing the likelihood of *E. canis* spread within dingo populations centre around the different behavioural ecology of wild dingoes compared to domestic dogs, and the ecology of the BDT. Wild dingoes are considered to have a lower likelihood than domestic dogs of being parasitised by BDT (see above). Wild dingoes of different populations are less likely to interact than domestic dogs, which frequently move (with their owners, or when they are rehomed) between different communities and settlements.

For these reasons, there is a reduced likelihood that *E. canis* will spread between dingo populations, compared to the same situation in domestic dog populations. We consider a low likelihood that wild dingoes could act as a reservoir for *E. canis*, or that spillback to domestic dogs from dingoes could occur, however this possibility should be considered, with appropriate risk management if needed, whenever wild dingoes and dogs make contact. We know relatively little about infectious disease transmission between wild dingoes, compared to domestic dogs, so our degree of certainty is low.

Therefore, the likelihood of *E. canis* spreading within wild dingo populations is considered LOW. The degree of certainty of this prediction is LOW.

15.4 What is the combined likelihood that *E. canis* could enter, establish and spread in wild dingoes in Australia?

Overall, the likelihood that *E. canis* could enter, establish and spread in wild dingoes in Australia is considered to be LOW. The degree of certainty of this prediction is LOW.

16. What are the possible consequences if *E. canis* enters, establishes or spreads in wild dingoes in Australia?

For the purposes of this risk assessment, we have assumed that dingoes are as intrinsically susceptible to *E. canis* disease as domestic dogs, and we assume that the impacts of disease on naïve wild dingoes would be similar to those seen in naïve domestic dogs in Australia.

The spectrum of *E. canis* disease in infected dogs can vary significantly from subclinical infection to transient disease to persistent, debilitating and fatal disease. It is assumed that host genetics play a role in the differing pathogenesis of infectious diseases in domestic dogs. The same could also apply for dingoes. If dingoes have a restricted gene pool, this could potentially make them either more or less susceptible to manifestations of disease compared to the average domestic dog.

Disease as a result of *E. canis* infection in dogs causes significant suffering and pain. The same would be expected to be the case for dingoes, so the expectation is that there would be significant welfare compromise, as a result of pain, debilitation and possibly secondary diseases or threats, if wild dingoes develop ehrlichiosis. Wild dingoes would be untreatable, with no effective method of administering antibiotics or other supportive care. Any attempts to restrain severely ill and debilitated dingoes for treatment would be highly stressful for the animal due to the wild nature of the patient. Such attempts might result in further complications such as self-trauma or other stress-related diseases. Dingoes would also be expected to experience distress as a result of illness or death of their pack-mates.

As dingoes in Australia are assumed to be immunologically naïve to this pathogen, impacts on dingoes are expected to be at least as severe as those seen during 2020-21 in community dogs in affected areas, where up to 30% mortality has been reported (Cumming 2021a). Many infected individuals might die from ehrlichiosis, and other individual dingoes could become sufficiently debilitated to succumb to other causes of death. Reproductive success might diminish. Dingo population sizes and dingo genetic diversity might both diminish. The impacts of chronic ehrlichiosis (in contrast to acute disease) are more difficult to estimate, but this aspect of infection would also place stress on dingo populations.

Dingoes are apex predators in Australia and the consequences of *E. canis* would extend beyond the impacts on dingoes themselves. The loss of dingoes as apex predators would result in disturbances of the trophic cascade and mesopredator release, with consequent significant impacts on prey populations and biodiversity in general (Newsome et al. 2017; Wayne et al. 2017).

Dingoes are culturally significant to Indigenous people in Australia. Sickness, death and decline of dingo populations may have deep emotional and cultural impacts on Indigenous communities and individuals. Deaths and sickness in wild dingoes are also likely to cause distress in people working with dingoes, the scientific community and the public in general.

Applying the criteria outlined in Appendix 3, Table 3, the consequences of *E. canis* disease in wild dingo populations could include considerable animal illness and/or deaths at multiple locations, or populations. There could be a moderate population decline in wild dingoes, if mortality rates were at the high end of what might be expected. Therefore, the consequences of entry, establishment and spread of *E. canis* in wild dingoes is assessed as MAJOR (and noting that one or more criteria within a consequence category may be met).

17. What is the overall risk if *E. canis* were to enter, establish or spread in wild dingo populations?

The overall estimation of risk of *E. canis* to wild dingoes in Australia, using the matrix provided in Appendix 3, Table 4, is considered MODERATE (the overall likelihood of entry, establishment and spread is considered LOW, with MAJOR consequences).

18. What are the possible mitigation measures to reduce the risk of *E. canis* to wild dingoes in Australia?

There are a range of actions that could be undertaken to mitigate the risk of *E. canis* to wild dingoes. Only those that are considered logistically feasible are discussed in any detail in this document and this is not an exhaustive list of all possible mitigation measures.

Management or control *E. canis* infections in wild dingoes would be extremely difficult, if not impossible. Attempts to manage transmission of disease from infected tick to dingoes, by stopping the infected tick from attaching and feeding on the dingo are considered both impractical and virtually impossible. The chances of success, if attempting to apply a topical anti-tick treatment or delivering an oral bait (e.g. oral long-acting tick treatment) are considered to be extremely low (Wildlife Health Australia 2020). Likewise, treatment of sick wild dingoes is considered impractical and virtually impossible. Control and/or eradication of *E. canis* from dingo populations, once established, is therefore considered to be practically impossible.

The method of transmission of the pathogen (via the BDT) is well-understood and transmission can be effectively managed in domestic dogs by use of appropriate tick control strategies. Likewise, antibiotic treatment and supportive care (although more complicated than tick prevention) can be effectively applied in infected domestic dogs. As explained above, the risk of transmission of *E. canis* to wild dingoes is considered greatest from dogs in remote communities. Mitigation of risk of *E. canis* to wild dingoes could be most effectively achieved by addressing the pathogen in remote community dogs. Eradication of *E. canis* or the brown dog tick from Australia is not considered feasible.

19. What are the gaps in knowledge?

The ability to estimate the risks of *E. canis* infection to dingoes, and the certainty of any estimations, is hampered by a paucity of knowledge in many areas. Information and data are lacking in the following areas:

- the true geographic distribution and prevalence in brown dog ticks in Australia
- the susceptibility of wild dingoes to parasitisation from the brown dog tick
- the susceptibility of dingoes to infection with *E. canis*
- the pathogenesis and clinical effects of ehrlichiosis in dingoes (assuming they are susceptible to infection)
- diagnostic test performance in dingoes, for *E. canis* detection, and more widely
- the geographic extent and prevalence of *E. canis* in both Australian dogs and ticks
- the likely and possible geographic extent of *E. canis* in Australia, assuming it becomes established
- the seasonal, climatic, and environmental factors that influence brown dog tick presence, life cycle, activity and infectivity in Australia
- the degree of indirect (e.g. shared spaces in the environment) or direct mixing of domestic dogs and dingoes in areas where *E. canis* is known or likely to occur and other at-risk geographic areas of Australia
- the factors that enhance or hinder mingling or spatial overlap of domestic dogs and wild dingoes.

Detailed recommendations for addressing identified gaps in knowledge are outside the scope of this project. Implementation (wherever possible) of the relevant actions outlined below will help to address some of these deficiencies.

Resourcing to allow monitoring of, and passive disease and tick surveillance on, wild dingoes will also help to establish baseline data if *E. canis* does emerge in wild dingoes. Surveillance in remote community and other domestic dogs will also assist in closing some of these knowledge gaps.

20. Key actions for risk mitigation

Key mitigating measures for reducing the risk of *E. canis* to wild dingoes are listed below. We note it may be logistically, socially and economically challenging to implement mitigation measures.

Key risk mitigation measures:

- gain a better understanding of the **true geographic extent** of both the **brown dog tick and *E. canis*** within Australia.
- implement **effective tick control and disease control and treatment in all domestic dogs in all at-risk areas, and in particular in community dogs and other at-risk dogs**, to reduce the impacts of the disease and limit further geographic spread. Effective tick and disease control in community dogs is

considered the most practical and effective way to reduce the risk of the pathogen spreading to wild dingoes (see more detail below).

- attempt to further limit the geographic spread of the pathogen, and mitigating the risks associated with the **movement of dogs (and the human-assisted movement of dingoes)**, by communicating the risks to people moving dogs and dingoes, so that they can take appropriate risk-mitigation actions.

The areas of focus in **domestic dogs (to mitigate risks in wild dingoes)** include:

- stringent tick control in domestic dogs in at-risk areas. A combination of an effective tick repellent for individual dogs, together with reduction in overall tick populations through effective systemically-acting acaricides, will minimise the risk to dogs. Environmental treatments may be needed to reduce tick burdens in houses, yards and kennels.
- prompt veterinary attention, diagnosis and appropriate treatment of sick dogs in at-risk areas, and prevention (by use of tick-kill and repellent treatments) of these dogs from passing *E. canis* to BDT
- monitoring for chronic ehrlichiosis cases in dogs, with appropriate treatment and management if detected
- monitoring or communication around the risks of human-enabled movement of domestic dogs to and from at-risk areas, to help minimise the further geographic spread of *E. canis.*

Ongoing surveillance in domestic dogs (including detection of chronically infected individuals), in particular in remote communities, will help to inform needs for treatment/ control programs and will help to focus the surveillance efforts on wild dingoes to the highest risk geographic areas.

Priority areas of focus to be considered in **dingoes** are:

- Passive surveillance in wild dingoes for both *E. canis* and the presence of brown dog ticks. This should include gathering of data on general health/ body condition score/ other indirect health assessment in dingo populations whenever wild dingoes are observed
- Opportunistic collection of biological samples and health data in both wild and rescued dingoes
- Activities to raise awareness of the pathogen and the need for data for those people who do research on, or manage, wild dingoes.

Additional areas of activity that would significantly contribute to Australia's understanding of *E. canis*, and ability to respond to disease threats include:

- working with Indigenous communities and other key stakeholders to implement effective tick control and *E. canis* awareness programs in risk areas.
- increased understanding of the factors that influence spatial overlap of domestic dogs and wild dingoes (e.g. availability of human-associated food sources) and develop strategies to minimise undesirable mingling events.
- increased awareness in wildlife managers, researchers and other stakeholders of *E. canis* risk to wild dingoes, as well as an understanding of risk mitigation measures, and appropriate pathways for reporting suspect cases in dingoes.
- established processes for timely and comprehensive reporting of suspect cases in dingoes.
- appropriate investigation of suspect cases in dingoes using appropriate diagnostic tests; to sample suspect individuals for genetic testing to determine dingo/dog heritage, and also sample and identify ticks found on suspect cases.
- gathering data to improve understanding of the likelihood and prevalence of BDT parasitisation of wild dingoes in endemic areas.
- collection of opportunistic biological samples from wild and rescued/homed/captive dingoes across Australia (with a focus on likely *E. canis* "endemic" areas) to establish an archive of "baseline" samples (and to analyse samples wherever possible) and for testing for evidence of exposure to *E. canis*.

- Strengthening of networks and communication between dingo researchers and managers nationally, and all those responsible for wild animal health and disease management
- continued appraisal of the risk of *E. canis* to wild dingoes, as new information, data and understanding becomes available, and in particular if new information becomes available that alters any of the assumptions or statements within this document.

We note that some areas of risk mitigation outlined above will be practically impossible to achieve effectively, without a very significant and ongoing financial investment. There are considerable difficulties, complexities and a high financial and resource burden to achieve the effective tick control to all dogs in at-risk areas, particularly in remote communities. We also note that since this Risk Assessment was drafted, Australia has decided that it is no longer feasible to regulate dog movements, and that the most practical method of mitigating the risk associated with the movement of at-risk dogs may be voluntary reporting of dogs with clinical signs, arriving from at-risk areas.

21. Conclusions

The risk to wild dingoes from *E. canis* is considered MODERATE. This includes impacts on individual dingoes, dingo populations and on the species at large. It also includes flow-on impacts to the environment, to ecological cascades and to both Indigenous and non-Indigenous peoples in Australia. Many gaps in knowledge exist, including the susceptibility of dingoes to parasitisation by brown dog ticks, the susceptibility of dingoes to disease following infection with *E. canis* and the degree of mingling between wild dingoes and domestic dogs.

Mitigation of risks is only practically possible by addressing risks at the domestic dog interface. The most practical and effective method available to control risk to dingoes would be to apply regular effective tick control to all at-risk dogs, in particular domestic dogs in remote Indigenous communities.

The continued movement of domestic dogs around the country will almost certainly result in the expansion of the geographic distribution of *E. canis* across Australia (Irwin 2020). The wider the geographic spread of the pathogen across Australia, and the more populations of naïve dogs that are infected, the greater is the likelihood of the pathogen moving into the wild dingo population.

This disease risk assessment concludes that the three the most effective ways in which the risk posed to dingoes can be managed are:

- to deploy resources to effectively manage brown dog ticks in remote communities and other areas where there is a transmission risk to wild dingoes
- where possible, to implement active and passive surveillance of health and disease in wild dingoes, along with surveillance to determine presence and prevalence of *E. canis* in dogs and ticks throughout Australia
- to minimise the further geographic spread of *E. canis* in Australia and to mitigate the risks associated with the movement of dogs into and out of risk areas, through communication, awareness raising, and clear pathways for reporting of suspect cases in both dogs and dingoes.

22. Acknowledgements

Wildlife Health Australia would like to thank all those who contributed to the development of this document, both within and outside the organisation. In particular, we would like to extend our thanks to Emeritus Professor Peter Irwin, Professor Michael Ward, Dr Ben Allen, Dr Bonny Cumming and all the staff at AMRRIC, and the members of Animal Health Committee for their expertise and generosity. We thank all the participants and leaders of the workshops, symposia and working groups on *E. canis* in Australia, who shared their experiences and knowledge with our organisation. Without their assistance, this project would not have been possible.

Wildlife Health Australia acknowledges the Traditional Owners of Country around Australia and their continuing connection to land, sea and community. We pay our respects to them and their cultures and to their Elders, past, present and emerging.

23. Appendix 1: Distribution of dingoes and brown dog ticks in Australia

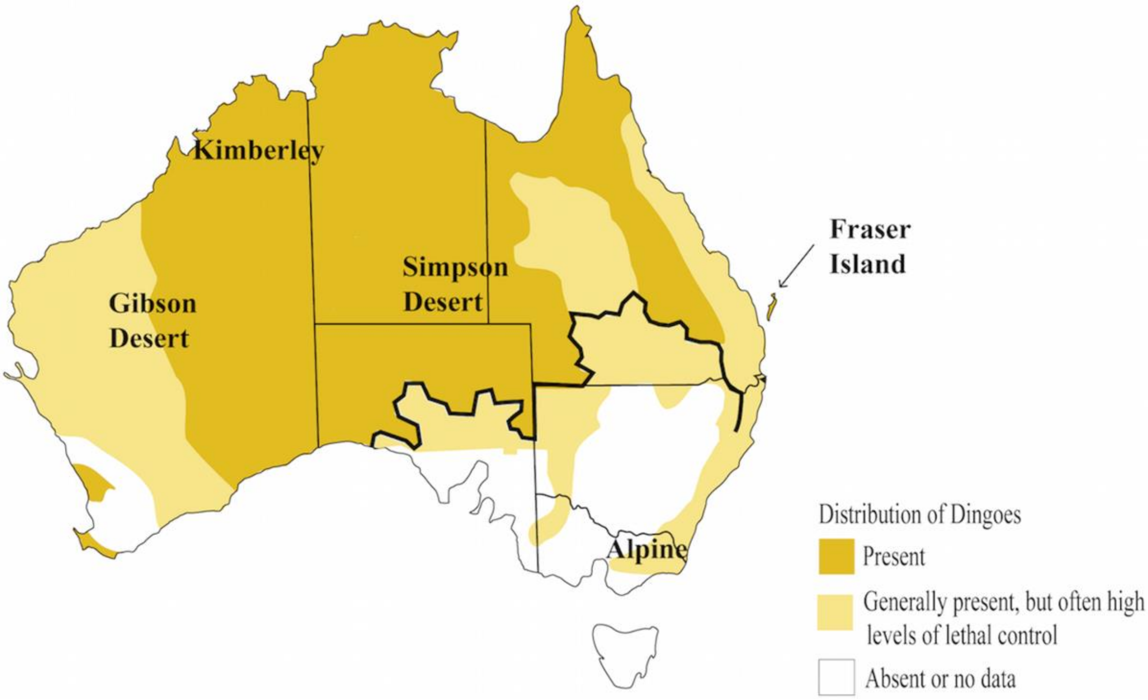

Figure 1: Dingo distribution in Australia [from (Cairns et al. 2018)]

Figure 2: Suggested brown dog tick distribution in Australia, including recent tick locations [Department of Agriculture, Water and the Environment, adapted from (Chandra et al. 2020)]

24. Appendix 2: Details of *E. canis* infection in non-domestic canids globally

Reports of *E. canis* include diagnoses made on the basis on molecular evidence and those based on serology, haematological or other pathological findings. Similarities between *E. canis* and related *Ehrlichia* spp. (or other related species) may make definitive diagnosis difficult.

Naturally acquired infections

Naturally acquired infections have been reported in a wide range of wild canid species, as well as in wild felids and other wild carnivore species, in endemic areas of the world, including South America, North America, Europe and Asia. Evidence of infection in wild carnivores is generally reported in areas where prevalence is high in domestic dogs, and where wildlife is in relatively close proximity to domestic animals and human habitation. Most surveys report low to very low prevalence of *E. canis* exposure.

Molecular evidence of *E. canis* has been reported in wild bush dogs (*Speothos venaticus*) and crab-eating foxes (*Cerdocyon thous*) from Brazil (André et al. 2012; De Sousa et al. 2017); artic foxes (*Vulpes lagopus*) from Canada (Mascarelli et al. 2015); red foxes (*Vulpes vulpes*)(Ebani et al. 2011; Torina et al. 2013; Cardoso et al. 2015; Millán et al. 2016; Santoro et al. 2016); and gray wolves (*Canis lupus*) (Santoro et al. 2016). Infection was also “confirmed” in a single captive gray wolf (*Canis lupus*) in the United States; the animal was not clinically affected (Harvey et al. 1979).

E. canis was demonstrated in 8 of 16 free-ranging wild black-backed jackals (*Lupulella mesomelas*) in Kenya, and at least 5 of these jackals also were parasitized by *R. sanguineus* (Price and Karstad 1980). In a later study in Kenya, only 1 of 36 jackals had detectable *E. canis*-reactive antibodies (Alexander et al. 1994).

In wild felids, molecular evidence of *E. canis* has been reported in wild ocelots (*Leopardus pardalis*); jaguarondis (*Herpailurus yagouaroundi*); little spotted cats (*Leopardus tigrinus*); pumas (*Puma concolor*); jaguars (*Panthera onca)*; and a captive lion (*Panthera leo*) in Brazil (André et al. 2010; André et al. 2012). Evidence has also been reported in free-ranging Iriomote cats (*Prionailurus iriomotensis*) and Tsushima leopard cats (*Prionailurus bengalensis euptilura*) in Japan (Tateno et al. 2013), and lions in captivity in Zimbabwe (Kelly et al. 2014). Molecular evidence of *E. canis* has been reported in raccoons (*Procyon lotor*) from the USA (Dugan et al. 2005) and Spain (Criado-Fornelio et al. 2018), coatis (*Nasua nasua*) from Brazil (De Sousa et al. 2017), and Eurasian otters (*Lutra lutra*) from Italy (Santoro et al. 2017).

Experimentally infected hosts

Experimental infections of *E. canis* have been established in black-backed jackals, African wild dogs (*Lycaon pictus*) (Van Heerden 1979), coyotes (*Canis latrans*) (Ewing et al. 1964), red foxes (*Vulpes vulpes*) and gray foxes (*Urocyon cinereoargenteus)* (Amyx and Huxsoll 1973).

25. Appendix 3: Risk assessment definitions, tables and matrices

Table 1: Categories and definitions of likelihoods

(Modified from Draft pest risk analysis for brown marmorated stink bug (*Halyomorpha halys*) DAWR 2017)

Likelihood	Descriptive definition	Indicative range*
High	The event would be very likely to occur	0.7 < to ≤ 1
Moderate	The event would occur with an even likelihood	0.3 < to ≤ 0.7
Low	The event would be unlikely to occur	0.05 < to ≤ 0.3
Very low	The event would be very unlikely to occur	0.001 < to ≤ 0.05
Extremely low	The event would be extremely unlikely to occur	0.000001 < to ≤ 0.001
Negligible	The event would almost certainly not occur	0 < to ≤ 0.000001

* Where 1 = certain

Table 2: Level of certainty of predictions
[Adapted from Cox-Witton et al. (2021)]

Description	Definition
High	Strong level of confidence in the assessment. Scientific evidence and/or previous experience of similar situations is available.
Medium	Moderate level of confidence in the assessment. Some scientific evidence and/or previous experience of somewhat similar situations is available.
Low	Limited level of confidence in the assessment. Scientific evidence and previous experience are lacking; high degree of variation across the scenarios considered; high potential for variability in the outcomes.

Table 3: Categories and definitions of consequence
(Adapted from NSW DPI Risk Assessment Template and Cox-Witton et al. (2021). One, or more, criteria may be met, for the category.

Consequence	Descriptive definition
Insignificant	Isolated impact on individual animals at a single location or in a single population. No detectable conservation effects.
Very minor	Limited animal illness &/or deaths at a single location or population. Individual morbidities and/or mortalities but no measurable decline in population numbers and no significant ecosystem effect. Only one host species affected.
Minor	Limited animal illness &/or deaths at one or more locations or populations. Possible individual morbidities and/or mortalities but little decline in

	population numbers. Some localised, reversible ecosystem impact. More than one host species possibly affected.
Moderate	Some animal illness &/or deaths at multiple locations or in multiple species. Small to moderate population level effects, with measurable long-term damage to populations and/or ecosystem, but little spread, no extinction.
Major	Considerable animal illness &/or deaths at multiple locations, (or populations) or in multiple species. Major population level effects in one or more species or a moderate population decline of one species. Long-term irreversible ecosystem change, spreading beyond local area.
Extreme	Significant animal illness &/or deaths in multiple locations and species. Significant population declines of >80%, including possibility of extinctions, of one or more species. Widespread ecological, ecosystem or economic consequences.

Table 4: Combining likelihood and consequence to determine overall risk
(Adapted from Department of Agriculture and Water Resources Biosecurity Import Risk Analysis Guidelines 2016)

Likelihood of hazard entry, establishment and spread	**Consequences of hazard entry, establishment and spread**					
	Insignificant	**Very minor**	**Minor**	**Moderate**	**Major**	**Extreme**
High	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Moderate	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Low	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk	High risk
Very low	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk
Extremely low	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk
Negligible	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk

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