Are urban bandicoots solely to blame for tick concerns?

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ABSTRACT

The paralysis tick *Ixodes holocyclus* bites humans, companion animals, and livestock in eastern Australia leading to symptoms that range between negligible and severe. Bandicoots (Family Peramelidae) are commonly cited as the "primary host" of *I. holocyclus* in the media and blamed for outbreaks of ticks and disease fears, creating conflicts between conservation and tick management. We discuss how evidence for bandicoots being essential to the *I. holocyclus* life cycle has originated from a small number of papers that were limited in scope. False assumptions of host-specificity have contributed to the extrapolation of studies in one ecosystem, yet no study has sampled the full range of hosts of *I. holocyclus* to understand the relative role of each species across the entire range of *I. holocyclus* in relation to health threats. Bandicoots are one of many potential tick hosts but cannot yet be considered the "primary host" of *I. holocyclus*. Researchers and media should refrain from highlighting bandicoots as the main *I. holocyclus* host without mentioning caveats, and work towards gaining a better understanding of tick–host interactions across the range of *I holocyclus* in order to better understand and mitigate public health risks.

Key words: *Ixodes holocyclus*, paralysis ticks, ticks, Ixodidae, bandicoots, Peramelidae, Lyme diasease

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Introduction

Bites of the Australian paralysis tick *Ixodes holocylus* are usually harmless for humans (Diaz 2010), but can lead to life threatening conditions or illnesses such as paralysis (Hall-Mendelin *et al.* 2011; Ross 1926), rickettsioses such as Queensland tick typhus and Flinders Island spotted fever (Russell 1998), and allergic reactions (including mammalian meat allergy) (Commins *et al.* 2011; van Nunen *et al.* 2011; Rappo *et al.* 2013). *Ixodes holocyclus* also bite human companion animals and livestock, potentially causing mild to severe symptoms including death (Bagnall and Doube 1975). Much debate currently surrounds the possibility of tick-borne pathogens (in particular, 12 species of *Borrelia* bacteria) causing Lyme Disease or a "Lyme-like" illness in Australia (Mackenzie 2013; Russell *et al.* 1994). *Ixodes holocyclus* is suspected of being the most likely local tick to vector the pathogen, as it is a member of the same genus as the known vectors of Lyme pathogens. However, it should be noted that research in the United States of America demonstrated that *I. holocyclus* was unable to transmit the main pathogen causing Lyme in the U.S., *Borrelia burgdorferi* (Piesman and Stone 1991). While the average *I. holocyclus* bite is uneventful, the risk of severe consequences makes understanding ticks and the organisms which support them necessary to prevent possible threats to humans and companion animals.

In the scientific literature (Barker and Walker 2014; Hall-Mendelin *et al.* 2011) and media (Bateman 2012; Chen 2013a; Chen 2013b; Kay 2011; Kruszelnnicki 2014; Williams 2013), ticks and their interactions with humans in Australia are commonly associated with a reference to bandicoots (members of family Peramelidae, the two most common being the Long-nosed *Perameles nasuta* and the Northern Brown *Isoodon macrourus*) being the "primary host" of *I. holocyclus*. This view has led to concern about bandicoot numbers, including calls for fox baiting to be stopped as a way to control ticks by decreasing the number of bandicoots (Chen 2013b).

In this paper we explore the perception that bandicoots are the primary host for ticks and review its origins. We explore whether the idea of bandicoots as the "primary host" of *I. holocyclus* might have emerged as a result of extrapolation of results across ecosystems and species, misguided assumptions of tick host specificity, and as a result of vague and rarely defined terminology. We also discuss gaps in our knowledge of the relative importance of different host species for *I. holocyclus* and its life cycle. Finally, we discuss the consequences of these results for public perception and conservation policy of bandicoots, with reference to an example from North America that demonstrates the pitfalls of tick control measures based on poor understanding of tick – host relationships, and provide some suggestions for future research directions in understanding and controlling the health risks of ticks.

Search strategy and selection criteria

Search Strategy

We searched for all available literature on *I. holocyclus* and its hosts by entering in the searches "*Ixodes holocyclus* + hosts", "paralysis ticks + hosts", and "ticks + hosts + Australia" into the Web of Science (WoS) and Scopus databases. Searching ended on 2/07/2014. Two search engines were used to improve comprehensiveness of the literature search, as WoS extends over a greater time period and Scopus provides a better coverage of Australian zoology.

Abstracts and full text, where available, were downloaded. Further information for this paper was found by reading the citations from the papers found during the searches.

Selection Criteria

15 articles were relevant to the question of *I. holocyclus* and its hosts, among these bandicoots were emphasised in all but 4 cases. Relevance was determined by checking if the article discussed *I. holocyclus* and it hosts. Scopus searches returned 138 results, of these only 9 articles were relevant (Barker and Walker 2014; Buettner *et al.* 2013; Cooper *et al.* 2013; Doube 1975; FitzGibbon and Jones 2006; Gemmell *et al.* 1991; Goodrich and Murray 1978; Jackson 1998; Masina and Broady 1999). 71 WoS searches produced 7 relevant articles, 1 of which was already found by Scopus, resulting in 15 articles between the two engines (Baxter *et al.* 2009; Buettner *et al.* 2013; Doube 1979; Kolonin 2007; Oxer and Ricardo, 1942; Roberts 1960; Scott *et al.* 1999).

Origins of assumed *I. holocyclus* dependence on bandicoots

In the 1970's, B.M. Doube at CSIRO's Long Pocket Laboratories in Queensland studied the ecology and biology of *I. holocyclus,* impacts on cattle, and possible management strategies (Doube 1975), and his work provides the starting point for the idea of *I. holocyclus* dependence upon bandicoots. Doube (1975) states that *I. holocyclus* has a "wide host range", and that there is little data on abundance of ticks on different host species, but then states that "the bandicoot is considered to be the principal host", without citation. His study trapped animals and counted ticks, concluding that *I. macrourus* is the "most favoured host animal", and "most other species carried very few ticks" (Doube 1975). However, *I. macrourus* comprised the majority of trapped animals (66.2%, 98 out of 148 animals) (Doube 1975), with the next most common animals being various possums, rodents and birds. Dogs or macropods were not trapped.

All of the articles we found which claim that bandicoots are the "primary" host of *I. holocyclus* cite Doube (1975) as the source of the claim. Doube's 1975 results are also cited in the most recent comprehensive publication about ticks that impact humans in Australia for the belief that bandicoots are the "principal host" (with the caveat "at least in south-eastern Queensland") (Barker and Walker 2014). None of these papers mention the limitations of Doube's study, and few acknowledged the wide host range of *I. holocyclus*. Conversely, there were several articles that did not specify bandicoots as the primary host of *I. holocyclus*, discussed the "wide host range" of *I. holocyclus* (Jackson 1998; Kolonin 2007; Oxer and Ricardo 1942; Roberts 1960), or used more conservative terms such as "a natural host" (Goodrich and Murray 1978).

Generalisations and Assumptions about *I. holocyclus* and Hosts

Assumed Host Specificity

Ixodes holocyclus dependence on specific hosts has been unduly emphasised by the media and some authors, despite current literature suggesting that tick-host relationships are plastic and explained by biogeography. Traditionally, the relationship between ticks and their hosts has been viewed as one of high host specificity – meaning that ticks have coevolved with their hosts – leading to dependence upon particular species (Klompen *et al.* 1996). Over the last two decades, this view has been challenged by both morphological and phylogenetic studies (Estrada-Peña *et al.* 2013 and Klompen *et al.* 1996). It is now believed that tick–host association patterns are not rigid and can be explained as artefacts of biogeography. While some ticks, particularly soft ticks, are dependent upon specific host species, most hard ticks – including *I. holocyclus* – can use a wide range of animals as hosts (see Table 1) (Barker and Walker 2014).

Extrapolation across geographic range

Studies of *I. holocyclus*'s ecology have largely been limited to south-eastern Queensland, and results from this region have been extrapolated across the entire range of *I. holocyclus*. The geographic range of *I. holocyclus* extends from Cape Tribulation in Queensland to Lake's Entrance in Victoria (Atlas of Living Australia 2014), and is mostly limited to within 20 kms of the coast. Within this range, *I. holocyclus* can be found in any habitat, but is most commonly found in forested areas with high humidity (Barker and Walker 2014, Doube 1979). Extrapolating results is made difficult as the two most common bandicoots have different, but overlapping distributions, which leads to cohabitation with different combinations of sympatric species. *I. macrourus* inhabit much of the northern and eastern coasts of Australia, while *P. nasuta* are limited to the eastern coast. *Ixodes holocyclus* may use bandicoots as hosts in areas where bandicoots are either the most common or most accessible organism. In some areas, other animals may be more common or accessible hosts. While *I. macrourus* and *P. nasuta* are similarly sized and nocturnal, they have different distributions resulting in cohabitation with different combinations of sympatric species and thus likely play differing roles as hosts for *I. holocyclus* across their respective ranges.

Pitfalls of trapping

The trapping studies that have been used to study bandicoots and *I. holocyclus* have limitations and less biased methods are now available. Studies on tick – host ecology typically use host animal trapping, but trapping is expensive, traps will not catch animals of all sizes, and some species are less easily trappable than others (Estrada-Pena *et al.* 2013). Genetic methods to analyse tick gut content, while even more expensive, are the best tools to identify the role of different species as tick hosts (Estrada-Pena *et al.* 2013), but no such studies have been done in Australia to date.

Exclusion of the Macropods

Members of the family Macropodidae – particularly many wallabies – are documented as hosting *I. holocyclus* (Roberts 1970; Barker and Walker 2014), yet they are rarely mentioned as a potential host and their relationship with *I. holocyclus* has not been studied. In Doube's 1975 study, no macropods were sampled, but are mentioned as being "known, at times, to carry numbers of [*I. holocyclus*] similar to those found on bandicoots". Several species of wallabies are mentioned in the literature as carrying *I. holocyclus* (Roberts 1970), and have overlapping ranges

Table 1. *I. holocyclus* has been recorded feeding on all of these organisms. Roberts 1970 provides a synthesis of host records up to 1970, and citations afterwards are provided. List adapted from information compiled and presented in Barker and Walker 2014. [1] Unpublished data discussed in Barker and Walker 2014.

Species	Common Name	Introduced?	Roberts (1970)	Citation after 1970
Isoodon obesulus	Southern Brown Bandicoot		Yes	
Isoodon macrourus	Northern Brown Bandicoot		Yes	Yes (Barker and Campelo)[1]
Perameles nasuta	Long-Nosed Bandicoot		Yes	
Trichosurus caninus	Short-Eared Brushtail Possum		Yes	Yes (Presidente *et al.* 1982)
Trichosurus vulpecula	Common Brushtail Possum		Yes	Yes (Marks and Cribb 1966)
Phascolarctos cinereus	Koala		Yes	Yes (Stone & Carrick 1990)
Aepyprymnus rufescens	Rufous Bettong		Yes	
Thylogale stigmatica	Redlegged Pademelon		Yes	
Wallabia bicolor	Swamp Wallaby		Yes	
Macropus dorsalis	Black-Striped Wallaby		Yes	
Macropus rufogriseus	Red-Necked Wallaby		Yes	
Dendrolagus lumholtzi	Lumholtz's Tree Kangaroo		Yes	Yes (Barker and Campelo)[1]
Bettongia tropica	Northern Bettong			Yes (Barker and Campelo)[1]
Petrogale godmani	Godman's Rock-Wallaby			Yes (Barker and Campelo)[1]
Dactylopsila trivirgata	Striped Possum			Yes (Jackson 1998)
Petrogale pencillata	Brush-Tailed Rockwallaby			Yes (Barnes *et al.* 2010)
Sminthopsis murina	Common Dunnart		Yes	
Antechinus flavipes	Yellow-Footed Antechinus		Yes	
Dasyurus hallucatus	Northern Qoull			Yes (Weaver 2014)
Phascogale tapoatafa	Brush-Tailed Phascogale		Yes	
Tachyglossus aculeatus	Short-Beaked Echidna		Yes	
Oryctolagus cuniculus	Wild Rabbit	Yes	Yes	
Melomys cervinipes	Fawn-Footed Melomys		Yes	
Uromys caudimaculatus	Giant White-Tailed Rat		Yes	
Mus domesticus	House Mouse	Yes	Yes	
Rattus sordidus	Canefield Rat		Yes	
Rattus tunneyi	Pale Field-Rat		Yes	
Rattus fuscipes	Bush Rat		Yes	
Rattus rattus norvegicus	Brown Rat	Yes	Yes	
Rattus rattus	Black Rat	Yes	Yes	
Hydromys chrysogaster	Water Rat		Yes	
Pteropus conspicillatus	Spectacled Flying Fox			Yes (Buettner *et al.* 2013)
Canis lupus familiaris	Domestic Dog	Yes	Yes	Yes (Barker and Campelo)[1]
Canis lupus dingo	Dingo		Yes	Yes (Marks and Cribb 1966)
Felis catus	Domestic Cat	Yes	Yes	
Equus caballus	Domestic And Feral Horses	Yes	Yes	
Sus scrofa	Feral Pig	Yes	Yes	
Capra hircus	Domestic Goat	Yes	Yes	
Bos taurus	Domestic Cattle	Yes		Yes (Barker and Campelo)[1]
Homo sapiens	Humans		Yes	
Gallus gallus	Domestic Fowl	Yes	Yes	
Meleagris gallopavo	Domestic Turkey	Yes	Yes	
Platycercus elegans	Crimson Rosella		Yes	
Pitta sp.	Pitta		Yes	
Corvus coronoides	Australian Raven		Yes	
Cracticus nigrogularis	Pied Butcher-Bird		Yes	Yes (Marks and Cribb 1966)
Cracticus tibicen	Australian Magpie		Yes	Yes (Marks and Cribb 1966)

with that of *I. holocyclus*. *Wallabia bicolor*, *Macropus dorsalis* and M. *rufogriseus* are three species of wallaby commonly found in the same range as *I. holocyclus*, and all are known to be hosts (Roberts 1970). These species, like bandicoots, are nocturnal and generally inhabit thick undergrowth (Menkhorst and Knight 2004). Wallabies could support *I. holocyclus*, however, research needs to be done to investigate their relative importance to the tick's life cycle.

Lack of standardised tick-host terminology

Parasite life cycles are complex (Figure 1) and often poorly understood, and terms such as "primary host", "preferred host" or "most important host" are arbitrarily defined and subjective, which has contributed to the assumption that bandicoots are the "primary host" of *I. holocyclus*. In the case of bandicoots and *I. holocyclus*, referring to bandicoots as a "main", "principal", "primary", or "preferred" host does not appear to be based upon empirical testing or standardised definitions. Development and usage of standardised terms is essential for future studies of tick – host relationships, in order to prevent confusion and unwanted extrapolation.

Media Perceptions and Conservation Consequences

Media articles involving ticks usually claim bandicoots to be the host of *I. holocyclus*, particularly in Northern Sydney where public concern over ticks is greatest (Arlington 2013; Chen 2013a; Chen 2013b; Williams 2013). Actual citations for this claim are rare, if ever provided. The association of bandicoots and ticks in the media is an important driver of public perception, and may have helped lead to calls to control ticks by reducing bandicoot conservation efforts, specifically by reducing predator controls like fox baiting.

The following case-study illustrates that without an adequate understanding of the ecology of the tick species, and tick – host interactions, control measures may not provide the desired outcomes.

Example – *Ixodes scapularis*, deer, and Lyme disease in North America

Lyme disease is the most common infection vectored by wildlife in both Europe and North America (Wormser *et al.* 2006), and efforts to control the disease by culling the hosts of ticks (True 2010) have met with limited success. In the north-eastern United States, where Lyme was first discovered, the pathogen is typically vectored by *Ixodes scapularis* (the Black Legged tick, also known as the "deer tick"). *Ixodes scapularis* is known to feed on many animals, including rodents, lizards, humans, and deer (Ostfeld *et al.* 2006). The rise of Lyme disease was correlated with the increase and spread of White-tailed Deer *Odocoileus virginianus* populations following the extirpation of grey wolves and reforestation of formerly clear-cut areas (Barbour and Fish 1993; Levi *et al.* 2012), and culling, as an alternative to insecticides, has been advocated as a way to control ticks and Lyme (McShea *et al.* 1997). Some trials, particularly in geographically isolated areas, showed that complete eradication of *O. virginianus* led to reduced *I. scapularis* abundance. Others in non-isolated areas and with limited culling failed to show a change in *I. scapularis* population or Lyme prevalence over time (Jordan *et al.* 2007).

While the health threats of *I. scapularis* and *I. holocyclus* are very different (bacterial and allergic, respectively), parallels can be drawn. Resurgent populations of "primary host" herbivores after predator removal provided an easy explanation for the apparent "rise" of ticks as a health threat in both cases, and culling of these hosts is advocated. The amount of culling required to show a reduction in *I. scapularis* – essentially eradication – is unfeasible, and runs the risk of leaving an ecological niche to be filled by another species which the generalist tick could then use as a new "primary" host. While there is no indication that eradication has been considered for either *O. virginianus* or bandicoots, tick control based upon host reduction should be thoroughly studied to see if it will truly meet public health goals.

Future Directions for Understanding Ticks as a Health Risk

To understand the health risks that *I. holocyclus* poses, there are more factors that should be considered besides the identity of any "primary" host. Wildlife that are less important in driving *I. holocyclus* populations may play a greater role in transferring ticks to areas where humans encounter them. Other factors that can influence tick populations besides local wildlife exist, including exotic plant invasions, land use changes, urbanisation, changing fire regimes, and the effects of climate change. Climate change in particular has been correlated with the expansion of *I. scapularis* range in North America (Brownstein 2005). All of these factors have the capacity to influence *I. holocyclus* abundance and distribution, as well as their interactions with humans, and they should be studied for their role as drivers of public health threats.

Conclusion

Bandicoots are claimed to be the primary host of *I. holocyclus* by many in the media and some academic papers, yet the literature does not fully support this claim. While some papers indicate that *I. macrourus* may have more ticks than other mammal species in a particular area, and that *P. nasuta* behaviours are compatible with the *I. holocyclus* life cycle, these results cannot be extrapolated to all of Australia and all bandicoots due to ecological and environmental variation across the range of *I. holocyclus*. Assumed tick – host specificity may have provided a basis for this extrapolation, but current understanding of *I. holocyclus* indicates that the tick is generalist and will use a wide range of hosts. Poorly defined and arbitrary terms for describing bandicoots as hosts of *I. holocyclus* make comparison between papers and citation even more difficult.

Despite the lack of scientific consensus, bandicoots are now cemented in the media as being the host of *I. holocyclus*, and individuals and groups concerned about ticks call for changes in bandicoot conservation policies as a way to control tick populations. Evidence from North America shows that tick control measures should be based on sound biological and ecological understanding of targeted tick species, unfortunately such an understanding of *I. holocyclus* and its hosts does not yet exist. It has been nearly 40 years since the last major study was undertaken on the hosts of *I. holocyclus*, and clearly another is needed if effective tick control is to be implemented.

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