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Invited Review

Parasite zoonoses and wildlife: One health, spillover and human activity

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ABSTRACT

This review examines parasite zoonoses and wildlife in the context of the One Health triad that encompasses humans, domestic animals, wildlife and the changing ecosystems in which they live. Human (anthropogenic) activities influence the flow of all parasite infections within the One Health triad and the nature and impact of resulting spillover events are examined. Examples of spillover from wildlife to humans and/or domestic animals, and vice versa, are discussed, as well as emerging issues, particularly the need for parasite surveillance of wildlife populations. Emphasis is given to *Trypanosoma cruzi* and related species in Australian wildlife, *Trichinella*, *Echinococcus*, *Giardia*, *Baylisascaris*, *Toxoplasma* and *Leishmania*.

1. Introduction

Nearly 30 years ago, Calvin Schwabe referred to the dynamic state of flux and new discovery that has always characterised studies on zoonoses (Schwabe, 1984). This statement still holds true today, although the emphasis has been on the emergence of infectious diseases from wildlife that threaten human health and the role of wildlife as originators of the infectious agents (Polley, 2005; Jones et al., 2008; Rhyan and Spraker, 2010; Plowright et al., 2011; Wood et al., 2012; Kooriyama et al., 2013). As such, models fail to include spillover from humans to wildlife (e.g., Lloyd-Smith et al., 2009). This is understandable but at the same time unfortunate as it tends to cloud the broader issues which, in theory, make up the so-called 'One Health' triad (Fig. 1). Diseases of human and domestic animal origin do infect wildlife (Thompson et al., 2009, 2010a; Salyer et al., 2012; Kooriyama et al., 2013). However, in practice the balance is often skewed towards demonstrating the 'source' of 'new' human diseases rather than determining 'why' in terms of One Health. As such, we need to better understand the factors that enable zoonotic transmission to humans from wildlife, and which may lead to outbreaks of disease. Is it purely a question of spillover from wildlife to humans, or are wildlife reservoirs resulting from spillover from a non-wildlife source? The impact of spillover of 'human' parasites to naïve species of wildlife is another emerging threat that is not well understood yet such spillovers are likely to increase in the future, establishing novel spill-back reservoirs of potential public health and economic significance, as well as threatening wildlife (Thompson et al., 2009, 2010a).

The situation is compounded by how little we know of what infectious agents occur naturally in wildlife and which of these could have the potential to establish infection in domestic hosts. There is a pronounced lack of knowledge about pathogen diversity and susceptibility in wildlife (MacPhee and Greenwood, 2013). Without improved and ongoing surveillance of wildlife hosts (Polley, 2005), not only will we always be behind in terms of predicting the possibility of reservoirs being established and/or outbreaks occurring, but also at a disadvantage in preventing declines of native fauna resulting from infectious disease and understanding the circumstances promoting an infection to a disease state. Much of the information on wildlife parasites has been obtained opportunistically, often at the level of individual animals. Furthermore, all extinction and many population decline studies are retrospective and this lack of knowledge affects our understanding of parasites that effect wildlife (MacPhee and Greenwood, 2013; Wayne et al., 2013a,b).

Much of the commentary in this area has focussed on viral diseases such as HIV, Severe Acute Respiratory Syndrome (SARS), Hendra, Nipah and bird flu (H5N1) (Jones et al., 2008; Quammen, 2012). Generalisations made in the context of these emerging infectious diseases (EIDs) are often not applicable to the broad range of other infectious zoonotic agents, both prokaryotes and eukaryotes. In this respect, a consideration of parasite zoonoses

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Fig. 1. The 'One Health' triad, encompassing the collaborative goals of providing optimal health for people, animals (domestic and wild) and the environment by considering interactions between all three systems.

caused by protozoa, helminths and arthropods is timely considering the diversity of the life cycle patterns and modes of transmission. In addition, considerations related to EIDs have often been reactionary (understandable due to the serious nature and rapid spread of viral diseases) with little consideration given to the ecology of the causative factors, such as the impact of biodiversity loss, human encroachment, the role of invasive species, and of course the conservation issues.

Furthermore, although some zoonotic infections cause frank disease in wildlife hosts, many infections of humans and domestic animals exist silently in wildlife species as infections which are not apparent (Schwabe, 1969). This usually reflects a long evolutionary history of adaptation and the acquisition of a balanced host parasite relationship. However, zoonotic infections are not always 'silent' in wildlife hosts and it is important to understand how some infections become diseases.

When such parasite zoonoses infect humans it is usually as a consequence of human influence or activity (anthropogenic). This may be passive as a result of poverty and other socioeconomic factors that enhance the risk of spillover, for example poor housing and Chagas disease; human encroachment on wildlife habitats and *Baylisascaris*; or climate change and waterborne diseases such as giardiasis. In contrast, there are numerous human activities, such as hunting, modifying wildlife populations by vaccination or translocation, tourism etc. (Table 1) that may increase the risk of zoonotic transmission.

In this review, I want to embrace the One Health philosophy and examine the circumstances promoting spillover of parasite zoonoses from wildlife to humans and domestic animals, as well as from domestic foci of transmission to wildlife, as a result of human activity (Fig. 2, Table 1). Fig. 2 illustrates the possible flow of parasite transmission between humans, domestic animals and wildlife in different host ecosystems. In urban areas, wildlife may be synanthropes (ecologically associated with domestic environments) or adapters (able to adapt to urban conditions but can utilise natural resources) (Blair, 1996; Shochat et al., 2006).

2. Spillover from wildlife to humans and/or domestic animals

The majority of parasite zoonoses for which wildlife are the main reservoir, and probably represent the hosts in which the parasite relationship evolved, are characterised by having little clinical impact on their wildlife hosts in terms of overt disease. However, there are a few zoonotic parasites such as *Echinococcus* with indirect life cycles that require the ingestion of larval stages in their intermediate hosts. This may enhance the chance of predation by

Table 1
Human activities that may influence the risk of zoonotic transmission involving wildlife.

Human activity impact	Impact	Parasite examples
Poor housing	Poor hygiene; encourage vectors/IHs	*Trypansoma cruzi*
Socioeconomic factors	Poor hygiene; lack of education/awareness	Many
Lack of surveillance	Lack of control/awareness	*Trichinella*; *Echinococcus*
Climate change	Distribution of vectors/IHs	*Leishmania*; *Trypanosoma*; *Echinococcus multilocularis*; Screworm/myiasis e.g., *Cochliomyia hominivorax*, *Dermatobia hominis*, *Chrysomya bezziana*, *Cordylobia anthrophoga*, *Callitroga* spp. etc.
Hunting (recreational/subsistence)	Exposure/ingestion of parasites by humans or domestic hosts	*Trichinella*; *Toxoplasma*; *Echinococcus*; *Sarcocystis*
Vaccination-wildlife host control	Changes to host distribution	Potentially many
Vaccination-disease control	Rabies control and increase in fox numbers	*E. multilocularis*
Therapeutic interventions in wildlife hosts	Altered host–parasite relationship/ polyparasitism	Various but e.g., *Baylisascaris*; *E. multilocularis*
Migration of humans	Exposure/introduction to novel parasites	*T. cruzi*; *Leishmania* spp; *Plasmodium knowlesi*
Tourism	Exposure to wildlife parasites	*Trichinella*; *Sarcocystis*
Pet travel	Exposure to exotic parasites	*Leishmania*; *Echinococcus*
Lack of control of domestic hosts (diet/roaming)	Exposure of wildlife to domestic parasites	*Echinococcus*; *Giardia*; *Toxoplasma*; *Sarcoptes*
Farming	Keeping wildlife/pasture management	*Echinococcus canadensis*/*E. multilocularis*
Landscape changes	Deforestation/expansion of vectors/IHs	*T. cruzi*; *E. multilocularis*; *P. knowlesi*; *Giardia*
Translocation of wildlife hosts	Introduction/altered distribution of zoonotic agents	*E. multilocularis*; *Baylisascaris*
Wildlife introductions	Introduction/altered distribution of zoonotic agents	*Echinococcus* spp; *Leishmania*; *Trypanosoma*
Culture/traditions	Dietary factors	*Trichinella*; *Toxoplasma*
Importation of food	Introduction of parasites to non-endemic regions	*Trichinella*
Livestock trade	Exposure to exotic parasites	Screworm/myiasis e.g., *C. hominivorax*, *D. hominis*, *C. bezziana*, *C. anthrophoga*, *Callitroga* spp. etc.
Environmental contamination	Aquatic, marine, terrestrial	*Giardia*; *Toxoplasma*
Feeding	Urban wildlife	*Toxoplasma*