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Review

The neglected navigating web of the incomprehensibly emerging and re-emerging Sarcoptes mite

Samer Alasaad [a,b,*], Luca Rossi [d], Jorg Heukelbach [e], Jesús M. Pérez [f], Omar Hamarsheh [g], Moses Otiende [h], Xing-Quan Zhu [c,*]

[a] Estación Biológica de Doñana, Consejo Superior de Investigaciones Científicas (CSIC), Avda. Américo Vespucio s/n, 41092 Sevilla, Spain
[b] Institute of Evolutionary Biology and Environmental Studies (IEU), University of Zürich Winterthurerstrasse 190, 8057 Zürich, Switzerland
[c] State Key Laboratory of Veterinary Etiological Biology, Lanzhou Veterinary Research Institute, Chinese Academy of Agricultural Sciences, Lanzhou, Gansu Province 730046, China
[d] Dipartimento di Produzioni Animali, Epidemiologia ed Ecologia, Università degli Studi di Torino, Via Leonardo da Vinci 44, I-10095 Grugliasco, Italy
[e] Department of Community Health, School of Medicine, Federal University of Ceará, Brazil
[f] Departamento de Biología Animal, Biología Vegetal y Ecología, Universidad de Jaén, Campus Las Lagunillas, s/n, E-23071 Jaén, Spain
[g] Al-Quds University, Department of Biological Sciences, P.O. Box 51000, Jerusalem, Palestine
[h] Kenya Wildlife Service, Veterinary Services Department, P.O. Box 40241-00100, Nairobi, Kenya

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ABSTRACT

Parasite presence in any ecosystem generates complex navigating webs (Parasite-NW) within the system, through which parasites move from one to another host. The appropriate assimilation of parasite navigating web is pivotal for a better understanding of pathogen flow in the ecosystem, with implications for disease control. Sarcoptes mite has been approached from medical, veterinary, entomological, physiological and, recently, molecular sides, to understand its epidemiological navigating web between isolates from different hosts and geographical regions. The obtained conclusions are still a matter of debate. Sarcoptes navigating web (Sarcoptes-NW) is intricate and uncertain, with unexplainable pathogenic flow. In this review we summarize by which routes, under what conditions and at what levels the Sarcoptes mite moves among its hosts.

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* Corresponding authors. Address: Estación Biológica de Doñana, Consejo Superior de Investigaciones Científicas (CSIC), Avda. Américo Vespucio s/n 41092 Sevilla, Spain. Tel.: +41 44 6354914; fax: +41 44 6355711 (S. Alasaad), tel./fax: +86 931 8342837 (X.-Q. Zhu).
E-mail addresses: samer@ebd.csic.es (S. Alasaad), xingquanzhu1@hotmail.com (X.-Q. Zhu).

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1. Introduction

The neglected parasite *Sarcoptes scabiei* affects humans and a wide range of mammalian hosts worldwide (Bornstein et al., 2001; Pence and Ueckermann 2002; Walton et al., 2004b; Alasaad et al., 2011a), entailing significant mortality in both wild and domestic animals, with considerable economic losses (Bornstein, 1995; Pence and Ueckermann, 2002; Heukelbach and Feldmeier, 2006; Dagleish et al., 2007), and ravages in human populations (Walton et al., 2004b; Hay et al., 2012).

There are no accurate estimates of the prevalence of *Sarcoptes* mite in the many animal populations worldwide, particularly in sylvatic animals. In humans, estimations indicate that hundreds of million people are infested with scabies worldwide (WHO, 2009). The prevalence of scabies in African children can be as high as 40–80%, and in remote indigenous communities in northern Australia, up to 50% of children and 25% of adults were found to be infested (Kristensen, 1991; Carapetis et al., 1997; Terry et al., 2001). Considering increasing resistance of topical chemotherapy, there is an urgent need to develop new control strategies (Currie et al., 2004; Bradberry et al., 2005; Sanderson et al., 2007), and the increasing need of sensitive and reliable diagnostic tests for humans and many domestic and wild animals (Haas et al., 2005; Heukelbach and Feldmeier, 2006).

Sarcoptes mite has been approached from morphological (Fain, 1978), medical (Carapetis et al., 1997; Feldmeier et al., 2009), veterinary (Bornstein, 1995), entomological (Fain, 1978), physiological (Arlian, 1989; Arlian et al., 1996; Haas et al., 2005) and, recently, molecular points of view (Zahler et al., 1999; Walton et al., 1997, 1999, 2004a; Alasaad et al., 2008b, 2009a,b, 2011b, 2012c; Rasero et al., 2010; Gakuya et al., 2011) aiming to understand its epidemiology between isolates from different hosts and geographical regions, but this issue is still a matter of vivid debate.

The objective of the present review is to summarize available evidence on *Sarcoptes* movement among hosts, in order to further elucidate transmission dynamics and provide an evidence-based rationale for sustainable control.

2. Emerging and re-emerging *Sarcoptes scabiei*

Parasite navigating webs (Parasite-NW) are the complex webs through which zoonotic parasites move from one host to another within the ecosystem (Polley, 2005). Pivotal to an appreciation of the function of parasite webs is an understanding of parasite flow: by which routes, under what conditions and at what levels the parasite flows among its various hosts, of the same or different species (including vectors where applicable), and between the hosts and the environment (Daszak et al., 2000).

Based on the definition of emergence and re-emergence of diseases by Lederberg et al. (1992), *Sarcoptes* mite emergence could be the result of the spread of *Sarcoptes* mites in one human/animal population from an infectious origin, or simply the realization that an infection has been present in a population but undetected for several reasons. The re-emergence of *Sarcoptes* is defined as the reappearance of *Sarcoptes* after a decline in incidence. Accordingly:

(i) A *Sarcoptes* mite mange outbreak can be 'genuine' emergence of an infestation, which is new to that particular and naive animal/human population. In this case, other infested hosts (humans, domestic and/or wild animals) sharing space with the non-infected population are suspected to be the reservoir and source of the mites through cross-infestation. In ruminants, the possibility that mites, adapted to a "main" reservoir host, may infest other sympatric species has been documented in mange foci in Europe (León-Vizcaíno et al., 1999; Rossi et al., 2007; Oleaga et al., 2008), and field evidence has been supported by the results of experimental infestations (Meneguz and Rossi, 1995; Lavín et al., 2000). Migration of human populations may also be a driving force for genuine emergence of scabies.

(ii) A *Sarcoptes* mite outbreak can be 'apparent' emergence/re-emergence, where Sarcoptes infestation is pre-existing, and the newly recognition is a result of increased detection opportunities (Kutz et al., 2003; Oleaga et al., 2008) and/or the modification of a pre-existing host-parasite equilibrium (Pence et al., 1983; Lloyd, 1995). In this second case, destabilizing modifications may have occurred on the host side, e.g. a diminished herd resistance, and/or the parasite side, e.g. the selection or of a more pathogenic strain or drug resistance (Pence and Windberg, 1994; Leung and Grenfell, 2003).

Further epidemiological studies should consider a third category, which is a mixture of genuine and apparent emergence of *Sarcoptes* mite outbreaks. Such mixture category can be revealed using both epidemiological and population genetic approaches.

3. Sarcoptes transmissions

It is thought that *Sarcoptes* mite originated from a human ancestor and then spread to domestic and then free-living animals (Fain, 1968; Walton et al., 2004b). *Sarcoptes* mites lack free-living stages, and individual hosts, depending on their susceptibility and behaviour, are essentially ephemeral habitats providing patchy environments that hamper random mating (Price, 1980; Criscione et al., 2005). All mites on an individual host may in fact form an 'infra-population' (Bush et al., 1997; Alasaad et al., 2008b) that has a number of recurrent generations. The number of generations is influenced by the short generation interval of this parasite (about three weeks), as well as by the infected host's life expectancy and susceptibility (Bornstein et al., 2001).

Transmission of *S. scabiei* may occur by direct or indirect contact. Larvae and nymphs of *S. scabiei* frequently leave their burrows and wander on the skin (Arlian and Vyszenski-Moher, 1988), which may, in the case of crusted scabies, harbour hundreds to several thousands of mites/cm^2 (Zeh, 1974; Arlian et al., 1988; Pérez et al., 2011). Some may become dislodged from the host and fall off (Arlian and Vyszenski-Moher, 1988). In controlled environments, mites may survive up until a few weeks if conditions (microclimate) are optimal (Arlian, 1989). Cooler temperatures and high humidy prolong off-host survival of *S. scabiei*, presumably because under these conditions mite metabolism is reduced (Davis and Moon, 1987; Arlian et al., 1989).

However, *Sarcoptes* navigating web (*Sarcoptes*-NW) is intricate and uncertain with fragility of parasite flow, and consequently transmission dynamics are not clear. For example, the mode of scabies transmission in humans is still discussed-whereas some authors define scabies as a sexually-transmitted disease, others suggest close body contact between children and their mothers to be the main route of transmission in endemic communities (Jackson et al., 2007). Clearly, these aspects depend on many interacting factors and differ from setting to setting.

The time needed for *S. scabiei* var. *hominis*, immediately transferred from one host to another, to initiate penetration into the stratum corneum was ~10 min (Arlian et al., 1984), and it took the mites ~35 min to become completely submerged into the epidermis. The time required for complete penetration into the stratum corneum increased as a function of the time the mites had been off their host. Experiments indicate that mites remain infective at least one-half to two-thirds of their survival time when dislodged from their host (Arlian, 1989). In historical but classical studies, Mellanby (1944) believed that the stage responsible for transmission was the young, newly fertilised adult female, which wandered around on the skin surface before burrowing. His studies