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ARTHROPODS AND MEDICAL ENTOMOLOGY - ORIGINAL PAPER

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Effects of temperature on the survival of *Sarcoptes scabiei* of black bear (*Ursus americanus*) origin

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Abstract

For two decades, the incidence and range of sarcoptic mange in black bears (*Ursus americanus*) in Pennsylvania has increased. The causative agent, *Sarcoptes scabiei*, can be directly or indirectly transmitted; therefore, data on environmental persistence is important for guiding management and public communications. The objective of this study was to determine the survival of *S. scabiei* at different temperatures. Full section skin samples and superficial skin scrapes were collected from bears immediately after euthanasia due to severe mange. After ~ 24 h on ice packs (shipment to lab), samples were placed in dishes at 0, 4, 18, or 30 °C and 60, 20, 12, and 25% relative humidity, respectively, and the percentage of mites alive, by life stage, was periodically determined. Humidity was recorded but not controlled. Temperature significantly affected mite survival, which was shortest at 0 °C (mostly ≤ 4 h) and longest at 4 °C (up to 13 days). No mites survived beyond 8 days at 18 °C or 6 days at 30 °C. Mites from full-thickness skin sections survived significantly longer than those from superficial skin scrapes. Adults typically survived longer than nymphs and larvae except at 30 °C where adults survived the shortest time. These data indicate that at cooler temperatures, *S. scabiei* can survive for days to over a week in the environment, especially if on host skin. However, these data also indicate that the environment is unlikely to be a long-term source of *S. scabiei* infection to bears, other wildlife, or domestic animals.

Keywords Black bear · Environmental transmission · *Ursus americanus* · Mange · *Sarcoptes scabiei*

Introduction

The mite *Sarcoptes scabiei* is the causative agent of scabies in humans and sarcoptic mange in animals (Arlian 1989; Bornstein et al. 2001). In humans, the disease is most commonly seen in facilities where there are large numbers of people, in close proximity, allowing efficient mite transmission (e.g., nursing homes, prisons, hospitals, and schools), and the disease is most severe in countries with limited health resources (Hengge et al. 2006; Romani et al. 2015). Dogs and pigs are the most commonly reported domestic species, but a wide range of other hosts have been reported (Fain 1978; Abu-Samra et al. 1981; Ibrahim and Abu-Samra 1987; Arends et al. 1990; Twomey et al. 2009).

Sarcoptic mange is also an important cause of disease in many wildlife species in North America including (but not limited to) red foxes (*Vulpes vulpes*), coyotes (*Canis latrans*), and, more recently, American black bears (*Ursus americanus*) (Pence and Ueckermann 2002; Peltier et al. 2018). While reports of sarcoptic mange have historically been rare in black bears, there has been an increase in the number of cases in certain parts of the USA, particularly in Pennsylvania (Niedringhaus et al. 2019). The cause of the increasing incidence of sarcoptic mange in black bears is currently unknown (Peltier et al. 2017). Transmission of mites between wildlife hosts likely involves both direct contact in more social species as well as indirect contact through the use of a shared environment, such as dens or burrows, as well as fomites (Skerratt et al. 1998; Almberg et al.

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2015). Additionally, some strains of *S. scabiei* have shown host specificity (Samuel 1981; Arlian et al. 1984b; Arlian et al. 1988). Transmission studies of mites between hosts generally indicate that mites have a higher degree of infestivity and cause more severe disease in hosts that are more closely related (Smith and Claypool 1967; Thomsett 1968; Samuel 1981; Arlian et al. 1984b; Arlian et al. 1988; Bornstein 1991; Mitra et al. 1995). There is little morphological and genetic difference between strains of mites from different wildlife hosts on a local scale (Arlian 1989; Peltier et al. 2017; Fraser et al. 2017). As a result, the mechanisms of mite transmission within and between wildlife systems, domestic animals, and humans are largely undefined.

Determining the survivability of black bear-origin *S. scabiei* mites in the environment is critical for understanding *S. scabiei* ecology in bears, managing risk factors for mite transmission, and communicating with the general public in situations where bears with mange are encountered. The aim of this study was to characterize the survival of black bear-origin *S. scabiei* in the environment at different temperatures.

Materials and methods

Black bears with severe mange were euthanized by personnel of the Pennsylvania Game Commission following an agency standard operating procedure. All sample collection protocols were approved by the Institutional Animal Care and Use Committee at the University of Georgia (A2013-10-016 and A2015-05-13). Skin scrapes were examined immediately after the bear was euthanized to confirm the presence of large numbers of living mites. Within hours of euthanasia, multiple large sections of full-thickness skin were obtained from areas of affected skin based on the distribution of gross lesions and confirmation with cytology at the time of sampling. These large skin samples were placed into zip-lock bags and immediately shipped overnight to the Southeastern Cooperative Wildlife Disease Study (SCWDS) on ice packs. Samples were received at SCWDS within 24 h of the bear being euthanized. Upon arrival, skin scrapes were examined again to determine that the mites were *S. scabiei* and that there was at least 95% survival of mites during shipment. Mites were determined to be alive based on visible movement within 10 s of observation and no apparent desiccation or trauma to the mite's body, or idiosoma.

If the aforementioned criteria were met, the skin sections were randomly processed into two sample types, 2.5- × 2.5-cm full-thickness sections (meant to represent bear carcasses) and superficial skin scrapes (meant to represent superficial mites left behind in dens, traps, etc.). Approximately 30 samples of both scrapes and full-thickness sections were obtained from each bear, and these were divided into eight groups. Skin scrapes were performed with sterile scalpel blades and contained epidermal scales, crusts, and hair follicles. Scrapes and full-thickness sections were obtained from adjacent areas on the skin and covered similar dimensions. The four groups of skin sections and four groups of skin scrapes were placed in individual petri dishes and placed into incubators maintained at 0 °C, 4 °C, 18 °C, and 30 °C with 60%, 20%, 12%, and 25% relative humidity (RH), respectively. For 18 and 30 °C groups, Fisherbrand™ Isotemp™ Biochemical Oxygen Demand Refrigerated Incubators were used, and standard household refrigerators and freezers were used for the 4 and 0 °C groups. These temperatures were chosen because they reflect gaps from other published studies investigating *S. scabiei* survival as well as because of the range of seasonal temperatures in Pennsylvania. No individual sample was examined more than twice to reduce the influence of repeated heating and handling on mite survival. Relative humidities from each incubator were recorded but not chosen/influenced. Both skin scrapes and skin sections at all temperature-humidity treatments were examined at 0, 4, 8, and 24 h and daily thereafter until a sample had no live mites at two consecutive time points. Prior to examination, all skin scrapes and skin section samples were placed into the 30 °C incubator for 20 min to allow mites to warm up and begin to move allowing for increased confidence in determining survival. The percentage of live mites, regardless of life stage, was determined at each time point relative to the number of live mites at time 0. Each sample was examined for approximately 10 min from which at least 50% of the surface of the sample was examined resulting in an estimate of survival rather than complete count. Skin scrapes were performed on the full-thickness sections immediately before examination to better visualize the mites.

Additionally, at each examination time point, the number of live and dead mites were determined for adult, larval, and nymphal (combining protonymph and tritonymph) stages from full-thickness sections (Fain 1968; Arlian 1989). Temperature and humidity were measured using commercial terrarium thermometers/hygrometer that were placed adjacent to the samples. A generalized linear mixed model with a logit link was used to estimate the effects of skin sampling type and temperature on mite survival. Each individual bear was used as a random effect in the model, and temperature was used as a factored predictor variable to allow for non-linear relationships with temperature. Statistics and figures were performed using R Statistical software, and the mixed effect model was performed using the "lme4" package (Bates et al. 2015; RCoreTeam 2017).

Results

Skin samples from 11 bears were included in the study. The mean number of days of survival of mites from each sample type and temperature-humidity treatment are summarized in Table 1. Mites in both skin scrapes and skin sections were inactivated after one freezing event, and no mites survived at freezing temperatures beyond 8 h. In only one trial did a small percentage of mites survive beyond 4 h at 0 °C (Fig. 1). In temperatures above freezing, mite survival in skin sections and scrapes was inversely related to temperature, with longest survival at 4 °C and 20% RH and shortest at 30 °C and 25% RH. Mites did not survive beyond 6 days at 30 °C, 8 days at 18 °C, and 13 days at 4 °C. The highest variation in survival was at 4 °C with the minimum survival at 5 days and maximum survival at 12 days; the least variation between trials in survival above freezing was at 18 °C with a range of 4 to 8 days.

Skin sample type significantly affected time to mite mortality ($X^2 = 15.91$; $p < 0.0001$), and mite survival was on average 1.2 days (sd 0.30) longer in full-thickness sample sections than on skin scrapes across all temperatures. Temperature also significantly affected time to mortality ($X^2 = 418.49$; $p < 0.0001$); mites survived an estimated 8.4, 5.4, and 3.8 days (sd 0.42) longer at 4 °C, 18 °C, and 30 °C than 0 °C regardless of skin sample type.

The maximum survival (days until 100% mortality) of different life stages of mites from full-thickness skin sections is shown in Fig. 2. Within the 4 °C and 18 °C groups, adult mites survived the longest followed by nymphs with larvae surviving the shortest time. At 30 °C, this trend was largely reversed with adults surviving the shortest time and larvae and nymphs surviving for nearly identical lengths of time. No differences in survival were noted among life stages at 0 °C.

Discussion

In this study, we examined, for the first time, the survival of black bear-origin *S. scabiei* under different simulated environmental conditions and found differences in survival at different temperatures and between mites in skin sections and mites derived from skin scrapes. Similar to previous studies on the environmental survival of *S. scabiei* mites from other hosts, we found that mites survived longest at lower temperatures (above freezing; optimum of 10 and 13 °C) and high RH (97 and 90%, although not controlled for in our study) (Cameron 1925; Mellanby et al. 1942; Arlian et al. 1984a; Arlian et al. 1989). These conditions provided the best environment for survival with adult females surviving up to 3 weeks in these conditions when dog and/or human-strain mites from a rabbit host were examined (Arlian et al. 1984a; Arlian et al. 1989). The maximum mite survival in our experiment was observed at 4 °C, suggesting that 4 to 10 °C is likely the optimum temperature for mite survival. Mites in the Arlian studies also survived less than 1 day at 30 °C, while at 30 °C in our study, mites survived for up to 6 days in one trial and typically all died between 2 and 5 days (Arlian et al. 1984a; Arlian et al. 1989). The differences in these times is likely related to the humidity and possibly to the presence of skin or skin crusts that may act as protection from these conditions or could provide a prolonged source of moisture that reduced desiccation in our study (Arlian et al. 1984a). In our study and previous studies (Mellanby et al. 1942; Arlian et al. 1984a; Arlian et al. 1989), mites very rarely survived freezing regardless of sample type. Temperature effects on general survival in our study was also generally similar to that in a fourth study, although RH was not recorded (Cameron 1925). Our study expands on the Mellanby et al. (1942), Arlian et al. (1984a), and Arlian et al. (1989) studies in two important ways. First, these data suggest that the presence of skin scrapes and, even more so, full sections of skin prolong survival of mites off of the live host compared to extracted mites without host hair or skin. Secondly, we included more replications ($n = 11$) and noted a wider a range of survival times for each environmental condition, some of which were quite variable. There was also an important difference in this study compared to the two Arlian et al. (1984a, 1989) studies as mites from the previous studies were taken immediately off of the live host whereas in our study, mites were transported overnight to another laboratory, and duration of survivability may have been affected by this delay.

In this experimental trial and previous studies, only temperature and relative humidity were evaluated for impacts on mite survivability. However, it is important to note that other environmental factors likely contribute to mite survivability including exposure to ultraviolet light, status of clinical disease of the host prior to euthanasia, and the type of substrate underneath the animal, among others. Another limitation of this study was that infectiousness of mites was not determined. Ideally, the maximum time mites would be capable of reinfesting new hosts and ultimately the ability to cause disease in a new host would have been determined. This study did not take into account the ability of mites to seek a new host or to colonize, burrow, and breed after prolonged duration off of the host, all of which are required for the development of clinical disease (Arlian et al. 1984a; Arlian et al. 1984c). It is estimated

Table 1 The mean and standard deviation of days until 100% mortality of *S. scabiei* mites from 11 trials

Temperature (°C)	Skin scrapes Mean ± sd	Full-thickness sections Mean ± sd
0	0.29 ± 0.08	0.38 ± 0.27
4	7.25 ± 1.89	8.75 ± 2.34
18	4.67 ± 0.63	5.75 ± 1.25
30	3.06 ± 1.84	4.50 ± 1.67

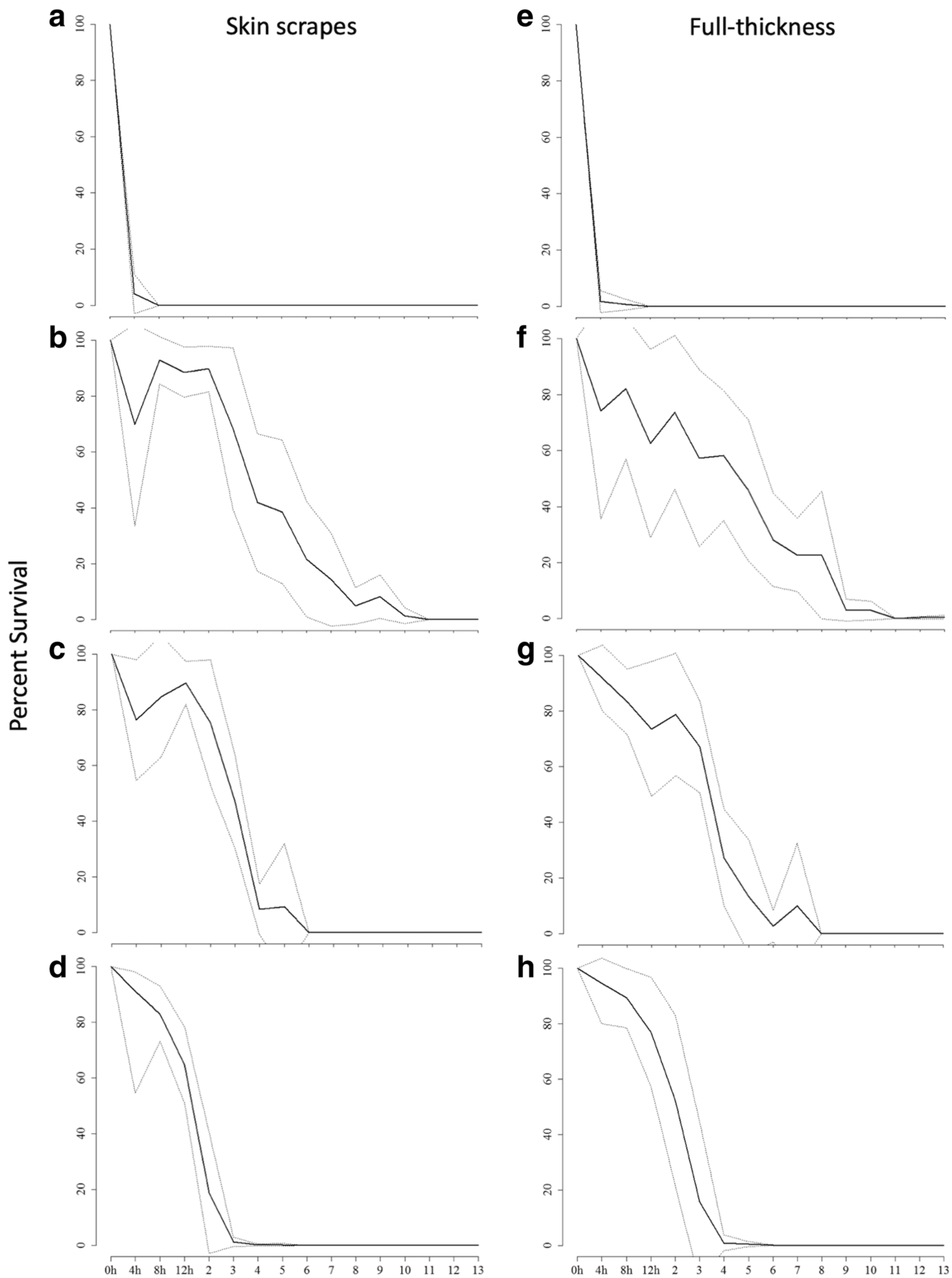

Fig. 1 Average percent survival (solid lines) and standard deviation (dashed lines) in days of *Sarcoptes scabiei* mites from full section skin samples and skin scrapes from 11 bears kept at various environmental conditions. **a**–**d** Survival at 0 °C, 4 °C, 18 °C, and 30 °C from skin scrapes, respectively. **e**–**h** Survival at 0 °C, 4 °C, 18 °C, and 30 °C from full-thickness skin sections, respectively

that mites retain their ability to penetrate host skin for less than half of the duration off of the host and may be even less if the mites were maintained in extreme environmental conditions (Arlian et al. 1984a; Arlian et al. 1988). When this is considered, the duration of potential risk of mite infestivity is likely even shorter than the times provided in this study allowing for an estimate of the maximum risk of additional transmission. The overestimation of risk for transmission provided in this study is important when making management decisions regarding the use of bear traps and communicating with the public on mite survival.

Collectively, these new data combined with previous studies indicate the environment is unlikely to be a reservoir or prolonged source of infestation for *S. scabiei*. However, it does show that the mite can persist off the host for a period of time, especially during cooler times of the year (e.g., spring and fall). Studies investigating the temperatures of dens of black bears at higher latitudes showed that den temperatures are often similar to the external environment suggesting that mites survive over winter on the host itself rather than in the den substrate (Folk Jr. et al. 1972; Rogers 1981). Unlike many canid species that are commonly infested with *S. scabiei*

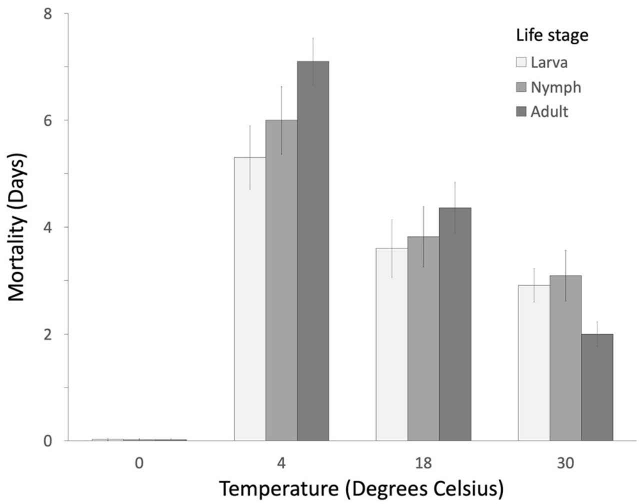

Fig. 2 Average maximum survival (days until 100% mortality) of *Sarcoptes scabiei* mites at different life stages and different temperatures from full-thickness skin sections

(coyotes, wolves, etc.), bears are not social animals for the majority of their lives, and this persistence in the environment allows for a "bridge" between animals that are unlikely to frequently be in direct contact (Almberg et al. 2015). This scenario is likely true for other solitary mammals affected by mange including wombats (Martin et al. 2018). Due to their solitary nature, artificial scenarios where bears would come in close contact (such as baiting, wildlife feeding, or other food attractants) could promote the potential for transmission (Sorensen et al. 2014). However, mites are unlikely to survive in the environment during winter months in colder climates, and transfer to new hosts during this time likely occurs through direct contact with infected bears. While fall and spring temperatures may support mite survival, transmission of mites between bears outside of hibernation possibly occurs most during the summer due to increased foraging activity and direct contact during mating; bear movement and subsequent direct or indirect contact may be minimized in extreme seasonal temperatures (Garshelis and Pelton 1980; Alt et al. 1980).

These data also are important for black bear management efforts. Black bears are frequently captured by state agencies for research or human-bear conflict mitigation, and during handling, equipment or capture sites that become contaminated with *S. scabiei* mites could serve as a risk for transmission to subsequent bears. Moreover, fomites near food attractants such as garbage dumpsters or bird feeders, regulated baiting during hunting seasons, or wildlife feeding by the public attracts multiple bears may also increase the risk of transmission. Consequently, these environmental survival data should be considered in the development of agency procedures for handling bears with mange, including establishing time periods for closing traps post-capture and possible environmental treatments. Knowledge of how freezing temperatures can kill mites may also be an effective management tool to disinfect equipment, clothing, or bear carcasses. Lastly, information on mite survival should be included in agency outreach materials to better inform the public about activities that may contribute to mange transmission.

Understanding the role of the environment in indirect transmission of mites between wildlife hosts is vital to understand and attempt to manage mange epizootics (Astorga et al. 2018; Martin et al. 2018). This study shows that the environment can potentially act as a source of indirect transmission of *S. scabiei* between hosts but is unlikely to be a reservoir for prolonged exposure. These data can be used to make informed decisions regarding the risk of transmission via fomites or carcasses of animals with clinical mange depending on the season or environmental conditions. Additional studies involving environmentally safe and effective products to promote inactivation of mites that can be used in the field are warranted, as are studies determining the specific scenarios where mites are transmitted between animals.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted.

Informed consent N/A

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