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Epidemiological study of sarcoptic mange in raccoon dogs (*Nyctereutes procyonoides albus*) in Hokkaido, Japan

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Abstract

Sarcoptic mange is a pruritic skin disease caused by *Sarcoptes scabiei*, and can impact wildlife populations. In Japan, sarcoptic mange has rapidly spread among medium-sized mammals, especially raccoon dogs, since the 1980s, and can cause regional extinction. We conducted an epidemiological survey on sarcoptic mange in raccoon dogs (*Nyctereutes procyonoides albus*) at two different sampling sites (Nopporo and Mukawa) in Hokkaido, Japan. We captured raccoon dogs using box traps in Nopporo from 2003 to 2018, and collected raccoon dog carcasses in Mukawa from 2005 to 2010; we investigated whether they were infested with *S. scabiei*. In Nopporo, sarcoptic mange incidences were detected from 2003 to 2004 and from 2016 to 2018, when the raccoon dog population density was high. Subsequently, the number of captured raccoon dogs decreased. Alternatively, when the raccoon dog population density was low, no *S. scabiei*-infested raccoon dogs were detected except in 2010. In 2010, three *S. scabiei*-infested raccoon dogs were captured at the southern end of the forest, and these individuals were subsequently confirmed to have died. Because they did not enter the central region of the forest, the incidence was localized. In Mukawa, 240 raccoon dogs were captured, of which 60 were infested with *S. scabiei* from 2005 to 2010, and a decrease in the number of captured raccoon dogs was confirmed after the sarcoptic mange epidemic. In conclusion, the increased population density might have resulted in the incidence of sarcoptic mange in raccoon dogs, and sarcoptic mange possibly impacted raccoon dog population density.

Key Words: population density, raccoon dog, sarcoptic mange, *Sarcoptes scabiei*

Introduction

Sarcoptic mange is a pruritic skin disease of humans and animals caused by a parasitic mite, *Sarcoptes scabiei*, and is an important disease that affects animal health[3]. Although sarcoptic mange affects various domestic animals, severe mange has also been confirmed in many kinds of wild mammals worldwide[2]. Sarcoptic mange has been confirmed in red foxes (*Vulpes vulpes*)

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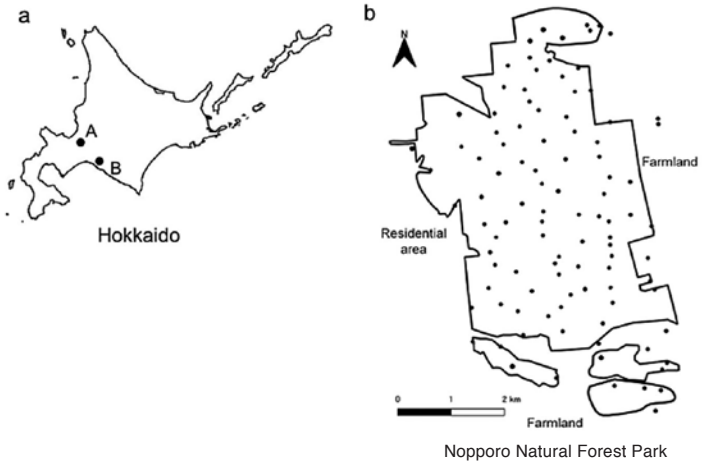

Fig. 1 a: Map of the study area; A: Nopporo Natural Forest Park, B: Mukawa. b: Map showing the trapping points in Nopporo Natural Forest Park.

and coyote (*Canis latrans*) since the 1800s, and it is considered a major cause of mortality among these animals[1,17]. The typical pathology of skin lesions includes alopecia and scabs. Sarcoptic mange is generally considered an opportunistic infection[16]. Stress of severe pruritus often causes the host to lose its appetite, energy, and physical strength, and causes secondary infections, such as bacterial infections. In severe chronic cases, infested animals may suffer from malnutrition and die[2,14,16]. Thus, sarcoptic mange epidemics can significantly impact wildlife population dynamics[5]. In Japan, sarcoptic mange was recognized in raccoon dogs (*Nyctereutes procyonoides viverrinus*) for the first time in 1981 in Gifu Prefecture[23]. Sarcoptic mange rapidly spreads among medium-sized mammals, especially raccoon dogs, and it can cause regional extinction[15,24].

Raccoon dogs (*Nyctereutes procyonoides*) are monogamous, perform child-rearing as a pair, and act as a family unit before the juveniles disperse. Additionally, raccoon dogs defecate at sites called latrines. Because latrines are shared by multiple individuals, they serve as a place of information exchange among conspecific individuals[18]. Therefore, raccoon dogs tolerate each other more than other wildlife. Because of these unique behaviors, there are many contact opportunities with other individuals and it is easy to spread infectious diseases. Raccoon dogs are distributed in eastern Eurasia, the Korean Peninsula, eastern Russia, China, northern Vietnam, and Japan[18]. Previously, Japanese raccoon dogs were considered a subspecies of the continental population; recently, Kim et al. (2013 & 2015) reported that Japanese raccoon dogs differed from the continental population based on morphological and molecular data[10,11]. If Japanese raccoon dogs become extinct, it will cause substantially damage to biodiversity. Infested animals may be a source of infection for other animals. Therefore, it is important to conduct an epidemiological survey of sarcoptic mange, which is thought to impact raccoon dog population dynamics. The purpose of this study is to monitor the epidemics of sarcoptic mange in raccoon dog populations and to investigate the possible association between the disease incidence and animal population density.

Methods

Our study was conducted in Nopporo Natural Forest Park, which spans Ebetsu, Sapporo, and Kitahiroshima cities in central Hokkaido, Japan (43°25'N, 141°32'E) (Fig. 1). This forest is a semi-isolated forest (2,053 ha). Twenty-one mammal

Fig. 2 Raccoon dog infested with *S. scabiei* in Nopporo Natural Forest Park.

(such as raccoon dogs and red foxes), 150 bird, and 1,300 insect species inhabit this forest[13]. A raccoon dog with severe scabies was recognized for the first time in 2002[12]; then, some raccoon dogs with alopecia were confirmed in the forest. We conducted an epidemiological survey of sarcoptic mange in raccoon dogs in the forest from 2003 to 2018. The study period was from May to July. Raccoon dogs were captured using box traps (Havahart Large Collapsible Pro Cage Model 1089, Woodstream Corp., Lititz, USA). We placed the traps at 80 to 100 sites every year. The sites where we could place traps differed yearly because of natural disasters, such as typhoons. There were 4,200 trap-nights from 2004 to 2010 and between 2,100 and 2,400 trap-nights per year in 2003 and from 2011 to 2018 (50,700 trap-nights total).

We anesthetized captured raccoon dogs using butorphanol tartrate (Vetorphale, 1.2 mg/kg; Meiji Seika, Tokyo, Japan), hydrochloric acid medetomidine (Dolbene, 40 μg/kg; Kyoritsu, Tokyo, Japan), and midazolam (10 mg Dormicum Injection, 0.2 mg/kg; Astellas, Tokyo, Japan) by intramuscular injection. We inserted microchips into their backs to identify individual animals. If a skin lesion was confirmed, we sampled the scabs (Fig. 2). A definitive diagnosis was conducted by detecting *S. scabiei* under stereomicroscope. We classified skin lesions as class I, class II, or class III based on how much of the body it covered (0%–30%, 30%–50%, or 50%–100%, respectively) [17]. As mentioned in the Introduction, once an infectious disease occurs, it spreads easily among raccoon dog populations because of the peculiar ecology of the raccoon dog. To confirm if sarcoptic mange spread among a family, we recorded whether raccoon dogs infested with *S. scabiei* were in a pair and parent–pup relationship based on their capture sites and capture date. Two adult raccoon dogs captured at the same capture sites on the same day were considered to be pairs, and any adult raccoon dogs and pups captured at the same capture sites on the same day were considered to be in parent–pup relationships.

After sampling and measurement, we injected the raccoon dogs with the antagonists naloxone (naloxone hydrochloride intravenous injection, 0.02 mg/kg; DAIICHI SANKYO, Tokyo, Japan), atipamezole hydrochloride (Atipame, 0.2 mg/kg; Kyoritsu, Tokyo, Japan), and flumazenil (Flumazenil intravenous injection, 0.02 mg/kg; Sawai, Osaka, Japan). We released the raccoon dogs at the capture site after they fully recovered. Raccoon dog carcasses found in Nopporo Natural Forest Park were also collected.

We also collected raccoon dog carcasses that were captured as part of nuisance control measures to prevent agricultural damage in Mukawa, Hokkaido. Raccoon dogs were killed by licensed hunters on behalf of Mukawa Town from 2005 to 2010. We examined these carcasses in the same way as we did with samples from Nopporo Natural Forest Park.

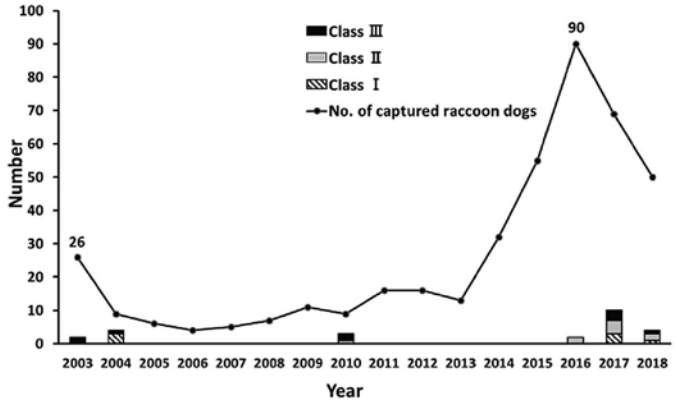

Fig. 3 Fluctuations in the numbers of total captured raccoon dogs (line graph) and captured raccoon dogs infested with *S. scabiei* including skin lesion classifications (bar graph) in Nopporo Natural Forest Park.

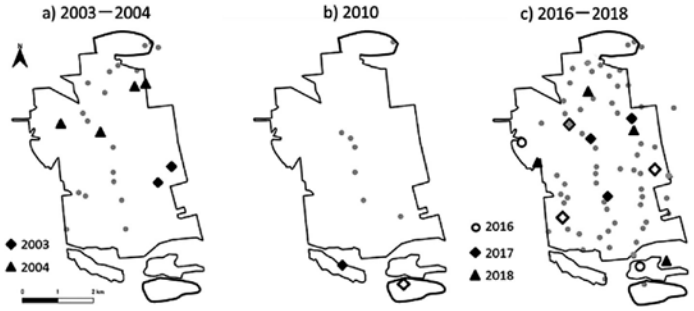

Fig. 4 Capture sites of raccoon dogs infested with *S. scabiei* in Nopporo Natural Forest Park. a) 2003–2004, b) 2010, c) 2016–2018. Gray circles show the capture sites of uninfested raccoon dogs. White diamonds show the capture sites of infested pair raccoon dogs. Gray diamonds show the capture sites of infested parent–pup relationship raccoon dogs.

Ethics approval

Permission to capture raccoon dogs for academic use was obtained from the Hokkaido Government. All procedures were conducted in accordance with the Guidelines for Animal Care and Use of Hokkaido University and were approved by the Animal Care and Use Committee of the Graduate School of Veterinary Medicine, Hokkaido University (permit number: JU17007).

Results

Nopporo Natural Forest Park

Fluctuations in the numbers of captured raccoon dogs and *S. scabiei*-infested raccoon dogs are shown in Fig 3. The capture sites of the infested raccoon dogs are shown in Fig 4. Twenty-six raccoon dogs were captured in 2003, when we started the survey, but only nine were captured in 2004. The number of captured raccoon dogs was low from 2004 to 2013. The raccoon dog population gradually increased after 2014. In 2016, the largest number of raccoon dogs was captured (90); however, the number of captured raccoon dogs began to decline in 2017. *S. scabiei*-infested raccoon dogs were captured in 2003, 2004, 2010, and from 2016 to 2018. Sarcoptic mange was detected in 2016, when the number of captured raccoon dogs was the largest, and the total number of captured raccoon dogs began to decline in 2017. The infested raccoon dogs were captured at sites in the north of the forest from 2003 to 2004 and in the south in 2010; after the raccoon dog population recovered, infested raccoon dogs were confirmed throughout the forest from 2016 to 2018. Although three raccoon

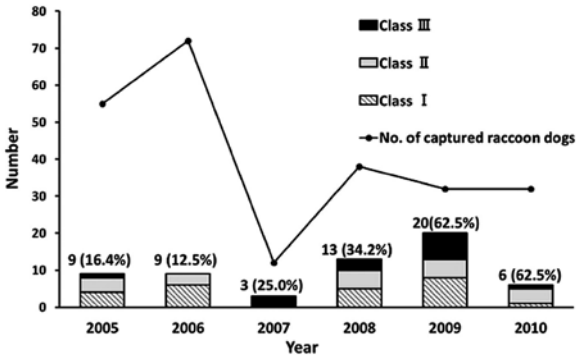

Fig. 5 Fluctuations in the numbers of total captured raccoon dogs (line graph) and captured raccoon dogs infested with *S. scabiei* including skin lesion classifications (bar graph) in Mukawa.

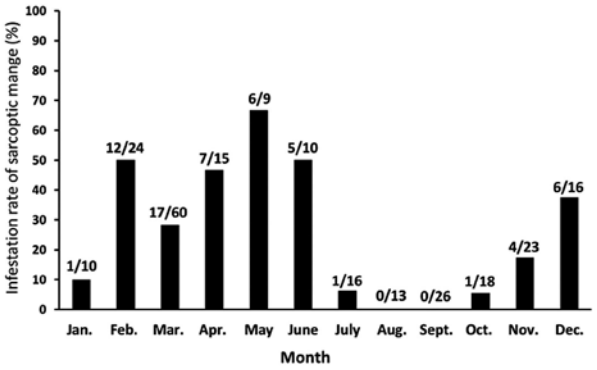

Fig. 6 Monthly changes in *S. scabiei* infestation rate in Mukawa from 2005 to 2010.

dogs infested with severe sarcoptic mange were captured at the southern end of the forest in 2010 (Fig. 4), we confirmed that these individuals subsequently died near the capture sites.

Regarding transmission of sarcoptic mange among raccoon dog families, of the 25 infested raccoon dogs confirmed between 2003 and 2018, three pairs were confirmed to be infested with *S. scabiei*. Two infested pups were captured where infested adult raccoon dogs were confirmed.

The raccoon dogs classified as class III were subsequently confirmed to have died. Even if classified as class I or class II, no infested raccoon dogs were subsequently recaptured.

Mukawa

Fluctuations in the numbers of captured and infested raccoon dogs are shown in Fig 5. From 2005 to 2010, 240 raccoon dogs were captured, of which 60 were infested with *S. scabiei*. The number of captured raccoon dogs decreased in 2007, and in 2008 it decreased to about half of that captured in 2006. The infestation rate of sarcoptic mange was around 15% in 2005 and 2006, but showed a higher infestation rate starting in 2007, which is when the number of captured raccoon dogs decreased. Over time, skin lesion classifications also changed; only one individual was classified with a class III lesions in 2005, but the number of individuals diagnosed with class III lesions started increasing in 2007 (Fig. 5). Additionally, the monthly changes in *S. scabiei* infestation rate are shown in Fig 6. *S. scabiei*-infested raccoon dogs were captured from winter to spring, but not from August to September. Winter and spring showed particularly high infection rates.

Discussion

In the study area, Nopporo Natural Forest Park, it was suggested that the number of raccoon dogs started decreasing around 2002 based on camera trap analysis (Hirakawa H., personal observation). Infectious diseases, such as sarcoptic mange and canine distemper virus, and invasive raccoons may impact raccoon dog population density[7,22]. In this forest, a feral raccoon control program has maintained the raccoon population at low densities (Hokkaido Prefecture, unpublished data); therefore, the impact of raccoons on raccoon dogs may be limited. Moreover, canine distemper virus infection is currently being investigated; although raccoon dogs that were sero-positive by neutralization tests have been confirmed, none have been confirmed to have died from severe cases of canine distemper virus infection (data not shown). In general, rich or poor food resources also affect wildlife populations. However, raccoon dogs are omnivores that eat easily found food items, such as wild fruits and insects[19]. It was not

confirmed that aino mulberry (*Morus australis*), hardy kiwi (*Actinidia arguta*), and crimson glory vine (*Vitis coignetiae*) were uncommon in the forest during the study period (data not shown). Therefore, one cause of the raccoon dog population decline might be a sarcoptic mange epidemic. However, there have been no detailed epidemiological studies of sarcoptic mange based on capture surveys in Japan[8,21]. Therefore, it was not possible to understand the impact of sarcoptic mange on wildlife population dynamics, and we conducted an epidemiological survey of sarcoptic mange in raccoon dogs.

In this forest, a raccoon dog infested with severe sarcoptic mange was recognized for the first time in 2002[12]; in this study, sarcoptic mange incidences were detected from 2003 to 2004 and from 2016 to 2018. Sarcoptic mange was detected following when the number of raccoon dogs captured was highest (2016: 90 raccoon dogs). Subsequently, the number of captured raccoon dogs decreased. Additionally, although there was no detailed capture survey data before 2002, it is possible that the raccoon dog population was high around 2001 based on camera trap surveys (Hirakawa H., personal observation). Therefore, the sarcoptic mange detected from 2002 to 2004 was thought to be caused by increased population density of raccoon dogs in the forest. Thereafter, the raccoon dog population remained low until 2013. No raccoon dogs infested with *S. scabiei* were captured when the number of captured raccoon dogs was low except in 2010. Although three raccoon dogs infested with severe sarcoptic mange were captured at the southern end of the forest in 2010, these individuals were subsequently confirmed to have died. These raccoon dogs with severe sarcoptic mange did not enter the central region of the forest, and the capture sites were in relatively isolated areas surrounded by residential areas. Therefore, the sarcoptic mange incidence in 2010 may have been localized and not have led to an epidemic. The same pattern was observed in Mukawa, and a decrease in the number of captured raccoon dogs was confirmed after the sarcoptic mange epidemic. Additionally, the raccoon dogs infested with *S. scabiei* were not subsequently recaptured, even though the raccoon dog recapture rate was about 73% in this study. We suggest that the symptoms of the infested raccoon dogs that were not recaptured got worse and the raccoon dogs may have died; it may be difficult for raccoon dogs to recover from the infestations without treatment[9]. These results revealed that a sarcoptic mange epidemic impacts raccoon dog population density.

Moreover, it is thought that there is a close relationship between sarcoptic mange epidemic and high population density because infestation was observed when the number of captured raccoon dogs was highest. Gonzalez-Candela et al. (2004) reported that sarcoptic mange had spread when the population density was highest in barbary sheep (*Ammotragus lervia*); subsequently, the population density declined[5]. We propose that this occurred because contact opportunities between individuals increase as population density increases, and this may be related to the peculiar ecology of the raccoon dog, which includes multiple individuals sharing latrines, child-rearing by a pair, and family unit activities[18]. In Nopporo Natural Forest Park, of the 25 infested raccoon dogs, three pairs infested with *S. scabiei* were captured, and two infested pups were captured where the infested adult raccoon dogs (potentially their parents) were captured. If the parents were infested, their pups were also infested. In Mukawa, 25 of the 60 infested raccoon dogs were captured at the same capture site. These results indicate that the sarcoptic mange epidemic in raccoon dogs is likely due to the ecological characteristics of raccoon dogs.

It was reported that the sarcoptic mange epidemic in Norwegian red foxes temporarily decreased the populations, but it did not impact long-term population changes[4]. However, the population density of raccoon dogs in the forest did not recover for 10 years. Other causes for the lack of recovery may be the influence of raccoons

and canine distemper virus infection. Raccoon dogs that have sero-positive for canine distemper virus confirmed in our investigation (data not shown).

Although the local population in Nopporo Natural Forest Park was also threatened at one time, this study revealed that raccoon dogs restored their population. This is an important finding because it is possible that the raccoon dog population was recovered by raccoon dogs not infested with *S. scabiei* in the forest and raccoon dogs from the outside of the forest.

In the study at Mukawa, winter and spring had particularly high infection rates. We suggest that because of the lack of food resources in winter and spring, weakened the infested raccoon dogs were likely to be captured near human houses. Additionally, alopecia makes it difficult to maintain body temperature in winter and spring when the ambient temperature is low[20].

The infestation rate was relatively lower in Nopporo Natural Forest Park compared with Mukawa. If the symptoms were only alopecia, it was difficult to detect *S. scabiei*[6]. We collected the raccoon dog carcasses in Mukawa and diagnosed if they were infested with *S. scabiei* by scraping their skin based on careful diagnosis all over the body. However, in Nopporo Natural Forest Park, we captured living raccoon dogs and had to release them; therefore, we could not conduct careful diagnosis of the raccoon dogs, because skin scraping damages raccoon dog skin and anesthesia would work approximately 30 minutes. Although we could not definitively diagnose sarcoptic mange in released raccoon dogs that had only alopecia, some of these individuals were not recaptured the following year. Raccoon dogs that were not recaptured might have been infested with *S. scabiei* and died. Therefore, the infestation rate was relatively lower in Nopporo Natural Forest Park than Mukawa. However, sarcoptic mange occurred from 2003 to 2004, in 2010, and from 2016 to 2018 in Nopporo Natural Forest Park. Alternatively, from 2005 to 2009 and from 2011 to 2015, infested raccoon dogs were not confirmed. From 2005 to 2009 and from 2011 to 2015, captured raccoon dogs that did not show any sarcoptic mange symptoms were recaptured for multiple years. Therefore, these raccoon dogs were likely not infested with *S. scabiei*, and we suggest that sarcoptic mange was not present in this raccoon dog population from 2005 to 2009 and from 2011 to 2015, which was when there were low raccoon dog population densities.

In conclusion, the increased population density might have resulted in the incidence of sarcoptic mange in raccoon dogs, and sarcoptic mange possibly impacted raccoon dog population density. Because no previous studies have carried out biological capture surveys for 16 years, our study provides the most detailed report on population dynamics of raccoon dogs and epidemiological survey of sarcoptic mange in Japan to date. Because this forest is adjacent to Sapporo City and there are contact opportunities between wildlife and companion animals, it is necessary to continue monitoring sarcoptic mange incidences.

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