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Resolution of Clinical Signs of Sarcoptic Mange in American Black Bears (*Ursus americanus*), in Ivermectin-Treated and Nontreated Individuals

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ABSTRACT: The parasitic mite *Sarcoptes scabiei* causes mange in nearly 150 species of mammals by burrowing under the skin, triggering hypersensitivity responses that can alter animals' behavior and result in extreme weight loss, secondary infections, and even death. Since the 1990s, sarcoptic mange has increased in incidence and geographic distribution in Pennsylvania black bear (*Ursus americanus*) populations, including expansion into other states. Recovery from mange in free-ranging wildlife has rarely been evaluated. Following the Pennsylvania Game Commission's standard operating procedures at the time of the study, treatment consisted of one subcutaneous injection of ivermectin. To evaluate black bear survival and recovery from mange, from 2018 to 2020 we fitted 61 bears, including 43 with mange, with GPS collars to track their movements and recovery. Bears were collared in triplicates according to sex and habitat, consisting of one bear without mange (healthy control), one scabietic bear treated with ivermectin when collared, and one untreated scabietic bear. Bears were reevaluated for signs of mange during annual den visits, if recaptured during the study period, and after mortality events. Disease status and recovery from mange was determined based on outward gross appearance and presence of *S. scabiei* mites from skin scrapes. Of the 36 scabietic bears with known recovery status, 81% fully recovered regardless of treatment, with 88% recovered with treatment and 74% recovered without treatment. All bears with no, low, or moderate mite burdens (<16 mites on skin scrapes) fully recovered from mange (n=20), and nearly half of bears with severe mite burden (≥16 mites) fully recovered (n=5, 42%). However, nonrecovered status did not indicate mortality, and mange-related mortality was infrequent. Most bears were able to recover from mange irrespective of treatment, potentially indicating a need for reevaluation of the mange wildlife management paradigm.

Key words: Control, epizootics, mange, mite, parasitic disease, *Sarcoptes scabiei*, scabies, wildlife.

INTRODUCTION

Sarcoptic mange, caused by the parasitic mite *Sarcoptes scabiei*, is a (re)emerging panzootic disease with increasing host diversity, geographic distribution, and disease severity observed across multiple continents (Escobar et al. 2022). *Sarcoptes scabiei* infests nearly 150 different species of mammals, with a worldwide distribution and numerous host-adapted variants (Bornstein et al. 2001; Pence and Ueckermann 2002; Simpson et al. 2016). By burrowing under the host's skin, *S. scabiei* can trigger severe hypersensitivity responses resulting in altered behavior, weight loss, secondary infections, and even death (Pence and Ueckermann 2002). Although this disease has a lengthy history affecting mammalian hosts, there remain numerous unknowns regarding the mite and the disease it causes (Arlian and Morgan 2017).

In North America, wild canids have historically been affected by sarcoptic mange with several documented epizootics, particularly within coyote (*Canis latrans*), gray wolf (*Canis lupus*), and red fox (*Vulpes vulpes*) populations (Niedringhaus et al. 2019a). Although black bear

(*Ursus americanus*) ranges in the northeast overlap with coyotes and red foxes, black bears were rarely affected by sarcoptic mange until the early 1990s, when cases were increasingly reported in Pennsylvania (Schmitt et al. 1987; Fitzgerald et al. 2008; Peltier et al. 2018; Niedringhaus et al. 2019b). Cases in black bears have substantially increased in Pennsylvania over the last 30 yr, with regional expansion to states in the northeast, mid-Atlantic, and southeast in recent years (Niedringhaus et al. 2019b). Even in historically affected species, infestation with *S. scabiei* may cause drastically different disease manifestation at the individual, species, and population level, contributing to difficulties in characterization and understanding of the disease syndrome (DeCandia et al. 2019). Further complicating diagnosis and treatment, sarcoptic mange lesions may appear similar to or be indistinguishable from other types of mange that can affect black bears, namely chorioptic (caused by *Chorioptes* sp.), demodectic (*Demodex ursi*), and audycoptic (*Ursicoptes americanus*) mange, and can appear similar to dermatitis or alopecia caused by other health conditions or infections (Yunker et al. 1980; Forrester et al. 1993; Foster et al. 1998; Costello et al. 2006; Niedringhaus et al. 2021). As it is a more recently documented disease in black bears, mange severity and recovery has not yet been characterized in this species.

There are numerous acaricides available to treat *S. scabiei* infestation; of these, ivermectin is commonly used to treat domestic animals and wildlife (Rowe et al. 2019). Because of ivermectin's lack of efficacy against the ova stage, veterinary practitioners typically recommend that domestic dogs receive 2–4 doses over several weeks to ensure that all mite life stages are eradicated in subsequent doses (Curtis 2004). This presents a challenge when treating noncaptive wildlife, as not all individuals can be easily confined for extended periods, particularly rabies reservoir species (e.g., red foxes, coyotes, and raccoons [*Procyon lotor*] in North America) and large mammals with challenging space requirements or habituation and handling concerns (e.g., black bears). Treatment with a single acaricidal dose is frequently administered to opportunistically captured wildlife, but there are little data on the efficacy of this treatment for clearance of mite infestation or resolution of overt disease (Rowe et al. 2019).

To evaluate the utility of single-dose ivermectin treatment and the ability of black bears to recover from sarcoptic mange, we outfitted black bears with GPS radio collars to: 1) evaluate the ability of black bears to recover from sarcoptic mange with and without single-dose ivermectin treatment, 2) develop a standardized classification scheme of mange severity, and 3) provide guidance to wildlife managers on mange management options in black bear populations.

MATERIALS AND METHODS

Study area

This study was conducted in Pennsylvania, US, in counties with the highest number of reports of sarcoptic mange in black bears, selected in consultation with the Pennsylvania Game Commission (PGC). Black bears were GPS-collared in 13 counties in northern and central Pennsylvania: Cambria, Cameron, Centre, Clearfield, Clinton, Huntingdon, Lycoming, McKean, Mifflin, Potter, Snyder, Tioga, and Union. Northern Pennsylvania is primarily wooded, with northern hardwood forest and Appalachian oak forests. South-central Pennsylvania is a mixture of Appalachian oak forests and agricultural land (Rhoads and Block 2005).

Black bear captures

Black bears were captured using barrel-style and culvert traps from 26 April 2018 to 15 September 2020 using PGC standard operating procedures, and monitored up to 4 yr for inclusion in this study, until 31 March 2022. In total, 61 adult black bears (37 females, 24 males) were captured and outfitted with GPS satellite collars with an activity sensor and VHF beacon (VERTEX PLUS Collar, VECTRONIC Aerospace GmbH, Berlin, Germany). All collars were programmed to acquire a location fix every 2.25 h, transmitted via iridium satellite link (Iridium Satellite Communications, McLean, Virginia, USA). Collars were equipped with mortality sensors if the collar remained motionless for >8 h. The GPS and activity fix rate data were downloaded during annual den checks, opportunistic recaptures, or when collars were retrieved.

Black bears were immobilized with 4.4 mg/kg ketamine (200 mg/mL ketamine hydrochloride solution, SaveWay Compounding Pharmacy, Newark, Delaware, USA) and 1.8 mg/kg xylazine (200 mg/mL xylazine hydrochloride solution, SaveWay Compounding Pharmacy) administered via dart pistol (Dan-Inject, Dan-Inject North America, Fort Collins, Colorado, USA) or jab stick, depending on situational requirements. After bears were anesthetized, individually marked ear tags (36.5×9.5 mm; style 56-L, Hasco Tag Company, Dayton, Kentucky, USA) were attached or recorded if present upon capture, and sex, body weight, morphometric measurements, and signs of estrus or lactation in females was recorded. To determine age, a premolar was removed for cementum annuli analysis (Matson's Laboratory, LLC, Milltown, Montana, USA; Willey 1974). When bears required drug reversal, and after >40 min postimmobilization to allow for metabolization of ketamine, 0.15 mg/kg yohimbine (10 mg/mL yohimbine, SaveWay Compounding Pharmacy) was administered by hand syringe into the femoral vein. Annual den checks were conducted in February and March to download collar data, gather reproductive information, and conduct health analyses. All procedures complied with PGC permit number 42115 and Pennsylvania State University Institutional Animal Care and Use Committee protocol numbers 47978 and 00871.

Study design

Black bears were assigned to one of three treatment groups when GPS-collared for the study: non-scabietic control (termed "healthy" hereafter), scabietic with treatment, and scabietic without treatment. The healthy controls were black bears without outward signs of mange or dermatologic disease when first captured and evaluated for the study. A complete experimental triplicate consisted of one bear of the same sex from each of these treatment groups, captured within similar landscape types (i.e., primarily forested or primarily agricultural), and similar mange severity. Treatment consisted of one subcutaneous injection of 0.4 mg/kg ivermectin (1% ivermectin sterile solution AGRI-MECTIN, AgriLabs, Huvepharma, Inc., Peachtree City, Georgia, USA) in accordance with PGC standard operating procedures at the time of the study. To reduce treatment bias, treatment was administered to every other scabietic bear captured for inclusion in the study in 2018. In the subsequent study years of 2019 and 2020, bears were GPS-collared to fill the 2018 preexisting treatment groups based on their sex, mange severity, and general habitat characteristics and given treatment or no treatment based on the needs of the empty triplicates. In total, 61 black bears were GPS-collared for the study: 18 healthy controls (11 females, seven males), 21 scabietic treated bears (13 females, eight males), and 22 untreated scabietic bears (13 females, nine males).

Whole-body examination for evidence of mange was conducted on all bears in the study. Skin scrapes from bears with suspected mange were collected from areas with thickened, crusted skin lesions and examined with a stereomicroscope in the field to confirm infestation with *S. scabiei.* Mange severity was determined using four categories: Body condition, skin condition, hair loss, and initial field evaluations of mite burden on a skin scrape (Table 1). Mite burden was quantified microscopically in the laboratory using the field-collected skin scrapes stored in ethanol, and total mange severity score was modified as needed. Mite burden was categorized based on the number of mites identified per skin scrape: none (0 mites identified; cytology score=0), mild (0–5 mites; cytology score=1), moderate (6–15 mites; cytology score=2), and severe (≥16 mites; cytology score=3). Total mange severity score was the sum of these four categories, with all categories scored from normal (0) to severe (3; Fig. 1). Black bears were categorized by overall mange severity according to total mange matrix score as follows: healthy (no signs of mange): 0.0; mild: 0.5–4.0; moderate: 4.5–8.5; severe: 9.0–12.0.

Statistical analyses

We used logistic regression to evaluate the effect of treatment (treated vs. not treated) and mange severity (using mange matrix scores as indicators of initial mange severity) on black bear recovery. Bear recovery was determined by the level of improvement in mange condition when last evaluated during the course of the study. Recovery was defined as "improved" for all bears that showed any level of improvement, and "not improved" for bears that did not improve or worsened in condition. Three models were fitted using different numeric predictors: 1) clinical signs of mange (i.e., hair loss, body condition, and skin condition scores), 2) mite burden (cytology score), and 3)

TABLE 1. Mange matrix scoring guide used on scabietic American black bears (*Ursus americanus*) to evaluate severity of clinical signs (hair loss, skin condition, body condition) and mite burden as evaluated by the number of mites present on a skin scrape taken from a scabietic lesion collected from bears in Pennsylvania, USA, 2018–22. Only whole number scores were recorded for hair loss and cytology categories; half scores could be used for skin condition and body condition categories.

Mange severity	0	1	2	3
Hair loss (field observation)	None	Hair loss <1/3 of body	Hair loss 1/3 to 2/3 of body	Hair loss >2/3 of body
Skin condition (field observation)	Normal	Skin not thickened or pigmented, areas of scaly skin small and diffuse	Patches of thickened, crusted, or black pigmented skin	Large areas of thickened, crusted skin; debris flaking from skin or on hair shafts; strong odor
Body condition (field observation)	Normal	Below average; spinal vertebrae knobby, pelvic crest and ribs can be felt but not protruding	Poor; spinal vertebrae well defined, pelvic crest and ribs visible, skull structures felt but not visible	Emaciated; skeletal muscle gone, zygomatic arches visible, eyes sunken
Mite burden (laboratory cytology or field microscope)	No mites	Mild; 1–5 mites observed	Moderate; 6–15 mites observed	Severe; 16+ mites observed

mange matrix total (sum of the four mange matrix categories).

To evaluate contributing factors to an individual black bear's fate during the course of the study, we used a Fisher's exact test to assess the effect of mange presence, treatment group, and sex on causes of death or removal from the study. Bears that could not be located because of collar malfunctions were excluded from analyses of bear recovery and fate, as their fate was unknown and collar malfunction was primarily due a hardware malfunction, not due to bear behavior or activity. The resulting fate categories included: bears that died of mange (i.e., emaciated bears with severe mange and no other evident causes of mortality and bears with severe mange that were euthanized because of crop predation and property destruction), bears that removed their collar during the study ("dropped collars"), bears harvested by hunters, bears that died because of vehicle collision, and bears that survived to the end of the study with working collars. Statistical inference was made using a significance level of $\alpha \leq 0.05$. We performed the Fisher's exact test and logistic regression using the *stats* package (version 4.1.2) in R (R Core Team 2022), implemented with RStudio (version 1.4.1717).

We estimated monthly survival using a staggered entry Kaplan-Meier estimator. Survival rates were calculated from a total of 52 GPS-collared black bears between 3 May 2018 and 1 April 2022, censored for loss of bears due to collar failures or bear removal of collars (dropped collars), as survival was unknown for these bears. For this analysis, sources of bear mortality included hunter harvest, vehicular impact, mange-related mortality, and nuisance removal. We constructed three models that allowed average monthly survival to vary by 1) treatment, 2) initial mange severity, and 3) month but not treatment or severity. We did not include any model interactions between treatment, severity, or month; nor did we include the effects of year or sex on survival probability, because of small sample sizes. We used Program MARK (White and Burnham 1999) to fit the survival models.

RESULTS

Of the 43 black bears with mange evaluated in this study, 36 had a known recovery status (Table 2). Overall, 81% of black bears with sarcoptic mange fully recovered over the course of the study regardless of treatment, and 86% of bears showed improvement in mange severity (Fig. 2). Although treatment with ivermectin was not a significant predictor of

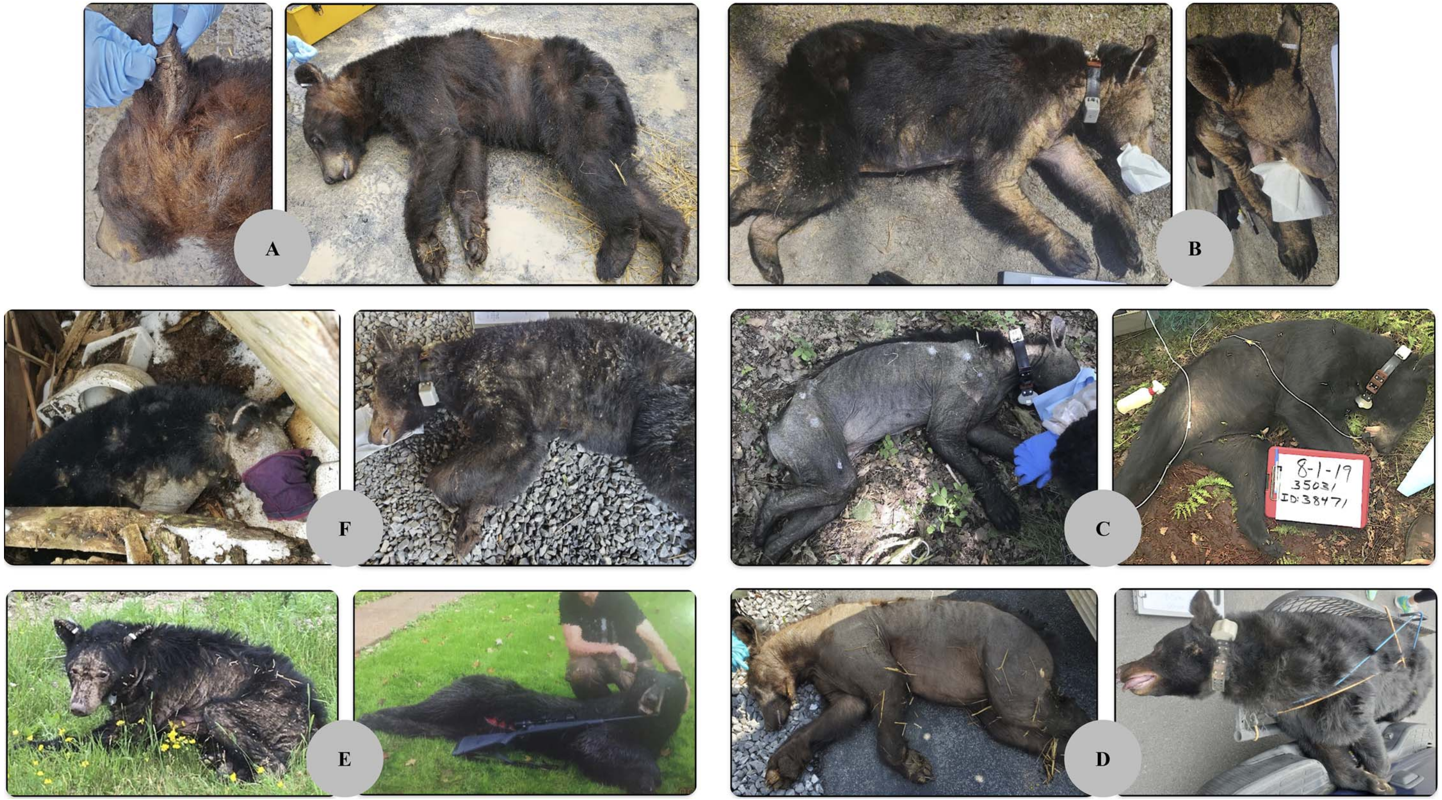

FIGURE 1. (a) American black bear (*Ursus americanus*) with mild signs of mange but severe mite burden when initially GPS-collared, probably indicative of early stages of infestation. Hair loss: 1.0; skin condition: 1.5; body condition: 0.5; cytology (mite burden): 3.0 (24 mites identified); 6.0/12.0 severity score, overall score indicated moderate mange severity. (b) American black bear (*Ursus americanus*) with moderate signs of mange and severe mite burden when initially GPS-collared in May 2020 (pictured). She was found dead and emaciated 3 mo later, probably related to worsened mange severity. Hair loss: 1.0; skin condition: 3.0; body condition: 1.0; cytology: 3.0; 8.0/12.0, overall score indicated moderate mange severity. Overall, when initially collared, bear had healthy body condition, particularly for springtime after den emergence and before food is readily available in the region. High mite burden and severe skin crusting is probably indicative of severe, active infestation. (c) Black bear with severe mange when originally collared (left). Hair loss: 3.0; skin condition: 2.0; body condition: 2.5; cytology: 3.0; 10.5/12.0, overall score indicated severe mange severity (evaluated from photos after mange matrix developed). The bear was not treated but made a full recovery with no signs of mange present when

re-trapped and evaluated 1 yr later (right). Leathery, hyperpigmented skin (left)is probably indicative of individuals in recovery stages. (d) Black bear with moderate mange when originally collared (left). Hair loss: 3.0; skin condition: 2.0; body condition: 0.0; cytology: 2.0; 7.0/12.0, overall score indicated moderate mange severity. The bear was not treated but made a full recovery with no signs of mange present when it was retrapped and evaluated 5 mo later (right). Leathery, hyperpigmented skin (left) is probably indicative of individuals in recovery stages. (e) Black bear (*Ursus americanus*) with severe mange when originally collared (left). Hair loss: 3.0; skin condition: 3.0; body condition: 2.0; cytology: 3.0; 11.0/12.0, overall score indicated severe mange severity. This bear was treated and had fully recovered when hunter-harvested 4 mo later (right). The individual showed little movement during the first month post-treatment, then traveled >100 miles in 5 wk before being harvested in New York, US. (f) Black bear (*Ursus americanus*) with severe mange when originally collared and treated in June 2018 (not pictured), and moderate to severe mange at every subsequent evaluation (left: February 2019, scored 8.0/12.0; right: September 2020, 8.5/12.0). This bear received treatment but continued to show signs of moderate to severe mange throughout the study period.

bear recovery (P=0.73), five of the seven bears that did not fully recover were in the untreated group (71% of bears that did not fully recover were not treated). Only two bears in the treated group did not fully recover from mange during the course of the study, but most bears made a full recovery and did not show signs of mange when last evaluated (15/17, 88% of treated bears fully recovered). Additionally, most bears that did not receive treatment fully recovered (14/19, 74% of untreated bears fully recovered) or showed improvement in mange condition (16/19, 84% of untreated bears improved or fully recovered) when last evaluated during the study.

All bears that did not show improvement had initial mange matrix scores $\geq$8.0 (range=8.0–9.5), indicating moderate to severe disease, and bears that showed improvement had much greater variation in initial mange matrix scores (range=1.5–11.0; Fig. 3). However, initial mange matrix score was also not a significant predictor of bear recovery (P=0.15).

We found no significant association between outward signs of mange and recovery, as determined by body condition, skin condition, and hair loss scores (Fig. 4); a weak inverse correlation between hair loss scores and recovery was detected, but was not significant (P=0.61). Severe skin condition and body condition scores were both weakly correlated with non-recovery, but these relationships were also not significant (P=0.35 and P=0.59, respectively). The model with mite burden as a predictor could not be fitted because all four of the bears that did not recover had severe mite burden (cytology score=3), whereas all 20 bears with no, low, or moderate mite burdens (cytology scores=0–2) recovered. Of the bears with severe mite burdens, 5/12 (42%) fully recovered from mange and two bears had improved mange condition when last evaluated, even if they did not show full recovery (7/12, 58% improved or fully recovered).

Approximately half of black bears with known survival status were harvested during Pennsylvania and New York hunting seasons (21/38,

TABLE 2. Status of American black bear (*Ursus americanus*) recovery from sarcoptic mange, categorized by mange severity and separated into treatment groups (healthy control bears without signs of mange, scabietic bears that received one subcutaneous injection of ivermectin when first entered into the study ("treated"), and scabietic bears that did not receive ivermectin ("not treated"), in Pennsylvania, USA, 2018–22 (n=61).

Treatment group	Mange severity	Sex	Recovered	Improved	Not improved	Worsened	Unknown	Group total
Healthy control	No mange	F	NA	NA	NA	NA	NA	11
		M	NA	NA	NA	NA	NA	7
Mange, treated	Mild	F	2	0	0	0	1	3
		M	1	0	0	0	0	1
	Moderate	F	5	0	0	0	0	5
		M	2	0	0	0	2	4
	Severe	F	3	0	1	1	0	5
		M	2	0	0	0	1	3
Mange, not treated	Mild	F	4	0	0	0	1	5
		M	2	0	0	0	0	2
	Moderate	F	1	0	0	1	1	3
		M	4	0	0	0	1	5
	Severe	F	2	2	1	0	0	5
		M	1	0	0	1	0	2
Recovery total			29	2	2	3	7	61

55%; Table 3). Other causes of mortality during the study included bears that were hit by vehicles (7/38, 18%), and mortality due to mange complications (4/38, 11%). However, there was no significant association between a bear's fate during this study and treatment (P=0.62), their initial mange status (P=0.46), or sex (P=0.73).

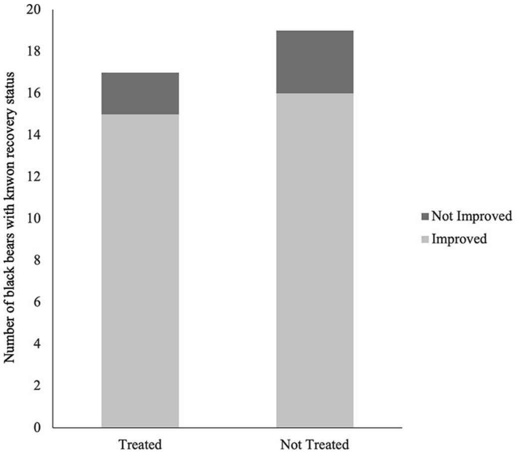

FIGURE 2. Most American black bears (*Ursus americanus*) showed improvement in mange severity after first being evaluated for inclusion in the study (86%) in Pennsylvania, USA, 2018–22, with no significant difference in recovery between treated and nontreated bears.

Black bear survival was high regardless of mange infestation, severity, or ivermectin treatment, with average monthly survival estimates above 0.90 across treatment groups and mange severity (Table 4). When comparing across treatment groups, bears with mange that did not receive treatment had the lowest survival estimates. However, the 95% confidence intervals overlapped among all estimates from the treatment and mange severity models. Survival was lowest in October (0.873, SE=0.037) and November (0.879, SE=0.040), coinciding with peak Pennsylvania black bear hunting seasons (Fig. 5). Outside the peak hunting season, monthly survival estimates exceeded 0.94, with no mortalities detected from January to June. Despite high bear harvest rates and expanded hunting seasons in 2019 and 2020, study bears had high survival estimates across all months.

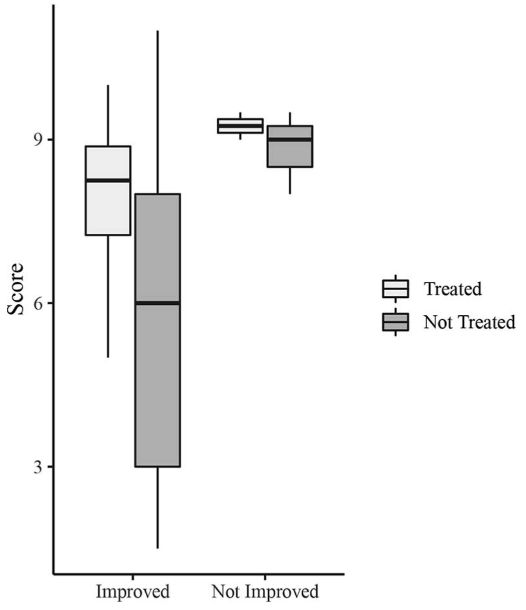

FIGURE 3. American black bears (*Ursus americanus*) showed improvement or full recovery from mange even without treatment during the study conducted in Pennsylvania, USA, 2018–22. However, all bears that did not improve or had a worsened condition when reevaluated during the study period had initial mange severity scores ≥8.0.

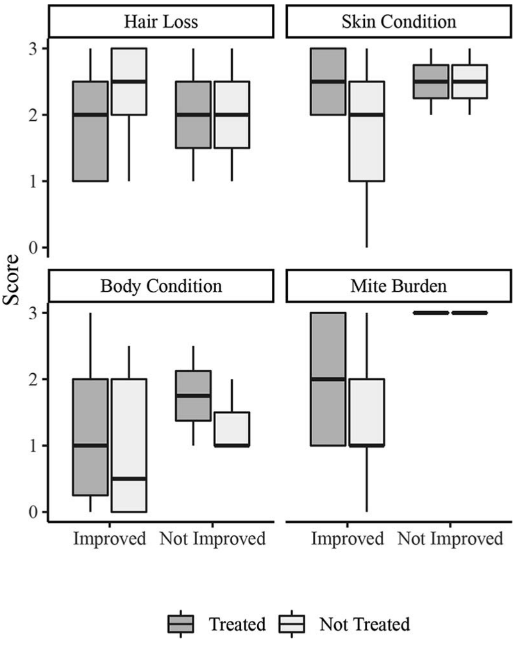

FIGURE 4. American black bears (*Ursus americanus*) showed improved condition or were fully recovered from mange when reevaluated, regardless of severity of clinical signs (hair loss, skin condition, body condition) in the Pennsylvania, USA, study conducted in 2018–22. All black bears that did not improve in mange severity had severe mite burdens (3.0) when initially GPS-collared; however, other bears with severe initial mite burden were able to improve or fully recover from mange.

DISCUSSION

Mange is a relatively recent disease in black bears, with a paucity of information on recovery and survival. This is the first study to evaluate noncaptive black bear recovery from sarcoptic mange and one of few studies assessing post-treatment recovery in noncaptive scabietic wildlife of any species. In contrast to many previous studies of mange in other wildlife species, most scabietic black bears were able to recover from the disease, and treatment was not correlated with recovery: Most bears recovered regardless of treatment status (Rowe et al. 2019; Escobar et al. 2022). With a paucity of long-term studies on sarcoptic mange in wildlife species and populations, it is challenging to assess the novelty of black bear recovery from sarcoptic mange. However, resistance to sarcoptic mange has been reported previously in several species, including cases of reported resistance in Iberian ibex (*Capra pyrenaica*) in southern Spain and suspected resistance or tolerance being developed in coyotes in Texas, US (Pence et al. 1983; Pérez et al. 2022).

Black bears were included in the study based on identification of suitable candidates to start new or fill preexisting triplicates. Interestingly, most male scabietic black bears included in the study had moderate mange, compared to an approximately equal distribution of mild, moderate, and severe mange for female scabietic black bears included in the study (Fig. 6). This might be related to ease of capture rather than mange severity distribution, with more females captured for inclusion in the study compared to male black bears.

Not surprisingly, healthy bears and bears with mild mange had the highest survival rates, and bears with moderate to severe mange had the lowest survival rates; however, survival was high and not significantly different across initial

TABLE 3. Cause of mortality or removal from study for GPS-collared American black bears (*Ursus americanus*; n=61) from 2018–22 in Pennsylvania, USA, grouped by presence or absence of sarcoptic mange when initially collared for study.

Fate	Mange present (%)	Healthy, no mange (%)
Hunter harvested	15 (35)	6 (33)
Vehicle collision	6 (14)	1 (6)
Died of mange[a]	4 (9)	0
Study conclusion[b]	3 (7)	3 (17)
Collar malfunction[c]	11 (26)	5 (28)
Dropped collar	4 (9)	3 (17)
Total	43	18

[a] Mortality due to mange infestation included bears found dead with severe mange (with mortality likely due to severe dehydration or emaciation; n=2) or euthanized for destruction of crops or property with severe mange (n=2).
[b] GPS collars were removed from black bears that had been tracked for ≥3yr during the study period; this includes bears that escaped capture for removal of GPS collars but will have their GPS collars removed when recaptured (n=2).
[c] A hardware anomaly in collars deployed between 2018–2020 caused a high proportion of collars to malfunction before bears could be recaptured and reevaluated for mange status and recovery. The collar malfunctions were unrelated to health status of black bears in the study.

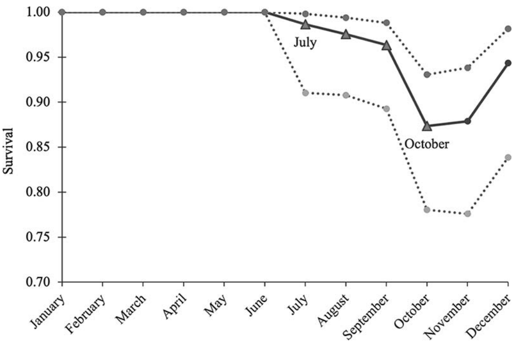

FIGURE 5. Kaplan–Meier survival curve for 52 GPS collared American black bears (*Ursus americanus*) released in Pennsylvania, USA, 2018–22. Triangles indicate months when survival decreased, with the first decrease in survival recorded in July and highest decrease in survival recorded in October.

mange severities. Hunting was five times as likely to be the cause of death for our study animals than mange or nuisance issues; this is not unexpected given the robust bear population and hunting interest and traditions common across Pennsylvania.

Typically described as a social disease, the transmission routes of mange in black bears, a solitary species except during the mating season and between sow and offspring, are perplexing and the primary routes of transmission are still unknown. Den sharing and reuse is a probable transmission route in other den- and burrow-obligate species, such as San Joaquin kit foxes (*Vulpes macrotis mutica*) and bare-nosed wombats (Montecino-Latorre et al. 2019; Loredo et al. 2020; Browne et al. 2021). However, den reuse is rare among black bears in Pennsylvania and mites survive less than 2 wk off-host under laboratory conditions, making winter dens an unlikely transmission route for black bears (Alt and Gruttadauria 1984; Niedringhaus et al. 2019c). Nevertheless, bears might become infested through environmental exposure in locations where bears congregate, such as baiting and feeding sites (Niedringhaus et al. 2019c). As mange can be transmitted through fomites in addition to direct contact, habitat areas with high

TABLE 4. Kaplan-Meier monthly survival estimates with 95% confidence intervals (CI) of 52 GPS-collared American black bears (*Ursus americanus*) by 1) mange treatment group (healthy control without signs of mange, mange with ivermectin treatment, mange without ivermectin treatment) and by 2) mange severity of scabietic black bears when initially entered into the study in Pennsylvania, USA, 2018–22.

Model	Group	Estimate (95% CI)
1) Treatment	Healthy control	0.971 (0.943–0.985)
	Mange, treated	0.965 (0.931–0.982)
	Mange, not treated	0.954 (0.918–0.974)
2) Mange severity	Mild mange	0.984 (0.950–0.995)
	Moderate mange	0.938 (0.880–0.968)
	Severe mange	0.947 (0.898–0.973)

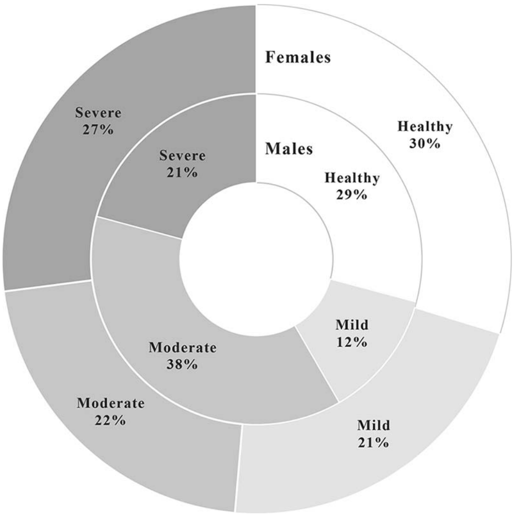

FIGURE 6. American black bears (*Ursus americanus*) were grouped into four categories depending on presence and severity of mange when first entered into the study: healthy (no signs of mange), and mild, moderate, or severe mange. More female bears were GPS-collared (outer circle, n=37) compared to male black bears (inner circle, n=24) for inclusion in the study in Pennsylvania, USA, 2018–22.

resource quality or high animal density may become foci for disease transmission events (Almberg et al. 2012).

The mange matrix was developed as a step towards an objective and systematic documentation of disease progression and severity in black bears and as a guide for management decisions. Without the ability to quantify mite burden in a typical field situation, outward signs of active infestation or recovery stages would provide a quick and efficient method to assess disease severity and guide management decisions. For instance, black bears with active infestations, indicated by a high mite burden and multiple life stages present on skin scrapes (≥16 mites), frequently had dispersed thickened, crusted skin lesions across their body, often concentrated on the front quarters. This is a similar characteristic in other species that is indicative of active, progressing infestation (e.g., bare-nosed wombats [*Vombatus ursinus*], Martin et al. 2018; and red foxes, Nimmervoll et al. 2013). Conversely, bears that were probably in recovery stages, indicated by low or no mite burden on skin scrapes, frequently had few or no skin lesions present, along with leathery blackened skin, and blunt fur indicating hair regrowth, similar to a red fox model of sarcoptic mange disease progression and recovery (Nimmervoll et al. 2013).

Importantly, although hair loss is frequently used as a metric for mange severity by wildlife managers, and has been found to be associated with energy loss due to disrupted thermoregulation (Cross et al. 2016), this metric was not an accurate assessment of overall mange severity by mite burden or bear recovery in this study. However, evidence of hair regrowth was not accounted for in the mange matrix and is probably useful in determining black bears in recovery stages (Pence et al. 1983; Pence and Ueckermann 2002; Nimmervoll et al. 2013). Conversely, skin condition was an important indicator of mange severity, with moderate to severe skin disease and severe mite burden observed in all individuals that worsened or succumbed to the effects of mange. This highlights the importance of evaluating clinical signs jointly, as black bears with alopecia but signs of hair regrowth and minimal skin crusting often had low or no mites present, indicative of recovery, compared to bears with alopecia and diffuse crusted skin lesions, which frequently had high mite burdens, indicating they were not in active recovery stages. Given the high proportion of bears that recovered in this study, an additional scoring criterion to account for bears probably in recovery phases is recommended for future iterations of the mange matrix used in this study (Table 5).

With a low sample size of bears that did *not* recover, we were unable to detect significant correlations between the four mange severity categories and bear recovery. It is also possible that these categories are not related to bear recovery and other factors were involved instead or in addition to the categories used in the mange matrix. Additionally, contrary to captive studies, it was not possible to monitor black bear continuously. Thus, the length of time to recovery was unknown and could not be compared to the

TABLE 5. Revised scoring system that accounts for characteristics probably indicative of recovery from mange in American black bears (*Ursus americanus*), with a negative score used to balance positive scores of previous or improving signs of disease (shaded column).

Mange severity	−1	0	1	2	3
Hair loss (field observation)	Hair regrowth (short, blunt fur)	None	Hair missing from less than 1/3 of body	Hair missing from 1/3 to 2/3 of body	Hair missing from more than 2/3 of body
Skin condition (field observation)	Hyperpigmented (blackened), leathery, smooth skin *and* minor or no skin crusting (for example, ears)	Normal	Skin crusting small and diffuse	Patches of thickened, crusted skin	Large areas of thickened, crusted skin; debris flaking from skin or on hair shafts; strong odor
Body condition (field observation)	N/A	Normal	Below average; spinal vertebrae knobby, pelvic crest and ribs can be felt but not protruding	Poor; spinal vertebrae well defined, pelvic crest and ribs visible, skull structures felt but not visible	Emaciated; skeletal muscle gone, zygomatic arches visible, eyes sunken
Mite burden (laboratory cytology or field microscope)	No live mites observed (no movement)	Normal (no mites observed)	Mild; 1–5 live mites or eggs observed	Moderate; 6–15 live mites/eggs observed	Severe; 16+ live mites/eggs observed

mange matrix classification scheme. Without continual monitoring of black bears, we also could not confidently distinguish between chronic infestation versus reinfestation in black bears that had mange when reevaluated during the study. Although most bears did not have clinical signs of mange when reevaluated at subsequent recaptures, this does not preclude the possibility that they had been previously exposed to *S. scabiei* before their initial inclusion in the study, or that they could become reinfested after the study concluded.

Given the continual increase in cases and geographic range of sarcoptic mange in black bears, these results are promising for individual bears' recovery from the disease. However, the ability of black bears to recover from this disease could prolong the period for which scabietic bears might infect other animals on the landscape. Additionally, the population-level effects of treatment and nontreatment are still unknown. Treatment within free-ranging wildlife depends not just on individual-level recovery but on population-level characteristics, such as the number of affected animals; size of the mange outbreak; overall population size and resilience; the species' social and grooming characteristics; and the vulnerability of the species to endangered or extinction status (Moroni et al. 2020). The potential for reinfestation and the effect treatment has on reinfestation severity is currently unknown in black bears. Although we did not observe reinfestation of any of the bears in this study, other researchers have noted reinfestation in other species, and it can become common in certain species (Loredo et al. 2020). Additionally, black bears are considered game animals in Pennsylvania and elsewhere within their North American range, limiting the type and timing of acaricide treatment that may be used, to allow for withdrawal periods before hunting seasons (Van Wick et al. 2020).

Although black bears in Pennsylvania currently have a robust population, there are subspecies of black bears that may be at risk because of low population sizes and habitat fragmentation (e.g., the Louisiana black bear, *Ursus americanus luteolus*) and recolonized populations that may be at higher risk because of small population sizes, population fragmentation, and genetic bottlenecking due to founder effects (Leydet and Liang 2013; Clark et al. 2015; McFadden-Hiller and Belant 2018). Additionally, as a highly contagious disease for nearly 150 mammalian species, there is concern about spillover of sarcoptic mange to species with reduced ability (low population size or other reasons) to withstand an epizootic (Escobar et al. 2022).

As a neglected zoonotic disease in humans (scabies) and a pan-emerging wildlife disease increasingly affecting more species worldwide, a One Health approach is crucial for sarcoptic mange disease surveillance and management. This approach emphasizes the connections between environmental, human, and animal health (Cartín-Rojas 2012; Allen 2015; Li et al. 2021). Because the transmission routes for black bears are not yet known but may include an environmental source component, along with the increasing number of spillover events between species, clearly a broad-scale, holistic approach to disease management is needed. In regions with few mange cases, individual treatment may provide successful disease management to reduce the amount of time an infected animal can spread mange on the landscape. In these cases, euthanasia of infected individuals is another option that may successfully mitigate disease on the landscape by removing the few infected individuals from the landscape entirely.

In regions with established or swiftly increasing numbers of disease cases, these strategies alone are not feasible to manage disease at the landscape level, as they are individual focused. For instance, for successful long-term disease management of human scabies in endemic regions, mass drug administration has been suggested as opposed to individually treating symptomatic patients, particularly in resource-poor communities (El-Moamly 2021). Unfortunately, there remains a paucity of landscape-level control options for sarcoptic mange outbreaks in wildlife populations, with individual treatment or euthanasia the most commonly used management options (Rowe et al. 2019). The success of other landscape-level disease management strategies, such as the distribution of oral baits to vaccinate wildlife against rabies virus (reviewed in Maki et al. 2017), provides potential strategies for sarcoptic mange management in wildlife populations. Nevertheless, an important caveat to consider is that most mange treatments are general antiparasitics and acaricides rather than active specifically against *S. scabiei*, thus possible negative environmental effects of widespread use must be considered in decision making.

There are still many unanswered questions about this complex disease, particularly in black bears as a relatively recently affected species. Long-term and captive studies would be particularly useful to evaluate the likelihood and severity of reinfestation, infectivity period, and time to recovery for treated compared to nontreated black bears to guide future management decisions for black bear populations. Lastly, research on transmission routes, particularly to determine if human activity contributes to mange transmission in black bears, would provide critical information for species and disease management.

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