



## Tick abundance and life-stage segregation on the American black bear (*Ursus americanus*)

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### ABSTRACT

Tick abundance and diagnosed cases of tick-borne diseases have been increasing in the United States. American black bear (*Ursus americanus*) populations have also been increasing in the eastern United States. As a competent host of several species of ticks and a mammal capable of traveling long distances, the role of black bears as hosts for ticks requires further evaluation. Ectoparasite surveys were conducted on black bears in Pennsylvania to evaluate tick presence, abundance, spatial distribution, and association with *Sarcoptes scabiei*, the etiological agent of sarcoptic mange, on bears to better understand their role in tick ecology and to improve on-host surveillance techniques. Tick burden was evaluated using standard area sampling (10.16 × 10.16 cm squares) on pre-designated body regions on black bears from June 2018–December 2019. In total, 278 unique individual black bears were evaluated, with all ticks identified as *Ixodes scapularis* ( $n = 1976$ ; 76.7% adults, 23.3% immatures). Tick presence differed by body region on bears, with the highest percentage of tick observations located on bear ears and muzzle. Ticks also partitioned on black bears by life-stage, with immature ticks primarily recorded on the lower extremities of bears and adult ticks primarily recorded on the front-quarters of bears. This includes the first known record of *I. scapularis* larvae parasitizing black bears, and observations of all three mobile life-stages concurrently parasitizing bears. Tick abundance was also statistically significant dependent on season, with the highest abundance of ticks recorded in spring and lowest abundance in fall. Adult ticks were less likely to be present on bears with mange. These data reveal the important role black bears may serve in tick ecology and dispersal as all three mobile life-stages of *I. scapularis* were found parasitizing a mammal capable of traveling far distances in a region with high numbers of Lyme disease cases.

### 1. Introduction

American black bear (*Ursus americanus*) populations are stable or increasing in many regions of the United States and populations in the northeastern United States have been increasing substantially since the 1980's (Hristienko and McDonald, 2007). Pennsylvania has seen a dramatic increase in its bear population, with the estimated population doubling between the late 1980's and 2001 and continuing to increase in the intervening twenty years (Hristienko and McDonald, 2007; Terrent, 2006).

Black bears have a broad geographic range across North America and can travel long distances, especially dispersing male bears (Lee and Vaughan, 2003; Liley and Walker, 2015), and this behavior may influence distribution of parasites that use this animal as a host. Ectoparasite surveys of black bears have been limited (Addison et al., 1978), but this species has been found to host several species of fleas (Rogers and

Rogers, 1976; Addison et al., 1978), lice (Hopkins, 1954; Scholten, 1962; Rogers and Rogers, 1976; Addison et al., 1978), and ticks (Rogers and Rogers, 1976; Furman and Loomis, 1984; Yabsley et al., 2009; Al-Warid et al., 2016). However, many of these ectoparasite surveys were conducted before the etiological agents of various tick-borne diseases were known and tick species distribution and abundance in many areas of the northeastern United States has changed in recent years (Pak et al., 2019; Sonenshine, 2018).

Reported cases of tick-borne disease in humans have increased substantially in recent decades, with the number of cases reported to the CDC nearly tripling between 2004 and 2017, and are likely vastly under-reported (Schwartz et al., 2017; Rodino et al., 2020). Lyme disease, caused by the bacterium *Borrelia burgdorferi* and primarily transmitted by the blacklegged tick, *Ixodes scapularis*, is the most frequently reported vector-borne disease and one of the most frequently reported infectious diseases in the United States (Schwartz et al., 2017). With the increased

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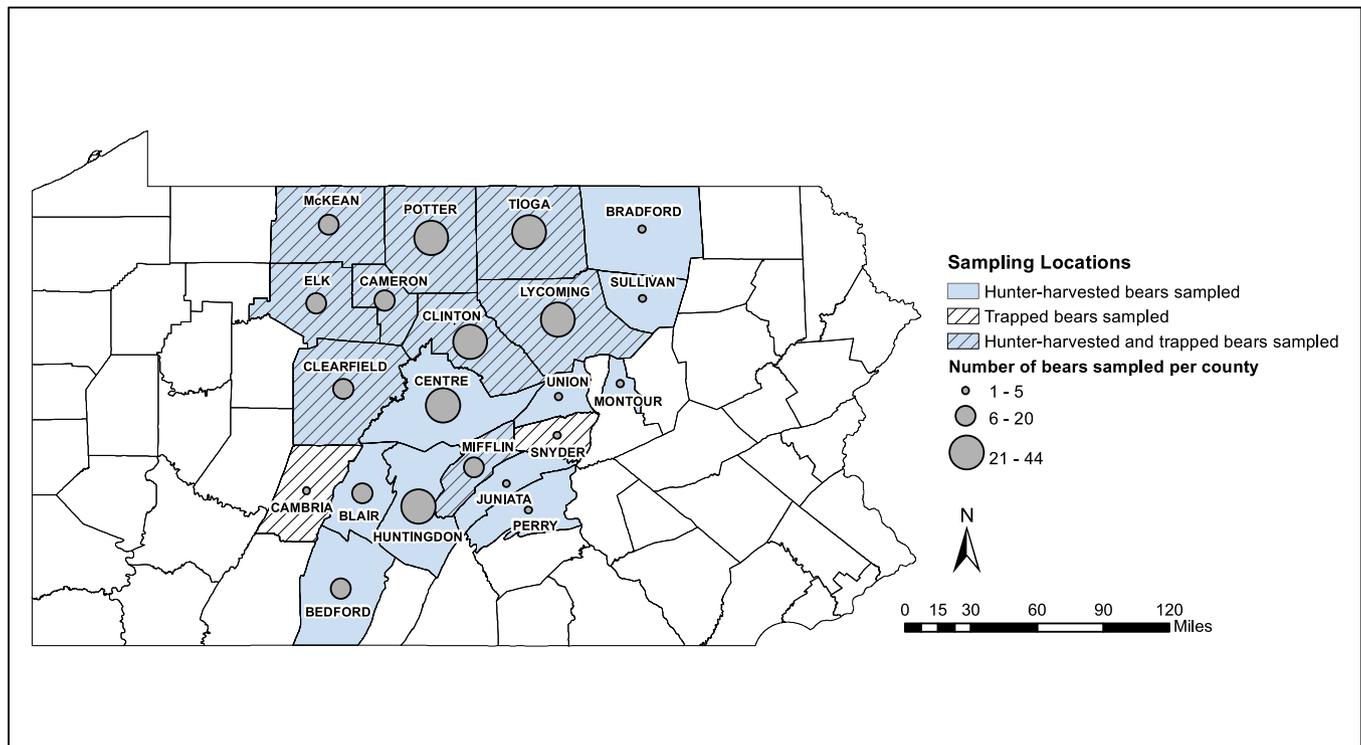


Fig. 1. Map of capture locations for bears surveyed for tick burden in Pennsylvania from June 2018–December 2019.

reports of tick-borne disease in humans and domestic animals and geographic expansion of several ticks of high medical importance, particularly *I. scapularis* (Pak et al., 2019; Sonenshine, 2018) and the lone star tick (*Amblyomma americanum*) (Sonenshine, 2018; Springer et al., 2015), it is probable that wildlife have increased contact with these medically-relevant tick species as well (Halsey et al., 2018; Springer et al., 2015).

The blacklegged tick and the American dog tick (*Dermacentor variabilis*) are common throughout the Northeast and can transmit a variety of pathogens to humans and animals (Eisen et al., 2017; Pak et al., 2019). Both tick species are host generalists and have been documented parasitizing a wide range of species (Bishopp and Trembley, 1945; Halsey et al., 2018; Keirans et al., 1996; Sonenshine, 2018). As immatures, both tick species have demonstrated higher host-specificity and in the Northeast most frequently feed on small mammals and mesocarnivores (Bishopp and Trembley, 1945; Eisen et al., 2017; Sonenshine, 2018). Common hosts for adult ticks are medium- and large-bodied mammals (Bouchard et al., 2013; Eisen et al., 2017).

To date, most wildlife studies of *I. scapularis* and *B. burgdorferi* in North America consist of research on two species – the white-tailed deer (*Odocoileus virginianus*) and the white-footed mouse (*Peromyscus leucopus*) (Halsey et al., 2018). This has led to a dearth of critical literature on the role of other species in tick dispersal, host suitability, and host reservoir status (Halsey et al., 2018). Wild animals, especially large-bodied, habitat generalist species like black bears, can also serve as sentinels for tick detection as on-host tick surveillance is less influenced by short-term weather and environmental conditions and vegetation that can disrupt host-seeking tick surveillance strategies (Merrill et al., 2018). Black bears could be important in tick dispersal and ecology (Al-Warid et al., 2016) as well as useful sentinel hosts for tick surveillance (Merrill et al., 2018).

Standardized tick surveillance methods have not been developed or consistently deployed for host species infrequently evaluated for tick burden and parasitism. Studies of ticks on wild mammals other than white-tailed deer and white-footed mice most frequently consist of opportunistic tick collections (e.g. Al-Warid et al., 2016; Skinner et al.,

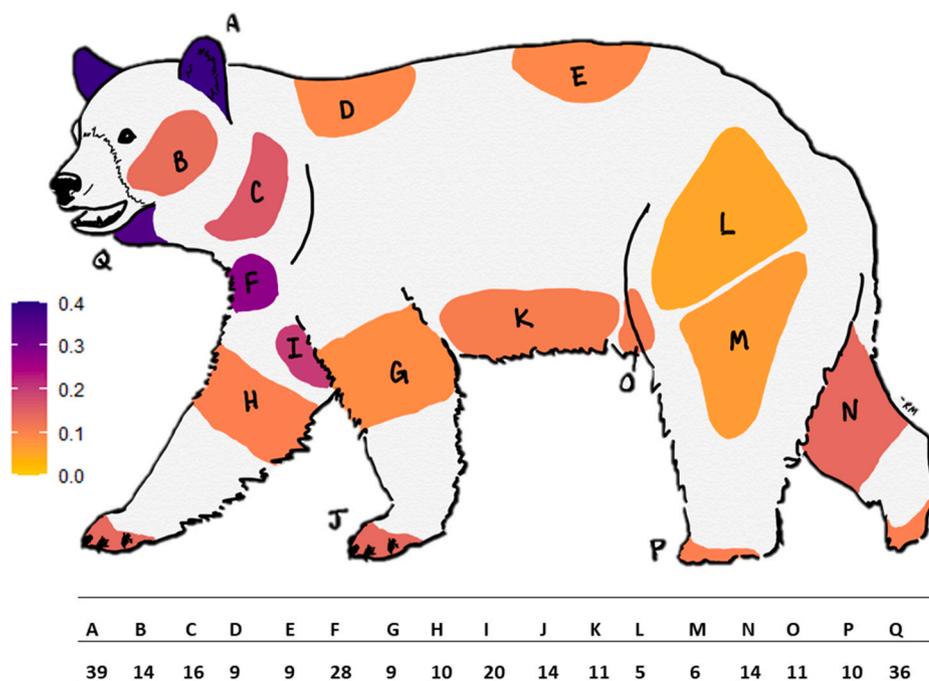
2017) or timed surveys (e.g. Zolnik et al., 2015). Opportunistic surveys have revealed that ticks are regularly found on black bears and have been documented parasitizing nearly all black bear populations evaluated in North America (Skinner et al., 2017). However, as a large mammal capable of hosting high tick burdens (Al-Warid et al., 2016), black bears present a particular challenge for accurate tick burden surveys, especially for live animals when time is a critical constraint for sampling efforts. A consistent and standardized method for assessing tick burden has not yet been developed for this large mammal.

The role of black bears as hosts for different tick species, tick life-stages, and movement of ticks over the landscape requires further evaluation to better understand the role these large mammals serve in tick ecology (Al-Warid et al., 2016; Zolnik et al., 2015). The purpose of this study was to evaluate tick species, abundance, and life-stages present on black bears in Pennsylvania and to evaluate tick spatial distribution on black bears in order to improve surveillance techniques. Additionally, as part of a concurrent project on sarcoptic mange in black bear populations, co-parasitism of ticks with *Sarcoptes scabiei*, the etiological agent of sarcoptic mange, was also investigated.

## 2. Material and methods

### 2.1. Black bear capture and mange evaluation

Black bears were evaluated for tick burdens between June 2018–December 2019. As part of annual Pennsylvania Game Commission (PGC) bear population research surveys, live black bears were evaluated for ticks between May–August 2018 and 2019. As part of a concurrent study evaluating health status and movement of black bears with sarcoptic mange, additional live and euthanized black bears with and without *S. scabiei* infestation were evaluated for tick burden between June 2018–October 2018 and March 2019–August 2019. PGC research surveys took place within the Sproul State Forest, Clinton County, in north-central Pennsylvania. As part of the study on *S. scabiei* infestation, bears were sampled in Cambria, Cameron, Clearfield, Clinton, Elk, Lycoming, McKean, Mifflin, Potter, Snyder, and Tioga counties,



**Fig. 2a.** Diagram of tick abundance on American black bears, based on 17 body regions surveyed on black bears from June 2018–December 2019 in Pennsylvania, USA. Figure colors based on percentage of observed tick presence out of all observations of that body region (table), to represent where ticks were most frequently observed within the body regions surveyed. Darker colors indicate higher percentages of observations when ticks were present and lighter colors indicate lower percentages of observations that had ticks present in that body region. Body location descriptors- A: ear; B: cheek; C: neck; D: upper spine; E: lower spine; F: chest; G: front outer leg; H: front inner leg; I: front axillary region; J: front inner toes; K: stomach; L: hip; M: hind outer leg; N: hind inner leg; O: hind axillary region; P: hind inner toes; Q: muzzle. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

in north-central and central Pennsylvania (Fig. 1).

Live black bears were trapped by PGC personnel using culvert traps and immobilized with 4.4 mg/kg ketamine hydrochloride (200 mg/mL ketamine solution, SaveWay Compounding Pharmacy, Newark, DE) and 1.8 mg/kg xylazine hydrochloride (200 mg/mL xylazine, SaveWay Compounding Pharmacy, Newark, DE) administered by tranquilizer dart under PGC standard operating procedures. Black bear vital signs were monitored while sedated. After at least 40 min had elapsed for the ketamine hydrochloride to metabolize and samples had been collected, the effects of xylazine were reversed with 0.15 mg/kg yohimbine (10 mg/mL yohimbine, SaveWay Compounding Pharmacy, Newark, DE) administered by hand syringe via femoral vein. Post-sedation, black bears were observed until they were ambulatory.

Black bears with clinical signs of mange, typically consisting of alopecia and thickened, crusted skin lesions, were confirmed to have sarcoptic mange by identifying *S. scabiei* mites present in skin scrapings. All sample collection protocols were authorized by the Pennsylvania Game Commission (PGC) permit # 42115 and conducted under Pennsylvania State University (PSU) Institutional Animal Care and Use Committee (IACUC) protocol #47978.

In addition to tick surveillance on live black bears, from November–December 2018 and 2019, hunter-harvested black bears were evaluated for ticks at PGC-designated hunter check stations where hunters are required to bring harvested bears during state-wide regular bear hunting season. Bears that were evaluated were harvested from Bedford, Blair, Bradford, Cameron, Centre, Clearfield, Clinton, Elk, Huntingdon, Juniata, Lycoming, McKean, Mifflin, Montour, Perry, Potter, Sullivan, Tioga, and Union counties (Fig. 1). Sample collection from hunter-harvested and euthanized bears was approved by a PSU IACUC protocol #00871.

### 2.2. Tick surveillance

To evaluate tick burden on black bears, standardized 10.16 × 10.16 cm (4 × 4”) squares were placed on pre-designated body locations (Fig. 2). Sixteen body regions were originally used at the start of this study in June 2018. However, the hunter-harvested bears frequently had ticks in a location that was not part of these original 16 body regions, so a seventeenth location (muzzle, “Q”) was added for the second year of

the study to evaluate tick burden in this additional location. Thus, between March 2019 to December 2019, 17 body regions were evaluated during tick surveys. Body region evaluations were conducted on one side of the bear that was determined by how the bear was laying after anesthesia or euthanasia.

### 2.3. Tick identification

Tick species, life-stage, and the number of ticks found within each square was recorded for each of the black bear body regions. When time and collection constraints allowed, ticks were collected and stored in 70% ethanol for pathogen testing as part of a different study. Adult ticks were identified to species in the field when they were located on black bears and confirmed using a stereoscope as needed. Larval and nymphal ticks were slide mounted in Hoyer’s medium (Krantz and Walter, 2009) and identified to species according to the key of Sonenshine (1979).

### 2.4. Statistical analyses

All statistical tests analyzing tick presence, abundance, life-stage segregation, and seasonality were conducted on bears that did not have signs of mange (242 of 278 unique bears). Bears with mange (36 of 278 unique bears) were only included in statistical tests evaluating tick and mange co-parasitism and body attachment selection of ticks on bears with mange compared to bears without signs of mange because of the potential influence that mange would have on tick abundance or location. All statistical analyses were conducted in program R version 4.1.0 (R Core Team, 2021). Differences were interpreted as statistically significant when  $p \leq 0.05$ .

To account for differences in movement between male and female bears, a Mann-Whitney test (Wilcoxon rank sum test in program R) was used to assess differences in the mean total number of ticks between males and females. To determine where ticks were most likely to be found on black bears, the percentage of ticks identified in a certain body region out of all observations of that body region was calculated for each body region. These percentages were overlaid onto a diagram of the body locations evaluated to visualize tick abundance on black bears. A logistic regression model was used to evaluate tick presence by bear body region. Each bear was assumed to have a random effect on the log-

**Table 1**

The number of ticks recorded on American black bears in Pennsylvania from June 2018–December 2019, by tick life-stage, bear mange status, and season. Spring was inclusive of March–May; summer inclusive of June–September; and fall inclusive of October–December. No bears were evaluated for tick burden during the months of January–February.

Bear Mange Status	Number of Ticks on Black Bears by Life-Stage and Season						Total Ticks	Mean Ticks (SD)
	Spring (n = 8 bears)		Summer (n = 48 bears)		Fall (n = 228 bears)			
	Immatures	Adults	Immatures	Adults	Immatures	Adults		
Healthy (n = 246 bears)	38	103	362	340	0	935	1778	7.23 (±12.68)
Mange (n = 38 bears)	10	6	51	24	0	107	198	5.21 (±8.78)
Overall Total (n = 284 bears)	48	109	413	364	0	1042	1976	6.96 (±12.24)

odds of tick presence to account for individual variation. Any body region that could not be evaluated at the time of the tick survey was excluded from analysis. To evaluate the correlation of tick presence in one body location with presence in other body locations, Kendall’s Tau was used to measure the correlation of every pair of body regions. To determine the likelihood of tick presence by body region, odds ratios were calculated for all pairwise comparisons of body regions and the Tukey method was used to determine significance for multiple comparisons.

A logistic regression model was used to determine the log-odds of a bear with adult ticks present compared to immature ticks present, by bear body region. Each bear was assumed to have a random effect on the log-odds of adult tick presence to account for individual bear variation. Body region A (ear) was used as the reference level; thus, all estimates can be interpreted relative to body region A. Body regions B (cheek) and D (upper spine) were not included in the model as they only had adult ticks recorded in these locations, thus their effects were unable to be estimated. Tick life-stage segregation was investigated by evaluating the percentages of adult and immature ticks recorded in each surveyed body region compared to the overall number of ticks found in that body region. These percentages were overlaid onto a diagram of a black bear to visualize abundance of adult ticks compared to immature ticks observed within the body regions evaluated.

Seasonality was determined by categorizing tick surveys by month according to northeastern U.S. *I. scapularis* phenology (Simmons et al., 2015). Seasons were categorized as spring = April–May; summer = June–August; fall = November–December. The months of March, September, and October were not included as only bears with mange were evaluated during these months and bears with mange were excluded from these analyses. No bears were evaluated for tick burden during January and February; thus, those months were also not included in these analyses. A zero-inflated negative binomial regression model (ZINB) was used to evaluate this data to account for a high number of body location counts that did not have ticks, with fall set as the reference group. The ZINB model combines two models, a logistic regression that modeled the presence of ticks by season and a negative binomial regression that modeled the abundance of ticks by season. The total number of ticks on a bear was used as the response and seasonality was used as the predictor.

To investigate co-parasitism between ticks and *S. scabiei*, the same logistic regression model used to evaluate tick presence by body region was used to evaluate the effect of mange status on the odds of tick presence. To evaluate the effect of mange status on tick life-stage presence, the logistical regression model used to evaluate tick life-stage presence by body region on non-mange affected bears was used to evaluate the effect of mange status on life-stage presence, assuming constant body location.

**3. Results**

In total, 278 unique black bears were evaluated, six of which were evaluated twice over the course of the study (n = 284 bear evaluations). Two of the bears evaluated twice had confirmed mange, with one bear with confirmed mange during both tick survey time-points and one bear

**Table 2**

Logistic regression models for a) tick presence by body region and mange status and for b) tick life -stage by bear body region and mange status, developed from 17 black bear body regions surveyed for ticks from June 2018–December 2019 in Pennsylvania, USA. Body region A was used as the reference level, all coefficients are interpreted in reference to body region A.

	Body Regions Surveyed	Logistic Regression Models			
		a) Tick Presence		b) Tick Life-Stage <sup>b</sup>	
		Estimate	p-value <sup>a</sup>	Estimate	p-value
Intercept	Ears (A)	-0.624	0.0004***	8.197	<0.0001***
Head	Cheek (B)	-1.875	<0.0001***	N/A	N/A
	Muzzle (Q)	-0.511	0.0335*	-0.217	0.888
Neck/ Chest	Neck (C)	-1.589	<0.0001***	1.061	0.508
	Chest (F)	-0.6893	0.0012**	0.730	0.648
Legs	Front outer leg (G)	-2.452	<0.0001***	-4.547	<0.0001***
	Front inner leg (H)	-2.247	<0.0001***	-5.006	<0.0001***
	Front axillary region (I)	-1.253	<0.0001***	-1.663	0.176
	Hind outer leg (M)	-1.837	<0.0001***	-5.559	<0.0001***
	Hind inner leg (N)	-1.837	<0.0001***	-5.531	<0.0001***
	Hind axillary region (O)	-2.144	<0.0001***	-4.327	<0.0001***
	Toes	Front inner toes (J)	-1.832	<0.0001***	-8.393
	Hind inner toes (P)	-2.248	<0.0001***	-8.196	<0.0001***
Trunk	Upper spine (D)	-2.446	<0.0001***	N/A	N/A
	Lower spine (E)	-2.448	<0.0001***	-2.324	0.134
	Stomach (K)	-3.307	<0.0001***	-5.499	0.002**
	Hip (L)	-3.181	<0.0001***	-2.996	0.050
Mange Status		-0.527	0.1174	-4.115	0.004**

<sup>a</sup> p < 0.001\*\*\*; p < 0.01\*\*, p < 0.05\*.  
<sup>b</sup> Body regions B and D are not included in the model as they were exclusively parasitized by adult ticks, thus were unable to be included in calculations.

that recovered with no clinical signs of mange the second time it was evaluated for tick burden. The other four bears did not show signs of mange during either tick burden evaluation.

**3.1. Tick species and life-stages identified**

All ticks collected were identified as *I. scapularis*. In total, 1976 ticks were recorded from the 17 body locations surveyed, of which 1515 were adults (76.7%), and 461 were immatures (23.3%) (mean: 6.96, SD: 12.24; Table 1). Only 188 of the 461 immature stages were collected due to various field constraints, including difficulty locating ticks if they detached or fell off the bear, when high numbers of ticks were found and time-constraints of live bear processing did not allow for collection of all ticks, or when partial ticks were collected and unable to be accurately identified via examination under a microscope. Of the 188 immature

*I. scapularis* collected, 135 were nymphs and 53 were larvae. Out of the 242 unique bears without mange evaluated, 171 bears had at least one tick located during the tick surveys ( $n = 242$ , 70.7% ticks present). Including bears sampled twice, 175 had ticks present ( $n = 246$ , 71.1% ticks present; Table 1).

### 3.2. Tick presence and abundance

Tick infestation severity did not differ by sex of the bear ( $W = 2428777$ ,  $p = 0.4675$ ). Overall, locations on the bears' head had the highest percentage of tick presence, with the ear (A) and muzzle (Q) with the highest percentages of tick presence out of all 17 body regions surveyed (percentage of observations with at least one tick present: ear (A) = 39%; muzzle (Q) = 36%; Fig. 2a). While the head and front-quarters of bears had the highest percentages of tick observations, the hindquarters of bears had the lowest percentages, with the outer hind leg (M) and hip (L) with the lowest percentages of tick presence recorded out of all locations surveyed (outer hind leg (M) = 6%; hip (L) = 5%; Fig. 2a). The log-odds of tick presence agreed with these findings with the highest odds of tick presence reported from the head and front of the bear compared to the other locations surveyed (Supp. Table 1).

The logistic regression model of tick presence related to bear body region resulted in all negative body region estimates, indicating that the reference group, the ear (A), had the highest odds of tick presence (Table 2a). The body regions with estimates closest to the reference group, indicating highest odds of tick presence after the reference group (A), were the muzzle (Q) and the chest (F), revealing that the three regions with highest likelihood of tick presence were the ear (A), the muzzle (Q), and the chest (F), in descending order. All the coefficients were statistically significant indicating that bear body region does have a significant effect on the odds of tick presence on the same bear.

To determine whether tick presence in one body region was correlated with tick presence in other body regions, Kendall's Tau test was used to compare correlations between each body location surveyed. Kendall's Tau test results in correlation estimates from  $-1$  to  $+1$ , with estimates of zero indicating no correlation, those closer to  $+1$  indicating a strong positive association, and closer to  $-1$  indicating a strong negative association. The front (J) and hind inner toes (P) had the highest estimated correlation ( $\text{corr} = 0.7$ ; Table 3). The second highest estimated correlation was between the front inner toes (J) and the front inner leg (H) ( $\text{corr} = 0.6$ ). Five body region pairs had an estimated correlation of 0.5: front inner leg (H) and hind inner leg (N); front inner leg (H) and hind inner toes (P); front axillary region (I) and hind inner leg (N); front inner toes (J) and hind axillary region (O); hind inner leg (N) and hind axillary region (O); lastly hind inner leg (N) and hind inner toes (P). Only one pair had a negative estimated correlation, that of the cheek (B) and stomach (K) ( $\text{corr} = -0.1$ ). Seven body region pairs were not correlated, with an estimated correlation of 0.0 (Table 3).

### 3.3. Tick life-stage segregation

The head and front-quarters of the bear were more likely to be parasitized by adult ticks compared to immature ticks. The cheek (B), upper spine (D), ear (A), neck (C), muzzle (Q), and chest (F) were the body regions most likely to be parasitized by adult ticks (cheek (B) = 100% adults recorded; upper spine (D) = 100%; ear (A) = 98%; neck (C) = 98%; muzzle (Q) = 98%; and chest (F) = 97%; Fig. 2b). In fact, the cheek (B) and upper spine (D) were exclusively parasitized by adult ticks and thus were unable to be included in the logistic regression model determining likelihood of adult tick presence (Table 2b). Conversely, the legs (body regions G, H, M, N) and toes (J, P) had strong negative associations for records of adult tick presence, indicating that they are more frequently parasitized by immature ticks compared to the reference group (A) (Table 2b). In particular, the toes were nearly exclusively parasitized by immature ticks (hind inner toes (P) = 83% immature ticks recorded; front inner toes (J) = 77%; Fig. 2b).

### 3.4. Seasonality

Tick abundance on black bears was dependent on season (Table 4a). With fall as the reference group, spring had the highest abundance of ticks on black bears compared to all other seasons. The expected tick count in spring was 7.26 times higher ( $=e^{1.9822}$ ) than the expected count in fall and was statistically significant ( $p = 0.003$ ). The expected tick count in summer was 4.25 times higher ( $=e^{1.4473}$ ) than the expected count in fall and was statistically significant ( $p < 0.001$ ). Tick abundance by season from highest to lowest was spring > summer > fall.

However, the odds of tick presence on a black bear were not dependent on season (Table 4b). With fall set as the reference group, the odds of a bear with ticks present in spring was  $3 \times 10^{-7}$  times lower ( $=e^{-14.844}$ ) than the odds of ticks present on a bear in fall, and the odds of a bear with ticks present in summer was 0.0003 times lower ( $=e^{-8.166}$ ) than the odds of ticks present on a bear in fall, but these were not significant.

### 3.5. Ticks and mange Co-Parasitism

Out of the 278 unique black bears surveyed for ticks, 36 unique bears had signs of mange at the time of tick burden evaluation. Of these 36 unique black bears, 20 bears had ticks present and 16 did not have any ticks located ( $n = 36$ , 55.6% mange bears with ticks present). Of the two bears evaluated twice over the course of the study, one bear had ticks present and one did not have any ticks present during the second tick burden evaluation ( $n = 38$ , 55.3% with ticks present). These percentages were lower than the percentages of bears without mange that had ticks present (70.7% unique bears without mange, 71.1% all bears without mange).

Overall tick presence was not dependent on mange status of black bears (Table 2a). However, tick life-stage was dependent on mange status, assuming a constant body location ( $p = 0.004$ ; Table 2b). The odds of a bear with mange with adult ticks present was 0.016 times the odds of the same bear without mange with adult ticks present.

## 4. Discussion

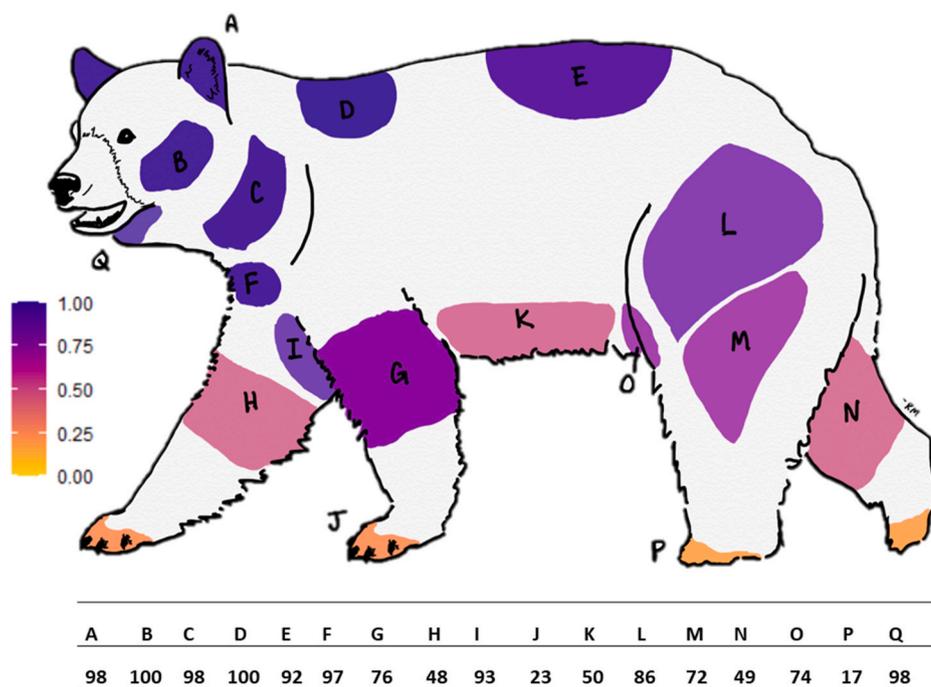
The purpose of this study was to evaluate the species and life-stages of ticks parasitizing black bears in Pennsylvania, to contribute to knowledge of black bears as a host in a region with high incidence of tick-borne disease in humans. Previous studies have identified that the five most common tick species in North America parasitizing black bears are *A. americanum*, *A. maculatum*, *D. variabilis*, *D. albipictus*, and *I. scapularis* (Leydet and Liang, 2013; Skinner et al., 2017; Zolnik et al., 2015). Those studies have generally found that ticks on black bears followed the known ranges of tick species in the U.S., with higher abundances of *D. variabilis* and *I. scapularis* in northern and northeastern states compared to higher abundances of *A. americanum* and *A. maculatum* on black bears surveyed in southern states (e.g. Al-Warid et al., 2016; Leydet and Liang, 2013; Skinner et al., 2017; Zolnik et al., 2015). However, *D. variabilis* has also been reported parasitizing black bears across a broad distribution of the United States and Canada (Yabsley et al., 2009). Additionally, a study conducted on black bears in the southern states of Florida and Georgia found *I. scapularis* in highest abundance, which could indicate the importance of habitat and microclimate on tick species abundance and host selection (Yabsley et al., 2009).

In the current study, all ticks parasitizing black bears were identified as *I. scapularis*. This is in direct contrast to the higher abundance of *D. variabilis* compared to *I. scapularis* ticks collected from black bears in the neighboring state of New Jersey in 2012 (Zolnik et al., 2015). However, these findings align with Pennsylvania tick record distributions that show higher abundances of *I. scapularis* and low to no records of *D. variabilis* in the counties surveyed during this study (Pak et al., 2019; personal communication, Christian N. Boyer, PA Department of

**Table 3**Kendall's Tau ( $\tau$ ) rank correlation for each of the 17 American black bear body regions surveyed for ticks from June 2018–December 2019 in Pennsylvania, USA based on the total ticks in each body region.

	Body Regions Surveyed	Head			Neck/Chest		Legs						Toes		Trunk			
		Ear (A)	Cheek (B)	Muzzle (Q)	Neck (C)	Chest (F)	Front outer leg (G)	Front inner leg (H)	Front axillary region (I)	Hind outer leg (M)	Hind inner leg (N)	Hind axillary region (O)	Front inner toes (J)	Hind inner toes (P)	Upper spine (D)	Lower spine (E)	Stomach (K)	Hip (L)
Head	Ear (A)	1																
	Cheek (B)	0.3	1															
	Muzzle (Q)	0.2	0.2	1														
Neck/Chest	Neck (C)	0.3	0.2	0.1	1													
	Chest (F)	0.3	0.2	0.2	0.2	1												
Legs	Front outer leg (G)	0.2	0.2	0.2	0.2	0.2	1											
	Front inner leg (H)	0.2	0.3	0.1	0.1	0.3	0.3	1										
	Front axillary region (I)	0.2	0.2	0.2	0.2	0.3	0.2	0.4	1									
	Hind outer leg (M)	0.1	0.1	0.1	0.2	0.2	0.1	0.3	0.3	1								
	Hind inner leg (N)	0.2	0.3	0.2	0.2	0.3	0.3	<b>0.5<sup>a</sup></b>	<b>0.5</b>	0.2	1							
	Hind axillary region (O)	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.3	0.3	<b>0.5</b>	1						
	Front inner toes (J)	0.2	0.3	0.2	0.2	0.4	0.3	<b>0.6</b>	0.4	0.4	0.4	<b>0.5</b>	1					
Toes	Hind inner toes (P)	0.1	0.2	0.1	0.1	0.2	0.3	<b>0.5</b>	0.3	0.2	<b>0.5</b>	0.4	<b>0.7</b>	1				
	Upper spine (D)	0.2	0.1	0.1	0.3	0.2	0.3	0.1	0.2	0.2	0.1	0.2	0.2	0.1	1			
Trunk	Lower spine (E)	0.2	0	0	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	1		
	Stomach (K)	0.1	-0.1	0	0.1	0.4	0	0.1	0.2	0.2	0	0.4	0.2	0.1	0.4	0.2	1	
	Hip (L)	0.1	0.1	0.2	0.1	0.2	0	0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.1	0	1

<sup>a</sup> Bolded values indicate correlations  $\geq 0.5$  in magnitude.



**Fig. 2b.** Diagram of tick segregation on American black bears, based on 17 body regions surveyed on black bears from June 2018–December 2019 in Pennsylvania, USA. Darker colors indicate higher percentages of adult ticks and lower percentages of immature ticks observed and lighter colors indicate lower percentages of adult ticks and higher percentages of immature ticks observed; based on percentages of adult ticks out of all ticks recorded in that body region (table). Percentages based on bears that had at least one tick recorded in the surveyed body locations. Body region descriptors- A: ear; B: cheek; C: neck; D: upper spine; E: lower spine; F: chest; G: front outer leg; H: front inner leg; I: front axillary region; J: front inner toes; K: stomach; L: hip; M: hind outer leg; N: hind inner leg; O: hind axillary region; P: hind inner toes; Q: muzzle. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

**Table 4**

Zero-inflated negative binomial model (ZINB) of seasonality of tick abundance and presence on black bears surveyed for ticks from June 2018–December 2019 in Pennsylvania, USA. Two models were generated as part of the ZINB, a) a negative binomial regression modeling tick abundance by season and b) a logistic regression modeling presence of ticks on black bears by season. Spring was inclusive of April–May; summer inclusive of June–August; and fall inclusive of November–December. No ticks were collected from bears during the months of January–February. Ticks were collected solely from bears with confirmed sarcoptic mange during the months of March (n = 1 bear), September (n = 1), and October (n = 1), these months were not included as bears with mange were not included in these analyses. Fall was used as the reference group (intercept); thus, spring and summer co-efficient estimates are interpreted relative to fall.

Term	a) Negative binomial regression (modeling number of ticks)		b) Logistic regression (modeling presence of ticks)	
	Estimate	P-value	Estimate	P-value
Intercept: Fall	1.5803	<0.001***	–2.521	0.0254*
Spring	1.9822	0.003271**	–14.844	0.9960
Summer	1.4473	<0.001***	–8.166	0.9030
Overdispersion	–0.5435	0.0024**		

Note: p < 0.001\*\*\*; p < 0.01\*\*, p < 0.05\*.

Environmental Protection, Tick Surveillance and Testing Program, 2021).

Previous studies have reported that most black bears evaluated were infested with at least one but typically many ticks (e.g. Al-Warid et al., 2016; Leydet and Liang, 2013; Skinner et al., 2017; Yabsley et al., 2009; Zolnik et al., 2015). However, in this study only 71% of black bears without mange were infested with at least one tick during standardized tick evaluations, leaving approximately 30% of black bears without any ticks found during the surveys. Bears with mange had even fewer ticks as only 56% of black bears with mange had ticks located during the standardized surveys. Regional differences in habitat, local and individual differences in bear movement patterns, and large sample sizes taken throughout the year in the current study compared to previous studies may account for identifying bears without ticks. Most previous studies of tick parasitism of black bears consisted of opportunistic collections on nuisance, vehicle-killed, or hunter-harvest bears (e.g. Leydet and Liang,

2013; Nims and Durden, 2011; Yabsley et al., 2009). The few previous studies that evaluated tick parasitism of black bears over several different seasons focused on collection of ticks for other secondary purposes compared to the current study that emphasized characterizing overall tick burden and spatial distribution of ticks on black bears (e.g. Yabsley et al., 2009; Zolnik et al., 2015). While collections were standardized and covered a broad range of the body, there could have been ticks present on bears in areas not surveyed during this study. However, black bears were surveyed for one month prior to the onset of the standardized surveys to select the locations most likely to harbor ticks, so additional ticks present outside of the standardized squares is likely negligible in terms of finding locations with high tick burden and life-stage aggregation and segregation. Additionally, while the amount of area surveyed remained consistent for each individual bear, the proportion of the individual evaluated varied by the bear’s size, with higher proportions of the body surveyed on smaller individuals and lower proportions surveyed on larger individuals. While the logistic regression models accounted for individual variability by including individuals as random effects, these differences in proportions surveyed could have resulted in lower estimates of total number of ticks observed on large male bears. However, no statistical difference was found between male and female bears regarding total number of ticks.

Evaluating black bears over this two-year period and throughout three distinct seasons provided a unique opportunity to evaluate seasonality of tick burden on black bears. While tick presence was not found to be related to season, abundance of ticks was seasonally dependent with spring having the highest abundance of ticks on bears and fall with the lowest abundance of ticks. This likely relates to *I. scapularis* phenology in the Northeast, with nymphs most active and abundant in the spring, larvae in the summer, and adults in the fall (Ogden et al., 2020). However, spring and summer had lower sample sizes of bears evaluated compared to the fall months and additional studies focused on evaluating bears in spring and summer months could aid in further evaluating these patterns.

Interestingly, *I. scapularis* larvae were recovered from black bears during this study. To the authors’ knowledge, this is the first report of larval *I. scapularis* found on black bears. In fact, several of the larvae were embedded and fully engorged when collected, which suggests they were not just incidentally on the bears but actively feeding.



**Fig. 3.** Photograph of a bear with severe sarcoptic mange. Note the high loss of fur and thickened skin on the ears, face, and along the sides of the body and higher amounts of fur remaining along the spine and lower limbs. This pattern of hair loss and thickened crusting skin is typical for bears with moderate to severe cases of sarcoptic mange in Pennsylvania, with mild cases also frequently exhibiting higher hair loss and clinical signs of sarcoptic mange on the face and front regions of the body.

Additionally, there were sampling periods in the current study where all three life-stages were present on the same bear in summer months. This is concerning as model simulations have indicated that synchronous seasonality of life-stages, particularly of larvae and nymphs, can increase transmission of *Borrelia burgdorferi* and *Anaplasma phagocytophilum* between ticks and hosts (Ogden et al., 2018). Previous studies have found numerous reactive antibodies or actively circulating tick-borne pathogens transmissible by *I. scapularis* in black bear blood samples, including *B. burgdorferi*, *Babesia microti*, and the agent of Human granulocytic ehrlichiosis (HGE, *Ehrlichia* sp.), as well as additional pathogens transmissible by other tick species (Schultz et al., 2002; Zolnik et al., 2015). Exposure of black bears to these pathogens and finding engorged *I. scapularis* larvae highlights the need for additional research into black bear reservoir status for pathogens transmissible by *I. scapularis* as well as their role in tick ecology more generally.

Tick aggregation and segregation has been shown to occur both at host population scales as well as at the individual scale across the host's body (Lydecker et al., 2019). In a study of white-tailed deer in Pennsylvania, two common tick species on deer, *I. scapularis* and *D. albipictus*, were found to segregate by host body location when both species were found parasitizing deer (Baer-Lehman et al., 2012). Another study conducted on white-tailed deer found that tick life-stages varied in abundance by host attachment site, potentially indicating life-stage induced aggregation or life-stage preference for specific host attachment sites (Bloemer et al., 1988). However, tick life-stage segregation on black bears had not been previously investigated.

As the host and reservoir status of black bears remains largely unknown, the segregation of tick life-stages on black bear bodies could present a unique opportunity to investigate black bears as a competent reservoir host for tick-borne pathogens in the future, particularly with this evidence of high attachment selection preference of immature ticks for the lower extremities of black bears (Fig. 2b). Along with the findings on locations of highest tick abundance (Fig. 2a), this would facilitate quick and selective tick surveys on black bears during future surveillance, although recovery of each life-stage would be dependent on tick seasonality. Future research could focus efforts on surveying locations with highest tick burden, such as the ears, muzzle, and chest when surveying for ticks overall, or focus efforts on the lower extremities, such as between the toes, when surveying for immature life-stages in particular.

Typically, *I. scapularis* has been considered to primarily parasitize

small- and medium-sized mammals as immatures (Keirans et al., 1996), but the results presented herein demonstrate that immatures of this species feed on large mammal hosts as well. This should be explored with other wildlife in the northeastern United States. These data could improve ecological models related to tick phenology, distribution, species expansion, and other components of tick-borne disease epidemiological risk, which typically rely on data from *Peromyscus* spp. and white-tailed deer (Cohnstaedt et al., 2012; Halsey et al., 2018; Merrill et al., 2018).

Co-parasitism was also investigated as studies have shown that individuals in a weakened physical condition or with a weakened immune system have a higher likelihood of occurrence or severity of infection and may be more susceptible to infection or parasitic infestation (Beldomenico and Begon, 2009). In this study, while black bear infestation with *S. scabiei* did not affect the overall presence of ticks, tick life-stage was significantly correlated with mange status. This is perplexing given the differing proportions of bears with mange that also had ticks (56%) compared to bears without mange that had ticks present (71%). However, the discrepancy in sample size (36 bears with mange; 242 without mange) may have hindered accurate comparisons of tick presence between the two groups.

While it is well-known that parasites vary in microenvironment selection on hosts, the complex mechanisms between host and parasite that affect on-host selection and attachment are still largely unknown (Fracasso et al., 2019) and co-parasitism of *S. scabiei* and ticks on black bears had not been previously investigated. As *S. scabiei* can result in significant changes to the host's epidermis, this may prevent or reduce successful tick attachment, and/or the host's loss of hair may not create a suitable microenvironment for ticks to attach. Mange infestation may have prevented ticks from finding adequate attachment sites on black bears, particularly adult ticks which were typically found in body locations on healthy bears that were most frequently and severely affected by sarcoptic mange (e.g., the ears and front portion of the body, Fig. 3). Conversely, immature ticks were most frequently found in locations that were typically less affected by mange, such as in between the toes, which may provide sufficient attachment sites for immatures as well as protection against bears increased grooming when affected by mange. Clinical signs of sarcoptic mange vary by individual and by disease state and progression. In this study, bears with varying clinical signs of mange were evaluated, ranging from mild to severe. Unfortunately, the sample size of this study did not allow for comparisons of tick burden between mange severity classifications (although individual bear was included as a random effect on the log-odds of the response in the logistic regression models of tick presence and tick life-stage in order to account for individual between-bear variation). Differences in mange severity could conceivably affect tick burden, so such differences in co-parasitism should be further investigated to better elucidate the relationship between tick attachment and bear infestation with *S. scabiei*.

This study highlights the important role the American black bear may serve in tick ecology and dispersal as all three mobile life-stages of *I. scapularis* were found parasitizing this mammal. The role of black bears in tick ecology and dispersal warrants additional study as these animals can travel far distances, particularly male bears that can travel over 100 miles when establishing a new territory (Liley and Walker, 2015). Additionally, wildlife can be used as sentinels for disease vectors of interest and surveyed to monitor tick species presence, host use, and range expansion (Merrill et al., 2018). The role of understudied tick hosts like black bears in the ecology of ticks warrants additional research as human cases of Lyme disease and other tick-borne diseases continue to increase in the United States.

#### Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijppaw.2021.10.004>.

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