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Jeffrey A. Prendergast
Emporia State University, Emporia, KS, jprender@emporia.edu

William E. Jensen
Emporia State University, Emporia, KS, wjensen1@emporia.edu

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CONSEQUENCES OF PARASITIC MITE INFESTATION ON MUSKRAT (*ONDATRA ZIBETHICUS*)

Jeffrey A. Prendergast¹ and William E. Jensen^{1,2}

ABSTRACT.—Ectoparasite infestation has been implicated in increased physiological costs and reduced fitness of several animals. The semiaquatic habit of muskrat (*Ondatra zibethicus*) restricts its ectoparasites to small mites. We assessed variation in muskrat reproductive effort and fat content in response to relative abundance of parasitic mites. There were no significant correlations between total number of placental scars, number of litters, or percent body fat and the relative abundance of ectoparasitic mites. Our results suggest that these measures of muskrat reproduction and physiology are generally unaffected by arachnid ectoparasites.

RESUMEN.—La infestación de ectoparásitos ha sido vinculada con el aumento de costos fisiológicos y una adecuación reducida de varios animales. El hábito semiacuático de la rata almizclada (*Ondatra zibethicus*) restringe sus ectoparásitos a pequeños ácaros. Evaluamos la variación en los esfuerzos de reproducción y el contenido graso en respuesta a una abundancia relativa de ácaros parasitarios. No hubo ninguna correlación significativa entre el total de las cicatrices placentarias, el número de camadas o el porcentaje de grasa corporal y la abundancia relativa de ácaros ectoparásitos. Nuestros resultados sugieren que estas medidas de la reproducción y fisiología de la rata almizclada no son generalmente afectadas por los ectoparásitos arácnidos.

Ectoparasites can negatively impact the fitness of their hosts. Higher ectoparasite loads can reduce numbers of offspring produced (Neuhaus 2003, Fitze et al. 2004) or cause complete reproductive failure (Vuren 1996). Lifetime reproductive success is further reduced through ectoparasitic effects on offspring survival and recruitment (Møller 1990, Richner et al. 1993, Brown et al. 1995, Vuren 1996, Fitze et al. 2004, Hillegass et al. 2010). Ectoparasites affect stress levels under certain environmental conditions (Quillfeldt et al. 2004) and the body condition (e.g., body mass) of host animals (Brown et al. 1995, Neuhaus 2003).

Parasitic mite infestation can carry serious implications for the health and fitness of mammalian hosts (Pence et al. 1983, Arnold and Anja 1993). Semiaquatic rodents' unique behavior restricts the ectoparasitic fauna that can successfully utilize them as a host (Whitaker 2006). The ectoparasitic fauna of muskrat (*Ondatra zibethicus*) has been well characterized for many regions and predominantly consists of host-specific, hair-clasping mites (Acarina) (Bauer and Whitaker 1981, Whitaker 1988, Whitaker 2006). Other parasitic arthropods (e.g., fleas) are occasionally found on muskrat but are not

considered regularly occurring (Bauer and Whitaker 1981). The largest of the regularly occurring mites is *Laelaps multispinosa* (family Laelapidae), a hematophagous mite (Grant 1947) that is rarely found on species other than muskrat (Whitaker 1982). The glycyphagid mite *Zibethacarus ondatrae* is also found in large numbers in its nonfeeding hypopial stage and is principally host-specific to muskrat (Whitaker 1982). The remainder of ectoparasitic mites consistently found on muskrat belongs to a suite of species from the genus *Listrophorus*. These included *Listrophorus americanus*, *L. dozeri*, *L. faini*, *L. ondatrae*, and *L. validus*, which are all largely host-specific to muskrat (Bauer and Whitaker 1981). The mites of this genus occur in high numbers on muskrat and feed on sebaceous secretions (Bauer and Whitaker 1981).

The purpose of our study was to determine the relative importance of ectoparasitic mites to the reproductive activity and nutritional condition of muskrat. Specifically, we compared muskrat seasonal fecundity and proportion of body fat to relative abundance of mites in muskrat pelage. We anticipated that reproductive activity and body fat of muskrat might be negatively related to *Laelaps multispinosa*

¹Department of Biological Sciences, Emporia State University, Campus Box 4050, 1200 Commercial St., Emporia, KS 66801.

²Corresponding author. E-mail: wjensen1@emporia.edu

abundance because of the hematophagous habit of this mite.

METHODS

Study Area

Muskrats were sampled from Squaw Creek National Wildlife Refuge in Holt County, Missouri. This refuge consists of approximately 2970 ha in the floodplain of the Missouri River, and was created primarily as a resting location for migratory birds. Water-obligate species have taken advantage of the site, including the muskrat, which occurs in high abundance on the refuge. There is a complex of pools and marshes on the refuge maintained by various water control structures. We used 3 of the pools on the refuge that were approximately 218 ha, 61 ha, and 21 ha and dominated by cattails (*Typha*) and arrowhead (*Sagittaria*).

Field Data Collection

We constructed 45 floating platforms to serve as summer feeding stations for muskrats in an ancillary study. A Tomahawk #103 live trap (Tomahawk Live Trap Co., Tomahawk, WI) was secured to each platform to facilitate capture. Feeding platforms were distributed in a linear arrangement along open water channels around marsh perimeters. Each platform was located 15 m offshore and 200 m from other platforms.

A rotating subsample of traps (approximately 10–15 daily) was set overnight for a period of 18 days (2–20 September 2009). When muskrats were captured, they were quickly transferred into a plastic tube to facilitate data collection. Several morphometrics were then taken, including weight (g), total length (cm), tail length (cm), and left hind foot length (cm). Animals were then sexed. Males were released after being given a temporary mark (removal of a small patch of hair) to facilitate identification of recaptures. Females were euthanized using specialized conibear traps and quickly placed in plastic sealable bags for transport to the lab. Immediately upon returning to the lab, we took an ectoparasite sample from the females by running a flea comb (60 mm wide, 0.70-mm-diameter prongs, and approximately 0.35-mm prong spacing) 10 times through the dorsal pelage and skin from the base of the skull to the base of the tail (Monello and Gompper 2009). This sample was placed in vials containing 70% ethanol for future quantification. Muskrats

were then frozen for future analyses. All procedures were approved by the ESU Animal Care and Use Committee (ESU-PROTOCOL-09-003).

Laboratory Data Collection

Ectoparasite samples were viewed under a dissecting scope. Parasites that were found in the sample were identified to species, with the exception of mites in the genus *Listrophorus*. Differences in energetic consequences among listrophorid mites should be negligible, as they are nearly ecological equivalents (Bauer and Whitaker 1981). The parasites were enumerated from each harvested muskrat to index species-specific relative abundances of ectoparasites and an overall ectoparasite load.

We used placental scars from the uteri of collected female muskrats to estimate seasonal fecundity, as these scars fade annually (Rolan and Gier 1967, Bray et al. 2003). Placental scars are frequently used to measure fecundity (Bergstrom and Rose 2004, Sacks 2005) and have been used previously to estimate seasonal fecundity in muskrat (Reeves and Williams 1956, Donohoe 1966). Female muskrats were thawed and the entire reproductive tracts were removed. The reproductive tracts were then stained following the procedure described by Bray et al. (2003). After staining, the uterine horns were cut lengthwise opposite the mesometrium to avoid damaging the placental scars. Uterine horns were viewed under a dissecting scope, and placental scars were enumerated and separated into litters based on scar morphology (e.g., size, color, etc.; Bray et al. 2003). This procedure allowed us to obtain a total number of scars and number of litters.

To determine the body condition of the captured muskrat, the percent of total body fat was quantified using nuclear magnetic resonance (NMR; Keeton et al. 2003). Samples of muskrat carcasses, after removal of reproductive tissues (above) and contents of the gastrointestinal tract, were transported to Kansas State University where they were ground into homogenous mixtures. Soxhlet extractions were performed on 3 samples to calibrate the NMR readings. Additionally, duplicate NMR readings were occasionally taken to ensure accuracy.

Statistical Analyses

Spearman's rank correlation was used to investigate correlations in the abundance of

each of the 3 parasite groups. Outliers in abundance per species were identified as being more than 2 standard deviations from the mean. Analyses were done with the statistical package SAS (SAS Institute, Inc., Cary, NC) using Proc CORR, and correlations were considered significant at the *a priori* level of $\alpha = 0.05$.

Three response variables were used to measure the effects of ectoparasites on female muskrat reproduction and nutritional condition, including (1) number of placental scars, (2) number of litters produced, and (3) percent body fat. Outliers in scars or fat per individual were identified as being more than 2 standard deviations from the mean. Multiple regression was used to assess the effects of relative abundance of each parasitic taxon on these response variables. Normality of response variables was first assessed before regression analyses proceeded. Percent body fat was log-transformed to produce normally distributed data. We used an information-theoretic approach incorporating a set of *a priori* models to examine variation in response to the relative abundance of different parasites. Additive effects of all possible combinations of 3 taxa (see results) were included among the models for each response, in addition to "total parasite load," which included the total number of individuals across mite taxa. Proc MIXED (SAS Institute, Cary, NC) was used for these analyses. We used Akaike's information criterion corrected for small sample size (AIC_c) to select among candidate models for each response that included various combinations of explanatory variables. Models with $\Delta AIC_c < 2$ were considered plausible, where model-averaging among slope parameters in this subset was done using AIC weights. Statistical significance of the effects of mite infestation was determined by comparing the 95% confidence intervals around slope estimates to 0.

RESULTS

In total, 20 female muskrats were collected. From these individuals, there were 0–24 placental scars per muskrat ($\bar{x} = 11.4$, $SD = 6.7$), with a mean litter size of 5.1 ($SD = 1.9$), and 0–4 litters produced ($\bar{x} = 2.2$, $SD = 1.0$). The mean percent body fat was 1.3% ($SD = 1.4$) per muskrat (0.9%–7.3%). From our parasite samples, we identified 2473 mites (18–467 per muskrat, $\bar{x} = 123.7$, $SD = 128.3$) from 4

parasite groups (3 species and the genus *Listrophorus*). There were a total of 290 *Laelaps multispinosa* found (0–42 per muskrat, $\bar{x} = 13.5$, $SD = 14.1$), 1191 *Z. ondatrae* (3–323 per muskrat, $\bar{x} = 59.6$, $SD = 75.8$), and 954 from the genus *Listrophorus* (4–322 per muskrat, $\bar{x} = 47.7$, $SD = 71.9$ SD). One parasite, *Myocoptes ondatrae*, was detected at a low rate, with only 38 individuals counted (0–7 per muskrat, $\bar{x} = 1.8$, $SD = 2.0$), and thus was included in the total ectoparasite load but not viewed for its individual effects on muskrat.

The relative abundance of *L. multispinosa* mites was not strongly correlated with the relative abundance of listrophorid mites ($r = 0.384$, $P = 0.094$) or the relative abundance of *Z. ondatrae* ($r = 0.436$, $P = 0.056$; Fig. 1). The relative abundance of the listrophorid mites was not significantly correlated to the relative abundance of *Z. ondatrae* ($r = 0.287$, $P = 0.220$). Following the removal of 2 outliers (1 *Z. ondatrae* and 1 *Listrophorus* sp.), the relative abundance of *Laelaps multispinosa* mites was not significantly correlated with that of the listrophorid mites ($r = 0.374$, $P = 0.114$) or that of *Z. ondatrae* ($r = 0.354$, $P = 0.138$; Fig. 1). Similarly, the relative abundance of the listrophorid mites was not significantly correlated to the relative abundance of *Z. ondatrae* after outliers were removed ($r = 0.073$, $P = 0.772$; Fig. 1).

The total number of placental scars found in females was best explained by the relative abundance of *L. multispinosa* ($\Delta AIC_c < 2$; Table 1). There was a positive relationship between the number of placental scars and *L. multispinosa* infestation; however, the relationship was not significant ($\beta = 0.0816$; CL_{95} : $-0.283, 0.445$). Following the removal of outliers in parasite abundance, there were 3 equally plausible models ($\Delta AIC_c < 2$), which included abundances of both *L. multispinosa* and *Listrophorus* mites (Table 2). There was a negative but nonsignificant relationship between the number of placental scars and *L. multispinosa* infestation (model average estimates: $\beta = 0.047$; CL_{95} : $-0.373, 0.467$). There was a positive but also nonsignificant relationship between the number of placental scars and *Listrophorus* infestation (model average estimates: $\beta = 0.061$; CL_{95} : $-0.187, 0.309$).

The number of litters produced per female was also best explained by the relative abundance of *L. multispinosa* (only model where $\Delta AIC_c < 2$; Table 3), for which there was a

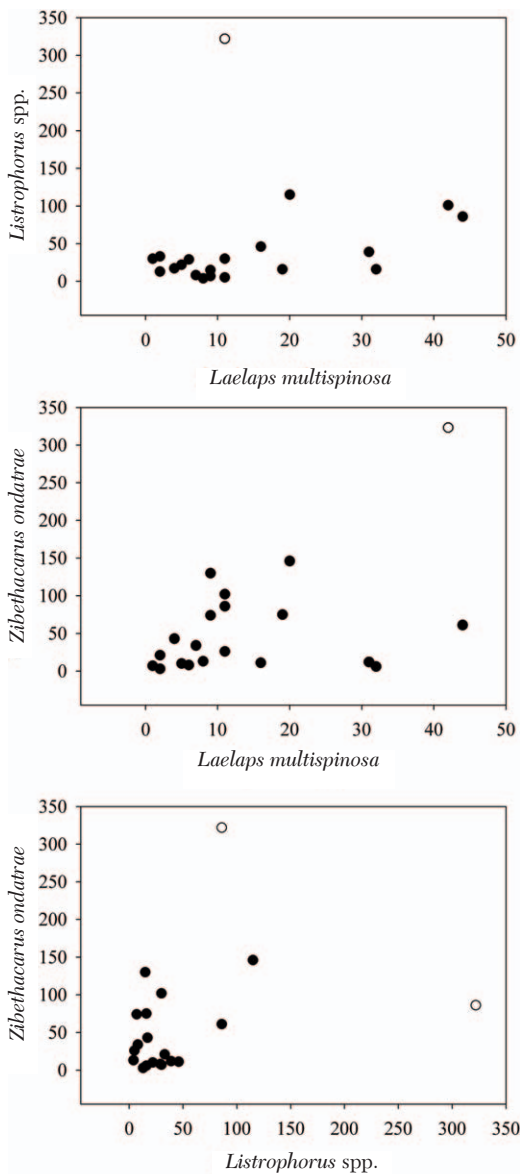


Fig. 1. Correlations among the relative abundances of 3 ectoparasitic mite taxa (*Laelaps multispinosa*, *Listrophorus* spp., and *Zibethacarus ondatrae*) found on female muskrat from northwestern Missouri. Open dots indicate outliers that were removed from further analyses.

positive but nonsignificant relationship between the number of litters produced and *L. multispinosa* infestation ($\beta = 0.020$; CL_{95} : $-0.033, 0.073$). Following the removal of outliers in parasite abundance, there were 4 equally plausible models ($\Delta AIC_c < 2$), which included the *L. multispinosa*, *Listrophorus*, *Z. ondatrae*,

and total parasite load variables (Table 4). There was a positive but nonsignificant relationship between the number of litters produced and *L. multispinosa* infestation ($\beta = 0.019$; CL_{95} : $-0.033, 0.071$). There was a positive but nonsignificant relationship between the number of litters produced and *Listrophorus* infestation ($\beta = 0.010$; CL_{95} : $-0.019, 0.039$). There was also a positive but nonsignificant relationship between the number of litters produced and *Z. ondatrae* infestation ($\beta = 0.008$; CL_{95} : $-0.007, 0.023$). Lastly, there was a positive but nonsignificant relationship between the number of litters produced and total parasite infestation ($\beta = 0.007$; CL_{95} : $-0.004, 0.019$).

In addition, the percent body fat in females was best explained by the relative abundance of *L. multispinosa* ($\Delta AIC_c < 2$; Table 5). There was a negative but nonsignificant relationship between percent body fat and *L. multispinosa* infestation ($\beta = -0.025$; CL_{95} : $-0.056, 0.005$). Following the removal of outliers of percent body fat (one individual had more than twice the percent body fat of any other muskrat in our sample) and parasite abundance (Fig. 1), there were 2 equally plausible models ($\Delta AIC_c < 2$) for explaining the percent body fat, which included the *L. multispinosa* and *Listrophorus* variables (Table 6). There was a negative but nonsignificant relationship between percent body fat and *L. multispinosa* infestation ($\beta = -0.005$; CL_{95} : $-0.035, 0.026$). There was a positive but nonsignificant relationship between percent body fat and *Listrophorus* infestation ($\beta = 0.003$; CL_{95} : $-0.009, 0.016$).

DISCUSSION

Our findings suggest that muskrat reproduction and nutritional condition are not substantially influenced by the relative abundance of ectoparasitic mites found on this mammal in northwestern Missouri. The lack of relationship between these measures could result from the muskrat's semiaquatic habit, which restricts the ectoparasite fauna to small mites. The deleterious effects from ectoparasites on other host species have been documented from larger hematophagous arthropods (e.g., ticks, fleas; Vuren 1996, Main and Bull 2000, Hoodless et al. 2002, Neuhaus 2003). While some ectoparasitic mites have been known to have serious consequences to vertebrate hosts (Pence et al. 1983, Møller 1990, Arnold and Anja 1993), there

TABLE 1. Ranks among models where total number of placental scars in muskrats was compared to additive effects of various ectoparasitic mites. Models were ranked using Akaike's information criterion corrected for small sample size.

Model	K	AIC_c	ΔAIC_c	w_i
<i>Laelaps multispinosa</i>	2	101.0	0.0	0.503
<i>Listrophorus</i>	2	103.6	2.6	0.137
<i>Zibethacarus ondatrae</i>	2	103.8	2.8	0.124
Total parasite load	2	104.8	3.8	0.075
<i>Listrophorus, L. multispinosa</i>	3	104.9	3.9	0.072
<i>Z. ondatrae, L. multispinosa</i>	3	105.2	4.2	0.062
<i>Listrophorus, Z. ondatrae</i>	3	107.7	6.7	0.018
<i>Z. ondatrae, Listrophorus, L. multispinosa</i>	4	109.0	8.0	0.009

TABLE 2. Ranks among models where total number of placental scars in muskrats was compared to additive effects of various ectoparasitic mites. The outliers in parasite abundance noted in Figure 1 were removed. Models were ranked using Akaike's information criterion corrected for small sample size.

Model	K	AIC_c	ΔAIC_c	w_i
<i>Laelaps multispinosa</i>	2	93.2	0.0	0.348
<i>Listrophorus</i>	2	94.1	0.9	0.222
<i>Listrophorus, L. multispinosa</i>	2	95.0	1.8	0.141
<i>Zibethacarus ondatrae</i>	2	95.6	2.4	0.105
Total parasite load	3	95.9	2.7	0.090
<i>Z. ondatrae, L. multispinosa</i>	3	97.3	4.1	0.045
<i>Listrophorus, Z. ondatrae</i>	3	98.2	5.0	0.029
<i>Z. ondatrae, Listrophorus, L. multispinosa</i>	4	98.9	5.7	0.020

TABLE 3. Ranks among models where total number of litters per muskrat, identified from placental scars, was compared to additive effects of various ectoparasitic mites. Models were ranked using Akaike's information criterion corrected for small sample size.

Model	K	AIC_c	ΔAIC_c	w_i
<i>Laelaps multispinosa</i>	2	51.0	0.0	0.633
<i>Zibethacarus ondatrae</i>	2	53.7	2.7	0.164
<i>Listrophorus</i>	2	54.4	3.4	0.116
Total parasite load	2	55.8	4.8	0.057
<i>Z. ondatrae, L. multispinosa</i>	3	58.7	7.7	0.013
<i>Listrophorus, L. multispinosa</i>	3	58.9	7.9	0.012
<i>Listrophorus, Z. ondatrae</i>	3	61.4	10.4	0.003
<i>Z. ondatrae, Listrophorus, L. multispinosa</i>	4	66.1	15.1	0.000

TABLE 4. Ranks among models where total number of litters per muskrat, identified from placental scars, was compared to additive effects of various ectoparasitic mites. The outliers in parasite abundance noted in Figure 1 were removed. Models were ranked using Akaike's information criterion corrected for small sample size.

Model	K	AIC_c	ΔAIC_c	w_i
<i>Laelaps multispinosa</i>	2	47.3	0.0	0.407
<i>Listrophorus</i>	2	48.6	1.3	0.213
Total parasite load	2	49.0	1.7	0.174
<i>Zibethacarus ondatrae</i>	2	49.1	1.8	0.166
<i>Listrophorus, L. multispinosa</i>	3	53.2	5.9	0.021
<i>Z. ondatrae, L. multispinosa</i>	3	54.4	7.1	0.012
<i>Listrophorus, Z. ondatrae</i>	3	55.4	8.1	0.007
<i>Z. ondatrae, Listrophorus, L. multispinosa</i>	4	60.0	12.7	0.001

are several examples of hosts being unaffected by ectoparasitic mites (Blanco et al. 1997, Dowl-ling et al. 2001, Lucan 2006).

When interpreting these results, there are several factors to consider. The mites of the genus *Listrophorus* were not separated into

TABLE 5. Ranks among models where percent body fat in muskrat was compared to additive effects of various ectoparasitic mites. Models were ranked using Akaike's information criterion corrected for small sample size.

Model	K	AIC_c	ΔAIC_c	w_i
<i>Laelaps multispinosa</i>	2	57.7	0.0	0.676
<i>Zibethacarus ondatrae</i>	2	59.8	2.1	0.237
<i>Listrophorus</i>	2	63.8	6.1	0.032
Total parasite load	2	63.8	6.1	0.032
<i>Z. ondatrae</i> , <i>L. multispinosa</i>	3	65.5	7.8	0.014
<i>Listrophorus</i> , <i>L. multispinosa</i>	3	67.1	9.4	0.006
<i>Listrophorus</i> , <i>Z. ondatrae</i>	3	68.4	10.7	0.003
<i>Z. ondatrae</i> , <i>Listrophorus</i> , <i>L. multispinosa</i>	4	73.9	16.2	0.000

TABLE 6. Ranks among models where percent body fat in muskrat was compared to additive effects of various ectoparasitic mites. The outliers in parasite abundance noted in Figure 1 were removed. Models were ranked using Akaike's information criterion corrected for small sample size.

Model	K	AIC_c	ΔAIC_c	w_i
<i>Laelaps multispinosa</i>	2	44.3	0.0	0.489
<i>Listrophorus</i>	2	45.8	1.5	0.231
<i>Zibethacarus ondatrae</i>	2	46.4	2.1	0.171
Total parasite load	2	47.8	3.5	0.085
<i>Listrophorus</i> , <i>L. multispinosa</i>	3	51.6	7.3	0.013
<i>Z. ondatrae</i> , <i>L. multispinosa</i>	3	53.0	8.7	0.006
<i>Listrophorus</i> , <i>Z. ondatrae</i>	3	53.6	9.3	0.005
<i>Z. ondatrae</i> , <i>Listrophorus</i> , <i>L. multispinosa</i>	4	59.1	14.8	0.000

species. There is the potential that these different species could have different effects on their hosts; however, we operated under the assumption that they have similar effects due to their occupation of similar niches (Bauer and Whitaker 1981). Evidence suggests that for some of these mites there may be some preferential site selection on the muskrat (Bauer and Whitaker 1981); thus, our sampling may have been unrepresentative of absolute levels of parasitism. However, we expect parasitism levels on the muskrat dorsum to be proportional to levels on other muskrat body parts, and we have no reason to anticipate differences in ectoparasite distribution between animals. Reductions in reproductive success in response to ectoparasites are often after birth through the abandonment or death of offspring (Møller 1990, Richner et al. 1993, Fitze et al. 2004). Placental scars are a measure of parturition and not of successful recruitment; thus, the ectoparasites could be causing a reduction in the survival of young (Arnold and Anja 1993, Neuhaus 2003, Hillegass et al. 2010), which was not measured in our analyses.

Musk rats appear to be unaffected by the presence of their ectoparasites, at least in our study region. While we anticipated that there would be differences in muskrat response to

the different parasite groups, the complete lack of a response was unexpected. The reduction of fitness of the host may be detrimental for these hair-clasping mites, driving them to adopt a lifestyle that has minimal costs to the host. Most of these mites have reduced mobility, excluding *L. multispinosa*, and are often isolated to a single hair (Bauer and Whitaker 1981). The reduced mobility and host specificity in muskrat mites makes it unlikely they could find a suitable replacement in the event of host death. In fact, some of these parasites have been observed on preserved specimens months after collection (Whitaker 1982), indicating that they do not leave to secure a replacement host, as many other ectoparasites do immediately following host death (Nelder and Reeves 2005). We had expected that *L. multispinosa* would be the most detrimental to muskrat due to its feeding habits and large size (Whitaker 2006). Even though *L. multispinosa* is large compared to the other mites occurring on muskrat, the lack of significant responses to this mite may still be attributable to its relatively small size compared to other hematophagous arthropods. The blood loss as a result of *L. multispinosa* could be small enough to be insignificant to the muskrat or only significant at higher parasite densities than observed on our specimens.

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