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By

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ABSTRACT

DESCRIBING THE SPATIAL DISTRIBUTION OF PARASITES ON *PEROMYSCUS* SPECIES IN SOUTHERN MICHIGAN

By

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Ecto-parasites can be important vectors for many diseases affecting both humans and wildlife. Thus, the ability to describe the distribution of these disease vectors could have far-reaching applications in conservation and human health. The goal of this study was to evaluate the role of habitat in ecto-parasite distribution. One hundred eighty-six *Peromyscus* spp mice from 6 study sites in southern Michigan were collected and examined for parasites during the summer of 2007. Sixty-nine hard ticks (46 *Ixodes scapularis* and 23 *Dermacentor variabilis*), 98 fleas (95 *Orchopeas leucopus,* 2 *Ctenophthalmus pseudagyrtes,* and 1 unknown) and 91 lice (*Hoplopleura hesperomydis*) were found across 66 study plots. Vegetation data were collected from the study plots as well. The vegetation, mouse and parasite data were analyzed using principal component and discriminate function analyses to distinguish the differences between plots without *Peromyscus*, with non-parasitized *Peromyscus* and with parasitized *Peromyscus*. There was significant separation of the three groups based on the vegetation for ticks, fleas and lice. Mice parasitized by ticks were more likely to be found in areas having undergone a recent disturbance and areas having species associated with dry soils. Mice parasitized by fleas and lice were also more likely to be found in areas having tree species associated with dry soils. The results of this study could be used to create risk assessment maps for current or future diseases spread by these species of ticks, fleas and lice.

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INTRODUCTION

Rodents are reservoir hosts for many human diseases (Weber 1982). The biological vectors and diseases associated with mice include ticks (Lyme disease, rocky mountain spotted fever, and babesiosis), fleas (plague, sylvatic and murine typhus), and lice (sylvatic typhus) (Center for Disease Control 2006b;2006a). White footed mice, *Peromyscus leucopus,* are competent reservoir hosts for all these diseases. Abundant species, such as mice, have higher abundance and species diversity of parasites than rare species (Arneberg et al. 1998). Lice, fleas, mites, ticks and botfly larvae are common ecto-parasites of *Peromyscus* spp (Whitaker 1968). *Peromyscus leucopus* is more sensitive to picking up tick presence than survey methods aimed at collecting parasites directly from the environment such as dragging (Hamer et al. 2009a). These characteristics make the white footed mouse a compelling study organism for examining the association between ecto-parasite presence and the host's habitat.

Ecto-parasite distributions among host populations are influenced by the characteristics of the host organism, e.g. sex (Wilson et al. 2002), age (Anderson and May 1991, Hudson and Dobson 1995), body condition (Wilson et al. 2002) and host density (Tompkins et al. 2002). Until recently hosts were considered "biological islands" for parasites, providing the habitat necessary to fulfill basic biological needs such as food, shelter and opportunities for mating (Krasnov et al. 1997, Krasnov et al. 2006). However, ecto-parasites are also under the influence of the external environment (Krasnov et al. 1997, Guerra et al. 2002, Krasnov et al. 2006) For instance, in Wisconsin, black-legged ticks (*Ixodes scapularis*) were associated with abiotic factors such as soil

texture, soil order, forest type, land cover, and bedrock within its hosts' range, possibly restricting the distribution of black-legged ticks (Guerra et al. 2002).

External influences may explain ecto-parasite distribution across the landscape. If presence of parasites is mainly a function of host characteristics, the expected distribution of black-legged ticks in Michigan would coincide with the statewide *Peromyscus* distribution. However, these ticks are limited in distribution to areas in Menominee County in the Upper Peninsula and along the west coast of the Lower Peninsula in Berrien, Van Buren, and Allegan counties (Walker et al. 1998, Michigan Department of Community Health et al. 2004, Hamer et al. 2007). One possible reason some mice have few or no parasites may be because the host's environment is inhospitable to potential parasites. Another reason is that the parasite may not have the opportunity to feed from mice because they are not yet present or have not yet invaded into the host's environment. Additionally, high ecto-parasite loads may be experienced in environments that are conducive for ecto-parasite survival. Ecto-parasite presence and parasite species assemblages are not just a function of host-parasite relationships but also host-habitat relationships: a parasite's distribution among its hosts is dependent on the right host in the right habitat (Krasnov et al. 1997, Krasnov et al. 2006).

Parasites that spend a portion of their life or whole life stages off their host should have stronger habitat associations than parasites whose life cycles are restricted solely to the host. Ticks, fleas and lice represent three different modes of interaction with their host: very little host-parasite interaction in the form of a few long term feeding opportunities (tick), moderate amount of host-parasite interaction through repeated short term feeding opportunities (flea), and permanent interaction where the parasite spends all

its life closely associated with the host (louse). By including species from different taxonomic groups, this study examines the association of vegetation attributes to different degrees of host interaction.

As *Peromyscus* abundance does not necessarily correspond to parasite presence and abundance, mapping *Peromyscus* habitat and distribution is insufficient when determining their parasite distribution. Parasite distribution and their potential habitat may be correlated with abiotic factors such as land cover, vegetation presence and distribution, soil and weather conditions. Parasite communities of *Peromyscus* may also vary between different habitat types. The focus of this study was to associate parasite occurrence to vegetation communities across the southern half of the lower peninsula of Michigan. I examined the habitat associations of fleas, lice and ticks of *P. leucopus* to determine the organisms' level of association with their hosts' environment.

STUDY AREAS AND METHODS

Study Areas

Six state game areas (SGAs) were studied (Figure 1.1). The SGAs surveyed included Sharonville State Game Area (Jackson and Washtenaw Counties), Flat River State Game Area (Ionia and Montcalm Counties), Three Rivers State Game Area (Cass and St. Joseph Counties), Deford State Game Area (Tuscola County), Verona State Game Area (Huron County), and Barry and Yankee Springs State Game Area (Barry County). These areas were chosen because they span different habitats including forested, lowland and agricultural land cover types, availability of GIS data and imagery, and IFMAP stand-level surveys completed by MDNR personnel (MDNR 2005, Roberts 2009).

Methods

Twelve 50 m circular plots were chosen from each SGA, except Three Rivers and Sharonville, which had 7 and 11 plots respectively for a total of 66 plots. Plots were randomly selected and stratified based on the relative proportion of each land cover type at each SGA projected to occur from satellite imagery (Roberts et al. 2006). Vegetation data were collected at each plot following the guidelines established by MDNR (2005) and conducted by Roberts et al. (2006). The following vegetation attributes were measured: tree species presence, percent canopy cover, average basal area, height of subcanopy species, ground cover density and the IFMAP cover class. GPS coordinates were taken at the center of each plot.

Mammals were collected from June 22 to August 5, 2007 across the 66 study plots sampling each plot once over 36 hours by setting 30 Sherman live traps (H.B. Sherman Traps, Tallahassee, FL) baited with rolled oats and placed 10 m apart in three parallel 100 m transects at each plot. These traps were checked in the early morning and evening at 10-12 hour intervals for 36 consecutive hours. All animals collected were identified to genus and species when possible, sexed, weighed and marked to recognize recaptures by removing a small tuft of fur from the rear thigh. Non-*Peromyscus* species were then released.

Additional information recorded for *Peromyscus* species were age class (juvenile or adult) as described by Baker (1983) and right ear and tail length to distinguish between *P. leucopus* and *P. maniculatus bairdii* by assessing these lengths (Baker 1983). Each *Peromyscus* was given a small dose of isoflurane (Isoflo, Abbott Laboratories, Chicago, IL), an inhaled anesthetic, by applying a prescribed amount to a cotton ball placed in a 1

gallon sealable plastic bag as advised by a veterinarian in order to incapacitate any fleas on its body.

From June to August several parasite species may be collected from *P. leucopus*. Black-legged tick larvae are active from May to September, peaking in mid-July, and the nymphs from mid-April to October, peaking in June (Hamer 2009b). The common dog tick (*Dermacentor variabilis*) is also active as larvae from mid-April to August and nymphs from May to August, with both stages peaking in June (Hamer 2009a). Different flea species may be active all year long or seasonally, either active during summer or winter months (Krasnov et al. 2005a, Krasnov et al. 2005b). Lice breed throughout the year (Marshall 1981) and are therefore active and can be collected during the summer months.

Peromyscus caught on the first trap night (hours 12-24) were examined for parasites and released. They received a dose of 0.2cc isoflurane to induce anesthesia, which was maintained with a dose of 0.1cc isoflurane while monitering the breathing continuously. Once anesthetized, the animal was removed from the chamber and examined for fleas and ticks, which were collected using #5 watchmakers' forceps. Engorged ticks were carefully removed from the epidermis taking special care to remove the mouth parts for identification. Fleas and unattached ticks were removed using forceps or by brushing the mouse's body with a hard bristle toothbrush over a white pan. The collected ecto-parasites were placed in vials filled with 100% ethanol and labeled with the animal identification number and SGA. Animals were allowed to fully recover, were released, then traps were immediately reset.

A partial lethal take was conducted to assess louse burden as follows. Mice caught on the second trap night (hour 36), including recaptured mice, were administered 0.3cc of isoflurane to induce a deep sleep and were euthanized by cervical dislocation. After examination for ticks and fleas as above, each mouse was individually wrapped in multiple layers of cheese cloth to prevent cross-contamination of parasites, as multiple animals were stored in the same collection jar in 100% ethanol.

Louse specimens were collected post-mortem in the lab by examining each mouse under a dissecting scope. The mouse and cheese cloth were then washed with dish detergent and rinsed with water over a 1 gallon jar; the washings were strained in a 200mm opening 75μm mesh sieve (U.S.A. Standard Sieve Series, Newark Wire Cloth Co., Newark, NJ) for lice missed during initial inspection. Lice were collected using forceps, and stored using the same method as described above for the fleas and ticks.

All procedures adhered to the Animal use guidelines established by Michigan State University Institutional Animal Care & Use Committee (IACUC). This project was authorized by the Animal Use Committee under Animal Use Form (AUF) number 04/07-039-00.

Parasite Species Identification

Each parasite was prepared for identification according to taxon-specific standards. Wet mount tick specimens were identified to species and appropriate life stage by examination under a dissecting microscope using Sonenshine's (1979) key. Fleas and lice were cleared based on guidelines from Fox (1940), Kim et al. (1986) and Ferris and Stojanovich (1951) in 10% KOH overnight to view informative internal anatomical features for identification. After clearing, each organism was rinsed in deionized water

and allowed to soak for thirty minutes to end the clearing process before they were dehydrated for mounting. Dehydration was achieved by running the specimens through the following alcohol series: thirty minutes each in 70%, 90% and 100% ethanol and a final soaking for 30 minutes in 100% ethanol. All specimens were then mounted on slides in Canada balsam and allowed to dry on the bench top overnight before examination. Each specimen was examined to determine the species, life stage and sex when possible. Fleas were identified using Fox's (1940) key and lice were identified using the keys of Kim et al. (1986) and Ferris and Stojanovich (1951).

Flea voucher specimens were deposited at Michigan State University Entomology Museum accession number MSU 2009-01, East Lansing, MI and United States National Museum of Natural History, Washington, D.C.; louse voucher specimens were deposited at Michigan State University Entomology Museum accession number MSU 2009-01, East Lansing, MI and United States National Museum of Natural History, Washington, D.C.; tick voucher specimens were deposited at United States National Museum of Natural History, Washington, D.C.; and *Peromyscus* vouchers were deposited at the Michigan State University Museum Mammal Research Collection accession numbers MSU 37467- 37595, East Lansing, MI.

Statistical Methods

Field observations yielded 210 different vegetation variables at each plot, given I had 66 plots I needed to reduce the number of variables to maintain degrees of freedom and to meet the condition for discriminant function analysis that the number of variables must be smaller then the number of observations. To reduce this number, I examined correlations within the canopy variables and subcanopy variables (i.e. canopy basal area

versus canopy closure) to remove highly correlated variables and select a subset of the vegetation variables. Variable reduction was further accomplished using principal components analysis (PCA) to maximize the amount of variation explained in the data while including the lowest number of variables possible (Johnson and Wichern 2002). The resulting 29 variables retained were the basal area of 11 canopy tree species, height of 10 subcanopy species and 8 ground cover types. Vegetation data were transformed to meet the assumption of multivariate normality by square root transforming the canopy and subcanopy variables and arcsine transforming the ground cover variables.

Discriminant function analysis (DFA) is a robust multivariate methodology often used in ecological studies to assess how different two or more groups are based on a consistent set of variables collected for each group (i.e. occupied versus unoccupied habitats) (McGarigal et al. 2000, McCune and Grace 2002). Quadratic DFA was conducted to assess the relationship between each parasite group (ticks, fleas, and lice) and the environment. Linear DFA could not be used because the data violated the assumption of equal variance/covariance matrices across groups. Each parasite group was evaluated separately by dividing the 66 plots into 3 groups: 1) plots where no *Peromyscus* were found, 2) plots with *Peromyscus* but no parasites, and finally 3) plots with *Peromyscus* that had parasites. After the DFA was conducted, each plot was classified using posterior probabilities as one of the 3 groups. Overall accuracy of the classification routine and kappa coefficient of similarity were calculated as an assessment of the model's ability to separate the groups (Cohen 1968, Hudson and Ramm 1987, McGarigal et al. 2000). I used kappa to determine the likelihood of the classification routine randomly assigning plots into the groups. Kappa values close to 0 are considered

randomly assigned, and therefore, the discriminant function did not adequately discriminate between the groups; values close to 1 are considered to be accurate and the discriminate function was able to statistically distinguish between the groups. All analyses were performed using R software (R Development Core Team 2008) with the exception of the DFA, which was conducted using SAS software (Proc Discrim in SASv9.1; SAS Institute, Cary, NC).

RESULTS

Three hundred four small mammals were captured in the field; 165 were identified as *Peromyscus leucopus* and 21 juvenilles could only be identified to the genus *Peromyscus.* These 186 mice were checked for ticks and fleas in the field, of which 105 mice, including the 23 recaptured animals, were euthanized and additionally inspected in the lab for louse infestations. Parasites from three taxa were collected: 69 larval and nymphal ticks (Acari), 98 adult fleas (Siphonaptera) and 91 adult lice (Phthiraptera) (Table 1.1). Of the 69 ticks collected, 46 were *Ixodes scapularis* (black-legged tick) and 23 were *Dermacentor variabilis* (dog tick). Of the 98 fleas collected, 95 were *Orchopeas leucopus,* 2 were *Ctenophthalmus pseudagyrtes*, and 1 was unknown; with males and females collected from both species. All 91 lice collected were *Hoplopleura hesperomydis* and both sexes were present. The average intensity of infestation across taxa ranged from 1.8 to 4.1 parasites per infected mouse (Table 1.1). While fleas had the lowest intensity of infestation, they were present on the most plots (28/66) and had the highest prevalence of the taxa examined, where prevalence is the proportion of mice infested with ecto-parasites of all examined mice (Margolis et al. 1982). Interestingly,

the intensity of infestation was different between the two species of ticks. The tick species were combined for the analysis because the observations for both species were too low to analyze separately. While there was only one case of co-infestation on a mouse, there were three instances of co-infestation at the plot level (2 plots from Three Rivers and 1 plot from Sharonville).

Parasite-to-Vegetation Relationships

Tick (Acari)

Vegetation characteristics were significantly different between the plots having mice parasitized with ticks and the plots with clean mice or no mice as determined by the separation of these three groups in the DFA (Table 1.2 and Figure 1.2). The first discriminant axis (Table 1.3) had a strong positive association with primary seedling ground cover, primary barren ground cover, secondary forb ground cover, black ash (*Fraxinus nigra*) canopy basal area, black oak (*Quercus velutina*) canopy basal area, and red pine (*Pinus resinosa*) canopy basal area and a strong negative association with primary grass ground cover, black cherry (*Prunus serotina*) subcanopy height, and secondary seedling ground cover; thus the first axis functionally represents a gradient from unsuitable to suitable mouse habitat. The second discriminant axis (Table 1.3) had a strong positive association with secondary leaf ground cover and secondary seedling ground cover, quaking aspen (*Populus tremuloides*) subcanopy height, black ash subcanopy height and white oak (*Quercus alba*) canopy basal area and a strong negative association with red oak (*Quercus rubrum*) canopy basal area, big tooth aspen (*Populus grandidentata*) canopy basal area, sassafras (*Sassafras albidum*) subcanopy height, elm (*Ulmus americana*) subcanopy height, and primary forb ground cover. The second axis

represents a gradient from dry and disturbed to wet and undisturbed vegetation associations.

The discriminant function accurately discriminated between plots with no mice, mice and mice parasitized by ticks. Classification accuracy was 97% (64/66 correctly classified), this represents a classification power roughly 95% better than random assignment (kappa = 0.95) (Table 1.4). Not only were the three groups different, but the model was able to discriminate between those groups with a high level of accuracy, indicating the centroids (mean in multivariate space) of each group were distinctly different. Therefore, habitat characteristics can be used to describe the presence of *P. leucopus* and ticks on plots.

Flea (Siphonaptera)

Vegetation characteristics were significantly different between the plots having mice parasitized with fleas and plots with clean mice or no mice as determined by the separation of these three groups in the DFA (Table 1.2 and Figure 1.3). The first discriminant axis (Table 1.5) had a strong positive association with big tooth aspen canopy basal area, black cherry canopy basal area, red pine canopy basal area, red maple canopy basal area, and secondary forb ground cover and a strong negative association with primary grass ground cover, secondary seedling ground cover and black cherry subcanopy height; thus functionally the first axis represents a gradient from unsuitable to suitable mouse habitat. The second discriminant axis (Table 1.5) had a strong positive association with dogwood (*Cronus* spp) subcanopy height, elm subcanopy height, black ash subcanopy height, black ash canopy basal area, and white pine (*Pinus strobus*) canopy basal area and a strong negative association with primary grass ground cover,

secondary leaf ground cover and quaking aspen subcanopy height. The second axis represents a gradient from dry to wet vegetation associations.

The discriminant function accurately discriminated between plots with no mice, mice and mice parasitized by fleas. Classification accuracy was 97% (64/66 correctly classified), this represents a classification power roughly 95% better than random assignment (kappa = 0.95) (Table 1.6). Not only were the three groups different, but the model was able to discriminate between those groups with a high level of accuracy; this indicates the centroids of each group were distinctly different. Therefore, habitat characteristics can be used to describe the presence of *P. leucopus* and fleas on plots.

Louse (Phthiraptera)

Vegetation characteristics were significantly different between the plots having mice parasitized with lice and plots with clean mice or no mice as determined by the separation of these three groups in the DFA (Table 1.2 and Figure 1.4). The first discriminant axis (Table 1.7) was strongly positively associate with white pine canopy basal area, red oak canopy basal area, black oak canopy basal area, white pine subcanopy height and primary forb ground cover and a strong negative association with white oak canopy basal area, quaking aspen subcanopy height and primary grass ground cover; thus functionally the first axis represents a gradient from unsuitable to suitable mouse habitat. The second discriminant axis (Table 1.7) had a strong positive association with secondary forb ground cover, red oak subcanopy height, dogwood subcanopy height, elm subcanopy height and red pine canopy basal area and a strong negative association with black ash canopy basal area, secondary leaf ground cover, secondary seedling ground cover and

black cherry subcanopy height. The second axis represents a gradient from dry to wet vegetation associations.

The discriminant function accurately discriminated between plots with no mice, mice and mice parasitized by lice. Classification accuracy was 97% (64/66 correctly classified), this represents a classification power roughly 95% better than random assignment (kappa = 0.95) (Table 1.8). Not only were the three groups different, but the model was able to discriminate between those groups with a high level of accuracy; this indicates the centroids of each group were distinctly different. Therefore, habitat characteristics can be used to describe the presence of *P. leucopus* and lice on plots.

DISCUSSION

As indicated by the high kappa values, each taxon can be described by the vegetation variables used in the DFA to separate the three groups (no mice, un-parasitized mice and parasitized mice). Therefore, tick, flea and louse presence can be described by vegetation characteristics distinctly different from those of un-parasitized mice, indicating the preferred habitats of the parasites and hosts are distinct. However, the mechanisms linking habitat to the presence of ticks, fleas and lice are unknown.

Tick (Acari)

Mice parasitized by ticks are more likely to be found in areas having undergone a recent disturbance and having vegetation species that tolerate or thrive in dry soils. Plots with ticks were characterized by colonizers such as black cherry, sassafras and elm which are indicators of disturbance (Table 1.9). Plots without ticks were characterized by tree species associated with wet soils such as silver maple, quaking aspen and big tooth aspen,

demonstrating a lack of water tolerant tree species may also be an indicator for tick presence (Table 1.9). The results of this study provide further evidence that the presence of tick species is associated with a subset of characteristics of their host's habitat; specifically tick presence is positively associated with the presence of early successional tree species and negatively associated with tree species that indicate past or current flood regimes.

The literature supports these findings. Lubelczyk et al. (2004) found tick abundance increased when invasive shrub species were present, indicating a change from the natural vegetation in Maine. The authors concluded disturbances leading to the introduction and successful establishment of invasive species were positive indicators of tick abundance. Guerra et al.(2002) found ticks to be present in forests characterized by high densities of oak and maple species in the canopy. They felt this was due to the influence of leaf litter on overwinter survival of black-legged ticks. They also found sites without ticks were dominated by clay soils, which retain water and support wetland vegetation species. Manangan et al.(2007) also found soil moisture played a role in tick presence. They found the presence of tick borne pathogens *Anaplasma phagocytophilum* and *Ehrlichia chaffeensis* was negatively associated with indicators of flooding such as high flood probability, low soil drainage, and wooded wetlands.

Flea (Siphonaptera)

Mice parasitized by fleas were more likely to be found in areas having tree species able to tolerate dry soils. Primary grass ground cover was characteristic of both plots without mice and plots with mice parasitized by fleas, suggesting less suitable mouse habitat is an indicator for flea presence. However, plots with fleas were

characterized by fewer associated variables than plots without fleas. Plots without fleas were characterized by tree species that thrive in wet soils such as dogwood, elm, and black ash, demonstrating a lack of water tolerant species is an indicator for flea presence (Table 1.9). Flea presence is negatively associated with tree species that indicate past or current flood regimes.

This study is the first to look at the relationship between individual vegetation species and the presence of fleas. Past studies have either looked at habitat types or collected vegetation data and described habitat types based on those data, not focusing on the potential effects of vegetation on flea presence, but rather on the effects of microclimate (i.e. temperature and humidity) (Eskey 1938, Marshall 1981, Christie 1982, Krasnov et al. 2001, Adjemian et al. 2006) and host species assemblages (Krasnov et al. 2005a). For instance, Krasnov et al. (2004) has produced a large body of work on flea species assemblages and various potential environmental influences such as vegetation and soil attributes. Their findings indicate host body parameters influence flea species richness far less than environmental parameters. Also, Krasnov et al. (1997) found the relationship between soil, vegetation, relief patterns and percent cover of various ground vegetation varied in strength depending on the flea species in question. Krasnov et al. (2002) found substrate influenced both larval flea survival and the rate of development. Finally, Krasnov et al. (2006) found the presence of flea species assemblages were based on habitat types - mountain versus lowland areas.

Louse (Phthiraptera)

Mice parasitized by lice are more likely to be found in areas having tree species that tolerate or thrive in dry soils or areas lacking colonizers, suggesting undisturbed sites

are also characteristic of louse presence. However, plots with lice were characterized by fewer associated variables than plots without lice. Plots without lice were characterized by tree species that thrive in wet tolerant soils such as dogwood, elm and aspen, indicating a lack of water tolerant species is an indicator for louse presence (Table 1.9). The presence of elm and aspen on plots without lice could also indicate a lack of early successional species is a descriptive characteristic for louse presence on mice (Table 1.9).

Few studies looking into potential environmental influences on the presence of lice have been conducted. Most studies have focused on the effects of the host's microclimate (i.e. temperature and humidity) on the presence of lice (Marshall 1981). Calvete et al. (2003) found louse intensity on red legged partridges in Spain was associated with mean environment temperature and Normalized Difference Vegetation Index (NDVI), which is highly correlated with environmental humidity. They suggest high temperature and humidity may increase the probability of transmission between individuals from communal resting or bathing areas. The most prolific studies conducted concerning the effects of the environment on louse survival focus on unique lice of several seal species able to survive while the host is at sea by withstanding extremely cold temperatures and long periods of starvation (Kim 2006).

Despite the fact that parasites all appeared on plots with vegetation that thrive or tolerate dry soils, there were subtle differences in the vegetation species composition associated with each particular taxa. The presence of ticks, fleas and lice on mice were characterized by completely different vegetation species. Though, the presence of secondary leaf ground cover was characteristic for plots with mice parasitized by fleas as well as plots with mice parasitized by lice.

Ecto-parasites collected and identified were found in similar abundance to two ecto-parasite surveys conducted in Indiana (Figure 1.10). Whitaker (1982) conducted a survey of the ecto-parasites of mammals in Indiana and Ritzi and Whitaker (2003) conducted a survey of ecto-parasites of small mammals from the Newport Chemical Depot in Vermillion County, Indiana. I collected 23 *D. variabilis* with a prevalence of 7% which is similar to that recovered by Whitaker (1982), but far lower prevalence than that collected by Ritzi and Whitaker (2003) (Figure 1.10). Neither of these studies collected *I. scapularis* from *P. leucopus*. I found a similar prevalence of *Orchopeas leucopus* to Whitaker (1982) and to Ritzi and Whitaker (2003). Though the prevalence of *Ctenophthalmus pseudagyrtes* was similar to Whitaker (1982), it was lower than that of Ritzi and Whitaker (2003). The prevalence of *Hoplopleura hesperomydis* was higher than Whitaker's (1982) study, but lower than that of Ritzi and Whitaker's (2003) study. The intensity of infection is not comparable to Whitaker's (1982) study, however the intensity of infection was higher for each species recorded except for *H. hesperomydis* which was lower for Ritzi and Whitaker's (2003) study than those recorded across my study.

Because mammal trapping only occurred during a short period of the summer months, it is possible not all of the potential parasite species were collected, limiting the implications of this study to those species of parasites found mid-June to August. While larval black-legged ticks were in peak abundance during the time of the collections, nymphal black-legged ticks and both larvae and nymphs of the dog tick had already peaked (Hamer 2009b;2009a). Flea species collections were biased toward fur or body fleas, as nidicolous (nest associated) fleas were not collected. Therefore, it is possible

both ticks and fleas' spatial distributions and vegetation associations are incomplete. A regular, year long trapping protocol would help discern any temporal relationships between parasite presence and vegetation variables, in addition to any uncertainty concerning the presence and distribution of parasites of *P. leucopus*.

Furthermore, it is not possible to fully describe the habitat associations of black-legged ticks, as it is unknown if their absence was because the habitat was unsuitable or they have not yet invaded those areas. Distribution of black-legged ticks in Michigan may also be limited by opportunity, as this species is currently invading the southern peninsula (Guerra et al. 2002, Hamer et al. 2007, Hamer et al. 2009b). Not only does host availability and movement impact tick distribution, but suitable habitat also affects the ability of ticks to become established (Manangan et al. 2007). The vegetation associations described in this study may be characteristic of invading tick populations and not necessarily characteristic of established populations. Lastly, *Orchopeas leucopus* and *Hoplopleura hesperomydis* are both specific to mice of the genus *Peromyscus* (Fox 1940, Kim et al. 1986), whereas both black-legged and dog ticks are generalist species. As generalists, the full extent of their habitat distributions cannot be fully discerned by examining only one of several host species. However, mice are considered to be one of the most important host species for *Ixodes scapularis* (Shaw et al. 2003).

Ixodes scapularis and *Dermacentor variabilis* were analyzed together because the sample sizes for both species were very low and there were three plots (4% 3/66) where both species were collected from parasitized mice. The literature suggests *I. scapularis* and *D. variabilis* may not have very different vegetation associations. Sonenshine et al. found that (1972) *D. variabilis* was associated with mesic deciduous plant species across

the eastern United States. Furthermore, adult, larval and nymphal *D. variabilis* were collected from several habitat types in a study conducted in Nova Scotia, they found adults and nymphs were in old field and Ecotones, and larvae were collected from a variety of areas including woodlots, fields and ecotones (Campbell and MacKay 1979). However, they hypothesized *Peromyscus* spp probably helped disperse engorged tick larvae from the woodland to the old field and ecotone areas. Flea species were also combined for analysis as there were only two observations of *C. pseudagyrtes*.

Implications

The results of this study could be used to create risk assessment maps for current or future diseases spread by these species of ticks, fleas and lice. This is potentially useful to wildlife managers and community health professionals as similar studies have used environmental data for this purpose. Carbajal de la Fuentae et al. (2009) found environmental information such as temperature, vapor pressure deficit, vegetation and altitude provided by remote sensors could be used to predict the geographic distribution of Chagas disease vectors *Triatoma pseudomaculata* and *T. wygondzinskyi*. Linard et al. (2009) created a model to assess the risk of humans contracting malaria in southern France if the malaria parasite were reintroduced in the area based on various types of land use such as rice fields, vineyards, marshes and urban areas, while noting many statistical models can predict the spatial distribution of *Anopheles* vectors based on environmental variables.

The decisions of wildlife managers can have a lasting impact on disease risk as demonstrated by the findings of Lubelczyk et al. (2004). They found the presence of ticks was positively associated with the presence of several invasive species in the shrub

layer and concluded landscape changes and alterations in species composition may create favorable tick habitat. As these individuals make decisions on how to manage state lands and resources, they can reduce disease risk by considering the impacts of management actions on the populations of potential arthropod vectors of disease.

This study provides strong evidence non-host habitat associations exist across a range of parasite taxa. These associations may be more important than previous research has indicated. In the areas examined in this study, disturbance was an indicator for the presence of ticks, warranting further investigation concerning, among other abiotic factors, the impact of disturbance on other parasite species and different areas.

Table 1.1:
Total number of parasites collected, prevalence, average intensity of infestation and the number of plots where each parasite was collected broken down by taxa and species.

Species	Total	Prevalence	Average intensity*	Plots	Degree of parasite aggregation k‡	Variance to mean ratio
Acari (Ticks)	**69**	**13% (24/185)**	**2.8**	**12/66**	0.919	6.868
Ixodes scapularis	46	6% (12/185)	3.8	6/66	0.826	7.812
Larvae	45	6% (11/185)	4.1	6/66	0.826	7.812
Nymph	1	<1% (1/185)	1	1/66	-	-
Dermacentor variabilis	23	7% (13/185)	1.8	8/66	2.611	1.667
Larvae	16	6% (12/185)	1.3	8/66	2.611	1.667
Nymph	7	3% (5/185)	1.4	4/66	1.765	1.750
Siphonaptera (Fleas)	**98**	**29% (54/185)**	**1.8**	**28/66**	1.863	3.062
Orchopeas leucopus	95	28% (52/185)	1.8	27/66	1.863	3.062
Female	68	22% (41/185)	1.7	24/66	2.589	1.111
Male	27	12% (22/185)	1.2	15/66	13.446	2.319
Ctenophthalmus pseudagyrtes	2	1% (2/185)	1	2/66	-	-
Female	1	<1% (1/185)	1	1/66	-	-
Male	1	<1% (1/185)	1	1/66	-	-
Unknown	1	<1% (1/185)	1	1/66	-	-
Phthiraptera (Lice)						
Hoplopleura hesperomydis	91	12% (22/185)	4.1	14/66	0.682	11.336
Female	61	10% (18/185)	3.4	11/66	0.726	2.600
Male	30	7% (13/185)	2.3	10/66	2.074	8.342

*number of parasites per infested mouse

‡ Corrected moment estimate of k (Elliott 1977)

Table 1.2:
Eigen values, proportion of variation among groups, Wilk's Lambda F approximation and P value for the discriminant function analysis used to separate plots into groups with parasitized mice, clean mice and no mice.

		Eigen value	Prop of variation among groups	Wilk's Lambda F approximation*	p value
Tick Data Set	1st Eigen Value	2.0154	66%	1.7852	0.009
	2nd Eigen Value	1.0384	34%	-	-
Flea Data Set	1st Eigen Value	3.1553	76%	2.2528	>0.001
	2nd Eigen Value	0.9776	24%	-	-
Louse Data Set	1st Eigen Value	2.1800	67%	1.9015	0.004
	2nd Eigen Value	1.0859	33%	-	-

* $F_{58,76}$

Table 1.3:
Standardized discriminant function coefficients from the discriminant function analysis were used to separate plots into groups with ticks parasitizing mice, clean mice and no mice. Analysis was conducted using the following variables: canopy basal area of eleven tree species, height of ten subcanopy species and eight ground cover variables.

Variable	Scientific name	First standardized discriminant function axis	Second standardized discriminant function axis
Silver maple cba	*Acer saccharinum*	0.779	0.628
White oak cba	*Quercus alba*	-0.137	0.991
Quaking aspen cba	*Populus tremuloides*	0.779	0.628
Black ash cba	*Fraxinus nigra*	0.978	-0.210
Big tooth aspen cba	*Populus grandidentata*	0.560	-0.829
White pine cba	*Pinus strobus*	0.874	-0.487
Red maple cba	*Acer rubrum*	0.930	-0.367
Black oak cba	*Quercus velutina*	0.967	-0.254
Red pine cba	*Pinus resinosa*	0.948	-0.319
Red oak cba	*Quercus rubra*	0.189	-0.982
Black cherry cba	*Prunus serotina*	0.840	-0.543
Primary seedling	NA	0.936	0.353
Secondary leaf	NA	-0.171	0.985
Secondary barren	NA	0.819	0.573
Primary forb	NA	0.810	-0.586
Secondary forb	NA	0.984	0.181
Secondary seedling	NA	-0.758	0.652
Primary barren	NA	0.999	-0.038
Primary grass	NA	-0.949	0.315
Dogwood sht	*Cornus spp*	0.929	-0.370
Black ash sht	*Fraxinus nigra*	0.715	0.700
Sassafras sht	*Sassafras albidum*	0.298	-0.955
White pine sht	*Pinus strobus*	0.895	-0.446
Olive sht	*Elaeagnus umbellata*	0.859	-0.512

Table 1.3 Cont.

Red oak sht	*Quercus rubra*	0.859	-0.512
Quaking aspen sht	*Populus tremuloides*	-0.079	0.997
Black cherry sht	*Prunus serotina*	-0.923	0.384
Elm sht	*Ulmus americana*	0.748	-0.663
Red maple sht	*Acer rubrum*	0.833	-0.553

Table 1.4:
Contingency table for discriminant function analysis used to separate plots with ticks parasitizing mice, clean mice and no mice. Top of the chart refers to the plot classification derived from the posterior probabilities of the DFA, while the side of the chart is the plot classification assigned from field observations.

Field/Lab	No *Peromyscus*	Without ticks	With ticks	Totals	Commission
No *Peromyscus*	**15**	0	0	15	100%
Without ticks	1	**38**	0	39	97%
With ticks	1	0	**11**	12	92%
Totals	17	38	11	**97.0%**	
Omission	88%	100%	100%		

KAPPA = 0.95
Overall = 97%
Total Observations N = 66

Table 1.5:
Standardized discriminant function coefficients from the discriminant function analysis were used to separate plots into groups with fleas parasitizing mice, clean mice and no mice. Analysis was conducted using the following variables: canopy basal area of eleven tree species, height of ten subcanopy species and eight ground cover variables.

Variable	Scientific name	First standardized discriminant function axis	Second standardized discriminant function axis
Silver maple cba	*Acer saccharinum*	0.506	0.863
White oak cba	*Quercus alba*	-0.732	0.681
Quaking aspen cba	*Populus tremuloides*	0.905	-0.426
Black ash cba	*Fraxinus nigra*	-0.261	0.965
Big tooth aspen cba	*Populus grandidentata*	0.988	0.153
White pine cba	*Pinus strobus*	0.424	0.906
Red maple cba	*Acer rubrum*	0.935	0.353
Black oak cba	*Quercus velutina*	0.759	0.651
Red pine cba	*Pinus resinosa*	0.945	-0.327
Red oak cba	*Quercus rubra*	0.924	-0.382
Black cherry cba	*Prunus serotina*	0.964	0.267
Primary seedling	NA	0.921	0.390
Secondary leaf	NA	0.554	-0.832
Secondary barren	NA	0.846	0.534
Primary forb	NA	0.626	0.780
Secondary forb	NA	0.995	-0.095
Secondary seedling	NA	-0.895	0.446
Primary barren	NA	0.494	0.870
Primary grass	NA	-0.813	-0.582
Dogwood sht	*Cornus spp*	0.153	0.988
Black ash sht	*Fraxinus nigra*	0.300	0.954
Sassafras sht	*Sassafras albidum*	0.903	0.429
White pine sht	*Pinus strobus*	0.861	0.509
Olive sht	*Elaeagnus umbellata*	0.900	-0.436

Table 1.5 Cont.

Red oak sht	*Quercus rubra*	0.929	0.370
Quaking aspen sht	*Populus tremuloides*	0.044	-0.999
Black cherry sht	*Prunus serotina*	-0.985	-0.172
Elm sht	*Ulmus americana*	0.167	0.986
Red maple sht	*Acer rubrum*	0.870	0.494

Table 1.6:
Contingency table for discriminant function analysis used to separate plots with fleas parasitizing mice, clean mice and no mice. Top of the chart refers to the plot classification derived from the posterior probabilities of the DFA, while the side of the chart is the plot classification assigned from field observations.

Field/Lab	No *Peromyscus*	Without fleas	With fleas	Totals	Commission
No *Peromyscus*	**15**	0	0	15	100%
Without fleas	1	**22**	0	23	96%
With fleas	1	0	**27**	28	96%
Totals	17	22	27	**97%**	
Omission	88%	100%	100%		

KAPPA = 0.95
Overall = 97%
Total Observations N = 66

Table 1.7:
Standardized discriminant function coefficients from the discriminant function analysis were used to separate plots into groups with lice parasitizing mice, clean mice and no mice. Analysis was conducted using the following variables: canopy basal area of eleven tree species, height of ten subcanopy species and eight ground cover variables.

Variable	Scientific name	First standardized discriminant function axis	Second standardized discriminant function axis
Silver maple cba	*Acer saccharinum*	0.853	0.521
White oak cba	*Quercus alba*	-0.625	0.781
Quaking aspen cba	*Populus tremuloides*	0.924	0.382
Black ash cba	*Fraxinus nigra*	0.656	-0.755
Big tooth aspen cba	*Populus grandidentata*	0.582	0.813
White pine cba	*Pinus strobus*	0.997	0.079
Red maple cba	*Acer rubrum*	0.870	0.493
Black oak cba	*Quercus velutina*	0.990	-0.140
Red pine cba	*Pinus resinosa*	0.569	0.822
Red oak cba	*Quercus rubra*	0.994	-0.106
Black cherry cba	*Prunus serotina*	0.962	0.272
Primary seedling	NA	0.936	0.352
Secondary leaf	NA	0.321	-0.947
Secondary barren	NA	0.907	0.421
Primary forb	NA	0.993	-0.115
Secondary forb	NA	0.298	0.955
Secondary seedling	NA	-0.388	-0.922
Primary barren	NA	0.977	0.214
Primary grass	NA	-0.994	-0.109
Dogwood sht	*Cornus spp*	0.488	0.873
Black ash sht	*Fraxinus nigra*	0.928	0.373
Sassafras sht	*Sassafras albidum*	0.946	-0.325
White pine sht	*Pinus strobus*	0.987	-0.162

Table 1.7 Cont.

Olive sht	*Elaeagnus umbellata*	0.976	-0.219
Red oak sht	*Quercus rubra*	0.299	0.954
Quaking aspen sht	*Populus tremuloides*	-0.732	0.681
Black cherry sht	*Prunus serotina*	-0.048	-0.999
Elm sht	*Ulmus americana*	0.546	0.838
Red maple sht	*Acer rubrum*	0.865	0.502

Table 1.8:
Contingency table for discriminant function analysis used to separate plots with lice parasitizing mice, clean mice and no mice. Top of the chart refers to the plot classification derived from the posterior probabilities of the DFA, while the side of the chart is the plot classification assigned from field observations.

Field/Lab	No *Peromyscus*	Without lice	With lice	Totals	Commission
No *Peromyscus*	**15**	0	0	15	100%
Without lice	2	**35**	0	37	95%
With lice	0	0	**14**	14	100%
Totals	17	35	14	**97.0%**	
Omission	88%	100%	100%		

KAPPA = 0.95
Overall = 97%
Total Observations N = 66

Table 1.9:
Common and scientific names as well as the wetland indicator status (USDA 2009), habitat and colonizer indicator (Szafoni 1990, Barnes and Wagner 2002) of the tree species included in the analysis.

Common name	Scientific name	Wetland indicator status	Colonizer	Habitat
Black ash	*Fraxinus nigra*	Facultative wetland		Poorly drained sites with organic soils
Black cherry	*Prunus serotina*	Facultative upland	x	Disturbed sites in dry mesic and mesic forests
Black oak	*Quercus velutina*	NA		Xeric and dry mesic forests with well to very well drained upland soils
Big tooth aspen	*Populus grandidentata*	Facultative upland	x	Mesic to dry mesic forests
Dogwood	*Cornus* spp	NA		Depends on species; alternate, wet loving; flowering, dry loving
Elm	*Ulmus americana*	Facultative wetland	x	River flood plains, poorly drained deciduous swamps, and disturbed sites
Autumn olive	*Elaeagnus umbellata*	NA	x	Disturbed sites in open woodlands, prairies and forest edges; rarely encountered in wet sites or dense forests*
Quaking aspen	*Populus tremuloides*	NA	x	Open lowland sites due to competition, colonizer, moisture demanding
Red maple	*Acer rubrum*	Facultative	x	Lowland very poorly drained deciduous swamps and colonized adjacent disturbed upland slopes
Red oak	*Quercus rubra*	Facultative upland		Mesic forests moist cool well drained sites
Red pine	*Pinus resinosa*	Facultative upland		Well drained dry highly acid sandy soils
Sassafras	*Sassafras albidum*	Facultative upland	x	Disturbed sites in dry mesic and mesic forests

Table 1.9 Cont.

Silver maple	*Acer saccharinum*	Facultative wetland	Alluvial flood plains and moist bottomland, occasionally deciduous swamps
White oak	*Quercus alba*	Facultative upland	Dry mesic upland sites with drought prone well drained sandy loam to clay loam soils
White pine	*Pinus strobus*	Facultative upland	Grows well on variety of conditions

* Based on Szafoni (1990)

Table 1.10: Abundance, prevalence and average intensity of infection for two ecto-parasite surveys from the nearby state of Indiana conducted by Whitaker (1982) and Ritzi and Whitaker (2003).

	Whitaker (1982) n = 272 Indiana			Ritzi and Whitaker (2003) n= 60 New Port Chemical Depot, Vermillion Co. Indiana		
Species	Total	Prevalence*	Average intensity of infestation‡	Total	Prevalence*	Average intensity of infestation†
Acari (Ticks)						
Ixodes scapularis	NR	-	-	NR	-	-
Dermacentor variabilis	88	9.90%	0.32	35	21.70%	2.69
Siphonaptera (Fleas)						
Orchopeas leucopus	140	21%	0.51	43	38.30%	2.87
Ctenophthalmus pseudagyrtes	5	1.80%	0.02	NR	-	-
Phthiraptera (Lice)						
Hoplopleura hesperomydis	27	5.10%	0.1	35	28.30%	2.06

NR = not reported

* Percent of rodents that were infested (Margolis et al. 1982)

‡ Per all hosts examined

† Per infested host

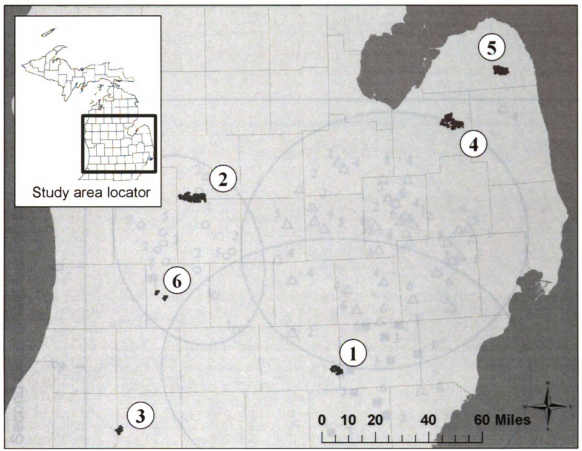

Figure 1.1:
Distribution of State Game Areas across southern Michigan: 1) Sharonville SGA, 2) Flat River SGA, 3) Three Rivers SGA, 4) Deford SGA, 5) Verona SGA and 6) Barry and Yankee Springs SGA.

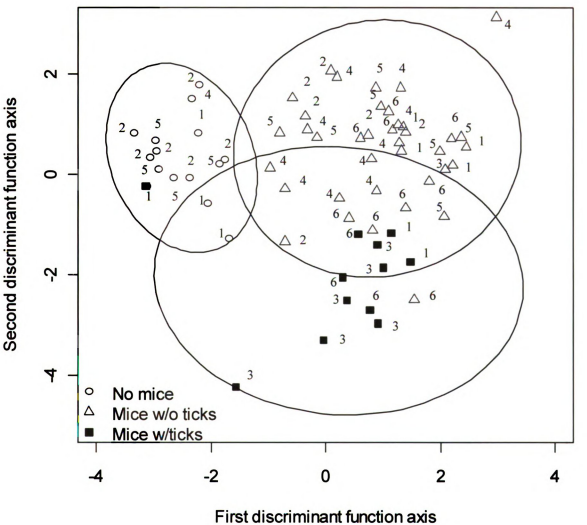

Figure 1.2:
Distribution of individual plots in discriminant function space into one of three groups: plots with no mice, un-parasitized mice and mice parasitized by ticks. Ellipses represent 95% confidence intervals around the population mean. Numbers refer to the SGA where the plot occurred: 1 Sharonville, 2 Flat River, 3 Three Rivers, 4 Deford, 5 Verona, and 6 Barry. The first discriminant axis had a strong positive association with 1° seedling ground cover, 1° barren ground cover and 2° forb ground cover and a strong negative association with 1° grass ground cover, black cherry subcanopy height and 2° seedling ground cover. The second discriminant axis had a strong positive association with 2° leaf ground cover, 2° seedling ground cover and quaking aspen subcanopy height (Table 1.3).

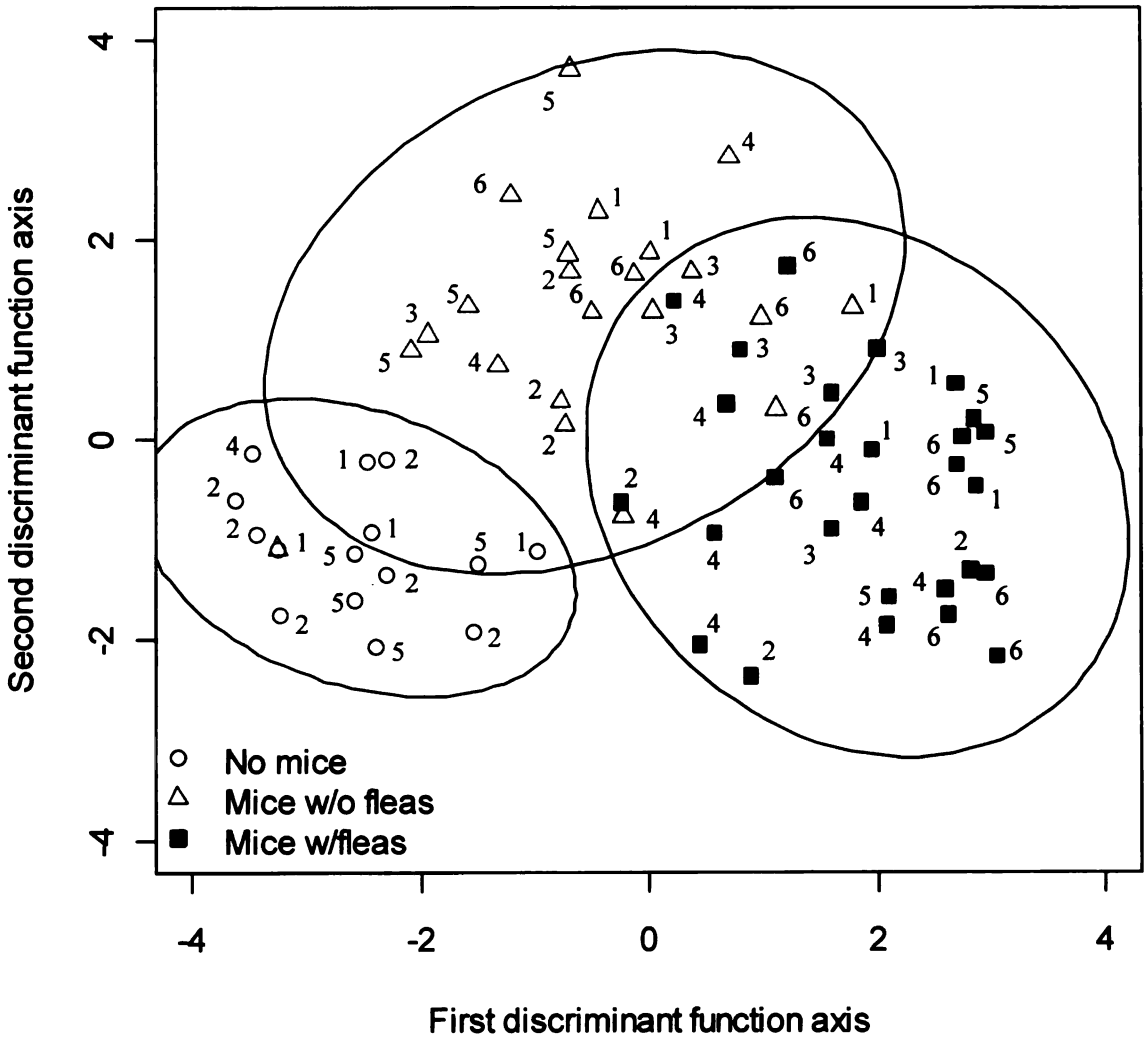

Figure 1.3:
Distribution of individual plots in discriminant function space into one of three groups: plots with no mice, un-parasitized mice and mice parasitized by fleas. Ellipses represent 95% confidence intervals around the population mean. Numbers refer to the SGA where the plot occurred: 1 Sharonville, 2 Flat River, 3 Three Rivers, 4 Deford, 5 Verona, and 6 Barry. The first discriminant axis had a strong positive association with big tooth aspen, black cherry, and red pine canopy basal area; and a strong negative association with 1° grass ground cover, 2° seedling ground cover, and black cherry subcanopy height. The second discriminant axis had a strong positive association with dogwood, elm, and black ash subcanopy height; and a strong negative association 1° grass ground cover, 2° leaf ground cover, and quaking aspen subcanopy height (Table 1.5).

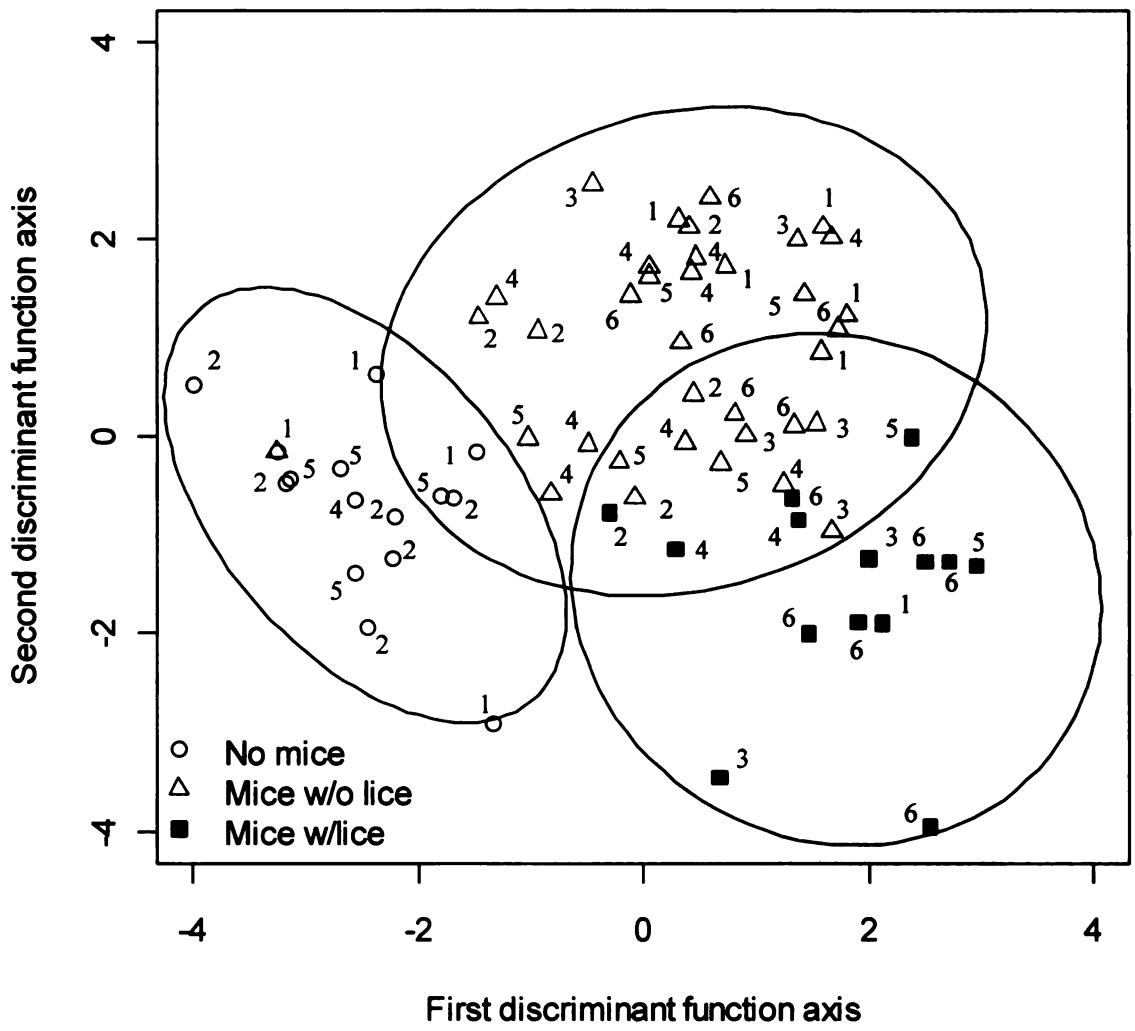

Figure 1.4:
Distribution of individual plots in discriminant function space into one of three groups: plots with no mice, un-parasitized mice and mice parasitized by lice. Ellipses represent 95% confidence intervals around the population mean. Numbers refer to the SGA where the plot occurred: 1 Sharonville, 2 Flat River, 3 Three Rivers, 4 Deford, 5 Verona, and 6 Barry. The first discriminant axis had a strong positive association with white pine, red oak, and black oak canopy basal area; and a strong negative association with 1° grass ground cover, quaking aspen subcanopy height and white oak canopy basal area. The second discriminant axis had a strong positive association with 2° forb ground cover, red oak and dogwood subcanopy height; and a strong negative association with black ash canopy basal area, 2° leaf ground cover and 2° seedling ground cover (Table 1.7).

APPENDIX 1
Record of Deposition of Entomological Voucher Specimens

Appendix 1

Record of Deposition of Entomological Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa, which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 2009-01

Title of thesis or dissertation (or other research projects):

DESCRIBING THE SPATIAL DISTRIBUTION OF PARASITES ON *PEROMYSCUS* SPECIES IN SOUTHERN MICHIGAN

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

United States National Museum of Natural History

Investigator's Name(s):
Erica L. Mize

Date: May 08, 2009

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America.
Bull. Entomol. Soc. Amer. 24: 141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.

Copies: Include as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

Appendix 1.1

Voucher Specimen Data

Page 1 of 2 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of:					
		Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Museum where deposited
Orchopeas leucopus	Barry S.G.A., MI (Barry Co.) - 2007				17	6	MSU
Orchopeas leucopus	Deford S.G.A., MI (Tuscola Co.) - 2007				22	10	MSU
Unknown flea	Deford S.G.A., MI (Tuscola Co.) - 2007					1	MSU
Orchopeas leucopus	Flat River S.G.A., MI (Montcalm Co.) - 2007				5	3	MSU
Orchopeas leucopus	Sharonville S.G.A., MI (Jackson Co.) - 2007				10	3	MSU
Orchopeas leucopus	Three Rivers S.G.A., MI (St. Joe Co.) - 2007				6	1	MSU
Orchopeas leucopus	Verona S.G.A., MI (Huron Co.) - 2007				7	3	MSU
Hoplopleura hesperomydis	Barry S.G.A., MI (Barry Co.) - 2007				22	9	MSU
Hoplopleura hesperomydis	Deford S.G.A., MI (Tuscola Co.) - 2007				3	3	MSU
Hoplopleura hesperomydis	Flat River S.G.A., MI (Montcalm Co.) - 2007				22	8	MSU
Hoplopleura hesperomydis	Sharonville S.G.A., MI (Jackson Co.) - 2007				1		MSU
Hoplopleura hesperomydis	Three Rivers S.G.A., MI (St. Joe Co.) - 2007					3	MSU
Hoplopleura hesperomydis	Verona S.G.A., MI (Huron Co.) - 2007				13	5	MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)
Erica L Mize

Date 8-May-09

Voucher
No. 2009-01
Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date

Appendix 1.1

Voucher Specimen Data

Page 2 of 2 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of:					Museum where deposited
		Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	
Orchopeas leucopus	Deford S.G.A., MI (Tuscola Co.) - 2007				1	1	USNM
Ctenophthalmus pseudagyrtes	Verona S.G.A., MI (Huron Co.) - 2007				1		USNM
Ctenophthalmus pseudagyrtes	Barry S.G.A., MI (Barry Co.) - 2007					1	USNM
Hoplopleura hesperomydis	Flat River S.G.A., MI (Montcalm Co.) - 2007				1		USNM
Hoplopleura hesperomydis	Deford S.G.A., MI (Tuscola Co.) - 2007					1	USNM
Dermacentor variabilis	Sharonville S.G.A., MI (Jackson Co.) - 2007	2	1				USNM
Ixodes scapularis	Three Rivers S.G.A., MI (St. Joe Co.) - 2007	2					USNM

(Use additional sheets if necessary)

Investigator's Name(s) (typed)
Erica L Mize

Date 8-May-09

Voucher No. 2009-01

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date

APPENDIX 2
Record of Deposition of Mammalian Vouchers

Appendix 2

Record of Deposition of Mammalian Vouchers

Accession and collector's numbers of all mammals deposited at Michigan State University Museum Mammal Research Collection. Non-*Peromyscus* species deposited were the result of trap mortality.

Accession No.	Coll. No.	Genus	Species	Subspecies
MSU 37491	73	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37492	109	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37493	106	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37494	108	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37495	110	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37496	112	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37497	128	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37498	129	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37499	130	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37500	131	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37501	132	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37502	136	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37503	151	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37504	152	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37505	154	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37506	155	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37507	160	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37508	161	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37509	164	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37510	166	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37511	167	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37512	179	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37513	177	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37514	178	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37515	180	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37516	182	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37517	183	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37518	215	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37519	216	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37520	217	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37521	218	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37522	219	*Peromyscus*	*leucopus*	*noveboracensis*

Appendix 2 Cont.

MSU 37523	220	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37524	221	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37525	222	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37526	223	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37527	225	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37528	226	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37529	227	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37530	229	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37531	232	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37532	233	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37533	234	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37534	235	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37535	236	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37536	237	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37537	238	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37538	265	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37539	266	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37540	267	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37541	268	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37542	270	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37543	271	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37544	272	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37545	273	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37546	274	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37547	275	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37548	276	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37549	277	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37550	278	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37551	280	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37552	281	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37553	282	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37554	323	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37555	329	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37556	338	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37557	342	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37558	343	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37559	345	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37560	346	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37561	347	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37562	371	*Peromyscus*	*leucopus*	*noveboracensis*

Appendix 2 Cont.

MSU 37563	372	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37564	373	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37565	374	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37566	375	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37567	376	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37568	377	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37569	378	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37570	380	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37571	382	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37572	383	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37573	384	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37574	387	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37575	390	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37576	391	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37577	392	*Peromyscus*	*leucopus*	*noveboracensis*
MSU 37578	105	*Peromyscus*	spp	
MSU 37579	111	*Peromyscus*	spp	
MSU 37580	153	*Peromyscus*	spp	
MSU 37581	154	*Peromyscus*	spp	
MSU 37582	162	*Peromyscus*	spp	
MSU 37583	165	*Peromyscus*	spp	
MSU 37584	224	*Peromyscus*	spp	
MSU 37585	228	*Peromyscus*	spp	
MSU 37586	230	*Peromyscus*	spp	
MSU 37587	231	*Peromyscus*	spp	
MSU 37588	275	*Peromyscus*	spp	
MSU 37589	324	*Peromyscus*	spp	
MSU 37590	344	*Peromyscus*	spp	
MSU 37591	379	*Peromyscus*	spp	
MSU 37592	381	*Peromyscus*	spp	
MSU 37593	388	*Peromyscus*	spp	
MSU 37594	389	*Peromyscus*	spp	
MSU 37595	393	*Peromyscus*	spp	
MSU 37467	120	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37468	124	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37469	126	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37470	127	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37471	158	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37472	163	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37473	176	*Blarina*	*brevicauda*	*kirtlandi*

Appendix 2 Cont.

MSU 37474	181	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37475	192	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37476	214	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37477	244	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37478	254	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37479	269	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37480	284	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37481	288	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37482	293	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37483	297	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37484	204	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37485	336	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37486	250	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37487	385	*Blarina*	*brevicauda*	*kirtlandi*
MSU 37488	94	*Microtus*	*pennsylvanicus*	*pennsylvanicus*
MSU 37489	103	*Microtus*	*pennsylvanicus*	*pennsylvanicus*
MSU 37490	337	*Microtus*	*pennsylvanicus*	*pennsylvanicus*
MSU 37596	150	*Sorex*	*cinereus*	*lesueurii*
MSU 37597	213	*Zapus*	*hudsonius*	*americanus*
MSU 37598	386	*Zapus*	*hudsonius*	*americanus*

APPENDIX 3
Estimate of Detection Error

Appendix 3

Estimate of Detection Error

The number of each parasite group collected from mice in the field and in lab. The estimate of detection error is calculated as the number of parasites collected in the lab (missed in the field) out of the total number of parasites collected.

	No. recovered in field	No. recovered in lab	Estimated detection error
Ticks	58	11	15.9%
Fleas	91	7	7.1%
Lice	8	83	91.2%

APPENDIX 4
Comparison of Linear Versus Quadratic Discriminant Function Analysis

Appendix 4

Comparison of Linear Versus Quadratic Discriminant Function Analysis

The classification accuracy, number of correctly classified plots, and kappa value for each parasite taxa using both the quadratic and linear modes of discriminant function analysis (DFA).

	Quadratic DFA Classification accuracy	Plots	Kappa value	Linear DFA Classification accuracy	Plots	Kappa value
Tick	97%	64/66	0.95	92%	61/66	0.87
Flea	97%	64/66	0.95	88%	58/66	0.81
Louse	97%	64/66	0.95	94%	62/66	0.90

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