1998

Heartwork and Lungworms in Illinois' Canids and Their Possible Effect on Coyote Condition and Reproduction

David G. Gregory
Eastern Illinois University

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Heartworm and Lungworms in Illinois' Canids
(TITLE)

BY

David G. Gregory

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

Master of Science

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
CHARLESTON, ILLINOIS

1998
YEAR

I HEREBY RECOMMEND THIS THESIS BE ACCEPTED AS FULFILLING
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Heartworm And Lungworms In Illinois' Canids And Their Possible Effect On Coyote Condition And Reproduction

David Gregory

Master's Thesis

Eastern Illinois University

Charleston, Illinois

ABSTRACT

This study focuses on the prevalence of heartworm and lungworms in Illinois' canid species, and the effect that they may have on condition (body weight, kidney fat, marrow fat) and reproduction (placental scars) on coyote populations. A total of 1,150 coyotes (*Canis latrans*), 2,269 domestic dogs, 47 red foxes (*Vulpes vulpes*), and 2 gray foxes (*Urocyon cinereoargenteus*) were examined. Prevalence of heartworms (*Dirofilaria immitis*) averaged 17.8% in coyotes, 3.0% in domestic dogs, 2.0% in red foxes, and 0% in gray foxes. Domestic dogs not receiving any type of prophylactic treatment had a higher prevalence (12.5%) of heartworms than dogs on a prophylactic program (0.3%). Heartworm prevalence varied regionally throughout the state in both coyotes and domestic dogs reflecting a lower prevalence in the northern regions of the states and a higher prevalence in the south.

Of the 341 coyotes examined for lungworms, 52 (15.2%) were infected with *Capillaria aerophila*, 10 (2.9%) with *Fillaroides sp.*, 8 (2.3%) with *Paragonimus kellicotti*, and 2 (0.6%) with *Crenosoma vulpis*. A stomach parasite, *Physaloptera rara*, was also recovered from 58 (17%) coyotes. Fifteen red foxes were examined for the presence of lung parasites, of which, 11 (73.3%) were infected with *Capillaria aerophila*, 1 (1.1%) was infected with *Crenosoma vulpis*, and 1 (1.1%) with *Physaloptera rara*.

Heartworm and/or a lungworm infection did not appear to significantly impact the condition or reproduction of coyotes since no significant differences were observed in the body weight, fat reserves, or number of placental scars of uninfected and infected individuals.

DEDICATION

This project is dedicated to my grandparents, Clarence and the late Helen Christin. Thank you for your years of love, kindness, memories, and support. You have taught me many lessons in family values and moral responsibilities that can only be taught by the exemplary life the two of you had in 57 years of marriage.

ACKNOWLEDGMENTS

The Illinois Department of Natural Resources provided funding for this research through Illinois Furbearer Fund project 96-04-R. The Illinois Trappers Association, through the Dick Daniel's Memorial Scholarship and member participation, also provided support. I would also like to recognize Dr. David Barber for allowing me to use his x-ray machine and other needed supplies along with providing personal support for this project. Sarah Bush Lincoln Memorial Hospital also donated needed supplies.

A deep appreciation is extended to all the furbuyers, hunters, and trappers of Illinois who provided an interest and support for this project. I am extremely grateful for all the assistance and patience of Bob Bluett and George Hubert of the Illinois Department of Natural Resources. Without them, this project probably never would have came into existence. I would like to thank Ron Boeser for his personal assistance, advice, and expertise on coyotes. I am forever grateful to Dan Lloyd for his personal investment in this project and for his portion of the age, condition and reproduction information. I would like to recognize Carrie Boroughs for her assistance examining hearts and lungs for parasites and Jason Keller for his assistance collecting specimens and performing lipid extractions.

I would like to extend a deep appreciation towards the Department of Biological Sciences at Eastern Illinois University for providing me with a quality education and the opportunity to do quality research. I am forever grateful to Dr. Tom Nelson and Dr. Jeff Laursen, my co-advisors, for their time, assistance, guidance, and patience. Dr. Gary Fritz also deserves a hearty recognition for his input in the editing of this manuscript.

LIST OF TABLES

LIST OF FIGURES

Figure Page

TABLE OF CONTENTS

INTRODUCTION

The focus of this study was to investigate heartworms and lungworms in Illinois' canid populations, including coyotes (*Canis latrans*), domestic dogs (*Canis familiaris*), red foxes (*Vulpes vulpes*), and gray foxes (*Urocyon cinereoargenteus*), with a special emphasis on coyotes. Heartworms are an important parasite causing disease in both wild and domestic canids, while the role of lungworms as pathogens in wild canids is poorly understood.

Heartworms (*Dirofilaria immitis*), and coyotes have prompted numerous studies, both separately and jointly, throughout the past 50 years (Hamlet, 1938; Walton, 1963; Alls, 1974; Agostine, 1982; Stromberg, 1995). Both species are important ecologically and economically. Ecologically, coyotes occupy a wide niche, are top carnivores in terrestrial ecosystems, are habitat generalists, and are prevalent throughout the continental United States. Economically, the coyote is important as a furbearer, game animal, and nuisance predator (Gier, 1968). Heartworms are one of the most important parasites of domestic dogs. They are economically important for the millions of dollars spent each year for testing and prophylactic treatment.

Ecological studies of parasite/host interactions suggest that some parasites inflict comparatively little damage on their host (Munger, 1989; Christian, 1995), while others cause acute or chronic disease (Bjerkas, 1990; Fell, 1991). Parasites may affect the physical condition and survival of the host (Murray, 1997), growth rates (Khan, 1989), or reproductive costs (Moller, 1993).

Heartworms can play an important role in coyote mortality, and *D. immitis* may be a limiting factor of coyote populations in enzootic areas (Kazacos, 1979). Heartworm

infections may be more detrimental to coyotes than domestic dogs because competition for survival is likely greater for wild populations, and parasite burdens may decrease the physiological efficiency of the host (Gier, 1959). Beckoff (1978) reported that coyotes burdened with heartworms were more vulnerable to mortality when chased regularly by dogs. Observations like these have led some biologists to question the effects of heartworms on coyotes or other wild canids.

The primary objectives for this study were to determine: (1) the regional prevalence of heartworm in Illinois' coyotes, domestic dogs, red foxes, and gray foxes, (2) the prevalence of lungworms in these species, (3) evaluate the effects of heartworms and/or lungworms on the physical condition and reproductive performance of coyotes.

LITERATURE REVIEW

Natural History of Heartworms

The heartworm (*Dirofilaria immitis*) is a filarial nematode transmitted to canid hosts by mosquitos. Adults typically live in the right ventricle and pulmonary artery of dogs, coyotes, and wolves, but have occasionally been recovered from the right atria, pulmonary arterial tree in the lung, and vena cava (Custer, 1981). In rare instances, recovery of a single heartworm from the brain (Hamir, 1987) and eye (Eberhard, 1977) of domestic dogs have been reported. In addition, this parasite has been reported in cats, foxes, dingoes, tigers, muskrats, chimpanzees, orangutans, California sea lions, and occasionally man (Levine, 1968).

Heartworms are slender and white in color, and exhibit sexual dimorphism. Males are 12-16 cm long with a spirally coiled tail that bears small lateral alae; females are 25-30 cm long (Soulsby, 1982). Ovoviviparous females shed microfilaria that exhibits daily periodicity in the peripheral blood stream of the host (Hirth, 1966). Microfilaria are at least 5 to 10 times more plentiful in the early evening and at night than in the morning or at midday. Evidence indicates that concentrations of microfilaria occur in the viscera, notably the spleen, during the daytime, but the precise mechanism is not understood completely (Otto, 1969). Microfilaria ingested by mosquitoes go through three developmental stages in the stomach, malpighian tubules, and labium of mosquitoes. Infection occurs when the infected mosquito takes a blood meal (Soulsby, 1982)

Pathology created by heartworms is primarily due to the physical obstruction of the heart chambers, valves, and vessels. Eventually, pulmonary endarteritis and obstructive fibrosis will lead to pulmonary hypertension and right heart failure.

Obstruction of the capillaries by microfilaria may also play a part in the pathogenesis of heartworm disease (Georgi, 1990). Canids that harbor a heartworm infection typically show signs of coughing and fatigue.

Heartworms are distributed worldwide (Levine, 1968) and are found throughout the United States in the Midwest (Franson, 1976), Atlantic Coastal Region (Otto, 1969), and Pacific Coast (Weinmann, 1980). In Illinois, heartworms have been documented in 5 species and in 7 different studies, coyotes (Kick, 1980), domestic cats (Todd, 1976), domestic dogs (McKinney, 1962; Marquardt, 1966; Todd, 1974; Ward, 1974; Jaskowski, 1977), gray foxes (Kick, 1980; Dyer, 1982a) and red foxes (Kick, 1980; Dyer, 1981). First reports of a difference in the regional prevalence of heartworms in animals from southern Illinois versus northern Illinois were made by Marquardt (1966), and then supported by Kick (1980).

Natural History of Lungworms

Respiratory helminths, including the genera *Capillaria*, *Crenosoma*, *Filaroides*, and *Paragonimus*, have not been studied as widely as heartworms in canids.

Capillaria aerophila

Capillaria aerophila is a nematode occurring in the trachea, bronchi, and rarely nasal cavities and frontal sinuses of dogs, foxes and coyotes. Additional infections have been reported in the cat, pine marten, beech marten, wolf and the badger (Soulsby, 1982). Males are generally 15-25 mm long with an esophagus 8.3 mm long. Females are typically longer, 20-40 cm, and have an esophageal length of 7.4 mm long. The eggs are greenish-brown with a plug at each end (Levine, 1968).

In foxes, *C. aerophila* causes rattling and wheezy respiration with coughing and weakness, poor growth, and poor fur quality (Georgi, 1990). Nasal discharges containing mucus or blood and labored breathing are prominent with heavy infections. Often, severely infected animals die from bronchopneumonia. *C. aerophila* affects younger animals more than older ones (Levine, 1968).

The life cycle for *C. aerophila* is direct. Eggs deposited in the lungs are coughed up, swallowed and passed in the feces of the host. After 5-7 weeks of development in ambient conditions, eggs are viable. Once ingested by the new host, eggs hatch in the intestine and the larvae migrate to the lungs in 7-10 days. Mature adults are present about 40 days after infection (Soulsby, 1982).

Besides North America, *C. aerophila* occurs in Europe, USSR, and South America (Levine, 1968). Levine found eggs in 10 of 175 (6%) domestic dogs examined in Illinois (Levine and Ivens, 1965). Fifty-one (31%) of 165 red foxes and 60 (11%) of 543 gray foxes examined from southern Illinois harbored *C. aerophila* infections (Dyer, 1982). Reports of *C. aerophila* in canids from other states include: Wisconsin (Dibble, 1983), Montana (Seesee, 1983), Arizona, California and New Mexico (Morrison, 1979), Kansas, Oklahoma, Texas, Colorado, Wyoming, South Dakota, Iowa and Nebraska (Morrison, 1978), and New York (Zeh, 1977).

Crenosoma vulpis

Crenosoma vulpis (Dujardin, 1945) is a metastrongyloid less than 16 mm long and characterized by longitudinally striated annulations, each of which overlaps the one behind it (Levine, 1968). *C. vulpis* is found primarily in foxes, but other hosts include: domestic dog, wolf, raccoon, badger, wolverine and black bear (Soulsby, 1982). The

disease caused by this parasite is similar to that caused by *C. aerophila*. Rhinotracheitis, bronchitis and nasal discharge are characteristic and heavy infections may result in bronchopneumonia. Traditionally, *C. vulpis* distribution is limited to the eastern United States (Levine, 1968). The only reference to the genus *Crenosoma* recorded in Illinois is *C. goblei*, found in the lungs of raccoons (Snyder, 1985).

Larvae produced by the females are coughed up, swallowed, and passed in the feces of the host. *C. vulpis* uses one of several species of mollusks (*Helix pomatia, Cepea hortensis, Cepea nemoralis, Arianta arbustorum, Agriolimax spp., Arion hortensis, Arion circumscriptus*) as its intermediate host. The larvae penetrate into the foot of land snails or slugs and are infective in 16-17 days. If the infected invertebrate is eaten by a predator, adult development is completed 21 days after the larvae pass, by way of the lymphatic glands and hepatic circulation, to the lungs (Soulsby, 1982).

Filaroides spp.

There are 9 species that belong to the genus *Filaroides* (Levine, 1968), but only 3 (*F. osleri, F. hirthi* and *F. milksi*) live in the lungs. Ovoviviparous females reproduce by releasing thin-shelled eggs containing first stage larvae that hatch before being excreted in the host's feces. These become immediately infective to a new host. Complete development of all five larval stages can occur in the lungs. Ingestion of regurgitated stomach contents, lung tissue, or feces of infected animals will lead to infection (Georgi, 1990).

F. osleri occurs in nodules in the trachea and bronchi and rarely in the lungs of canids. Clinical signs of a *F. osleri* infection include a chronic, rasping cough due to the granulomatis lesions formed on the trachea (Soulsby, 1982). Distribution of this parasite

is worldwide (Soulsby, 1982). Pence (1984) found 92 (52%) of 177 coyotes from Texas infected with *F. osleri*. Additional reports of *F. osleri* occurrence include: Alberta, Canada (Holmes, 1972), Arizona, California, Colorado, Kansas, New Mexico (Morrison, 1979), Washington and Idaho (Foreyt, 1982), Texas (Ludwig, 1983), Connecticut (Carlson, 1984), Saskatchewan, Canada (Polley, 1986), and Georgia (Lappin, 1987).

F. hirthi and *F. milksi* are quite similar species, except *F. hirthi* is smaller. Neither species causes clinical disease (Soulsby, 1982). *F. hirthi* and *F. milksi* exist in the lung parenchyma of the dog and striped skunk (*Mephitis mephitis*). Several authors indicate *F. milksi* presence in New York (Whitlock, 1956), Iowa (Peckham, 1960), and Connecticut (Mills and Nielsen, 1966).

Paragonimus kellicotti

Paragonimus kellicotti is a trematode parasite that encyst in pairs within the lung parenchyma. Adults are reddish-brown in color and spines cover the tegument (Soulsby, 1982). *P. kellicotti* infections occur in cats, dogs, coyotes, foxes, and a wide range of other species (Dubey, 1978). In Illinois, Dyer (1984) found *P. kellicotti* infections in 7 (1.2%) of 543 gray foxes and 4 (2.4%) of 165 red foxes. Reports of *P. kellicotti* from other states include West Virginia (Davidson, 1992a), Ohio (Beckett, 1966), Minnesota (Bemrick, 1971) and Georgia (McKeever, 1958). The first record of *P. kellicotti* infection in coyotes is from southwestern Ontario (Ramsden, 1975).

The life cycle for this parasite requires 2 intermediate hosts. Eggs passed in feces of carnivores develop into miracidia 2-3 weeks after being laid, infect the first intermediate host, small aquatic snails. Once in the snail, miracidia reproduce asexually producing cercaria. These cercaria leave the snail, are free in the water, and infect the

second intermediate host, crayfish. Once in the crayfish, the cercaria develops into metacercaria and are infective to animals predating on the crayfish. After ingestion, flukes penetrate the wall of the intestine, migrate through the peritoneal and pleural cavity and into the lungs to form cysts in the alveolar tissue (Dubey, 1978).

Natural History of Coyotes

In Illinois, coyotes are abundant and fill the ecological role as top carnivore in most terrestrial ecosystems. Their diet is highly variable and omnivorous. Primary prey species include rabbits, pigs, small rodents, deer fawns, and raccoons. They also consume birds, crayfish, and grasshoppers in lesser amounts (Hoffmeister, 1989).

Coyotes breed annually, with mating usually occuring in February. After a 63-day gestation period, pups are born. Females are in estrus during the months of February and March (Hamlet, 1938). If a female breeds and produces offspring, pigmented areas or "placental scars" are left on the endometrium of the uterus, marking the site of placental attachment. These scars are indicators of the number of young produced (Bookhout, 1996). Placental scars visible in the uterus of coyotes harvested in December-February indicate the number of fetuses produced in the previous breeding season. Windberg (1995) found females coyotes in good physical condition reached sexual maturity sooner and produced larger litters than those in poor condition.

Natural History of Red Foxes

Distribution of red foxes in Illinois is statewide but most commonly inhabit the open grasslands and brushland areas adjacent to woodlots. Diet varies seasonally. During the winter and spring, small mammals are the main source of food. Plant material and insects seem to be the preferred diet during the summer and fall. Pups are born in

late March or in April, following a 51-day gestation period. Until the red fox pups reach maturity, a family unit remains intact and all activity is centered around the den site (Hoffmeister, 1989).

Natural History of Gray Foxes

Gray foxes also occupy a statewide distribution in Illinois, but are less abundant throughout the northern third of the state. Deciduous forest or woodlots are preferred habitat for gray foxes as they are excellent tree climbers. Diet is quite varied but primarily includes cottontails, a wide variety of mice and birds, domestic chickens, insects, various nuts and fruits, apples, persimmons, dry corn, roots, and even breads if they are available. Reproduction occurs in late January and February and gray fox pups are born in April or May. In Illinois, the mean litter size for a gray fox is about 3.8, based on embryos, placental scars, and uterine swellings (Hoffmeister, 1989).

METHODS

Coyote (n=1,150), red fox (n=47) and gray fox (n=2) carcasses were collected by contacting furbuyers, hunters and trappers throughout the state of Illinois during the 1994-95, 1995-96 and 1996-97 hunting and trapping seasons. An effort was made to collect carcasses from each of the 10 wildlife management regions in Illinois (Schwegmann, 1973) (Fig. 1). Carcasses typically were stored at winter temperatures while in the possession of these suppliers. Organs and tissues collected for this study then were frozen for subsequent examination.

Each animal was assigned an individual identification number, and the date, county of harvest, sex, body weight, and body length were recorded. Some carcasses were intact when collected while others were skinned. Skinned animals were classified as having no fat, moderate fat, or abundant fat, based on visual estimates of subcutaneous fat. For intact animals, fur quality and the presence or absence of mange were recorded. Fur quality was recorded as excellent, good, fair, poor, or bad, based on overall appearance, coat luster, and fur density.

During the 1994-97 seasons, the heart, female reproductive tract (for assessing reproduction) and canine teeth (for age determination) were collected. Kidneys, kidney fat, and bone marrow also were collected during the 1995-96 season to better assess body fat levels. Lungs were collected in 1996-97 to look for migrating heartworms and assess the prevalence of lung parasites.

All 4 chambers of each heart were inspected for heartworms by gross examination. Heartworms were collected and stored in a solution of 70% ethanol and 5%

glycerin for further examination. Heartworms in each animal were counted and sexed using physical attributes (Soulsby, 1982).

Lungs were inspected for parasites by inserting a small tube into the pulmonary artery and flushing with tap water for a minimum of 3 minutes (Conboy, personal communication). Water and parasites were flushed from the trachea and onto a 120 μm sieve. During flushing, lungs were massaged to extrude any parasites and palpated to check for *P. kellicotti* cysts. After flushing, pulmonary arteries were dissected and inspected for heartworms. Bronchioles were dissected and the bronchioles, pulmonary artery and heart were rinsed into the 120 μm sieve. This was subsequently back flushed into a 90 μm sieve that was examined for lung parasites at 15X using a dissecting scope. Lung parasites were preserved in 70% ethanol and 5% glycerol. Nematodes were identified using a compound microscope after being mounted in lactophenol.

The age of each animal was determined using a mandibular canine tooth. Teeth were removed by soaking a section of the lower mandible in a water bath at 40°C for 1-2 weeks. Teeth were radiographed and identified as either adult or juvenile, based on the width of the pulp cavity (Kuehn and Berg, 1983). Teeth from adults were sent to Matson Laboratories, Missoula MT, for more precise aging based on counts of cementum annuli (Linhart, 1967).

Various methods have been employed to estimate health and condition of wild mammals including: body weight (Windberg, 1991), kidney fat (Riney, 1955), and marrow fat (Neiland, 1970). Although these provide only a general index of physical condition, they are some of the best tools researchers have to measure condition in these populations. For coyotes, the best estimate of fat or lipid reserves is an index based on

the percentage of kidney fat and femur marrow fat (Huot, 1995). Lajeunesse (1993) also used marrow and kidney fat to estimate the condition of gray wolves (*Canis lupus*).

For this study, body weight, kidney fat, and marrow fat were used to assess nutritional condition. Body weight for each animal (either skinned or whole) was measured using a spring scale accurate to 0.5 kg. Body length (tip of nose to tip of last caudal vertebra) also was measured (nearest cm) to standardize the body weight based on body length (body weight/body length). The kidney fat index (KFI) was calculated by dividing the weight of the perirenal fat by the weight of the kidneys, and multiplying this ratio by 100 (Riney, 1955). Percent marrow fat was estimated by extracting marrow from the middle third of the femur, drying the marrow at 60^0C, and extracting all lipids using ether (Neiland, 1970).

The number of offspring produced by individual females was estimated by counting the number of placental scars present on the uterus (Bookhout, 1996). For certain analyses, coyotes were assigned as breeders or non-breeders. Breeders were females that had 1 or more placental scars; non-breeders were those females lacking scars.

To assess the prevalence of heartworms in domestic dogs, 37 veterinarians throughout the state of Illinois were asked to record the results of all heartworm tests performed in their respective clinic during a 3-week period in May, 1996. Veterinarians were asked to record the date the test was performed, breed and age of dog, test result, test type (antigen versus other), if the dog was on a prophylactic heartworm medication, and if so, what type.

Data were analyzed on a statewide and regional basis. State regions were defined as the 10 wildlife management regions of Illinois; each represents unique topography, climate and land use (Schwegmann, 1973). However, Region 6 was subdivided into two regions because it was disproportionately large (Fig. 1).

Heartworm and lungworm prevalence was determined for each region to assess spatial trends in parasite prevalence for both wild canids and domestic dogs. Arithmetic mean intensity and relative density were determined for each parasite species as described by Margolis (1982). Mean intensity is defined as the total number of individuals of a particular parasite species in a sample of a host species divided by the number of infected individuals of the host species in the sample. Relative density is defined as the total number of individuals of a particular parasite species in a sample of hosts divided by the total number of individuals of the host species (infected + uninfected) in the sample. Data were analyzed using the SAS statistical software package (SAS Inc., 1995). Fischer's exact test was used for statistical comparison of parasite prevalence between the wildlife management regions. Data published by Suloway, 1994 was used to correlate wetland availability with heartworm prevalence.

RESULTS AND DISCUSSION

Prevalence of Heartworms in Coyotes

Heartworms were recovered primarily from the right ventricle, its associated pulmonary artery, and to a lesser extent in the right atrium, vena cava, and jugular veins. Statewide, 17.8% of 1,150 coyotes, ranging in age from 0.5 to 13.5 years, were infected with adult heartworms. I assessed the relationship between heartworm prevalence and age using 5 age classes: juveniles (0.5 years), yearlings (1.5 years), 2.5 years, 3.5 years, and ≥4.5 years, under the hypothesis that older coyotes would have a higher prevalence of heartworms due to increased exposure to the parasite. Heartworm prevalence, in general, increased with age (Table 1). It was lowest among juveniles (8.6%) and highest among adults ≥4.5 years of age (51.3%), while yearlings, 2-year olds, and 3-year olds had a prevalence of 14.7%, 27.2% and 26.3% respectively (X^2=83.1; p=0.001).

The prevalence of heartworms was significantly higher in male coyotes (20.3%) then in females (15.7%) (X^2=4.065; p=0.044) (Table 2). Apparently, males were at a slightly higher risk of becoming infected with heartworms, possibly do to greater exposure to mosquitos. Male coyotes engage in more daily movements than females (Moore and Millar, 1984), which could result in increased exposure to mosquito bites.

Heartworm prevalence in coyotes throughout the United States has been demonstrated to vary geographically (Table 3). Generally, prevalence tends to be higher in mild southern climates and lower in northern states. For example, New Hampshire has the lowest reported prevalence (3.4%) of heartworms in coyotes (Agostine, 1982), while

71% of coyotes in Texas and Louisiana contained adult heartworms (Custer, 1981). Kick (1980) reported a prevalence of 21.8% among Illinois coyotes; however, his sample was collected primarily from the southern portion of the state.

Regional prevalence of heartworm varied significantly ($p<0.001$) throughout out the state (Table 4). The lowest prevalence (3.4%) was in Region 1, and the highest (40%), was in Region 9 (Figure 2). The age-structure of my sample did not differ significantly among regions ($X^2=17.3$; $p=0.067$), nor did sex ratios ($X^2=5.42$; $p=0.796$). Therefore, differences in the sex-age composition of the samples did not appear to influence regional differences in prevalence. The prevalence of heartworm in coyotes did not differ annually for any region ($p=0.12$-0.82).

The geographic distribution of *D. immitis* is influenced by at least 5 factors: (1) definitive host (coyotes and domestic dogs) densities, (2) distribution and density of the mosquito species that transmit heartworm, (3) the distribution and abundance of suitable habitat for mosquito vectors, (4) the length of the mosquito season, (5) and the seasonal patterns of hosts and mosquito vectors.

Numerous studies have been conducted during the past 30 years to determine which mosquitoes transmit the third larval stage of heartworm to canid hosts (Ludlam, 1970; Frimeth, 1983; Grieve, 1983; Russell, 1990, 1992; Scoles, 1993a, 1993b, 1994, 1995). The list of mosquitoes surveyed is still incomplete, but the primary genera that transmit *D. immitis* include *Aedes, Anopheles, Culex,* and *Psorophora*. Scoles (1994) reviewed several studies and created a table of 16 species of mosquitoes that were naturally infected with *D. immitis*.

To fully understand how mosquitoes contribute to heartworm disease, more thorough surveys of mosquito distribution and densities are needed. In addition, an inventory of mosquito habitat characteristics could prove useful. All mosquitoes need wetlands, ponds, puddles, or tree cavities for reproduction. When suitable temperatures for development occur in a region, mosquito densities most can be expected to increase with increases in these habitats. These data would allow managers and mosquito abatement districts to limit the densities of disease spreading species more efficiently.

Additional factors besides whether or not a mosquito species transmits heartworm larvae may influence the etiology of heartworm disease. Larvae in mosquitos do not develop well below 21° C, and larvae mortality occurs in mosquitos below 15.6°C (Otto, 1969). Because Illinois is a long state latitudinally, temperature variations may be important in understanding the regional differences in prevalence. The difference in heartworm prevalence between regions 6a (6.7%) and 6b (13.0%) support this hypothesis. Region 6 (Grand Prairie Region) is a vast plain formerly occupied primarily by tallgrass prairie. Topography is generally level to rolling and the forests are associated with the stream valleys and moraines (Schwegmann, 1973). Plant and animal communities are similar throughout the area. The most notable difference between regions 6a and 6b is the temperature difference between the northern and southern portions of this region.

To further assess the latitudinal trend in heartworm prevalence, I divided the state into 3 broad sections: north, central, and south (Fig. 3). Heartworm prevalence differed among the sections, being lowest (7.0%) in the north and highest in the south (29.7%),

and moderate in the central section (14.1%; X^2=21.2; p<0.001). The prevalence of heartworm in each of these sections was inversely correlated with the number of heating degree days (U.S. Bureau of the Census, 1994), defined as the number of days that the mean daily temperature is below 65°F (Fig. 4; r^2= -0.99871; p<0.033).

Since mosquito density may be correlated with availability of surface water for reproduction, I tested for and found a significant correlation between the percentage of wetlands in each region (Suloway, 1994)and heartworm prevalence in coyotes and domestic dogs (Fig. 5; r^2 = 0.61472; p<0.007).

The intensity of heartworms in individual coyotes varied from 1 to 111 worms with a mean intensity of 8.8 worms/infected heart. This was similar to the mean (8.1 worms/infected heart) reported in a previous Illinois study (Kick, 1980). Heartworm intensity differed among the 10 regions (F=3.65; p=0.0002) and among the 3 sections (F=12.19; p=0.001). The highest intensity was found in the southern portion of the state and the lowest in the north. Mean intensity has ranged in other studies from 3.8 in Tennessee to 25 in Texas (Custer, 1981, Van Den Bussche, 1987). The mean intensity of female heartworms (4.6) did not differ significantly from male heartworms (4.3; X^2=2.28; p>0.05). This re-enforces the observation that heartworms typically exist in a 1:1 ratio as reported by previous authors (Kick, 1980; Wienmann, 1980; Custer, 1981; Pappas, 1985).

The relative density of heartworms throughout Illinois was 1.4 worms/coyote. Female and male heartworms had similar relative densities: females = 0.76 worms/coyote and males = 0.70 worms/coyote (x^2=2.633; p>0.05). These data suggest that heartworms

are clearly endemic in Illinois. Heartworm infections in coyotes reflected a typical negative binomial curve indicating that most coyotes had low intensity infections, but a few had high intensity infections (Fig. 6).

Heartworm intensities do not differ significantly among age classes ($F=0.85$; $p=0.85$); juveniles averaged 7.0 heartworms/infected heart, yearlings averaged 8.1 heartworms/infected heart, and adults averaged 6.5 heartworms/infected heart. Mean heartworm intensity for male coyotes (9.2) was not statistically different from female coyotes (8.1; $F=0.37$; $p=0.546$).

Lungworm Prevalence in Coyotes

Lung parasites collected from coyotes included *Capillaria aerophila*, *Crenosoma vulpis*, *Paragonimus kellicotti*, and *Filaroides sp*. A stomach parasite, *Physaloptera rara*, also was found in the lung lavage, which may have resulted from contamination of the lavage by a portion of the esophagus still attached to the heart and lungs leading to a conservative estimate of prevalence. Of the 341 coyotes examined for lungworms, 58 (17%) were infected with *P. rara*, 52 (15.2%) were infected with *C. aerophila*, 10 (2.9%) were infected with *Fillaroides sp*., 8 (2.3%) were infected with *P. kellicotti*, and 2 (0.6%) were infected with *C. vulpis*. This is the first recorded collection any of these adult lung parasites in Illinois coyotes.

These parasites revealed different regional distribution patterns. *C. vulpis* was found only in 2 coyotes from region 9. *P. kellicotti* was limited in distribution to the south-eastern portion of Illinois. *P. rara*, *C. aerophila*, and *Fillaroides sp.* Were found statewide.

No age-related differences in the prevalence of lungworms were apparent (p=0.11-0.83), although we expected to find a higher prevalence of *C. aerophila* and *Fillaroides sp.* among juveniles. Parasites with direct life cycles such as these tend to infect juveniles at higher rates since pups live close together in dens. *F. osleri* can easily be passed from dog to dog during periods of oral contact such as the washing of the young or feeding (Ludwig, 1983).

Prevalence of Heartworm and Lungworms in Foxes

Forty-seven red foxes and 2 gray foxes were examined for heartworm during this study. Of these, heartworms were only recovered from in a single female red fox (2%). Previous studies of heartworm in gray foxes (Table 5) and red foxes (Table 6) have indicated a low prevalence of heartworms in both fox species. Previous studies in Illinois have reported low heartworm prevalence among foxes (Dyer, 1981; Dyer, 1982a; Kick, 1980).

Fifteen red foxes from 5 regions and 1 gray fox from Region 8 were examined for lungworms. Lungworms found in red foxes included *Capillaria aerophila* and *Crenosoma vulpis*. This is the first recorded collection of adult *C. vulpis* in Illinois red foxes. The stomach parasite, *Physaloptera rara*, also was recovered. No lung parasites were recovered from the single gray fox examined.

C. aerophila, the most prevalent species among foxes in my sample, occurred in 11 individuals (73.3%), much higher than previously reported in Illinois (31.0%) by Dyer, 1982. No regional differences in the prevalence of this species was found (x^2=3.733; p=0.443). All foxes infected with *C. aerophila* were juveniles. The prevalence of *C. aerophila* in other states has not been as high as in my study (Tables 5 &

6). This parasite was found in 0.06% in gray foxes and was absent in red foxes in Indiana (Davidson, 1992b). It was reported in 28% of gray foxes and 42% of red foxes in New York (Zeh, 1977). The method of recovering lungworms may account for some of the differences in prevalence among studies. Flushing lung parasites into a sieve may result in higher recovery rates and a higher prevalence.

Single infections of *C. vulpis* and *P. rara* each occurred in a single red fox. *C. vulpis* was previously recorded in both gray foxes (1.1%) and red foxes (21.3%) in New York (Zeh, 1977).

Prevalence of Heartworms in Domestic Dogs

The 37 veterinary clinics surveyed statewide performed 2,269 heartworm tests on domestic dogs during May 1996. Types of heartworm tests varied among veterinarians, but most (89.3%), used some form of antigen test. Other tests used less frequently were modified Knotts test (5.8%) and direct blood smears or direct filter tests (4.8%); all which looked for the presence of microfilaria in blood.

Overall, only 67/2,269 (3.0%) dogs tested positive for heartworms. However, 80.2% of the dogs surveyed were taking some type of prophylactic before testing. Dogs on a prophylactic program (n=1,807) had a significantly lower number of positive tests (0.4%) compared to dogs that were not receiving prophylactics (12.5%) (n=441) (X^2=193.7; p=0.001).

The heartworm prevalence we found in domestic dogs was similar to those reported in other Illinois studies (McKinney, 1962; Marquardt, 1966; Ward, 1974) (Table 7). These studies took place when heartworm prophylactics were uncommon and probably not used by pet owners. Additionally, the three previous studies occurred in

localized geographic areas in Illinois. Other studies on heartworm disease have indicated a prevalence as low as 0.002% in Colorado (Macy, 1991) and as high as 65.8% in Minnesota (Stromberg, 1995) in dogs not receiving any type of prophylactic treatment.

Dogs less than one year of age and dogs greater than ten years of age had the lowest prevalence of heartworms (Fig. 7). The highest prevalence occurred in 10 year olds. The prevalence of heartworm in untreated dogs differed among the 10 regions of Illinois demonstrating a regional trend (X^2=193.016, p=0.001; Table 8). Dogs in westcentral Illinois (Region 4) showed the lowest prevalence (0%) while those in southeastern Illinois (Region 9) showed the highest (31%; Fig. 8).

The regional prevalence of heartworms in domestic dog not receiving prophylactic treatment correlates quite well (r=0.80853; p=0.0151) with the prevalence of heartworms coyotes (Fig. 9). From this, one could conclude that coyotes and dogs show similar regional pattern of susceptibility to heartworm disease, and that each species serves as an important reservoir for heartworms.

Effect of Heartworms and Lungworms on Coyote Physical Condition

In order for a parasite to survive, it must extract nutritional energy from its host. One way to study a parasite's effect on an individual or population of parasite hosts is to examine the effects a parasite may have on the host physical condition and fat reserves (Munger, 1989).

The skinned weight of male coyote (mean = 11.5kg) was significantly greater than females (mean = 9.5kg) (F=271.74; p=0.0001) and adults were significantly heavier than juveniles (F=6.39;p=0.003). However, the body weights of coyotes infected with heartworms did not differ from those of uninfected coyotes, as no interactions between

sex-age class and heartworm infection were observed (F=0.56; p=0.64), nor was the body weight of infected individuals affected by heartworm intensity (F=0.43; p=0.7335). Standardized body weights (skinned weight/body length) were not significantly different between heartworm infected and uninfected individuals in the sex-age classes (F=0.35; p=0.79). Neither lungworms alone nor combined with a heartworm infection affected body weight (p=0.08-0.99) except for *C. aerophila*. Coyotes infected with *C. aerophila* (mean = 9.4 kg) weighed significantly less than uninfected coyotes (mean = 10.4kg; p=0.02).

Fur quality differed significantly between heartworm infected and uninfected coyotes (X^2=9.9741; p=0.041). Fifty-seven percent of uninfected coyotes had fur quality ratings of excellent or good, whereas only 40% of the heartworm infected coyotes had fur quality ratings this quality. Coyotes afflicted with mange did not have a significantly higher prevalence of heartworms than uninfected coyotes (x^2=1.275; p=0.259). The relationship of lungworms and mange was not examined due to small sample size.

Fat reserves vary seasonally in canids, typically peaking during the fall (Meech and Delgiudice, 1985). The first fat depot that responds to an increase in metabolic energy is bone marrow fat, followed by the fat around the kidney, intestines, and stomach. The last area for fat to be stored is over the back. As winter progresses, mobilization of fat occurs in the reverse order (Riney, 1955).

The majority (57.3%) of pelted coyotes were assigned visual fat scores of "moderate". In contrast, 32.2% of the sample showed "abundant" fat and 10.5% of the

coyotes were scored as having no fat. Neither infection with heartworms, lungworms, or heartworms and lungworms affected the visual fat score of coyotes. Visual fat scores did not vary in relation to heartworm intensity.

Neither kidney fat index ($F=0.56$; $p=0.4563$) nor % marrow fat ($F=0.08$; $p=0.7739$) differed between heartworm infected and heartworm uninfected coyotes. Uninfected coyotes had a mean KFI of 51% and mean % marrow fat of 87%. While infected coyotes had a mean KFI of 49% and a mean % marrow mass of 88%. Of heartworm infected coyotes, mean KFI ($F=0.92$; $p=0.4286$) and mean marrow fat ($F=1.01$; $p=0.3932$) did not differ in relation to heartworm intensity. The presence of any of the 5 types of lungworms did not reduce the KFI or marrow lipid analysis ($p=0.11$-0.96).

The presence of heartworms and/or lungworms does not seem to affect amount of fat storage by coyotes. These results do not support the hypothesis that these parasites alone lead to higher coyote mortality by reducing energy reserves.

Effect of Heartworms and Lungworms on Coyote Reproduction

Limited energy reserves may lead canids to postpone or reduce reproduction. Presumably, the energy savings of reducing reproduction enhances their survival through the winter so as to breed the next reproductive season (Stearns, 1992). Alternatively, the energetic costs of reproduction and lactation may reduce a female's resistance to parasites or pathogens. Festa-Bianchet (1989) found lactating ewes had more lungworm than non-lactating ewes. He demonstrated that this resulted from a decreased resistance during reproduction and lactation.

The proportion of females that bred in each age-class did not differ between heartworm infected and uninfected groups (X^2=1.933; p=0.164 for adults $\geq$ 2.5 years; X^2=0.085; p=0.771 for yearlings), nor between lungworm infected and uninfected groups (p=0.09-0.85). Adult female coyotes ($\geq$3.5 years) averaged 5.6 scars/breeding female, compared to 2.9 and 1.8 scars/ breeding female in 2-year-olds and yearlings, respectively. Age-specific reproductive rates did not differ significantly between infected and uninfected females (p=0.35), however infected females tended to have fewer placental scars (Fig. 10). Coyotes with a low heartworm burden (< 5 heartworms/heart) did not differ in mean number of placental scars from those with high heartworm burdens (> 15 heartworms/heart) (p=0.60-0.69). Reproductive rates were not affected by lungworm infections (p=0.09-0.85). In Illinois' coyotes, the presence of heartworms and/or lungworms does not appear to affect reproduction or fat indices.

MANAGEMENT IMPLICATIONS

Heartworm distribution in Illinois coyotes varies regionally, among age-classes, and between sexes. Foxes appear to be far less vulnerable to heartworm disease than coyotes. Heart and lung parasites do not appear to significantly impact the condition or reproduction in coyotes.

Coyotes and untreated domestic dogs have a high prevalence of heartworms, and prevalence is highly correlated between these 2 sympatric species, suggesting that each species serves as a potential reservoir of disease for the other. Heartworm prevalence correlates positively with the percentage of wetlands in a region, and negatively with the number of heating degree days. Four species of lung parasites, *Capillaria aerophila*, *Crenosoma vulpis*, *Paragonimus kellicotti*, *Fillaroides sp*. and one stomach parasite species *Physaloptera rara*, were found in Illinois' coyotes, but do not appear to affect the condition or reproductive success of infected individuals at the intensities recorded. Two species of lung parasites, *Capillaria aerophila* and *Crenosoma vulpis,* and a single stomach parasite species *Physaloptera rara,* were found in Illinois' red foxes.

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Table 1. Number of heartworm infected and uninfected coyotes in each age class.

	(Years)				
	0.5	1.5	2.5	3.5	>4.5
Heartworm Infected	44	28	37	10	28
Heartworm Uninfected	469	163	99	28	30
TOTAL	513	191	136	38	58

Table 2. Number of heartworm infected and uninfected coyotes by sex.

	Females	Males
Heartworm Infected	87	118
Heartworm Uninfected	467	463
TOTAL	554	581

Table 3. Prevalence of heartworm in coyotes according to various studies completed throughout the United States.

Citation	State	N	Prevalence
Agostine (1982)	New Hampshire	234	3.4%
Franson (1976)	Iowa	220	3.6%
Pappas (1985)	Nebraska	44	8.9%
Wixsom (1991)	Missouri	293	7.0%
Graham (1975)	Kansas	113	8.0%
Graham (1975)	Colorado	20	10.0%
Gregory (1998)	**Illinois**	**1,150**	**17.8%**
Kick (1980)	Illinois	472	21.8%
Thorton (1974)	Southern Texas	13	23.1%
Kazacos (1979)	Indiana	8	25.0%
Weinman (1980)	California	115	37.4%
Van Den Bussche (1987)	Tennessee	267	38.5%
Smith (1984)	Tennessee	55	40.0%
Holzman (1992)	Georgia	17	47.0%*
Custer (1981)	Texas and Louisiana	24	70.8%

*microfilaria positive

Table 4. Frequency of heartworm infection in coyotes for the wildlife management regions of Illinois.

	1	**2**	**3**	**4**	**5**	**6a**	**6b**	**7**	**8**	**9**
Heartworm Infected	3	4	6	5	4	11	36	11	90	34
Heartworm Uninfected	85	72	43	24	101	54	235	38	231	51
TOTAL	88	76	49	29	141	65	270	49	321	85

Table 5. Prevalence of heart, lung, and stomach parasites in gray foxes according to various studies completed throughout the United States.

	Citation	State	N	Prevalence
Dirofilaria immitis	Davidson (1992b)	Indiana	18	0.0%
	Gregory (1998)	**Illinois**	**2**	**0.0%**
	Wixsom (1992)	Missouri	70	0.0%
	Dyer (1982)	Illinois	267	1.1%
	Hubert (1980)	Illinois	136	2.2%
	Kick (1980)	Illinois	99	3.0%
Capillaria aerophila	**Gregory (1998)**	**Illinois**	**1**	**0.0%**
	Davidson (1992b)	Indiana	18	0.1%
	Dyer (1982a)	Illinois	543	11.0%
	Zeh (1977)	New York	89	28.0%
Fillaroides spp.	**Gregory (1998)**	**Illinois**	**1**	**0.0%**
Paragonimus kellicotti	Davidson (1992b)	Indiana	18	0.0%
	Gregory (1998)	**Illinois**	**1**	**0.0%**
	Davidson (1992a)	S.E., U.S.	57	0.01%
	Dyer (1984)	Illinois	543	1.2%
Physaloptera rara	**Gregory (1998)**	**Illinois**	**1**	**0.0%**
	Davidson (1992b)	Indiana	44	55.6%

Table 6. Prevalence of heart, lung, and stomach parasites in red foxes according to various studies completed throughout the Unites States.

	Citation	State	N	Prevalence
Dirofilaria immitis	**Gregory (1998)**	**Illinois**	**47**	**2.0%**
	Dyer (1981)	Illinois	145	3.4%
	Kick (1980)	Illinois	225	3.6%
	Pappas (1985)	Nebraska	21	4.8%
	Wixsom (1992)	Missouri	85	6.0%
	Davidson (1992b)	Ohio	28	21.4%
	Stuht (1972)	Michigan	39	28.2%
Capillaria aerophila	Davidson (1992b)	Ohio	44	0.0%
	Dyer (1982b)	Illinois	165	31.0%
	Zeh (1977)	New York	211	41.0%
	Gregory (1998)	**Illinois**	**15**	**73.3%**
Crenosoma vulpis	**Gregory (1998)**	**Illinois**	**15**	**15.0%**
	Zeh (1977)	New York	211	21.3%
Fillaroides spp.	**Gregory (1998)**	**Illinois**	**15**	**0.0%**
Paragonimus kellicotti	**Gregory (1998)**	**Illinois**	**15**	**0.0%**
	Davidson (1992b)	Ohio	44	2.0%
	Dyer (1984)	Illinois	165	2.4%
	Stuht (1972)	Michigan	39	10.3%
Physaloptera rara	**Gregory (1998)**	**Illinois**	**15**	**15.0%**
	Davidson (1992b)	Ohio	44	18.2%

Table 7. Prevalence of heartworm in domestic dogs according to various studies completed throughout the United States.

Citation	State	N	Prevalence
Macy (1991)	Colorado	1,012	0.002%
Knapp (1993)	Montana	3,490	0.007%
Stromburg (1995)	Minnesota	88,299	0.19%
Foreyt (1991)	Washington	601	0.5%
Stromburg (1995)	Minnesota	61,493	0.82%
Stromburg (1995)	Minnesota	67,156	1.39%
McKinney (1962)	Illinois	212	1.4%
Pyle (1978)	Colorado	?	1.8%
Gregory (1998)	**Illinois**	**2,269**	**3.0%**
Ward (1974)	Illinois	>100	3.0%
Njaka (1980)	West Virginia	100	3.0%
Stromburg (1995)	Nebraska	2,598	3.3%
Pratt (1981)	Missouri	22,414	3.8%
Alls (1974)	Iowa	385	6.5%
Butts (1979)	North Carolina	1,332	10.1%
Marquardt (1966)	Illinois	331	19.3%
Utroska (1979)	Tennessee	231	24.7%
Stromburg (1995)	Minnesota	1,378	65.8%

Table 8. Frequency of heartworm infection in domestic dogs for the wildlife management regions of Illinois.

	2	**3**	**4**	**5**	**6a**	**6b**	**7**	**8**	**9**	**10**
Heartworm Infected	2	1	0	2	0	8	13	14	5	7
Heartworm Uninfected	48	15	4	23	53	79	87	39	11	19
TOTAL	50	16	4	25	53	87	100	53	16	26

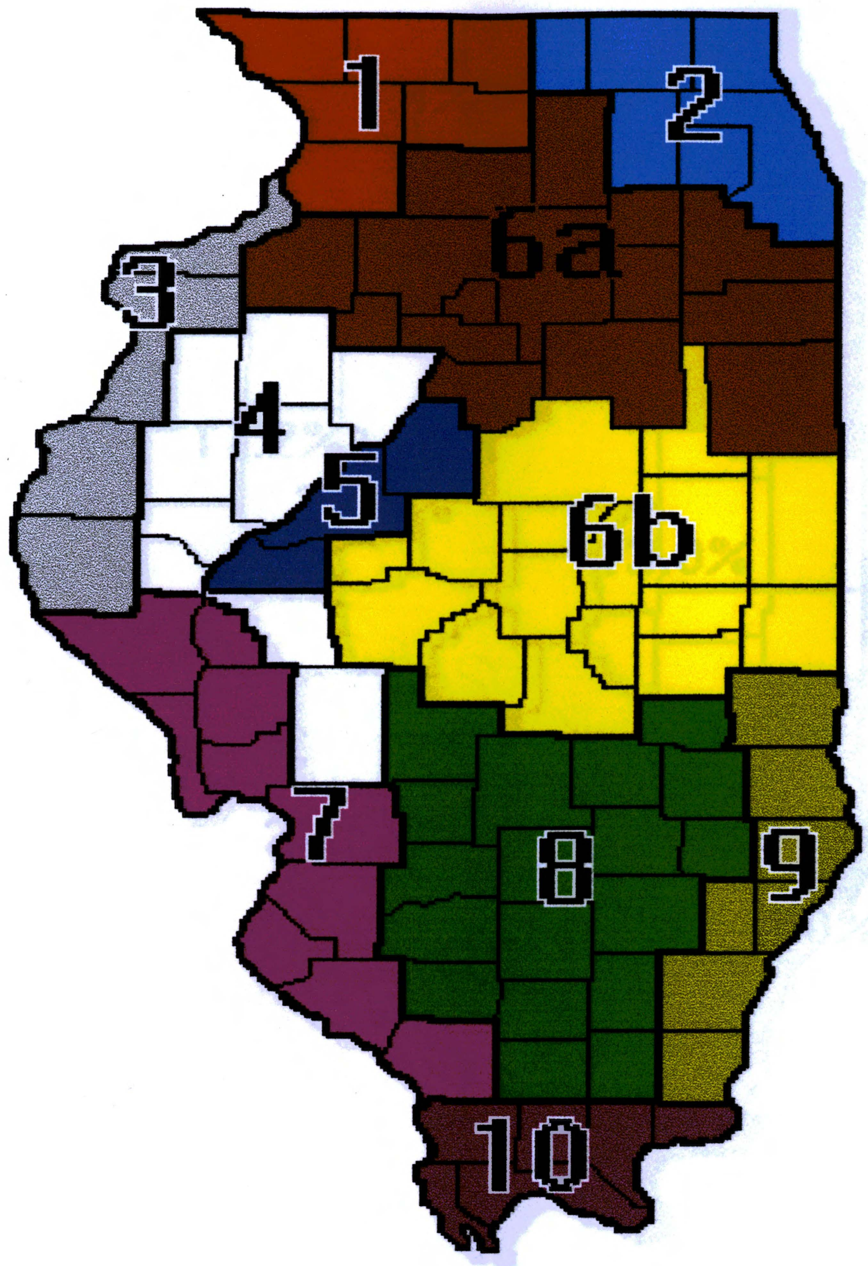

Figure 1. Modified Illinois wildlife management regions of Illinois using political boundaries based upon criteria set by Schwegmann, 1973.

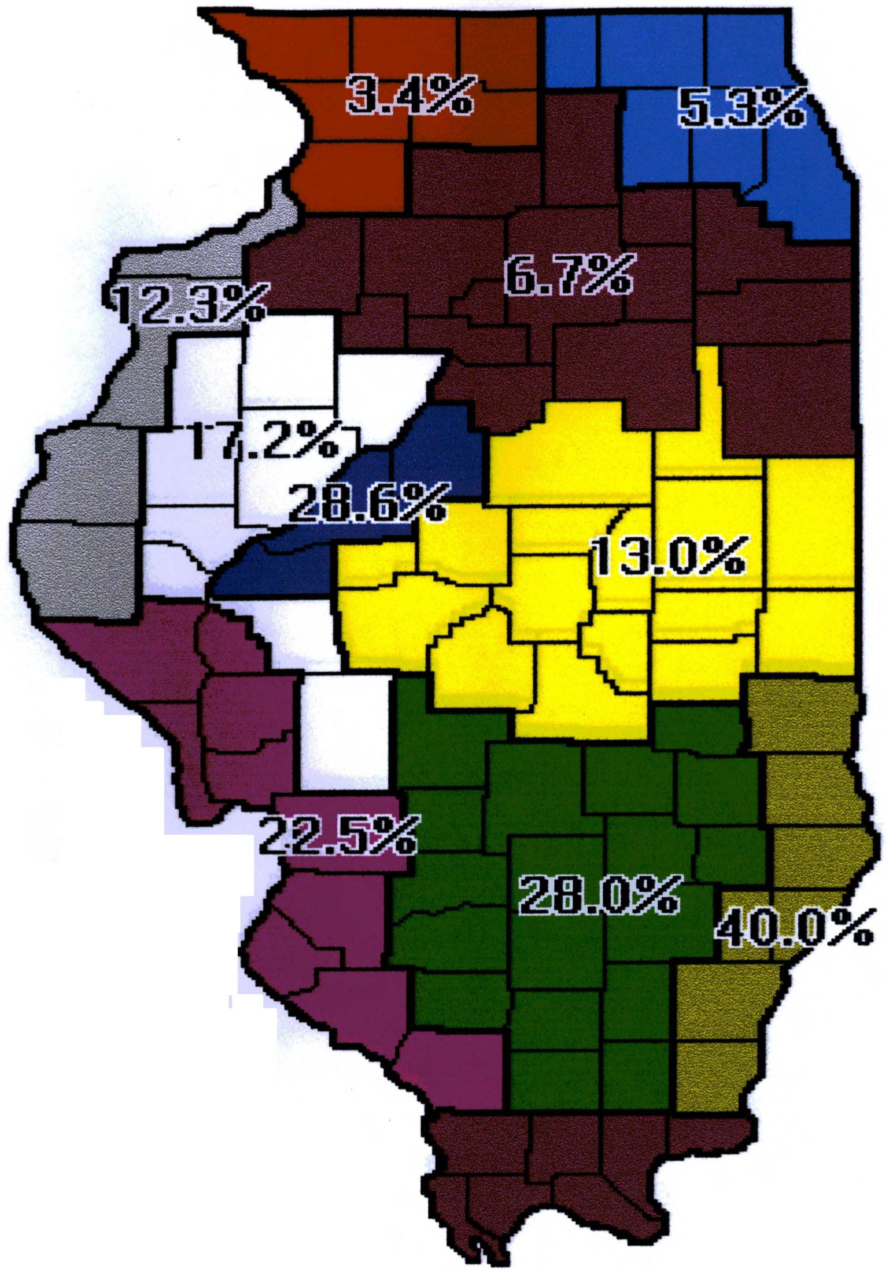

Figure 2. Regional prevalence of heartworm in Illinois coyotes.

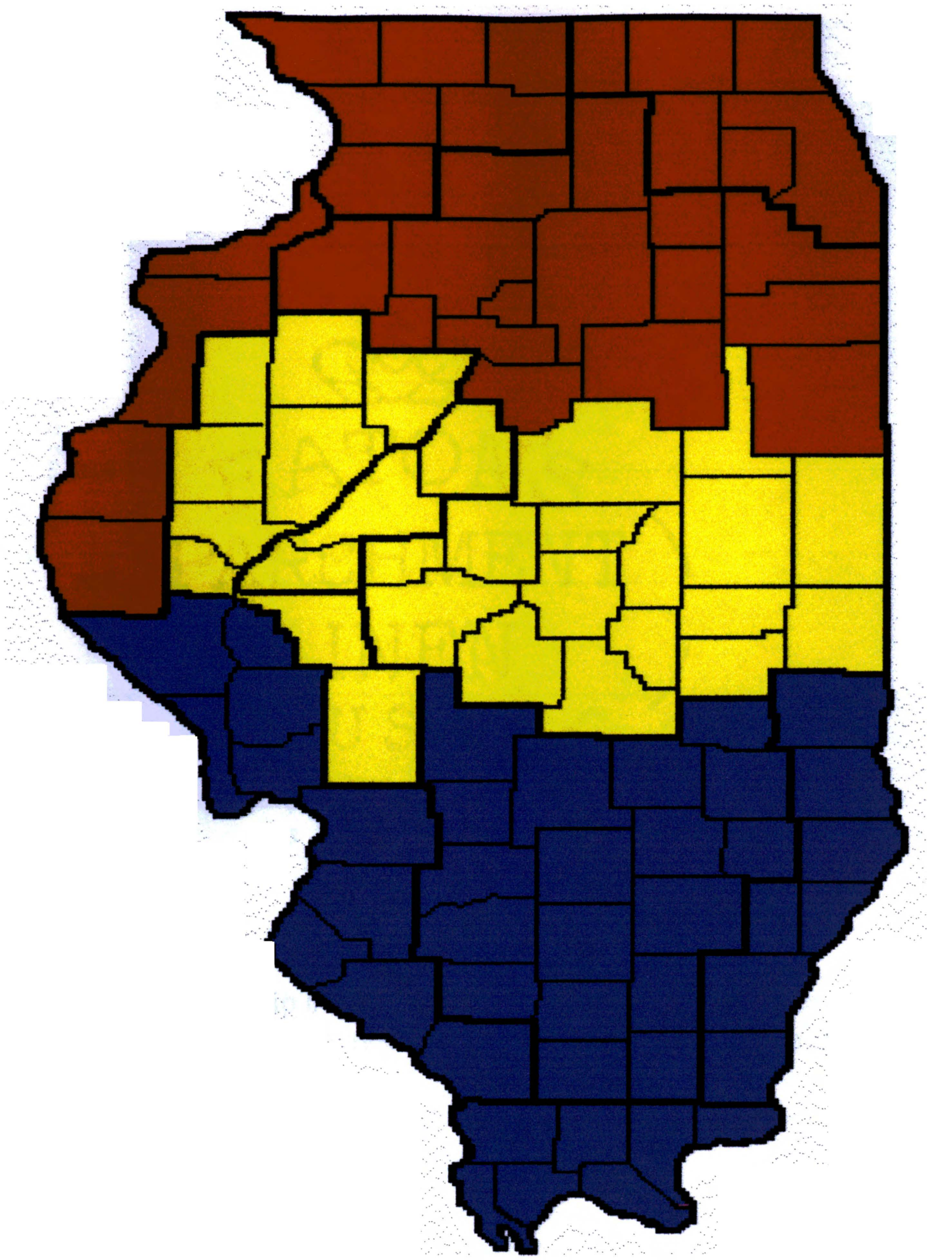

Figure 3. Three general geographic sections (north, central, south) of Illinois used to determine latitudinal influence of heartworm prevalence in coyotes.

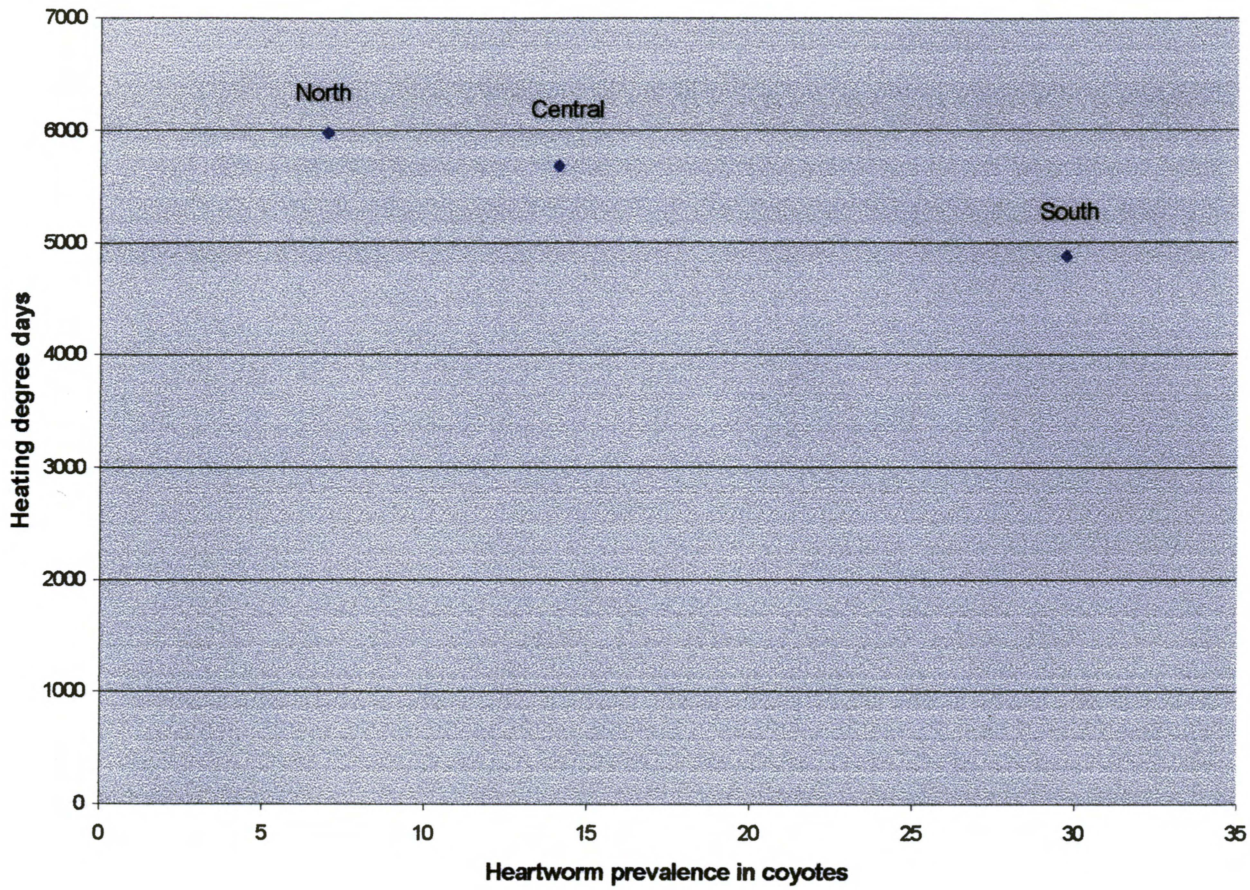

Figure 4. Relationship between the prevalence of heartworm in coyotes and the number of heating degree days (number of days that the mean daily temperature is below 65°F) in each latitudinal area.

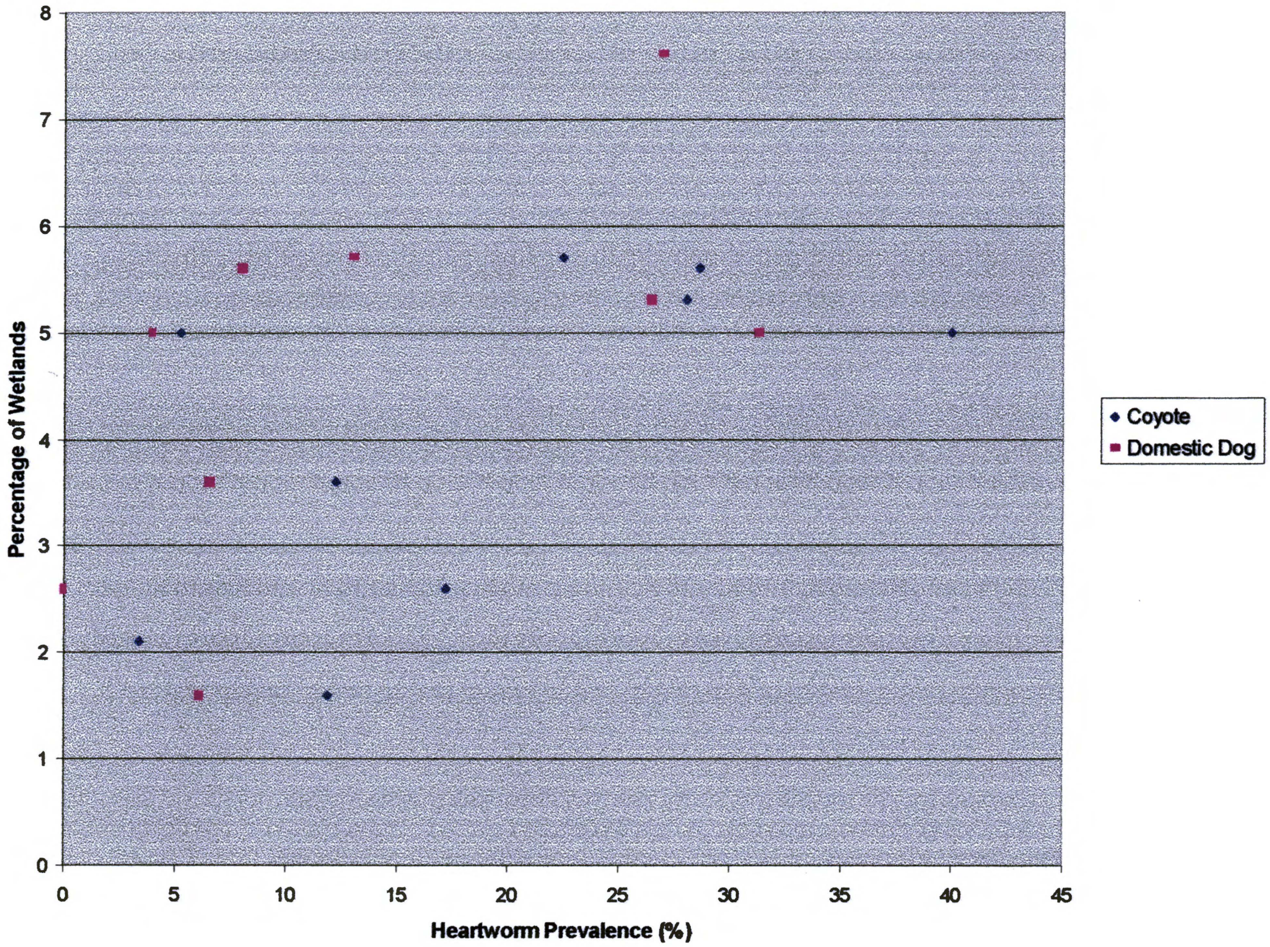

Figure 5. Relationship between the prevalence of heartworm in coyotes and domestic dogs with the percentage of wetlands in each wildlife management region in Illinois.

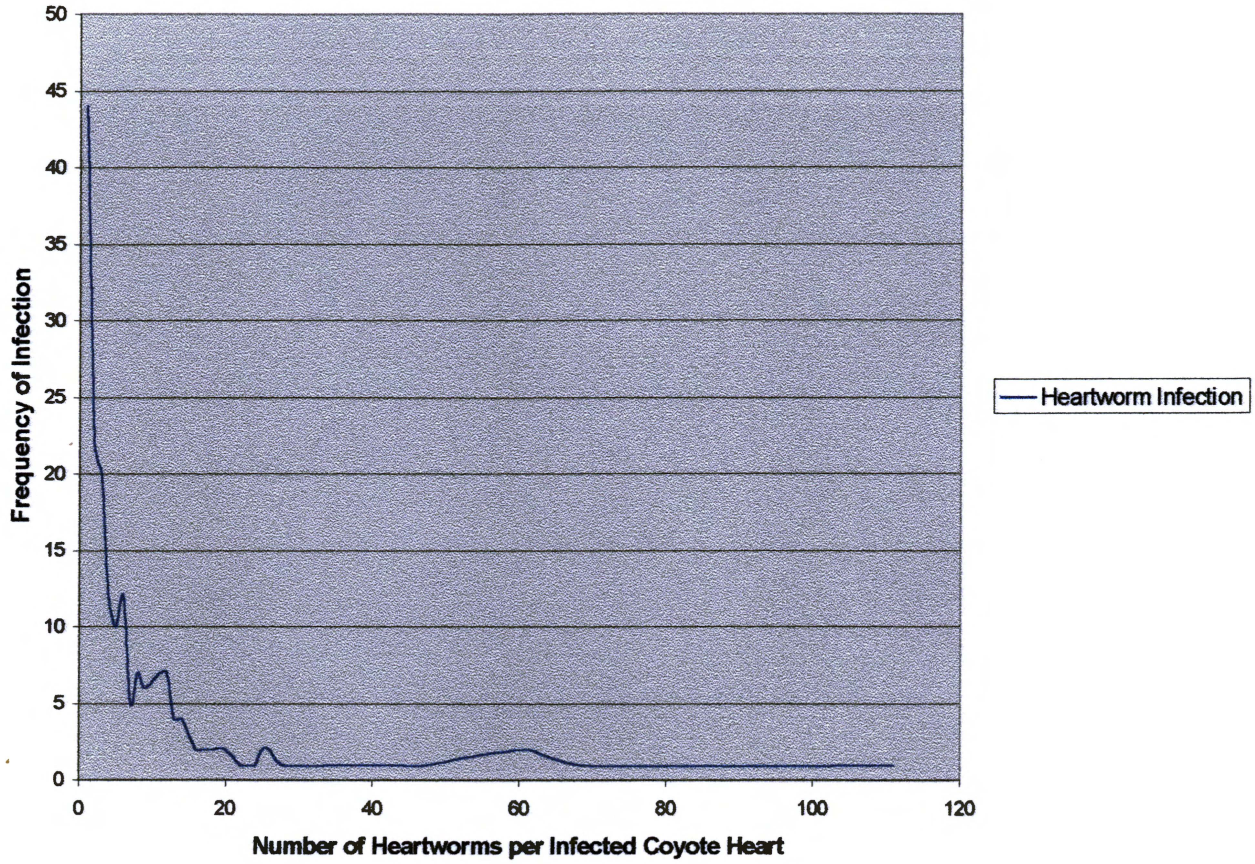

Figure 6. Negative binomial curve demonstrating the relationship between parasite intensity and parasite relative density.

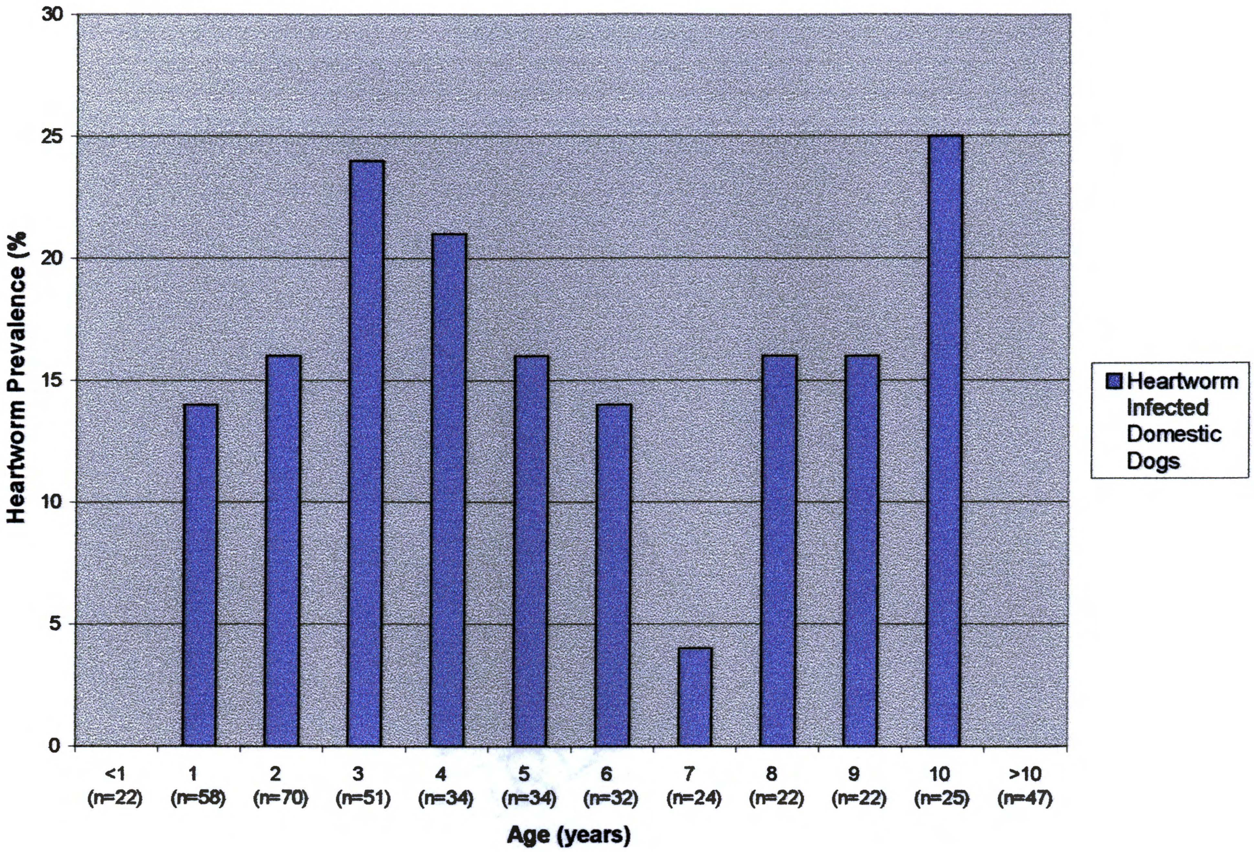

Figure 7. Prevalence of heartworms in each age class for Illinois domestic dogs not receiving prophylactics.

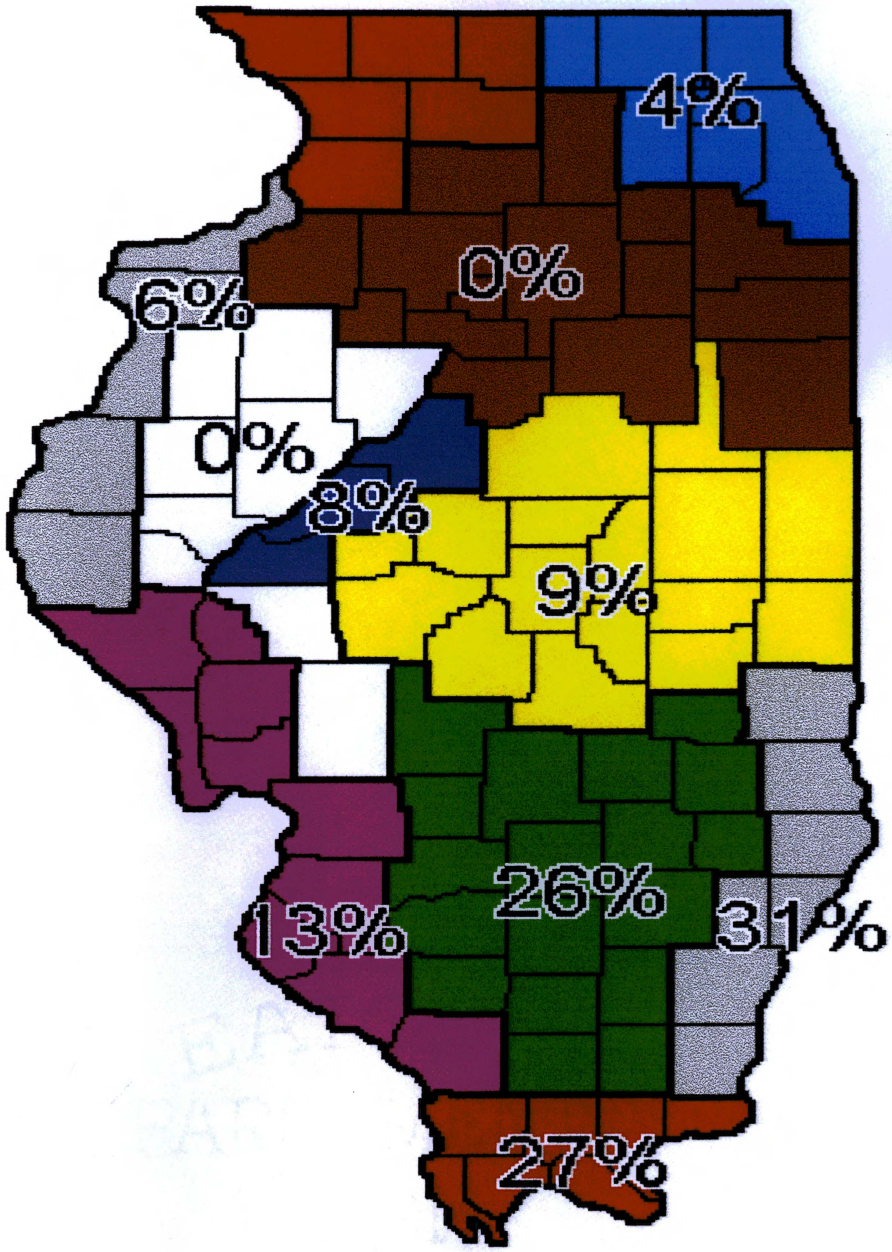

Figure 8. Regional prevalence of heartworm in Illinois domestic dogs not receiving prophylactics prior to testing in May 1996.

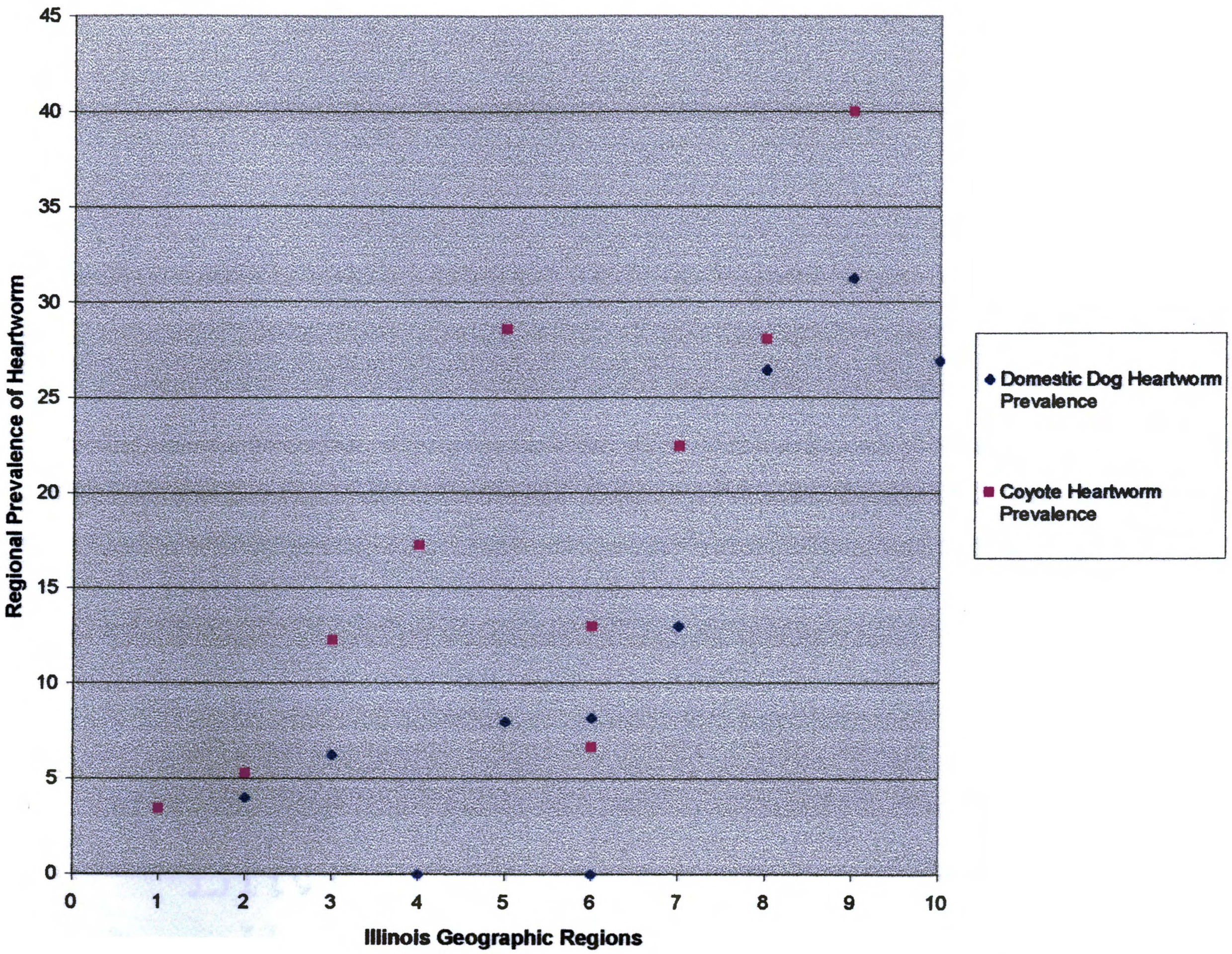

Figure 9. Correlation (r=0.80853; p=0.0151) between the regional prevalence of heartworm in Illinois domestic dogs and Illinois coyotes.

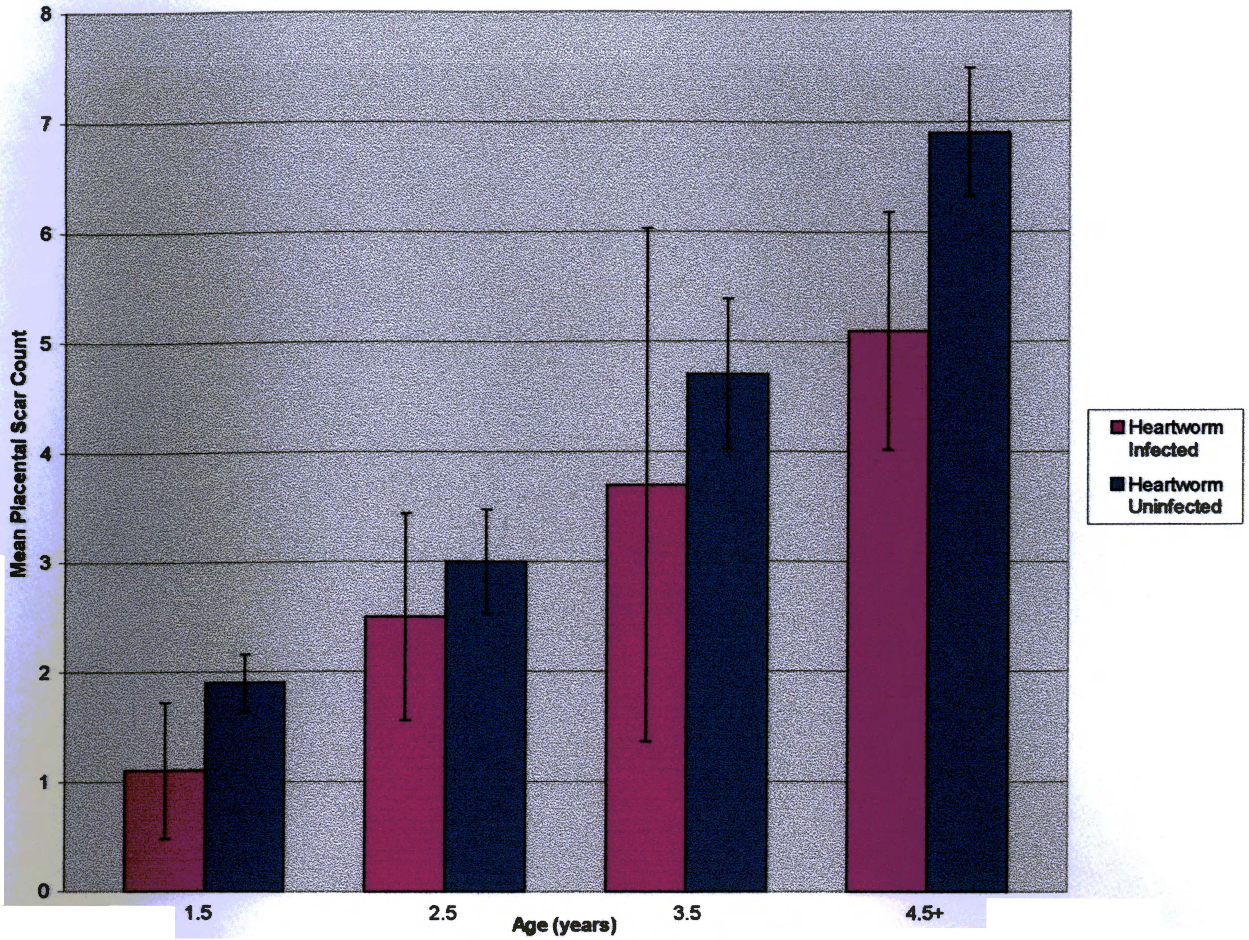

Figure 10. Relationship between the presence of heartworms and the reproductive status of Illinois coyotes.