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Dirofilaria immitis in the Wild Canids of Illinois

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Dirofilaria immitis in the Wild Canids of Illinois

(TITLE)

BY

Thomas J. Kick
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THESIS

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Dirofilaria immitis in the
Wild Canids of Illinois

by

Thomas J. Kick

a candidate for the degree of Master of Science
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Abstract: The heartworm, Dirofilaria immitis, is widespread in dogs in North America and has been reported in wild canids in many states. This is a report of this parasite in hearts removed from coyote, red fox and gray fox carcasses collected in Illinois. A total of 415 coyotes had a significantly higher infection rate (23.6%) than 225 red foxes (3.6%) and 99 gray foxes (3.0%). Infection rates in red foxes and coyotes were significantly higher in or near the Wabash Border Natural Division along the eastern side of the state, suggesting a relationship between infection rates and this region. The mean number of worms in coyotes (8.1), red foxes (6.8) and gray foxes (1.3) did not differ significantly. Coyotes supported a maximum of 52 worms; red foxes, 21 worms; and gray foxes, 2 worms. An exponential decrease in the number of infected coyotes was noted as worm loads increased; 56.5% of 85 infections consisted of one to four worms, while only 16.5% of the infections had 15 or more worms. The percentage of the coyote sample with the potential to provide microfilariae to vectors (13.1%), based on the presence of both male and female worms, was significantly greater than the same parameter for both red foxes (1.3%) and gray foxes (1.0%).

INTRODUCTION

The wide distribution (Otto 1969a) and pathologic effects (Winter 1959, Kotani et al 1975) of the heartworm (Dirofilaria immitis) in the domestic dog has stimulated studies of the relationship of this parasite with the coyote (Canis latrans),

red fox (Vulpes fulva) and gray fox (Urocyon cinereoargenteus) in the United States. Overall, past surveys on wild canids have suggested a decrease in the incidence of D. immitis with increasing latitude (Monson et al 1973, Crowell et al 1978), as well as an increase in incidence within states during recent years (Gier and Ameel 1959, Graham 1975).

The earliest report of heartworms in wild canids from the southern states revealed no infections in 50 foxes from Georgia (Walton et al 1963). A more recent study, conducted in a highly enzootic area of Louisiana, yielded infection rates of 58% for 71 coyotes, 16% for 31 red foxes and 10% for 20 gray foxes (Crowell et al 1978). The Southwest has been poorly represented in heartworm studies; one study, involving 13 Texas coyotes, revealed an infection rate of 23.1% (Thornton et al 1974). No data have been published on heartworms in wild canids from states west of the Rocky mountains.

Incidence of heartworms among the wild canids from the north-central and north-western states were generally the lowest in the country, although areas of high infection have been reported. One such area in Michigan had an infection rate of 28% in 39 red foxes (Stuht and Youatt 1972). More typically, infection rates ranged from 0% to 5%. This pattern is reflected in two recent studies, one in Minnesota, in which 4.3% of 92 red and gray foxes were infected (Schlotthauer 1964), and the other in New York, where 3.9% of 51 coyotes, 0.4% of 551 red foxes and 0% of 179 gray foxes had heartworms (Monson et al 1973).

Midwestern surveys were almost exclusively directed toward

coyotes. Infection rates varied, yet were generally between the reported rates for the northern and southern states. Recent infection rates calculated for reasonably large samples ranged from 3.6% for 220 Iowa coyotes (Franson et al 1976) to 8.0% for 133 coyotes from Kansas and eastern Colorado (Graham 1975).

Heartworms have not been reported in wild canids in Illinois; however, four studies have been conducted on the incidence of this parasite in Illinois dogs. An infection rate of 1.4% in 212 dogs from Champaign County was reported in 1962 (McKinney 1962). Marquardt and Fabian (1966) subsequently found 29.1% of 331 dogs infected, statewide. Todd and Mark (1974) reported the parasite to be in dogs from every county of the state. They found an overall infection rate of 10%, and a maximum incidence of 32.6% in the southern counties. Jaskowski and Akande (1977) also reported a widespread distribution of this parasite, as well as a 7% infection rate in 55 dogs from the northeastern part of the state. This is a report of a survey to determine the incidence and distribution of D. immitis among coyotes, red foxes and gray foxes in Illinois.

MATERIALS and METHODS

Licensed furbuyers were contacted prior to the 1977-1978 and 1978-1979 fur hunting and trapping seasons and asked to hold skinned carcasses for this study. Carcasses of coyotes, red foxes and gray foxes, purchased by these cooperators, were stored under ambient conditions until we could pick them up

and remove the heart and short portions of attached blood vessels. In some cases, hearts were not saved after being examined for heartworms. Most hearts were placed in plastic bags and frozen. Data recorded with each heart included: accesion number, species, sex, collector, kill location and date.

Kill locations were recorded by county when possible. Furbuyers purchasing large numbers of whole animals did not record each kill location but instead expressed carcass origins as being within a radius encompassing their market area. All kill locations were mapped and data were analyzed on the basis of regional concentrations of each species collected.

All worms removed from frozen hearts were preserved in 70% ethanol with 4% glycerine and labeled with the accesion number and collection data. Worms were counted, cleared in lactophenol, and then identified and sexed using a 150X compound light microscope and criteria in Yorke and Maplestone (1969). Heartworms from each species of host were submitted to the National Parasite Museum, Beltsville, Maryland. Specimens from Canis latrans are catalogued as 75856, those from Vulpes fulva as 75548 and 75549 and those from Urocyon cinereoargenteus as 75550.

The nonparametric binomial test was used when comparing infection probabilities, chi-square for sex ratios and Student's t-test for means (Daniel 1977).

RESULTS

Carcasses from 739 wild canids were collected for heartworm

analysis. As shown in table 1, carcasses were obtained from 19 counties in five of the Natural Divisions of Illinois. Those carcasses received from commercial furbuyers (Fig. 1) did not necessarily come from the same county, since the buyers often had extensive market areas. The nine furbuyers (Table 2) had a mean buying radius of 69.3 km.

Worms were removed from the right side of intact hearts and from the pulmonary artery. Occasionally, worms were found in the thoracic cavity, but only when the heart had ruptured. All worms were identified as the heartworm, Dirofilaria immitis, except for one worm recovered from the heart of a female coyote from the Richland County furhouse. This worm, a male spirurid tentatively identified as the genus Chlamydonema, was in association with nine heartworms.

Coyote: A total of 415 coyotes (43.9% male, 40.0% female and 16.1% sex unknown) were examined for heartworms during two consecutive fur seasons, 1977-1979 (Table 1). The heartworm infection rate was 23.6%, as shown in table 3; there was not a significant difference ($P>.05$) in infection rates for the two years. The percentage of coyotes infected from the Bond-Marion County sample (15.2%) was significantly lower than either the Coles-Edgar-Moultrie County sample (28.9%, $P<.01$) or the Clay-Jasper-Richland County Sample (26.8%, $P<.05$) (Table 3).

An average of 8.1 worms was recovered from infected coyote hearts (Table 3), with a standard error of 1.1 and a range of 1 to 52 worms. The number of infected coyotes, when grouped and plotted according to increasing parasite loads (Fig. 2), resulted in a negative binomial curve, characterized by a

Table 1. Locations of canid carcasses collected for heartworm analysis during 1977-1978* and 1978-1979 fur seasons in Illinois.

Natural Division**	County	Coyote	Red Fox	Gray Fox	Total
Rock River Hill Country	Carroll	1	-	-	1
Middle Mississippi Border	Hancock	2	-	-	2
	Henderson	6	-	-	6
	Mercer	1	-	-	1
Grand Prairie	Bureau	2	-	-	2
	DeKalb	2	80	-	82
	Ford	3	21	-	24
	LaSalle	1	-	-	1
	Lee	1	-	-	1
	Livingston	1	-	-	1
	Coles	1-1	2	1	1-4
	Edgar	69	29	15	113
	Moultrie	5	25	3	33
Southern Till Plain	Clay	35-54	-	-	35-54
	Jasper	8	11	9	28
	Richland	29-87	8	-	29-95
	Bond	39-35	33	46	39-114
	Marion	31	16	25	72
Shawnee Hills	Pope	1	-	-	1
Total by Year		104-311	225	99	104-635
Two Year Total		415	225	99	739

*Single numbers represent 1978-79 carcasses. Paired numbers represent 1977-78 and 1978-79 carcasses respectively.

**Schwegman 1973

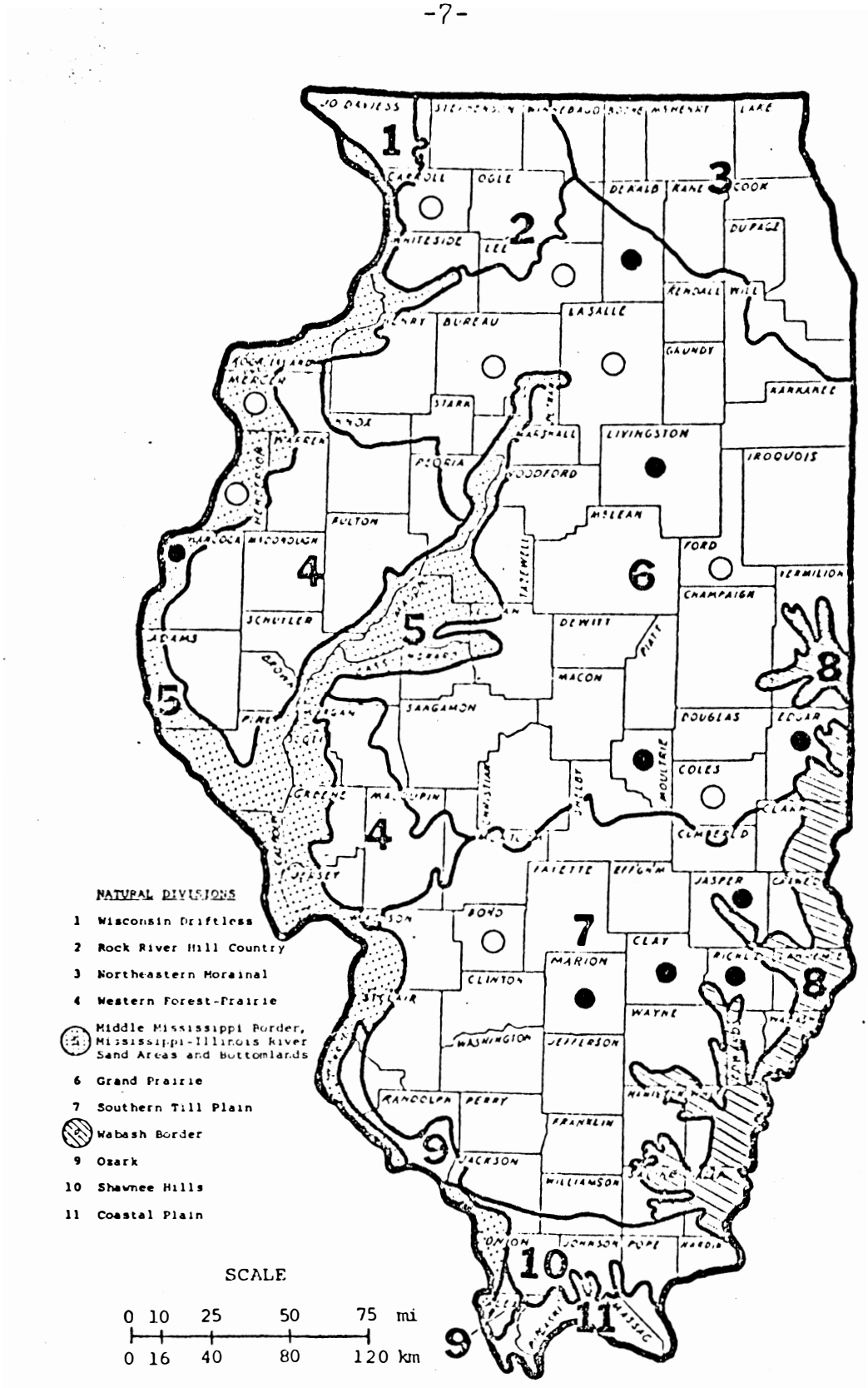

Figure 1. Locations of furbuyers (solid circles) and known collection points (open circles) from which coyote, red fox and gray fox carcasses were obtained for heartworm analysis.

Table 2. Market areas for commercial furbuyers from which wild canid carcasses were obtained for heartworm analysis.

County	Town/City	Collection Radius
Hancock	Nauvoo	80 km
DeKalb	Waterman	80 km
Livingston	Cornell	80 km
Edgar	Paris	80 km
Moultrie	Lovington	24 km
Clay	Hord	100 km
Jasper	Hidalgo	32 km
Richland	Noble	100 km
Marion	Centralia	48 km

Table 3. Characteristics of *D. immitis* infections in coyotes from selected county areas in Illinois .

	Coyote				Heartworm			
	Heartworm Incidence		Sample with both ♂ and ♀ Heartworms		Recovered		Sex ratio	
County Area	N	%	N	%	N	X̄/host	N	M:F
Coles-Edgar-Moultrie Co.	76	28.9	76	15.8	120	5.5	113	1:1.6
Clay-Jasper-Richland Co.	213	26.8	149	16.0	473	9.7	436	1:1.1
Bond-Marion Co.	105	15.2	66	7.6	91	8.3	78	1:1.3
Statewide	415	23.6	312	13.1	691	8.1	631	1:1.2

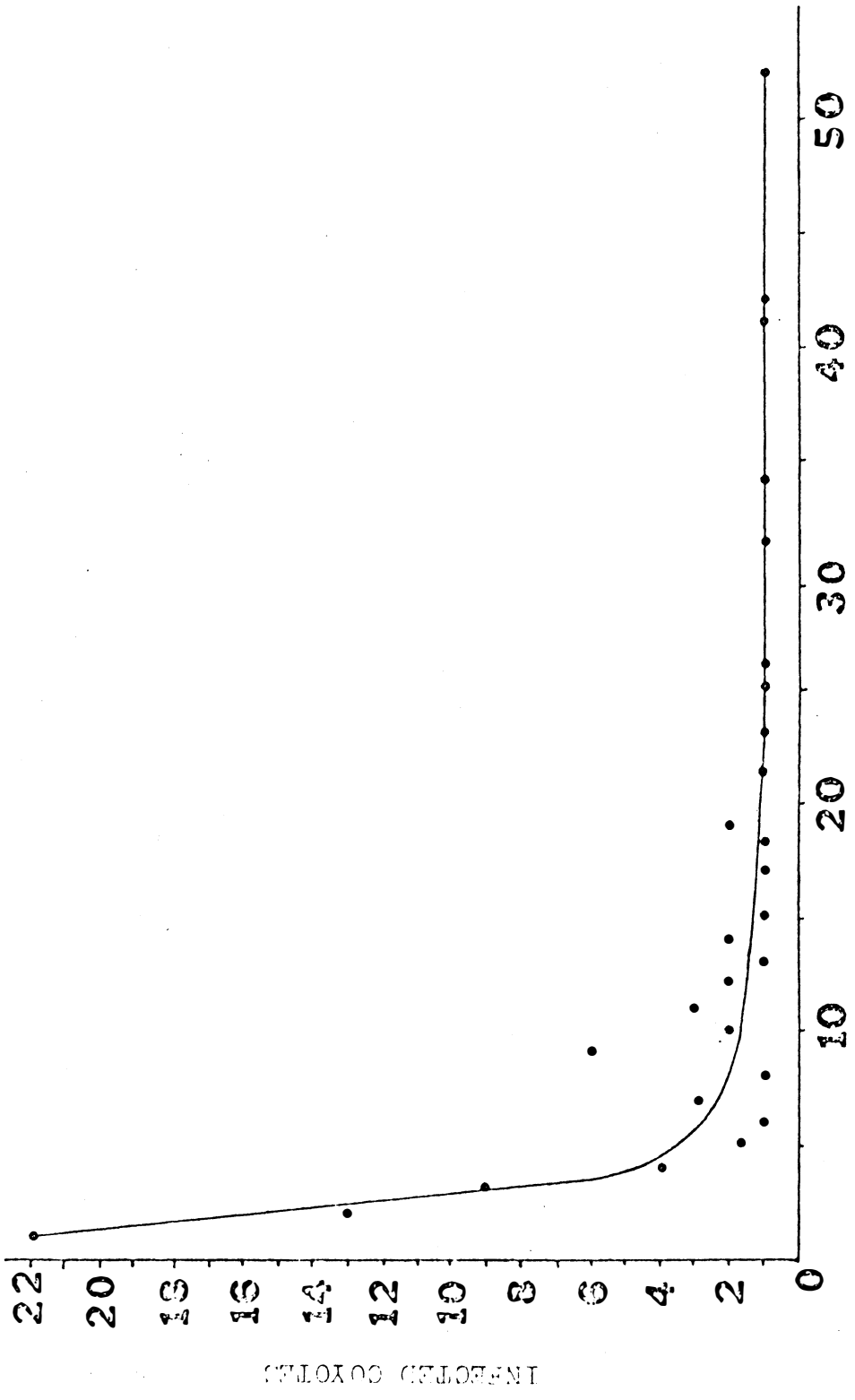

Figure 2. Relationship between number of heartworms and infected coyotes (N=85) collected in the winters of 1977-1979.

rapid reduction in host frequency as the parasite load increased. Worm loads of one to four worms represented 56.5% of the 85 infections for which worms were saved, while 27.0% of the infections contained five to 14 worms. Fifteen or more worms were found in 16.5% of the infections, with 8.2% of the infections consisting of 25 to 52 worms.

Heartworm sex ratios (males:females) ranged from 1:1.1 for the Clay-Edgar-Richland County area to 1:1.6 for the Coles-Edgar-Moultrie County area, with a statewide sex ratio of 1:1.2 (Table 3). The Coles-Edgar-Moultrie County area and the state as a whole had significantly more female worms in the heart than the hypothesized 1:1 sex ratio ($X^2_{.05,1df}=5.53$ and $X^2_{.05,1df}=5.90$, respectively). Based on the presence of at least one male and one female worm in the heart, 13.1% of all coyotes had the potential to provide microfilariae to vectors (Table 3). The percentage of the Bond-Marion County sample with the potential to produce microfilariae (7.6%) was significantly lower than either the Coles-Edgar-Moultrie County sample (15.8%, $P<.05$) or the Clay-Jasper-Richland County sample (16.0%, $P<.05$) (Table 3).

Red Fox: A total of 225 red fox carcasses (51.1% male and 48.9% female) examined for heartworms had an infection rate of 3.6% (Table 4). The infection rate for the Coles-Edgar-Moultrie County sample (10.7%) was significantly higher than either the DeKalb-Ford County sample (0.0%, $P=0$) or the Bond-Marion County sample (2.0%, $P<.05$).

The number of worms per infected heart (Table 4) ranged from 1 to 21, with a mean of 6.8 and a standard error of 2.7.

Table 4. Characteristics of *D. immitis* infections in red foxes from selected county areas in Illinois.

	Coyote				Heartworm			
	Heartworm Incidence		Sample with both ♂ and ♀ Heartworms		Recovered		Sex ratio	
County Area	N	%	N	%	N	$\bar{X}$/host	N	M:F
Coles-Edgar-Moultrie Co.	56	10.7	56	5.4	51	8.3	48	1:1.1
Clay-Jasper-Richland Co.	19	5.3	19	0.4	1	1.0	1	0:1
Bond-Marion Co.	49	2.0	49	0.0	2	2.0	2	2:0
DeKalb-Ford Co.	101	0.0	101	0.0	0	0.0	0	0:0
Statewide	225	3.6	225	1.3	54	6.8	51	1:1

Heartworms removed from red foxes reflected a 1:1 sex ratio, as shown in table 4. Statewide, 1.3% of all red foxes examined had the potential to provide microfilariae to vectors (Table 4).

Gray Fox: Ninety-nine gray fox carcasses (45.5% male, 50.5% female and 4.0% sex unknown) were examined; 3.0% were infected (Table 5). Differences in infection rates in the three areas of concentration were not significant (P>.05).

The mean number of worms per infected heart (Table 5) was 1.3, with a standard error of 0.33 and a range of 1 to 2 worms. Statewide, 1.0% of the sample of gray foxes had the potential to provide microfilariae to vectors.

Interspecies Relationships: Comparisons of the three canids (Tables 3,4,5) showed that coyotes had a significantly greater rate of infection (23.6%) than either the red fox (3.6%, P=0) or the gray fox (3.0%, P=0). There was not, however, a significant difference (P>.05) in the mean number of worms per heart in coyotes (8.1), red foxes (6.8) or gray foxes (1.3) or in the occurrence of worms in males or females. Furthermore, a significantly greater percentage of coyotes (13.1%) had both male and female heartworms, that is to say, the potential to provide microfilariae, than the red fox (1.3%, P=0) or the gray fox (1.0%, P=0).

DISCUSSION

The heartworm infection rate in Illinois coyotes (23.6%, Table 3) was higher than that reported among coyotes from Texas (23.1%) (Thornton et al 1974), Kansas (0.6%) (Gier and Ameel 1959) (8.0%) (Graham 1975), Colorado (10.0%) (Graham

Table 5. Characteristics of *D. immitis* infections in gray foxes from selected county areas in Illinois.

	Gray Fox				Heartworm			
	Heartworm Incidence		Sample with both ♂ and ♀ Heartworms		Recovered		Sex ratio	
County Area	N	%	N	%	N	$\bar{X}$/host	N	M:F
Coles-Edgar-Moultrie Co.	19	5.3	19	0.0	1	1.0	1	0:1
Jasper Co.	9	11.1	9	11.1	2	2.0	2	1:1
Bond-Marion Co.	71	1.4	71	0.0	1	1.0	0	0:0
Statewide	99	3.0	99	1.0	4	1.3	3	1:2

1975), Nebraska (11.1%) (Gier et al 1977), Iowa (3.6%) (Franson et al 1976), Minnesota (0%) (Erickson 1944) and New York (3.9%) (Monson et al 1973). A higher incidence than Illinois has been reported from only two states; Kazacos (1977) found the one coyote he examined to Indiana to be infected and Crowell et al (1978) reported an infection rate of 58% among 71 coyotes from Louisiana.

The statewide infection rate among Illinois coyotes also exceeded infection rates in Illinois dogs. Marquardt and Fabian (1966) found 19.3% of 331 dogs infected, although they believed their statewide sampling technique was not random. However, 55 of those dogs from the southern part of the state were randomly collected and had an incidence of 29.1% which exceeds both state and regional infection rates for coyotes from the present study. Differences in infection rates for these two species in Illinois cannot be critically compared since the surveys were not conducted at the same time. However, variations could be expected due to preventive measures employed by dog owners, differences in habitats and perhaps most importantly, the different detection methods used to reveal the presence of this parasite. Since the statewide infection rate for dogs was determined by finding microfilariae in the blood, it is possible that unisexual heartworm infections may have gone undetected. Streitel et al (1977) reported that 13 of 24 infected dogs from Ohio did not exhibit microfilaremia, mainly due to only one sex of the worm being present. The infection rate among coyotes from this study is based upon

finding worms in the heart, not microfilariae. Since microfilariae checks were not made in this study, the percentage of animals with microfilariae is unknown; however, both male and female worms were recovered from 13.1% of 312 coyotes, indicating that this percentage of the sample had the potential to provide microfilariae. It is possible that a host may have both sexes of heartworms present, yet microfilariae may not be found if all worms of one sex or the other are immature. Conversely, microfilariae may be detected when only one sex of the heartworm has been recovered; death and absorption may occur to worms of the opposite sex or worms in other locations may be present, yet go undetected during necropsy. However, data published by Streitel et al (1977) suggests that these two apparently incongruous situations occur at about the same rate. These workers detected no microfilariae in two of 10 (20%) dogs with both sexes of heartworms present, while three of 14 (21.4%) dogs with unisexual infections, exhibited microfilaremia. In spite of these variations, there is a striking similarity between the statewide percentage of coyotes with the potential to produce microfilariae (13.1%, based on finding worms of both sexes, Table 3) and the statewide percentage of infected dogs reported by Todd and Mark (1974) (10%, based on finding microfilariae). These data suggest that dogs and coyotes share comparable roles as potential sources of microfilariae for the transmission of heartworm disease in Illinois. It should be noted, though, that the distribution of the dog sample and the coyote sample were not the same and, as shown in table 3, significant differences in infection

rates exist within the state. In contrast, only 1.3% of the red fox sample (Table 4) and 1.0% of the gray fox sample (Table 5) had the potential to provide microfilariae. The roles these two species play in the transmission of heartworms in Illinois, appear to be insignificant when compared to dogs and coyotes.

Significant differences in infection rates were observed not only between the Grand Prairie and Southern Till Plain, but also within these two natural divisions (Tables 3,4). No distinct physiographic differences were observed which might account for the differences in infection rates. However, it is interesting to note that the Wabash Border Division (Fig. 1) includes much of Edgar County as well as portions of Clay, Jasper and Richland County and these counties were within the market areas which yielded significantly higher infection rates found among both coyotes and red foxes. Furthermore, market areas for Edgar County and Richland County (Table 2) suggest that animals were received not only from the Grand Prairie, Southern Till Plain and Wabash Border Divisions but also from adjoining areas in Indiana. It is possible that conditions in the Wabash Border Division of Illinois and Indiana are more conducive to the development and transmission of heartworm disease than any other major physiographic region.

The relationship between infected coyotes and the number of parasites occupying the hearts of those animals was illustrated graphically. Figure 2 shows that 56.5% of the infected coyotes had worm loads of one to four worms, 83.5% had worm loads of less than 15 worms and, at the other extreme, only

8.2% harbored 25 or more worms per heart. A similar relationship was observed among 24 infected dogs (Streitel et al 1977). Data published by these workers show 83.3% of the dogs had four worms or less, 95.8% had six worms or less and the remaining 4.2% (one dog) had 19 worms. Three possible mechanisms may be responsible for these observations between the heartworm and the host.

First, an immune reaction could explain the observation that few coyotes from this study (16.5%) harbored 15 or more worms. As suggested by Otto (1969b), a partial immune reaction may exist in response to a current or recent infection, and act by fending off at least some of the developing larvae from subsequent exposures. In line with these ideas, an occasional heavy parasite load would probably correspond to frequent exposures over a short period of time and prior to the establishment of a reaction by the host.

Secondly, the relatively low percentage of coyotes with large worm loads suggests that animals which were heavily parasitized had a lower chance of survival. Although naturally occuring infections among dogs are usually not greater than 50 worms, worm loads of over 100 worms have been reported (Otto 1969a, Giles and Hildebrandt 1973); Jackson (1969) found one infection of 512 worms. However, the maximum published worm load which I could find for the coyote was 58 worms (Crowell et al 1978). The absence of large worm loads among coyotes, coupled with the fact that heartworm disease changes observed in both the coyote and red fox do not appear as severe as those observed in dogs, suggests that wild canids with more

severe symptoms may die in the field and therefore, never appear in a sample (Gier and Ameel 1959, Stuht and Youatt 1972, Crowell et al 1978).

The third and final explanation for the shape of figure 2 lies not in the coyote's response to the parasite, but instead in the probability of being bitten by an infected mosquito. Within the context of this explanation, figure 2 reflects the negative binomial curve (Bliss and Fisher 1953). Simply stated, the negative binomial describes a relationship between two events, one of which decreases exponentially as the other increases arithmetically. Applying this concept to figure 2, the probability of being bitten repeatedly, and therefore acquiring more and more worms (reflected in the number of animals in each worm load category), decreases at an exponential rate as the worm load increases arithmetically.

Infection rates for both red and gray foxes can generally be reported as being less than 5% (Erickson 1944, Walton et al 1963, Schlotthauer 1964, Miller and Harkema 1968-red fox only, Monson et al 1973). Infection rates in red foxes (3.6%, Table 4) and gray foxes (3.0%, Table 5) from this study concur with these previously published findings. Higher infection rates have been reported for both fox species. Stuht and Youatt (1972) found an infection rate of 28.2% in 39 Michigan red foxes. Crowell et al (1978) reported an incidence of 16.1% in 31 red foxes and 10% in 20 gray foxes from Louisiana. Miller and Harkema (1968) also reported a generally higher incidence (11.8%) in 17 gray foxes from North and South Carolina. In addition, Kazacos (1977) found one of four (25%) gray foxes

and two of seven (28.6%) red foxes infected in Indiana.

Mean and maximum worm loads reported in the literature varied considerably for each of the three wild canid species. The two parameters for coyotes ($\bar{x}$=8.1, Table 3; maximum 52, Fig. 2), red foxes ($\bar{x}$=6.8, Table 4; maximum 21) and gray foxes ($\bar{x}$=1.33, Table 5; maximum 2) fell within the range of reported values, except that a higher mean for red foxes was reported for this study than had been reported from any previously published study.

Heartworms recovered from 85 coyotes, 8 red foxes and 3 gray foxes did not differ significantly from a 1:1 (male:female) sex ratio except that among coyotes, both the Coles-Edgar-Moultrie County sample and the state as a whole had significantly more female worms (Table 3). Two other surveys have yielded significantly greater numbers of female worms: Graham (1975) reported 20 male worms and 9 female worms from 11 Kansas-Colorado coyotes (1:1.95, $X^2_{.05,\ ldf}$=6.12, my calculation) and Crowell et al (1978) recovered 65 male worms and 135 female worms from 41 Louisiana coyotes (1:2.1, $X^2_{.05,ldf}$=24.50, my calculation). It is not known if significantly fewer male worms reflect a true sex ratio other than a 1:1 for this parasite or if this difference is an indication of a shorter life expectancy, or a greater mobility by the male worm, resulting in more female worms being recovered.

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LITERATURE REVIEW

Dirofilaria immitis, the heartworm, occurs in a wide variety of wild and domestic animals, as well as humans; however, dogs are the most frequently reported hosts. (Dayal and Neafie 1975, Otto 1975). This parasite is worldwide in distribution, but has most often been reported in temperate climates.

Dirofilaria immitis was first described by Leidy, in 1856 (Levine 1968). More recent descriptions are outlined in Yorke and Maplestone (1929), Yamaguti (1961) and Levine (1968). Reviews of the life history are contained in Orihel (1961) and Levine (1968).

Because of the prevalence of heartworms in domestic dogs and the severe effects that often accompany infections, a myriad of literature concerning the geographic distribution of this parasite, host-parasite interactions, vectors, detection, pathology and treatment of D. immitis has been published.

Numerous surveys have been conducted to determine the geographic range of D. immitis in North America. An apparent increase in the range of the heartworm has been observed during the last 20 years (Anon. 1970, Kazacos 1978). A very substantial list of heartworm surveys among dogs has been compiled by Marquardt and Fabian (1966). A supplement to this earlier review is presented in table 1.

Factors bearing on the susceptibility of dogs to D. immitis are complex. The availibility of the mosquito vector to the host is instrumental in this regard. Dogs which were not

Table 1. Summary of studies on the prevalence of *D. immitis* in dogs in the United States as a supplement to Marquardt and Fabian (1966).

Locality			
South			
Ft. Stewart, GA	61	67	Walton et al 1963
North East			
Western New York	100	2*	Sengbusch et al 1975
Central New York	--	1	Todaro et al 1977
S.W. Connecticut	539	3.2	Tritch et al 1973
Maryland	102	44	Mallack et al 1971
Greensboro, NC	105	19.05	Wilkerson 1976
N.W. Ohio	274	5.1	Rabalais and Votava 1972
N.W. Ohio	160	3.75	Rabalais et al 1978
North and West Central			
Tippecanoe Co., IN	112	15.2	Kazacos 1978
Illinois	55	7	Jaskowski & Akande 1977
Illinois	--	10	Todd and Mark 1974
Detroit, MI	248	1.6	Zydeck et al 1970
S.E. Mich.-Belleville	880	22	Prouty 1972
S.E. Mich.-Detroit	399	6	Same
S.E. Mich.-Farmington	698	6	Same
Kansas	288	16.7	Graham 1974
South West			
South Texas	522	19.7	Keegan et al 1968
Taylor Co., Texas	700	5	Joiner and Jardine 1970
West Coast			
N. California	800	1*	McGreevy et al 1974

*based on finding adults

**number found

housed indoors or in screened kennels, were infected significantly more often than those with physical protection (Graham 1974, Christensen 1977). Several intrinsic characteristics of dogs have been tested to determine their roles in the susceptibility of these hosts to heartworm disease. Host color (Prouty 1972) and hair length (Brotn 1939, Lindsey 1961) were not found to affect infection rates. Boxers were infected more often than other breeds (Wallenstein and Tibola 1960). It is uncertain if a correlation exists between the sex of the host and susceptibility. Wallenstein and Tibola (1960) and Prouty (1972) found that male dogs were infected more often than female dogs; however, Lindsey (1961) and Graham (1974) found no significant differences in infection rates based on the sex of the host.

Immunity to infection by D. immitis has not been demonstrated conclusively. Arguments presented by Otto (1969) and Todd and Mark (1974) indicate that this parasite may elicit an immune response in dogs.

Although stable flies (Phillips 1939), as well as fleas (Brown 1939, Stueben 1954), have implicated, the mosquito has generally been recognized as the primary vector of heartworm disease. Bemrick and Sandholm (1966) and Ludlam et al (1970) have published lists of mosquito species in which complete larval development of D. immitis has been reported. Mosquitoes of the genus Aedes, Anopheles and Culex are the primary vectors of this disease. Aedes canadensis and A. excrucians are thought to be important vectors in the eastern and northeastern areas

of the United States (Arnott and Edman 1978, Magnarelli 1978). Christensen and Andrews (1976) reported Aedes trivittatus as a major vector in central Iowa while Culex pipiens quinquefasciatus is believed to be instrumental in the transmission of heartworms in southern Louisiana (Villavaso and Steelman 1970).

The presence of microfilariae in the blood of the dog usually indicates a present or recent infection by adult worms; however, it has been shown that microfilariae can pass across the placenta of the bitch to her pups, in which case microfilariae will be present in the pups with no adult worms being present (Mantovani and Jackson 1966). It has also been demonstrated that all microfilariae present in the host do not circulate simultaneously (Pacheco 1974). Within a single host, daily and annual variations in microfilaria levels occur. On a daily basis, the highest microfilaria levels occur in the late afternoon to early evening (Church et al 1976). On a yearly cycle, July and August have been shown to yield the highest counts of microfilariae (Aoki 1971). Three popular techniques for the detection and isolation of microfilariae are, in their order of efficiency, (1) hemofiltration, (2) centrifuging hemolyzed blood and (3) the blood smear examination. The advantages and disadvantages of these three techniques, as well as others, have been discussed by Dennis and Kean (1971) and Stein and Lawton (1973).

The effects produced by D. immitis in dogs may vary. When infections occur in the right side of the heart and its closely associated blood vessels, right ventricular dilation and hypertrophy may be observed (Rawlings and Lewis 1977, Kazacos

1978). Pulmonary arterial damage by rupture (Giles and Hildebrandt 1973) or partial blockage of the pulmonary artery resulting in pulmonary distress and fatigue (Kazacos 1978, Todd and Mark 1974) have also been reported. Often there are respiratory problems ranging from a nonproductive chest cough to emphysema (Winter 1959, Bengis 1976). Secondary to heart and lung complications, damage can occur to the liver (Morgan 1969, Kazacos 1978) and kidneys (Dalton et al 1971, Simpson et al 1974).

D. immitis has been recovered from locations within the host, other than the heart. Eberhard et al (1977) reported and reviewed the presence of heartworms as they occur in the eye of the dog. Worms have also been recovered from the brains of several dogs (Kotani et al 1975) and the brain of a cat (Mandelker and Brutus 1971), with symptoms ranging from depression and dullness to convulsions and blindness. Hind limb paralysis in a dog has also been observed, resulting from the obstruction of the femoral arteries (Slonka et al 1977).

Two methods of heartworm treatment have been developed. The first, involves the surgical removal of the parasite. Various techniques for approaching the worms by surgery are given by Jackson (1969), but until a reliable method to determine the magnitude of infection can be devised, surgery will be difficult to accurately prescribe. The second method is chemotherapy. Todd and Mark (1974) have outlined a general procedure for chemically eliminating the parasite from dogs. Instrumental to chemotherapy is an effective vermicidal agent.

Thiacetarsamide, an arsenic compound, has been widely used against the adult worm. After the adult worms have been irradicated, elimination of microfilariae can be accomplished by Fenthion, (Garlick 1971), Dithiazanine (Bengis 1976) or Mebendazole (McCall and Crouthamel 1976). When the dog is free of both adult worms and microfilariae, prophylaxis should begin and continue throughout the mosquito season. Diethylcarbamazine citrate, taken orally on a daily basis, is an effective prophylactic agent against reinvasion by this parasite (Fowler et al 1970, Bengis 1976).

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