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Increasing Prevalence of Canine Heartworm in Coyotes from California

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ABSTRACT: Thirty-seven subadult and adult coyotes (*Canis latrans*), collected August 1992 through December 1996 from a coastal foothill area in northern California (USA), were examined for adult heartworm (*Dirofilaria immitis*). During 1992 through 1993, at the end of a 6 yr drought, none of four coyotes examined were infected with heartworms. However, during 1994 through 1996, after the drought had ended, prevalences were 91% in 23 adult coyotes and 40% in 10 subadult coyotes. Heartworm intensity did not differ by sex of coyote, and averaged (±SE) 19.4 ± 3.8 among adults; one subadult had >238 heartworms. The prevalence and intensity of heartworm infection in coyotes reported here for 1994 through 1996 are the highest reported anywhere in the United States.

Key words: *Canis latrans*, coyote, *Dirofilaria immitis*, heartworm, survey.

The range of canine heartworm (*Dirofilaria immitis*) in dogs in the United States has been expanding outward from its core in the mesic southeast for several decades (Otto, 1972). Canine heartworm is a filarial nematode with a 6 mo life cycle that requires both mosquito and canid hosts (Courtney, 1989). Earlier studies in the plains states suggested that heartworm infection was rare in coyotes relative to dogs, making the coyote an unlikely reservoir (Gier, 1968; Franson et al., 1976; Graham, 1975). However, later studies in the southeastern United States (Crowell et al., 1978; Custer and Pence, 1981) and California (Weinmann and Garcia, 1980; Acevedo and Theis, 1982) found prevalences of heartworm in coyotes to be at least as high as in dogs, indicating that coyotes constituted an important reservoir for heartworm in those areas.

Heartworm infection was not commonly found in dogs (or presumably coyotes) in northern California until the 1970's, when the prevalence reportedly increased substantially (Weinmann and Garcia, 1980). Since then, the rate of infection has varied; heartworm prevalence in dogs declined steadily throughout a drought beginning in the late 1980's (Theis et al., 1996). Infection rate also has varied geographically; the Sierra-Nevada foothills showed a significantly higher prevalence of heartworm in both coyotes (Acevedo and Theis, 1982) and dogs (Theis et al., 1996) than other regions of the state such as the coastal foothills. The western tree-hole mosquito (*Aedes sierrensis*), which is thought to be the primary vector for heartworm in northern California, is abundant in both the Sierra-Nevada and coastal foothills (Weinmann and Garcia, 1974). It is possible that heartworm had not become fully established in the coastal foothills when the aforementioned studies were conducted. As part of a larger investigation of coyote behavioral ecology and predation of sheep (Sacks, 1996), I surveyed for adult heartworms in coyotes collected from a coastal foothill site over a 4.5 yr period (1992–96) beginning at the end of a 6 yr drought.

This study was conducted at the University of California's Hopland Research and Extension Center (HREC) (39°00′N, 123°05′W). The HREC encompasses 2,168 ha of north-coastal mountains and is situated approximately 65 km inland in the Russian River drainage, with elevations ranging from 150 m to 900 m. Oak (*Quercus* spp.) woodland, annual grassland, mixed evergreen-deciduous forest, and chaparral vegetation types dominate the landscape; Murphy and Heady (1983) provide a detailed description of plant communities at HREC. The climate is characterized by hot, dry summers and mild, wet winters. Average annual precipitation is about 100 cm and falls mostly as rain,

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between November and February (Murphy and Heady, 1983). Average temperature is 21 C in summer and 7 C in winter, with summer temperatures frequently reaching over 38 C (Murphy and Heady, 1983).

Coyotes removed from HREC and vicinity (≤10 km) by specialists (United States Department of Agriculture/Animal-Plant Health Inspection Service/Animal Damage Control, Fort Collins, Colorado, USA) or shepherds August 1992 through December 1996 (n = 34) were examined, in addition to three coyotes that died of natural causes including one each due to predation by a mountain lion (*Felis concolor*) and another coyote, and one of an unknown cause. No carcasses were collected 13 March 1993 to 13 August 1994. Ages of coyotes were determined by counting the cementum annuli of sectioned lower canines (Matson Laboratory, Milltown, Montana, USA). Coyotes at HREC are usually whelped between mid-March and mid-April (Sacks, 1996); to estimate ages, all coyotes were assumed to be whelped on 1 April. Six- to 12-mo-old coyotes were considered subadults and coyotes ≥12-mo-old were considered adults. The occurrence of adult heartworm in coyotes was determined primarily by inspection of the internal surfaces of the right ventricle and pulmonary artery; remaining chambers of the heart and associated blood vessels were also examined. Fisher exact tests (Zar, 1984) were used to detect differences in heartworm prevalence in adult coyotes between 1992–93 (August through March) and 1994–95 (August through July), and between 1994–95 and 1995–96 (August through December). Significance was set at $P \leq 0.05$ for analyses.

Heartworms were counted in infected coyote hearts. Heartworms were fixed in a solution of 20 parts 70% ethyl alcohol and one part glycerin at 62 C, and stored in the same solution (Orihel, 1961). Because coyotes were sometimes found several days after death, some heartworms were partly decomposed. In such cases, it was not always possible to determine exactly the numbers present and intensity was estimated as follows: the ratio of the volume of unidentifiable nematode tissue to countable (intact or pieced-together) individuals from the same heart was multiplied by, and the product added to, the number of countable nematodes; most of the heartworms were countable ($\bar{x}$ ± SD = 84 ± 13% of the total number estimated). Intensity was compared between years and between coyote sexes using Mann-Whitney U-tests (Zar, 1984). Voucher specimens were deposited in the U.S. National Parasite Collection (Animal Parasitology Institute, Beltsville, Maryland, USA; accession number 87091).

TABLE 1. Prevalence and intensity of infection by adult *Dirofilaria immitis* in 37 coyotes from Hopland Research and Extension Center and vicinity (≤10 km), California, August 1992 through December 1996.

Period	Age[a]	Prevalence % (n[b])	Intensity ($\bar{x}$ ± SE number/infection)
1992–93	subadult	0 (1)	—
	adult	0 (3)	—
1994–95	subadult	38 (8)	—[c]
	adult	90 (10)	21.4 ± 6.1[c]
1995–96	subadult	50 (2)	>238[d]
	adult	92 (13)	18 ± 4.9[c]

[a] Subadults are <1-yr-old and adults are ≥1-yr-old.
[b] Number of coyotes examined.
[c] Five hearts were inadvertently discarded after determining presence/absence, before nematodes could be counted; these included all three infected hearts from the 1994–95 subadult sample and one infected heart from each of the 1994–95 and 1995–96 adult samples. The remaining 20 infected hearts were used to determine intensity of infection.
[d] Only heartworms in good condition (n = 238) were counted in this particular heart; based on the volume of unidentifiable fragments, the total number was probably closer to 300.

Hearts of 37 adult and subadult coyotes were examined (Table 1). Prevalence of heartworm infection in 1994–95 (90%) was significantly higher ($P < 0.01$) than in 1992–93 (0%) in adult coyotes, although the sample size in 1992–93 was small (n = 3). There was no difference ($P > 0.5$) between the adult infection rate in 1994–95

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and 1995–96 (92%). Sample sizes of subadult coyotes were too small in 1992–93 and 1995–96 for between-year comparisons of heartworm prevalence; in 1994–95, prevalence in subadults was 38%. Heartworm intensity did not differ between 1994–95 and 1995–96 ($P > 0.50$) in adult coyotes, nor was there a difference in the number of heartworms found in male versus female coyotes of all ages, in both years combined ($P > 0.10$).

The higher prevalence of heartworm in adult coyotes from HREC since 1994 may have been related to a drought that ended in 1993 ($\bar{x} \pm$ SE annual rainfall 1987–92 = 65.6 ± 2.3 cm, 1983–86 = 91.9 ± 28.7 cm, and 1993–96 = 74.5 ± 26.7 cm) and its influence on vector populations. The sample size from 1992–93 ($n = 3$ adults) was sufficiently small to warrant caution; nevertheless, heartworm prevalence in northern California domestic dogs was relatively low during the same drought (Theis et al., 1996), supporting the trend found in this study. Western tree-hole mosquito (vector) density varies with rainfall (Hawley, 1985); therefore, it is likely to be a primary limiting factor in prevalence of heartworm. In contrast, density of coyotes (host) probably does not vary substantially as a function of rainfall in north-coastal California (Sacks, 1996) and density of dogs almost certainly does not. Heartworm abundance in coyotes tends to increase with age (Custer and Pence, 1981; Holzman et al., 1992; this study). However, the coyote with the most heartworms in this study ($n > 238$) was a subadult, indicating either that heartworm infection can occur very frequently in some circumstances or that some mosquitoes harbor and inject large numbers of larvae.

Earlier reports of canine heartworm in coyotes from California showed the Sierra-Nevada foothills as having the highest prevalence among five regions of northern California, which included the coastal foothills, where the present study was conducted (Weinmann and Garcia, 1980; Acevedo and Theis, 1982). A more recent (1983–1988) survey of domestic dogs (Theis et al., 1996) supported this pattern: prevalence was nearly eight times greater in the Sierra-Nevada foothills (9%) than in the coastal foothills (1%). However, prevalence of heartworm in adult coyotes in the Sierra-Nevada foothills was only 45% in the late 1970's (Weinmann and Garcia, 1980), as compared to 92% in the coastal foothills during the present study. Even in the southeastern United States, where heartworm prevalence has historically been highest in domestic dogs (Otto, 1972), prevalence in coyotes at approximately 70% (Crowell et al., 1978; Custer and Pence, 1981) was lower than currently at HREC.

Heartworm intensity in coyotes also was higher at HREC (total $\bar{x} \pm$ SE = 30.4 ± 11.8, not including one individual with unusually high intensity = 19.4 ± 3.8) than previously reported in northern California ($\bar{x} = 9$ and 16 for female and male coyotes, respectively) by Weinmann and Garcia (1980) or in Texas and Louisiana ($\bar{x} =$ 13.6) by Custer and Pence (1981). The intensity of >238 heartworms found in one coyote at HREC was far greater than in any other coyote in this study or any other reported; maximum numbers of worms were 12, 23, 58, 82, and 84 in the studies of Graham (1975), Franson et al. (1976), Crowell et al. (1977), Weinmann and Garcia (1980), and Custer and Pence (1981), respectively. Although heartworm intensity reported in this survey was not exact, estimates appeared to be good approximations. It is likely that nearly all male heartworms were identified because their posterior ends are easily recognized even after considerable decomposition; these counted males comprised 42% (B. N. Sacks, unpubl. data) of the total number of heartworms estimated, which is similar to the proportion of males reported at 47% by Weinmann and Garcia (1980) and at 45% by Custer and Pence (1981).

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