

Relationship of Fox Rabies to Caves

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UNTIL RECENT YEARS rabies occurred throughout Tennessee, primarily among dogs. Since 1956, however, the occurrence of laboratory confirmed rabies among foxes has exceeded that for dogs. In the western part of the State, a rabid dog has not been reported since 1958.

A vaccination program to control canine rabies was initiated in Memphis and Shelby County in 1948 (1). The success of this venture encouraged other metropolitan areas to undertake similar programs. In 1951 the Tennessee Legislature declared the owning or harboring of an unvaccinated dog a misdemeanor, and in 1953 it provided for a rabies control service in the Tennessee Department of Public Health. Since the enactment of this legislation, state-wide canine vaccination programs have been sponsored by local health departments. As a result of these programs, the number of rabid dogs reported in the State decreased from a high of 747 in 1947 to 14 in 1957, after which the number fluctuated to 29 in 1964.

Fox Rabies

Annual analysis of the results of laboratory examinations for species and county was begun in 1946. In the late 1940's approximately 88 percent of the rabid animals were dogs, and foxes accounted for only 1 to 2 percent. Foxes were the only wild animals reported at this time, and these reports came from middle and east Tennessee.

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Rabid foxes were first reported in 1946, but only two reports, in 1954 and 1963, came from the western part of the State. Rabies ceased to be a problem in west Tennessee with the reduction of canine rabies. According to a study in Georgia by Starr and co-workers (2): "Observations indicate that with a good immune barrier in the dog population, rabies in wildlife (i.e., fox) will exhaust itself in a year or two."

Tennessee's experience with fox rabies appears to be different from that of other southeastern States. Most of these other States have had epizootics of fox rabies somewhat concurrently with outbreaks of dog rabies. In middle and east Tennessee, however, we suspect that the foxes are being continually reinfected through a cave-rabid bat-susceptible fox relationship in a manner that is not yet completely understood. In the situation that Starr described, foxes are probably infected by rabid dogs. A fox-to-fox infection probably continues until the epizootic burns itself out through (a) a decrease in the fox population, (b) a decline in the virus' invasiveness of salivary tissue, or (c) a reduction in canine rabies.

A study conducted by Schultz in 1950-51, indicated that foxes were distributed throughout Tennessee, although he did not attempt to determine the comparative fox population in the various sections of the State (3). Based on this study, and in the absence of any contradictory information, we assumed for the investigation reported here that there was an approximately equal distribution of the fox population throughout the State.

The changing locations and the persistence of the rabid fox in middle and east Tennessee suggest an endemic source of the virus in these areas. The changing locations of rabid foxes

from county to county suggest that a buildup of a fox population within a county is the main requirement for an epizootic.

It is not for lack of foxes in west Tennessee that this area has not experienced an outbreak of fox rabies. Rather, this area has a greater proportion of land under cultivation than does the rest of the State, and, according to Davis and Wood (4): "Detailed analysis of trapping results show clearly that foxes are most abundant in areas supporting cultivation." These authors also stated: "The important conclusion here is that the fox population is essentially an annual crop." We do not believe that the fox population remains constant in the various counties year after year.

In west Tennessee, agriculture has become diversified as it has elsewhere in the South in recent years. The State department of agriculture reported the following decrease in harvesting of cropland from 1949 to 1959: west Tennessee, 15 percent; middle and east Tennessee, 33½ percent; and the Cumberland Plateau (between middle and east Tennessee), 27½ percent.

Davis and Wood stated (4): "The agricultural trend in recent years has been from cultivated areas to woods (for pulp and timber) and pasture. This change greatly reduces the suitability of the area for foxes and should result in a decline in numbers." This information suggests that a greater density of foxes should be expected in west Tennessee than in the middle and eastern sections. West Tennessee's largest city is Memphis. Although no reports of fox rabies have come from this area, dog rabies have been reported in the past. For the 3-year period 1962-64, a total of 13 rabid bats were reported from 4 counties in this section. In our opinion, if rabid foxes were found in this area these foxes would be submitted for laboratory examination with the same alertness as the dogs and bats.

Bat Rabies

Since the laboratory confirmation of rabies in insectivorous bats in Florida in June 1953, most States have reported the disease in one or more species of bats (5). In July 1961 Tennessee became the 31st State to report bat rabies.

Since then, rabid bats have been examined from 10 counties in east, middle, and west Tennessee. Four species, possibly more, were included in these laboratory confirmed specimens. By the end of 1964, a total of 23 laboratory confirmed rabid bats had been reported from east, middle, and west Tennessee. Although no census has been made of the bat population, 13 species have been identified in the State (6).

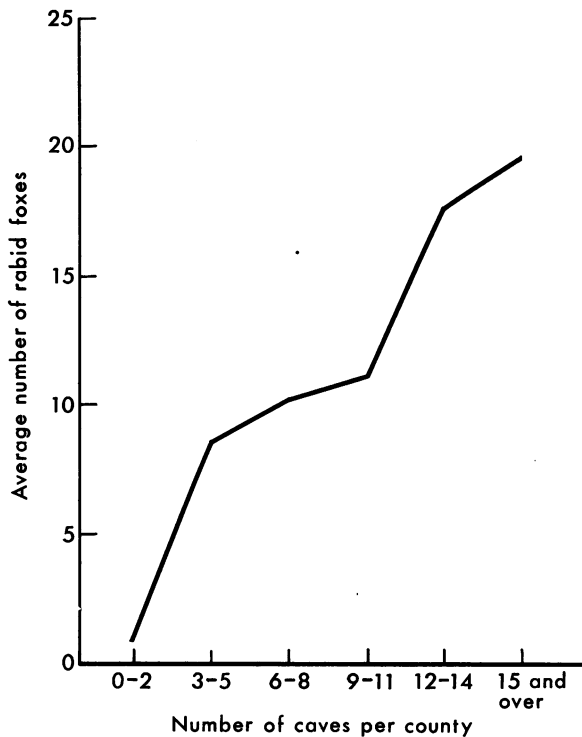
Bats are known to dwell in all sections of the State. Barr has reported that middle and east Tennessee contain as many caves as any comparable area of the world (7). He described 703 caves in 74 of Tennessee's 95 counties, with a distribution of 1.3 percent in west Tennessee, 79.0 percent in middle Tennessee, and 24.8 percent in east Tennessee. No attempt has been made to establish accurately the number of caves in the State that harbor bats. However, all cave-dwelling bats must of necessity be limited to middle and east Tennessee, since these are the sections which have caves.

Some bats (*Pipistrellus subflavis*) hibernate in the State's caves in the winter and live in the open during the summer; some bats (*Myotis grisescens*) occupy caves throughout the year; and other bats occupy caves in the summer and migrate farther south in the winter. Although 13 laboratory confirmed rabid bats were reported from west Tennessee, where there are no caves, we feel that caves appear to be an important catalyst in bringing the rabid bat and the susceptible fox together in a manner that permits the fox to become infected in Tennessee.

Table 1. Average number of rabid foxes per county, by number of caves per county, Tennessee, 1946-61

Caves in county	Number of counties	Rabid foxes	
		Number	Average per county
Total	95	867	9.1
0-2	30	27	.9
3-5	18	154	8.6
6-8	16	163	10.2
9-11	8	89	11.1
12-14	8	141	17.6
15 and over	15	293	19.5

Figure 1. Average number of rabid foxes per county, by number of caves per county, Tennessee, 1946-61



An adequate fox population and rabid bats by themselves do not appear to result in epizootics of fox rabies. We do not as yet understand the mechanics of this phenomenon.

In 1962 the State health department sampled the bat population of two caves in Franklin County in the middle section of the State. Of 18 *P. subflavis* bats captured in Lost Cove Cave, 1 was positive for rabies by fluorescent antibody examination. Caney Hollow Cave harbored a large number of *M. grisescens*, and 232 of these bats were captured. Of this group, 15 were reported positive.

Distribution of Caves and Foxes

The results of this sampling operation, the persistence of the fox rabies in the areas of the limestone caves, and Constantine's report of transmission of rabies by a nonbite route (8) suggested a new look at rabies in Tennessee.

An evaluation was undertaken by the statistical service of the health department of (a) the number of laboratory confirmed reports of rabid

foxes in each county from 1946 to 1961, (b) the number of years in which one or more rabid foxes were identified, and (c) the number of caves per county. The results are shown in the tables and figures.

As the frequency of caves per county increases, the number of rabid foxes also increases (table 1 and fig. 1). The group of counties which have fewer than 3 caves per county had an average of 0.9 rabid fox during 1946-61, and those counties with 15 or more caves averaged 19.5 rabid foxes per county.

The percentage distribution of 703 caves and of 867 rabid foxes reported during 1946-61 are shown according to frequency of caves per county in table 2 and figure 2.

In table 3 the counties are separated into groups according to the indicated number of caves to show the average number of years in which rabid foxes were reported per county. The average number of years for counties with many caves was much higher than for counties with few or no caves, ranging from 0.6 year for counties with no caves to more than 4.0 years for those with seven or more caves each. The average incidence increased according to increasing numbers of caves, except in the groups having 15 or more caves.

Figures 3, 4, and 5 show the number of caves in each county, the number of rabid foxes identified by county, and the number of years in which one or more rabid foxes were reported.

There are 15 counties with 15 or more caves each, and most of these are located along the

Table 2. Percentage distribution of 703 caves in Tennessee and of 867 rabid foxes reported during 1946-61, by frequency of caves per county

Caves in county	Number of counties	Caves		Rabid foxes	
		Number	Per cent	Number	Per cent
Total	95	703	100.0	867	100.1
0-2	30	15	2.1	27	3.1
3-5	18	70	10.0	154	17.8
6-8	16	111	15.8	163	18.8
9-11	8	83	11.8	89	10.3
12-14	8	102	14.5	141	16.3
15 and over	15	322	45.8	293	33.8

eastern boundary of middle Tennessee. The 14 counties showing 20 or more rabid foxes are located mainly in the middle portion of middle Tennessee and the upper portion of east Tennessee. Three nonadjacent counties, Davidson, Franklin, and Claiborne, show 15 or more caves and 20 or more rabid foxes. Also, Davidson, Franklin, and Putnam Counties show both 15 or more caves and 6 or more years in which rabid foxes were reported.

Of 30 counties having 2 or fewer caves and the 30 counties which had no rabid foxes reported during 1946-61, 22 had both 0 to 2 caves and no rabid foxes (figs. 3, 4). Most of these counties are located in one section of west Tennessee. West of the Tennessee River, only Henderson County had one rabid fox during this period and only Hardin and Decatur Counties contain caves. Benton, an adjacent county, reported one rabid fox in 1963.

The percentage distributions of caves and rabid foxes during 1946-61 are shown by region

Figure 2. Percentage distribution of 703 caves in Tennessee, by frequency of caves per county, 1946-61

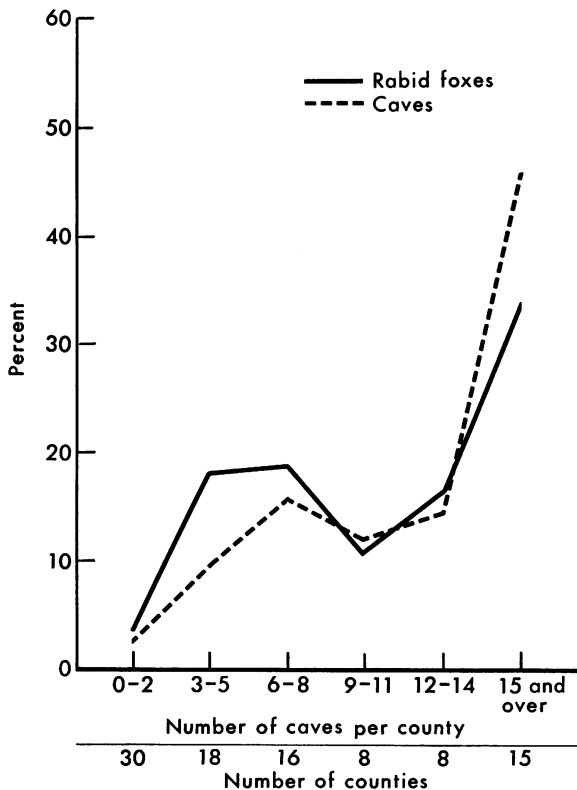


Table 3. Average number of years of one or more positive reports of rabid foxes per county, by number of caves in county, Tennessee, 1946-61

Caves in county	Number of counties	Years of positive reports	
		Total number	Average per county
Total.....	95	267	2.8
0.....	21	12	.6
1-2.....	9	7	.8
3-4.....	13	30	2.3
5-6.....	12	39	3.2
7-9.....	10	48	4.8
10-14.....	15	67	4.5
15-19.....	7	32	4.6
20 and over.....	8	32	4.0

Table 4. Distribution of caves and rabid foxes, by region of Tennessee, 1946-61

Region	Caves		Rabid foxes	
	Number	Percent	Number	Percent
Total.....	703	100.1	867	100.0
West.....	9	1.3	1	.1
Middle.....	520	74.0	608	70.1
East.....	174	24.8	258	29.8

in table 4. We wish to emphasize that the validity of these comparisons depends on the approximately equal distribution of foxes throughout Tennessee. West Tennessee has 1.3 percent of the caves and 0.1 percent of the rabid foxes; middle Tennessee with 74.0 percent of the caves has 70.1 percent of the rabid foxes; and east Tennessee with 24.8 percent of the caves has 29.8 percent of the rabid foxes.

From whatever point of view the data are examined, a certain measure of positive association is exhibited. Particularly interesting is the fact that in every instance the distinction is marked between the counties with few caves and those with many caves as to incidence of fox rabies. It is not possible to determine from the available data whether this association is causal or whether the observed facts are independent

Figure 3. Number of caves by county of Tennessee

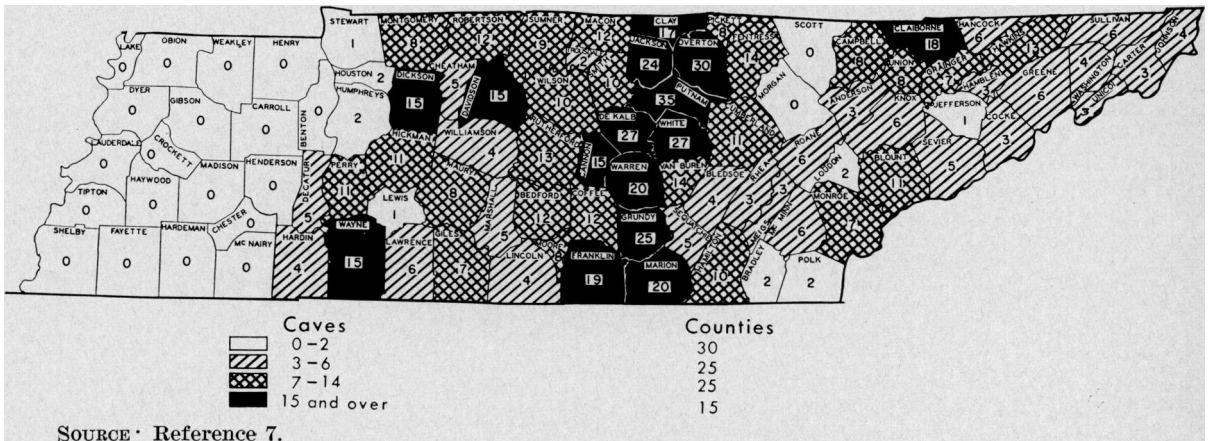


Figure 4. Number of rabid foxes per county, Tennessee, 1946-61

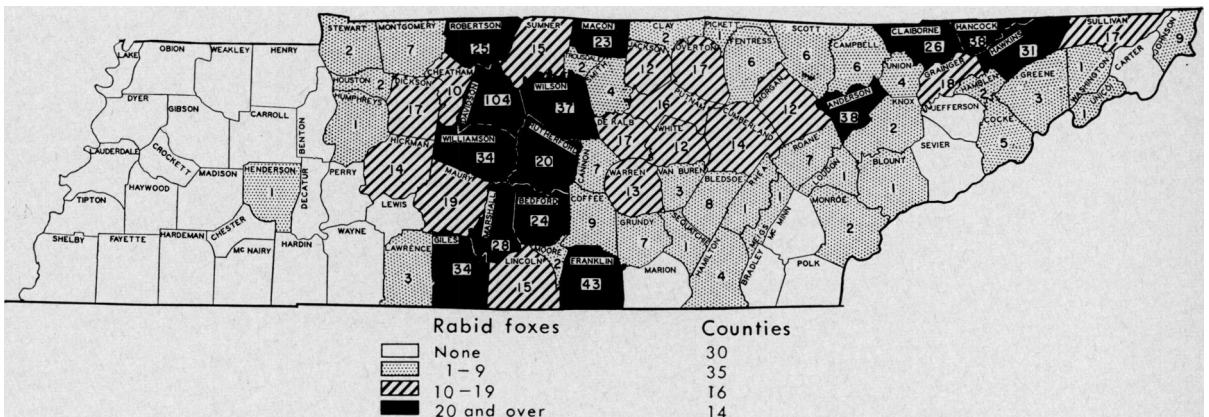
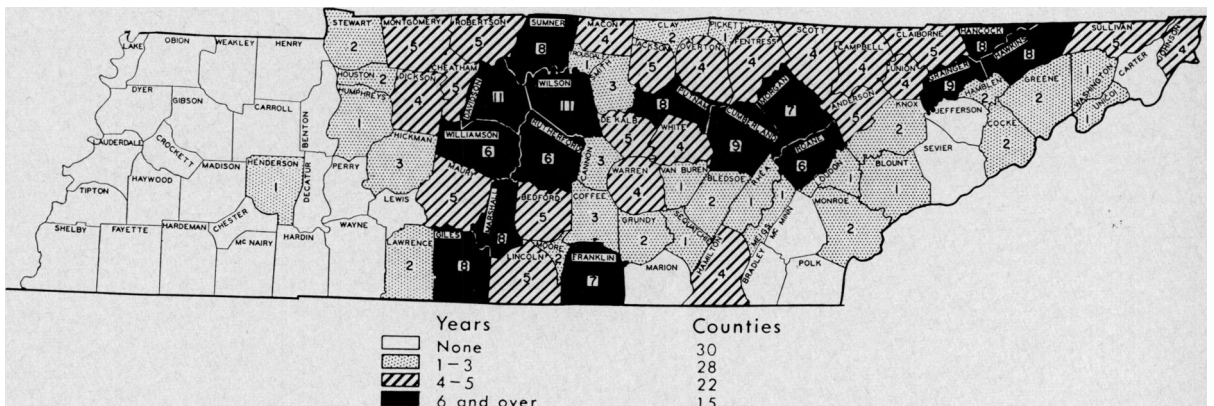


Figure 5. Number of years with one or more rabid foxes reported, by county of Tennessee, 1946-61



results of other factors; however, the data strongly suggest a nonrandom relationship.

Sikes has recently reported that foxes infected with a minimum of virus inoculum have the greatest percentage of saliva virus excretion (9). This would suggest that foxes that might be infected by rabid bats would be likely to continue the chain of infection in an area of dense fox population.

Discussion

Further investigations may be undertaken to attempt to clarify the basis for the positive relationship between the number of caves and the number of rabid foxes suggested by the data presented. These investigations will probably include:

1. Trapping of foxes in the areas surrounding caves that are known to have rabid bat populations as well as in areas surrounding caves that do not have bats. Comparisons will be made of the serum-neutralizing antibody titers in the two groups of foxes.

2. Studies of fox movements within caves.

3. The acceptability of bats as food for foxes.

Rabies has been observed in Tennessee during summer months as well as winter months. Although the data presented cover the period from 1946 to 1961, the data for 1962-64 are consistent with these earlier reports. Moreover, in 1964 there were 405 rabid foxes reported. This was the highest yearly number ever recorded, and all of these foxes were from middle and east Tennessee counties. Franklin County alone had 65 rabid foxes in 1964, and this is the county in which we sampled the bat populations in two caves in 1962.

Summary

Until recent years rabies was observed primarily among dogs throughout Tennessee. Vaccination programs have reduced the incidence of canine rabies, and the fox has emerged as the problem species. Fox rabies, however,

has been restricted to middle and east Tennessee. This confinement of the disease has been puzzling because foxes are located throughout the State.

Thirteen species of bats have been identified in Tennessee, and reports of rabid bats have been confirmed from all sections of the State. Previous investigators have noted that rabid bats can transmit the virus without biting, under certain cave conditions. Epidemiologic evidence presented in our report suggests that bats may infect foxes in caves in certain areas of Tennessee.

Although the data presented do not prove conclusively that these caves permit rabid bats to infect the local fox population, they do suggest a positive relationship between the number of caves and the number of rabid foxes.

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