Environmental and Human Demographic Features Associated with Epizootic Raccoon Rabies in Maryland, Pennsylvania, and Virginia

Authors: Jones, Meghan E., Curns, Aaron T., Krebs, John W., and Childs, James E.

Source: Journal of Wildlife Diseases, 39(4) : 869-874

Published By: Wildlife Disease Association

URL: https://doi.org/10.7589/0090-3558-39.4.869

SHORT COMMUNICATIONS

Journal of Wildlife Diseases, 39(4), 2003, pp. 869–874

Environmental and Human Demographic Features Associated with Epizootic Raccoon Rabies in Maryland, Pennsylvania, and Virginia

Meghan E. Jones,[1] Aaron T. Curns,[2,3] John W. Krebs,[2] and James E. Childs[2] [1] Community Health Assessment and Service Evaluation Unit, Northeast Health District, Athens, Georgia 30605, USA; [2] Viral and Rickettsial Zoonoses Branch and Office of the Director, Division of Viral and Rickettsial Diseases, National Center for Infectious Diseases, Centers for Disease Control and Prevention, Atlanta, Georgia 30333, USA; [3] Corresponding author (email: agc8@cdc.gov)

ABSTRACT: We assessed land use and demographic data as predictors discriminating between counties experiencing large or small first epizootics of rabies among raccoons (*Procyon lotor*). Monthly county reports of raccoons testing positive for rabies were obtained from rabies surveillance databases from Maryland, Pennsylvania, and Virginia (USA). Environmental and demographic data for the three states were obtained from public sources. On the basis of total reports of raccoon rabies during the first defined epizootic period, the 203 counties were dichotomized at the 75th percentile as having a large epizootic (≥24 rabid raccoons in the first epizootic) (51 counties) or a small epizootic or no epizootic (152 counties). A high percentage of agricultural land use [OR=9.1, 95% CI (3.6–23.1)], high water coverage in combination with low human population density [OR=8.8, 95% CI (2.9–27.0)], and low water coverage with high human population density [OR=11.7, 95% CI (4.0–34.1)] were positively associated with large rabies epizootics. Counties with more than 15% of mixed forest were less likely to experience large epizootics than were counties with ≤15% of mixed forest [OR=0.3, 95% CI (0.1, 0.9)]. A combination of land use and human population density measures provided the best model for determining epizootic size and may be important predictors of epizootic behavior and risk of exposure to this reservoir species.

Key words: Epizootic, *Procyon lotor,* rabies, raccoons.

Since the 1950s, rabies has been more frequently reported among wildlife species than among domestic animals (Rupprecht et al., 1995). Since 1990, the raccoon (*Procyon lotor*) has been the animal most frequently reported rabid in the United States, with most reports originating from states in the mid-Atlantic and New England regions (Childs et al., 2001). Rabies among raccoons in the eastern United States is associated with a particular variant of the rabies virus adapted to this species (Smith, 2002).

Rabies affecting raccoons was first recognized in central Florida (USA) in the 1940s and this enzootic focus has gradually spread northward into adjacent states. In 1977, the first rabid raccoon was reported in West Virginia (USA), several states away from the existing enzootic rabies area in the southeastern United States. From West Virginia, rabies spread to Virginia and eventually throughout the mid-Atlantic and New England region, progressing at approximately 40–48 km per year (Jenkins and Winkler, 1987; Wilson et al., 1997; Smith et al., 2002).

Raccoons are a highly adaptable species and thrive living in close proximity to humans, with some of the highest raccoon population densities measured in urban parks and suburban sites (Riley et al., 1998). High raccoon population densities in these areas increase the probability that humans and domestic animals will encounter rabid raccoons during epizootics and contribute to human exposures to rabies virus (Wilson et al., 1997; Hanlon and Rupprecht, 1998). The expanse of favorable raccoon habitat in the mid-Atlantic region has likely contributed to the rapid emergence of rabies in this area (Hanlon and Rupprecht, 1998). Disparities in the size of epizootics of raccoon rabies among counties in the mid-Atlantic region suggest that biological factors influencing raccoon populations may be important determinants of epizootic size, although human population density and surveillance activities also contribute to observed patterns (Childs et al., 2001). Direct quantitative assessments of raccoon population densities over broad geographic regions by using conventional trapping methods would be prohibitively expensive. Consequently, other approaches to estimating relative raccoon population density, such as using measures of environmental features and other factors that are predictive of favorable raccoon habitat, offer an attractive alternative approach.

Our objectives were to examine the association between various environmental and demographic features of counties and the magnitude of raccoon rabies epizootics in Maryland, Pennsylvania, and Virginia. If consistent patterns in rabies epizootics were discernable at the scale of a county, these preliminary findings could help focus future geographically based studies on landscape features of particular interest.

Data were acquired through rabies surveillance records submitted by Maryland, Pennsylvania, and Virginia to the Centers for Disease Control and Prevention (Atlanta, Georgia, USA) for the years 1978 through 1997 or 1998 in the case of Maryland. All raccoons were tested for rabies by using direct fluorescent-antibody staining of brain tissue and positive results were reported monthly. Rabies epizootics were identified by using an algorithm described in detail previously (Childs et al., 2001). In brief, an epizootic was defined as beginning when the number of rabies-positive raccoons was greater than the county median for two consecutive months and ended when the number of rabies-positive raccoons was less than or equal to the county median for two consecutive months. Epizootics also had to have a minimum duration of five consecutive months. The algorithm discriminated epizootics of rabies among raccoons from low-level endemic activity occurring along a time series of monthly reports from the counties. The period of endemic rabies was defined from the month of the first rabies-positive raccoon reported in the county through 31 December 1997 or 31 December 1998 (Maryland).

Due to lack of reporting in certain cities located within county boundaries, rabies data were pooled for these areas and census data were combined. All counties included in the analysis had one of the following characteristics: 1) a defined epizootic, 2) raccoon rabies reported throughout the rabies-endemic period with no defined epizootic, or 3) no reported raccoon rabies but were adjacent to counties with endemic raccoon rabies and therefore presumed to be at risk for raccoon rabies. A total of 203 counties from three states were used for analysis.

Counties having 24 or more rabid raccoons ($\geq$75th percentile) in the first epizootic were defined as experiencing large epizootics and those below were defined as counties with small or no epizootics. Independent variables included percent land use categories and population density (km^2) for each county. Census data were from the 1990 U.S. Census (United States Census Bureau, 2000). Land use categories for individual counties, obtained as proportions of total use or coverage, were water, low-intensity residential, high-intensity residential, transitional, deciduous forest, high-intensity commercial/industrial/transportation, quarries/strip mines/gravel pits, evergreen forest, mixed forest, agricultural use, other grasses, woody wetlands, and emergent herbaceous wetland (US Geological Survey, 2002). After descriptive analyses were completed, all of the independent variables were dichotomized on the 75th percentile, with values greater or equal than the 75th percentile considered high, and those below considered low.

Both SPSS (version 10.0 SPSS Inc. Chicago, Illinois, USA) and SAS (version 6.12 SAS Institute, Cary, North Carolina, USA) were used for data analysis. Descriptive analyses of the data were conducted to obtain the mean, standard deviation, and

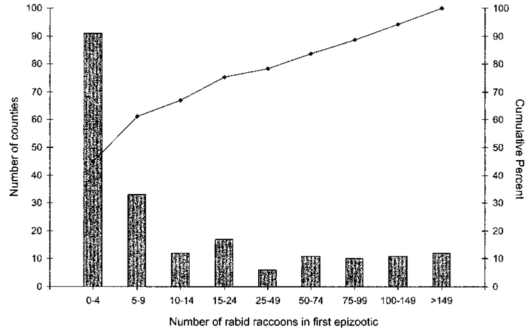

FIGURE 1. Number of rabid raccoons reported and the cumulative percent of counties (n=203) reporting that number of rabid raccoons during the first defined epizootic in Maryland, Pennsylvania, and Virginia. Counties with ≥24 rabid raccoons were considered to have experienced a large epizootic.

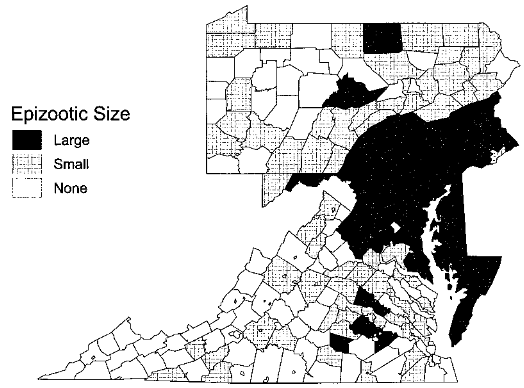

FIGURE 2. Counties classified as experiencing large, small, or no initial epizootic of raccoon rabies in Maryland, Pennsylvania, and Virginia. Fifty-one of 203 counties were classified as having a large epizootic, 65 had a small epizootic, and 87 had no epizootic.

quartiles of the continuous variables. Unadjusted odds ratios for risk of a large epizootic were calculated for independent variables along with associated chi-squares, P-values, and 95% confidence intervals. Multivariate logistic regression analysis was used to assess confounding and interaction, as well as to determine the best predictive model for identifying variables associated with high-risk counties. All variables that had statistically significant associations with large epizootics in the unadjusted analysis were included in the full model. A hierarchical backwards selection approach was used in logistic modeling to derive the final model. Variables that were not statistically significant and were not confounders were eliminated from the model. A variable was considered to be a confounder if its inclusion resulted in at least a 10% change in the adjusted odds ratio obtained for the variable of high human population density. Interaction terms with P-values less than 0.05 were considered effect modifiers.

The 203 counties in Maryland, Pennsylvania, and Virginia reported 7,485 rabid raccoons during the first defined epizootic. One hundred twenty-four counties (61%) reported less than 10 rabid raccoons (Fig. 1). Fifty-one (25%) reported more than 23 rabid raccoons in the first epizootic and were considered to be large epizootic counties (Figs. 1, 2). Sixty-five counties (32%) were recognized as small epizootic counties and 87 counties (43%) had no epizootic (Fig. 2). The land use categories accounting for most coverage among the 203 counties were deciduous forest and agricultural (median values 40% and 23%, respectively) (Table 1). All other land use categories contributed less than 10% of the total county cover based on median contribution. The median human population density for the 203 counties was 35 persons per km^2, with a 75th percentile value of 132.7 persons per km^2.

In unadjusted analyses, high percentages of county land use or coverage in agricultural, water, low-intensity residential, high-intensity residential, grasslands, and emergent herbaceous wetlands were significantly associated with counties experiencing large rabies epizootics (Table 1). High percentages of deciduous forest and mixed forest were significantly associated with counties experiencing smaller or no rabies epizootics. High human population density was also significantly associated with a county having a large rabies epizootic.

Stratified analysis showed that the effect of percentage of water coverage was modified by human population density with re-

TABLE 1. Population density and land use categories and risk for large epizootics of raccoon rabies (≥24 rabid raccoons) in counties of Maryland, Pennsylvania, and Virginia.

			No. and (%) of counties ≥75th percentile			
Variable	Median % land use	75th percentile	Small epizootic	Large epizootic	OR[a]	(95% CI)
Population density (km^2)	35.22	132.66	27 (18)	23 (45)	3.8[f]	(1.9, 7.4)
Water[b]	1.15	3.15	31 (20)	19 (37)	2.3[d]	(1.2, 4.6)
Low intensity residential[b]	1.56	5.04	31 (20)	20 (39)	2.5[e]	(1.3, 5.0)
High intensity residential[b]	0.07	0.53	28 (18)	22 (43)	3.4[f]	(1.7, 6.6)
High intensity commercial/industrial/transportation[b]	0.36	1.0	30 (20)	21 (41)	2.8[e]	(1.5, 5.6)
Quarries/strip mines/gravel pits[b]	0.04	0.26	34 (22)	16 (31)	1.6	(0.8, 3.2)
Transitional[b]	0.33	1.0	43 (28)	8 (16)	0.5	(0.2, 1.1)
Deciduous forest[b]	40.26	54.49	46 (30)	4 (8)	0.2[f]	(0.1, 0.5)
Evergreen forest[b]	5.91	8.77	42 (28)	8 (16)	0.5	(0.2, 1.1)
Mixed forest[b]	9.87	15.35	47 (31)	4 (8)	0.2[f]	(0.1, 0.5)
Agricultural[b,c]	23.47	34.37	24 (16)	27 (53)	6.0[f]	(3.1, 11.7)
Other grasses[b]	0.04	0.12	30 (20)	21 (41)	2.8[e]	(1.5, 5.6)
Woody wetlands[b]	0.42	2.72	36 (24)	15 (29)	1.3	(0.7, 2.7)
Emergent herbaceous wetlands[b]	0.21	0.77	30 (20)	20 (39)	2.6[e]	(1.3, 5.2)

[a] OR = odds ratio.
[b] Percent land use.
[c] Combination of pasture/hay and row crops.
[d] $P<0.05$.
[e] $P<0.01$.
[f] $P<0.001$.

spect to the risk of a county having a large epizootic. An interaction term involving these two variables was included in the logistic model along with all the variables identified as significant in unadjusted analyses (Table 1). Through backwards elimination, high-intensity residential, high-intensity commercial/industrial/transportation, low-intensity residential, deciduous forest, other grasses, and emergent herbaceous wetlands variables were removed from the model. The final logistic model included the land use categories of agriculture, water coverage, and mixed forest, in addition to human population density, and the interaction term human population density by water coverage (Table 2).

Counties with high agricultural use had a significantly increased risk of having a large raccoon rabies epizootic (OR=9.1); whereas counties with a high percentage of mixed forest had a reduced risk (OR=0.3) (Table 2). The interaction between human population density with water coverage resulted in counties with human population density less than the 75th percentile, with high percentage of water coverage having a significantly elevated risk of experiencing a large epizootic (OR=8.8). In addition, counties with high human population density but low percentage water coverage also had significantly elevated risk of experiencing large epizootics (OR=11.7).

Our results indicated that several land use patterns, such as the percentage of a county in water coverage, agricultural use, and mixed forest were significantly asso-

TABLE 2. Summary of multivariate analysis of risk factors for large epizootics of raccoon rabies (≥24 rabid raccoons) in counties of Maryland, Pennsylvania, and Virginia.

Variable	Adjusted odds ratio	(95% Confidence interval)
Agricultural[a,b] (high vs. low)	9.1[c]	(3.6, 23.1)
Mixed forest[a] (high vs. low)	0.3[d]	(0.1, 0.9)
Population density (km^2)		
High		
Water coverage[a]		
High	1.3	(0.3, 5.4)
Low	11.7[c]	(4.0, 34.1)
Low		
Water coverage[a]		
High	8.8[c]	(2.9, 27.0)
Low	0.6	(0.2, 2.2)

[a] Percent land use.
[b] Combination of pasture/hay and row crops.
[c] $P<0.001$.
[d] $P<0.05$.

ciated with the magnitude of the first epizootic of raccoon rabies experienced by that county. Our analyses also demonstrated that the effect for human population density in a county varied depending on water coverage. The positive association between high percentages of agricultural land use and large rabies epizootics among raccoons is consistent with expectations that land use variables indicative of the quality of raccoon habitat and with the potential for human interaction should be associated with the magnitude of initial epizootics. In contrast, the protective effect of increasing coverage by deciduous forest on raccoon rabies epizootics might be mediated by the low human population density in heavily forested areas, rather than the lack of suitable habitat to support raccoons.

Numerous reports document that raccoon abundance is highest in areas of mid- and high level agricultural activities, particularly in association with edge habitats created by the mosaic of farm land mixed with deciduous forest (Pedlar et al., 1997). An accepted ecological principle is that favorable habitat provides for a higher carrying capacity (*K*) capable of sustaining more dense populations of raccoons prior to the introduction of rabies. The higher density of susceptible raccoons can increase the absolute number of rabid raccoons affected during the initial epizootic (Coyne et al., 1989). The initial rabies epizootic among raccoons in a county is different from all subsequent epizootics because it involves significantly more animals (Childs et al., 2000, 2001).

An interesting finding in our analyses was the interaction between human population density and water coverage with respect to epizootic characteristics. The association between human population density and water coverage with epizootics was clearly dependent on which character was in greater abundance. A compensatory model can explain this result if one considers that any report of animal rabies depends on a human participant who collects the animal and submits it for rabies testing. Up to some level, increasing the density of human observers should increase the likelihood of a rabid animal being detected and tested. Where human population density is low, a greater number of rabid raccoons may have to be present to result in a reported epizootic of equal magnitude. Close proximity to water has been shown repeatedly to be just such a critical factor in determining the quality of raccoon habitat with marshes, riparian areas, and other semi-aquatic environments supporting exceptionally high densities (Leberg and Kennedy, 2001).

The results of this study demonstrated the association between the magnitude of rabies in raccoons during initial epizootic and environmental features and human demography at a course-scale. Both land use characteristics and human population density needed to be considered to accurately define areas at risk for large rabies epizootics. The ability to classify a county on the basis of land use attributes indicative of habitat quality will permit more accurate prediction of where and how epizootics develop. In addition, knowing where epizootics might have been expected but were not observed can help identify gaps in surveillance information. These efforts could ultimately prove useful in future modeling of zoonotic disease outbreaks in addition to helping define locations where surveillance coverage is not sufficient to detect disease outbreaks.

LITERATURE CITED

CHILDS, J. E., A. T. CURNS, M. E. DEY, L. A. REAL, L. FEINSTEIN, O. N. BJORNSTAD, AND J. W. KREBS. 2000. Predicting the local dynamics of epizootic rabies among raccoons in the United States. Proceedings of the National Academy of Sciences of the United States of America 97: 13666–13671.

———, A. T. CURNS, M. E. DEY, L. A. REAL, C. E. RUPPRECHT, AND J. W. KREBS. 2001. Rabies epizootics among raccoons vary along a north-south gradient in the eastern United States. Vector Borne and Zoonotic Diseases 4: 253–267.

COYNE, M. J., G. SMITH, AND F. E. MCALLISTER. 1989. Mathematic model for the population biology of rabies in raccoons in the mid-Atlantic states. American Journal of Veterinary Research 50: 2148–2154.

HANLON, C. A., AND C. E. RUPPRECHT. 1998. The reemergence of rabies. *In* Emerging infections, W. M. Scheld, D. Armstrong and J. M. Hughes (eds.). ASM Press, Washington, D.C., pp. 59–80.

JENKINS, S. R., AND W. G. WINKLER. 1987. Descriptive epidemiology from an epizootic of raccoon rabies in the Middle Atlantic States, 1982–1983. American Journal of Epidemiology 126: 429–437.

LEBERG, P. L., AND M. L. KENNEDY. 2001. Demography and habitat relationships of raccoons in western Tennessee. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 42: 272–282.

PEDLAR, J. H., L. FAHRIG, AND H. G. MERRIAM. 1997. Raccoon habitat use at 2 spatial scales. Journal of Wildlife Management 61: 102–112.

RILEY, S. P. D., J. HADIDIAN, AND D. A. MANSKI. 1998. Population density, survival, and rabies in raccoons in an urban national park. Canadian Journal of Zoology 76: 1153–1164.

RUPPRECHT, C. E., J. S. SMITH, M. FEKADU, AND J. E. CHILDS. 1995. The ascension of wildlife rabies: A cause for public health concern or intervention? Emerging Infectious Diseases 1: 107–114.

SMITH, D. L., B. LUCEY, L. A. WALLER, J. E. CHILDS, AND L. A. REAL. 2002. Predicting the spatial dynamics of rabies epidemics on heterogeneous landscapes. Proceedings of the National Academy of Sciences of the United States of America 99: 3668–3672.

SMITH, J. S. 2002. Molecular epidemiology. *In* Rabies, A. C. Jackson and W. H. Wunner (eds.). Academic Press, New York, New York, pp. 79–111.

UNITED STATES CENSUS BUREAU. 2000. 1990 summary tape file 1C. US Census Bureau, Washington, D.C.

UNITED STATES GEOLOGICAL SURVEY. 2002. National land cover class definitions. http://landcover.usgs.gov/classes.html.

WILSON, M. L., P. M. BRETSKY, G. H. COOPER, JR., S. H. EGBERTSON, H. J. VAN KRUININGEN, AND M. L. CARTTER. 1997. Emergence of raccoon rabies in Connecticut, 1991–1994: Spatial and temporal characteristics of animal infection and human contact. American Journal of Tropical Medicine and Hygiene 57: 457–463.

Received for publication 14 October 2002.