Trends in national surveillance for rabies among bats in the United States (1993–2000)

Alison M. Mondul, MSPH; John W. Krebs, MS; James E. Childs, ScD

Objective—To describe surveillance trends and epidemiologic features of rabies in bats in the United States, focusing on 3 bat species primarily associated with variants of the rabies virus that affect humans.

Design—Retrospective study.

Animals—31,380 bats.

Procedure—Data on rabies for bats identified to species and reported by state laboratories from 1993 to 2000 were analyzed, focusing on silver-haired, eastern pipistrelle, and Brazilian free-tailed bats. Categoric variables were derived from other provided information.

Results—Data were reported from 37 states during the study interval; complete species-specific data were not reported by any state for the entire interval. Bats primarily associated with rabies virus variants affecting humans were more likely to yield positive test results for rabies (22.7%), compared with all other bats (5.5%) in most seasons and from most regions of the United States. However, certain other bat species had higher percentages of positive results. Risk of positive results was highest in the fall and highest among bats originating in the southwestern United States.

Conclusions and Clinical Relevance—Increased risk of rabies among certain groups of bat species was consistently found across seasons and most geographic regions of the United States. Results were in general agreement with those of previous studies conducted within smaller geographic regions. There are ongoing efforts to improve surveillance of rabies in bats, although surveillance is incomplete in some regions. (*J Am Vet Med Assoc* 2003;222: 633–639)

Rabies is a viral zoonosis caused by a single-stranded negative-sense RNA virus. In nature, rabies virus is maintained by various mammalian reservoirs. Dogs serve as a major reservoir of rabies virus in developing countries, whereas various wildlife species are the most common reservoirs in the United States.[1]

With the development of monoclonal antibodies and genetic typing and sequencing techniques during the late 1980s and early 1990s, it became possible to distinguish variants of rabies virus circulating in the United States. Each variant of rabies virus is primarily associated with a single mammalian species, and in terrestrial animals, each variant of rabies virus predominantly circulates within a discrete geographic area of the United States.[2,3] Most rabies infections within the well-defined enzootic regions of the United States occur among recognized reservoir species, although transmission of the variant of rabies virus associated with the principal reservoir species into additional species of mammals occurs sporadically.

As is true for rabies in terrestrial animals, rabies in bats is caused by variants of rabies virus associated with certain species.[4,5] However, unlike rabies in terrestrial animals, rabies infections resulting from bat-associated variants of rabies virus are more difficult to localize to a specific geographic area. Rabies surveillance reports during the 8-year period from 1993 to 2000 have consistently revealed a diffuse geographic pattern of rabies in bats throughout the continental United States.[6-8] Although spillover infection of bat variants of rabies virus among terrestrial animals such as dogs and cats appears rare,[9] these variants of rabies virus have been associated with 92% (24/26) of the indigenously acquired human rabies infections in the United States since 1990.[8,10] Most (71% [17/24]) human rabies cases caused by bat variants of rabies virus have been traced to a single variant associated with silver-haired (*Lasionycteris noctivagans*) and eastern pipistrelle (*Pipistrellus subflavus*) bats known as the Ln/Ps variant.[5] The bat variant of rabies virus next most commonly (20.8% [5/24]) implicated in human rabies since 1990 circulates among Brazilian free-tailed bats (*Tadarida brasiliensis*). Two human deaths were caused by other rabies virus variants, one of which is primarily associated with big brown bats (*Eptesicus fuscus*), while the other is primarily associated with bats of the genus *Myotis*.[5]

The link between human deaths and the Ln/Ps variant of rabies virus could not have been predicted. As occurs with other species of bats that roost alone or in small social groups, submissions of silver-haired and eastern pipistrelle bats for rabies testing are relatively infrequent (1.8 and 0.4%, respectively), suggesting that they only rarely come into contact with humans and domestic animals.[11,12] Other species, such as Brazilian free-tailed bats, little brown bats (*M lucifugus*), and big brown bats (*E fuscus*), can be found roosting in large colonies that in the case of Brazilian free-tailed bats can number in the millions.[13] Transmission of rabies virus appears to be enhanced among bats living in large, densely packed colonies.[14] If these colonies are proximate to human dwellings, the likelihood of exposure of humans and domestic animals to rabid bats might also be increased.

Several factors have been explored to help explain the disparate number of human infections with the Ln/Ps variant of rabies virus. The infectivity of this

From the Rollins School of Public Health, Emory University, Atlanta, GA 30322 (Mondul) and the Viral and Rickettsial Zoonoses Branch, Division of Viral and Rickettsial Diseases, National Center for Infectious Diseases, Centers for Disease Control and Prevention, 1600 Clifton Rd MS/G13, Atlanta, GA 30333 (Krebs, Childs).

Address correspondence to Dr. Childs.

variant of rabies virus appears enhanced for non-neuronal tissue and for cell cultures maintained at unusually low temperature,[15] suggesting increased potential for establishing infection when virus is introduced at peripheral body sites. Other studies have found that the infection rates in bat species known to live either solitarily or in small groups were higher than those in colonial species that were submitted for rabies testing to state laboratories.[16-18] However, extrapolating these findings for the entire United States is difficult because most studies of rabies among bats have been geographically restricted and often limited to 1 state, and the number of species of bats is highly varied across North America.[19]

The purpose of the study reported here was to assess the present status of national surveillance for rabies among bats identified to species, determine whether the species of bats most commonly associated with the variants of rabies virus known to have caused human disease are more frequently reported rabid than are other species of bats, and examine other epidemiologic factors that could contribute to observed differences in the incidence of rabies among various species of bats tested at diagnostic laboratories in the United States.

Criteria for Selection of Cases

The database was composed of the results (positive or negative) of direct fluorescent antibody testing for detection of rabies virus antigen in the brain tissue of bats that were submitted to state diagnostic laboratories and identified to species or in some circumstances genus.

States or territories excluded a priori from consideration were Hawaii (rabies free), Alaska (rabies in bats infrequent, as documented by routine laboratory-based surveillance), and Puerto Rico (no reported rabies in bats). States reporting only the species of bats with rabies or providing only partial denominator data (ie, the total numbers of bats tested) at the county level, including California, Florida, and South Carolina, were excluded from analysis.

Procedures

In addition to frequencies determined on the basis of the state laboratory submission data, several categoric variables were derived. The categoric variables included 2 groupings of bat species made on the basis of the species' association with variants of rabies virus causing human deaths, the season of year when the bat was tested, the region of the country where the bat originated, and the dominant epizootiologic pattern of wildlife rabies in a state.

Bats belonging to the 3 species associated with the variants of rabies virus that have caused most human rabies cases were grouped into a single class containing either 3 species (**silver-haired, eastern pipistrelle, and Brazilian free-tailed bats [LNPSTB]**) or 2 species (**silver-haired and eastern pipistrelle bats [LNPS]**) for comparison with other bats. The LNPS group was considered separately because eastern pipistrelle and silver-haired bats are associated with a shared variant of the rabies virus. In addition, both species are solitary or form small colonies and have overlapping geographic ranges in the eastern United States.

The period in which bats were tested for rabies was categorized into 4 seasons: winter (December–February), spring (March–May), summer (June–August), and fall (September–November).

Regions in which a bat was tested in the United States were divided into Northwest, Southwest, Northeast, and Southeast. The Northwest included 12 states (Idaho, Iowa, Kansas, Minnesota, Missouri, Montana, Nebraska, North Dakota, Oregon, South Dakota, Washington, and Wyoming), the Southwest included 10 states (Arizona, Arkansas, California, Colorado, Louisiana, Nevada, New Mexico, Oklahoma, Texas, and Utah), the Northeast included 14 states (Connecticut, Illinois, Indiana, Maine, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and Wisconsin), and the Southeast included 12 states (Alabama, Delaware, Florida, Georgia, Kentucky, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia). Not all the states in a region reported data used in this report **(Fig 1)**.

The final variable, epitype, was assigned to indicate the rabies-dominant public health concern among wildlife species that may serve as rabies virus reservoirs within a particular state, as indicated by the type and frequency of animals submitted for rabies testing. A state was considered as having a dominant public health concern for bat-associated rabies (ie, a bat state) if > 75% of total submissions for rabies testing during the study period were bats. All other states were considered to have a dominant concern for rabies in terrestrial carnivores (ie, a terrestrial state).

Statistical analyses—Frequencies of the data were determined with a software program[a] for descriptive analyses. Mantel-Haenszel **odds ratios (ORs)** with **95% confidence intervals (CIs)**, χ^2 test statistics, and associated *P* values were calculated for all independent variables. An alpha level of 0.05 was considered when determining significant associations for all analyses.

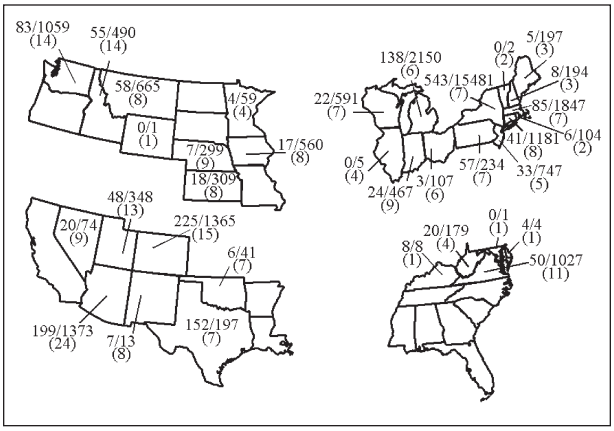

Figure 1—Overall distribution of the proportion of bats with rabies (number of rabid bats/number of all bats tested) in states reporting bat species data in 4 geographic regions of the United States, 1993–2000. Values in parentheses indicate number of bat species identified in each state.

All *P* values reported are for 2-tailed tests. When significant interactions between covariates were detected by use of the Breslow-Day test for homogeneity,[a] a stratified analysis was conducted to measure the association between rabies test outcomes and the species groups (LNPSTB or LNPS) associated with variants of rabies virus causing human disease.

Results

From 1993 to 2000, reports for 776,534 animals were sent to the **Centers for Disease Control and Prevention (CDC)** by state health departments; among these, 11,481 (1.5%) were either not tested for rabies or yielded an equivocal test result and were excluded from further consideration. Bats accounted for 93,337 (12.0%) of the animals submitted for rabies testing during this period, and 33,663 (36.1%) of these bats were identified to the level of species or genus. Of these submissions, 1,710 (5.1%) were not tested or yielded an equivocal rabies test result, leaving a potential database of 31,953 individual bats with an interpretable test result and identified to species or genus. During the 8-year study interval, 37 states (Arizona, California, Colorado, Connecticut, Delaware, Florida, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Texas, Utah, Virginia, Vermont, Washington, West Virginia, Wisconsin, and Wyoming) and New York City reported some information on the species of bats tested for rabies to the CDC (Fig 1). From 1993 to 2000, the number of rabid bats (speciated and nonspeciated) reported annually to the CDC ranged from 631 (1994) to 1,240 (2000; **Fig 2**). During this 8-year interval, 2,395 (7.5%) of the 31,953 bats tested for rabies and identified by species in the United States were found to have rabies. During the same period, 8.9% (4,702/57,474) of unspeciated bats submitted for testing were found to be rabid. These rabies test results from speciated bats originated from 37 states and New York City, although the annual number of states or geographic units reporting this information never exceeded 27 in a given year. Caution is warranted when analyzing these data and drawing conclusions from percentages of positive results overall, because certain states report data only for bats that had positive results for rabies.

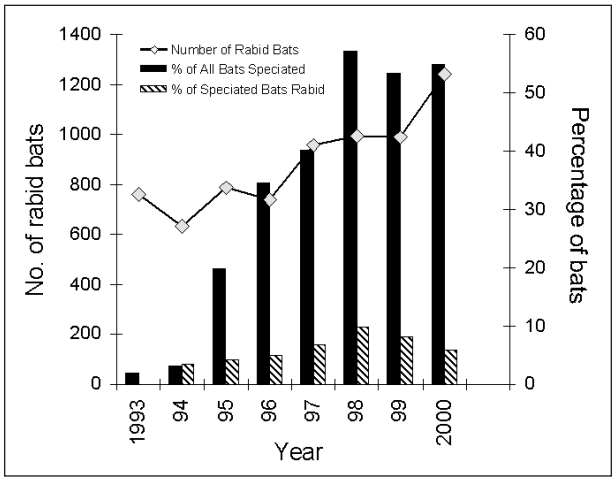

Figure 2—Yearly distribution of overall numbers of rabid bats (speciated and nonspeciated), percentages of all bats tested that were speciated, and percentages of speciated bats that were rabid in the United States, 1993–2000.

Among reports to the CDC, the percentage of all bats tested for rabies that were speciated increased from 1.8% in 1993 to 55% in 2000 (Fig 2). The percentage of speciated bats that were found to be rabid varied between 0% (1993) and 9.8% (1998) with a mean of 5.4%. Surveillance findings in the early 1990s were strongly influenced by reporting from New York, which has tested more bats than any other state (49.3% of all bats tested and speciated during the study interval) but reported 1 of the lowest positive result rates for bats (3.5% during the study interval [Fig 1]).

From 1993 to 2000, 39 of the approximately 41[20] species of bats that occur in the US were tested for rabies and reported to the CDC, and 4 additional groupings were identified to the level of genus. Of this total, 7 species and 2 genus-level groupings were excluded from further analysis because they were exotic species not indigenous to the United States. Exotic animals are usually zoological or privately held individuals. Reasons for testing these animals varied, but usually involved human exposures or unexplained deaths of individual animals. After exotic bats were excluded, the final data set consisted of 31,380 bats of 32 species and 2 genus-level groups (unspeciated bats of the genera *Myotis* and *Tadarida* [**Table 1**]). The number of species of bats tested for rabies from different states ranged from 1 (Delaware, Kentucky, Maryland, and Wyoming) to 24 (Arizona; [Fig 1]).

Among those bats that were identified to the level of species, the big brown bat (*E fuscus*) was the most frequently submitted species for rabies testing (66.6% of the total) in the United States, followed by the little brown bat (*M lucifugus* [18.2%]). Each of the other 32 categories of bats contributed < 3% of the total number of individuals tested; silver-haired, eastern pipistrelle, and Brazilian free-tailed bats constituted 1.8, 0.4, and 2.1% of the total, respectively (Table 1).

There was marked variation in the completeness of regional reporting of data used in these analyses (Fig 1). Overall, data were provided by 8 of 12 states in the Northwest region (although 1 state reported only a single record of a speciated bat tested for rabies), 7 of 10 states in the Southwest region, 14 of 14 states in the Northeast region (although 4 states reported < 5 speciated bats tested for rabies), and 5 of 12 states in the Southeast region. All 5 states in the Southeast were on the northern border of this region.

Big brown (*E fuscus* [5.8%]) and little brown (*M lucifugus* [1.7%]) bats infrequently had rabies, although these species were most often submitted for rabies testing (Table 1). Among the 14 bat species that were frequently (≥ 100 individuals) tested for rabies, big brown bats ranked tenth and little brown bats tied for last with Yuma bats (*M yumanensis*) with regard to the percentage of bats that yielded positive results. The species with the highest percentage of bats with positive results for rabies among frequently tested bat

Table 1—Distribution of bats with rabies among various species tested in selected states in the United States, 1993–2000

Species	Common name	No. tested	No. positive (%)	Rank*
Antrozous pallidus	Pallid bat	100	21 (21.0)	4
Choeronycteris mexicana	Mexican long-tongued bat	14	0 (0.0)	
Eptesicus fuscus	Big brown bat	20,911	1,216 (5.8)	10
Euderma maculatum	Spotted bat	1	1 (100.0)	
Eumops perotis	Western bonneted bat	5	0 (0.0)	
Idionycteris phyllotis	Allen's big-eared bat	1	0 (0.0)	
Lasionycteris noctivagans	Silver-haired bat	566	73 (12.9)	6
Lasiurus borealis	Red bat	520	47 (9.0)	8
Lasiurus cinereus	Hoary bat	254	97 (38.2)	1
Lasiurus ega	Southern yellow bat	32	7 (21.9)	
Lasiurus intermedius	Northern yellow bat	3	3 (100.0)	
Lasiurus seminolus	Seminole bat	1	0 (0.0)	
Leptonycteris curasoae	Southern long-nosed bat	15	0 (0.0)	
Macrotus californicus	California leaf-nosed bat	4	0 (0.0)	
Myotis auriculus	Southwestern Myotis	9	0 (0.0)	
Myotis californicus	California Myotis	338	12 (3.6)	11
Myotis evotis	Long-eared Myotis	196	19 (9.7)	7
Myotis keenii	Keen's Myotis	572	11 (1.9)	12
Myotis leibii	Eastern small-footed Myotis	32	0 (0.0)	
Myotis lucifugus	Little brown bat	5,721	96 (1.7)	13
Myotis sodalis	Indiana bat	3	0 (0.0)	
Myotis thysanodes	Fringed Myotis	4	0 (0.0)	
Myotis velifer	Cave Myotis	2	0 (0.0)	
Myotis volans	Long-legged Myotis	23	3 (13.0)	
Myotis yumanensis	Yuma Myotis	241	4 (1.7)	13
Myotis (unspeciated)	Unspeciated Myotis	668	41 (6.1)	9
Nycticeius humeralis	Evening bat	62	6 (9.7)	
Pipistrellus hesperus	Western pipistrelle	193	41 (21.2)	3
Pipistrellus subflavus	Eastern pipistrelle	117	20 (17.1)	5
Plecotus townsendii	Townsend's big-eared bat	29	3 (10.3)	
Tadarida brasiliensis	Brazilian free-tailed bat	673	214 (31.8)	2
Nyctinomops (*Tadarida*) *femorosaccus*	Pocketed free-tailed bat	53	7 (13.2)	
Tadarida macrotis	Big free-tailed bat	14	3 (21.4)	
Tadarida unspeciated	Unspeciated free-tailed bats	3	1 (33.3)	
Total		**31,380**	**1,946 (6.2)**	

*Among species with ≥ 100 individual bats tested.

species was hoary bats (*Lasiurus cinereus* [38.2%]) followed by Brazilian free-tailed bats (31.8%). Eastern pipistrelle and silver-haired bats ranked fifth and sixth, with 17.1% and 12.9% of submitted individuals testing positive, respectively (Table 1).

Univariate analyses revealed that the risk of a bat in the LNPSTB group testing positive for rabies (22.6%) was significantly increased and > 5-fold higher than the corresponding value (5.5%) for the referent group containing all other bat species (**Table 2**). Restricting the analysis to the LNPS group (13.6% positive) and excluding Brazilian free-tailed bats from the referent group resulted in a similar outcome, although the OR was reduced. Brazilian free-tailed bats were excluded from the referent group in this analysis in order to make the referent groups identical and, therefore, make the results comparable to each other.

The number of bats tested for rabies varied by season; 5.7% of the bats tests were tested in winter, 11.3% in spring, 67.6% in summer, and 15.4% in autumn. The percentage of bats testing positive for rabies was highest in autumn (11.6%) and lowest in winter (3.1%; Table 2). With winter used as the referent group, the risk of a bat testing positive for rabies was significantly increased in all other seasons, with ORs ranging from 1.61 in summer to 4.07 in autumn.

Most (74.3%) of the bats tested for rabies originated from states in the Northeast, followed by the Northwest (11.0%), the Southwest (10.9%), and the Southeast (3.9%; Fig 1). The highest percentage (19.3%) of bats testing positive for rabies was found in the Southwest, followed by the Northwest (7.0%), the Southeast (6.7%), and the Northeast (4.1%; Table 2). With the Northeast used as the referent group, the risk of a bat testing positive for rabies was significantly increased in all other regions, with ORs ranging from 1.67 in the Southeast to 5.52 in the Southwest. Because the number of bats originating from New York contributed disproportionately to the overall sample (49.3% of the total), this state was removed from the analysis of the region, but this change did not affect the overall outcome, and the same regional relationships were apparent.

Most (81%) of the bats tested for rabies originated from states in which terrestrial carnivores constituted most rabies submissions and were the primary public health concern. Prior to data adjustments, a higher percentage of the bats originating from states with predominantly bat submissions tested positive for rabies (10.0%) than did bats originating from states testing predominantly terrestrial carnivores for rabies (5.3%; Table 2).

Table 2—Risk factors associated with speciated bats testing positive for rabies in the United States, 1993–2000

Risk factor	Rabid (No.) Yes	Rabid (No.) No	Rabid (%)	Rabid nonspeciated (%)	OR	95% CI	OR*
Species group							
LNPSTB = 1	307	1,048	22.7	NA	5.07	(4.43, 5.82)	2.75
LNPSTB = 0	1,639	28,385	5.5	NA	1.00		1.00
LNPS = 1	93	590	13.6	NA	2.73	(2.18, 3.42)	1.48
LNPS = 0	1,639	28,385	5.5	NA	1.00		1.00
Season							
Winter	56	1,737	3.1	3.8	1.00		1.00
Spring	285	3,258	8.0	8.9	2.72	(2.03, 3.64)	2.30
Summer	1,045	20,161	4.9	6.8	1.61	(1.22, 2.12)	2.19
Fall	560	4,275	11.6	15.2	4.07	(3.07, 5.38)	2.48
Region							
Northeast	965	22,342	4.1	5.0	1.00		1.00
Southeast	82	1,137	6.7	5.6	1.67	(1.32, 2.11)	2.19
Northwest	242	3,200	7.0	6.6	1.75	(1.51, 2.03)	1.74
Southwest	657	2,754	19.3	11.2	5.52	(4.96, 6.15)	4.42
Epitype							
Bat	593	5,365	10.0	7.1	1.97	(1.78, 2.18)	0.68
Terrestrial mammal	1,353	24,068	5.3	6.8	1.00		1.00

*Big brown and little brown bats excluded.
LNPSTB (1) = Silver-haired, eastern pipistrelle, and Brazilian free-tailed bats; LNPSTB (0) = All other bats. LNPS (1) = Silver-haired and eastern pipistrelle bats; LNPS (0) = All other bats except Brazilian free-tailed bats. OR = Odds ratio. CI = Confidence interval. NA = Not applicable.

Table 3—Factors associated with the odds of a bat testing positive for rabies, stratified by species group

Variable	LNPSTB (1) vs all other bats: All bats	LNPSTB (1) vs all other bats: No big brown or little brown bats	LNPS (1) vs all bats (Brazilian free-tailed bats excluded): All bats	LNPS (1) vs all bats (Brazilian free-tailed bats excluded): No big brown or little brown bats
Winter	2.80 (1.45, 5.42)	1.50 (0.47, 4.81)*	NC	NC
Spring	2.78 (2.06, 3.74)	1.92 (1.22, 3.01)	0.30 (0.10, 0.96)	0.21 (0.06, 0.70)
Summer	11.86 (9.29, 15.15)	5.17 (3.91, 6.82)	7.97 (5.76, 11.04)	3.47 (2.44, 4.93)
Fall	2.83 (2.26, 3.56)	2.93 (2.19, 3.93)	1.38 (0.97, 1.97)*	1.43 (0.96, 2.14)*
Northeast	2.60 (1.61, 4.20)	2.31 (1.32, 4.04)	2.63 (1.63, 4.25)	2.34 (1.34, 4.08)
Southeast	1.16 (0.35, 3.85)*	0.62 (0.18, 2.17)*	1.16 (0.35, 3.85)*	0.62 (0.18, 2.17)*
Northwest	4.08 (2.89, 5.75)	4.12 (2.71, 6.25)	4.12 (2.92, 5.82)	4.16 (2.74, 6.32)
Southwest	1.80 (1.51, 2.17)	1.92 (1.55, 2.37)	0.54 (0.34, 0.85)	0.57 (0.34, 0.92)
Bat epitype	1.82 (1.40, 2.36)	1.98 (1.45, 2.71)	1.53 (1.14, 2.06)	1.67 (1.19, 2.35)
Terrestrial mammal epitype	7.45 (6.34, 8.76)	3.15 (2.56, 3.87)	3.23 (2.26, 4.60)	1.36 (0.93, 1.99)*

Data are given as ORs and 95% CIs.
*Not significant ($P > 0.05$).
NC = Not calculated, because at least 1 cell contains a zero. *See* Table 2 for remainder of key.

Because big brown and little brown bats contributed disproportionately to the sample (85% of the total), all univariate analyses examining factors associated with a bat testing positive for rabies were repeated without these species (Table 2). Although the strength of association was in many instances reduced, removing these 2 species had no significant effect on the outcome with regard to species group (LNPSTB or LNPS), season, or region. However, when big brown and little brown bats were removed from the analysis, the odds of a bat testing positive for rabies from a bat state were reduced significantly (OR, 0.68), compared with bats originating from terrestrial states.

Because there were significant interactions between species groups (LNPSTB or LNPS) and the other covariates, adjusted ORs were not determined. However, stratum-specific ORs were derived, and results indicated that the likelihood of a silver-haired, eastern pipistrelle, or Brazilian free-tailed bat (LNPSTB) testing positive for rabies was increased in all seasons, most regions, and in all states regardless of whether the major pattern of wildlife rabies was bat or terrestrial (**Table 3**). For both of the species groups, the greatest odds of a bat testing positive for rabies were associated with summer season, the Northwest region, and origin from a state with predominantly terrestrial rabies (OR, 7.45). Removing big brown and little brown bats from the stratified analyses had little effect on the direction and significance of most outcomes.

Discussion

Results of these analyses indicated that Brazilian free-tailed, eastern pipistrelle, and silver-haired bats, when considered as a single group, were rabid more frequently than were other bat species. However, important exceptions were noted; hoary bats

(*L cinereus*) had the highest percentage of individuals with rabies (38.2%) among frequently tested species. Other notable results among infrequently tested bats were observed for spotted bats (*Euderma maculatum*) and northern yellow bats (*L intermedius*), which were always found rabid, although only 4 individuals of these 2 species were tested. Furthermore, although eastern pipistrelle and silver-haired bats had a higher percentage of individuals with rabies than many species in this study, pallid bats (*Antrozous pallidus*, [21%]), southern yellow bats (*L ega*, [21.9%]), and western pipistrelle bats (*P hesperus*, [21.2%]) each had higher percentages of individuals with rabies.

These descriptive results were generally consistent with those of other studies that were based on bats submitted for rabies testing to state laboratories. Frequently, analyses of data derived from these sources have a higher frequency of rabies among solitary or small-group-forming bat species, such as hoary, silver-haired, and red bats, than for most of the colonial species, such as big brown and little brown bats.[11,12,16-18,21] Among the bat species that roost in large colonies, one of the highest percentages of bats with rabies (> 50% in many monthly samples) has been reported for Brazilian free-tailed bats grounded (unable to fly) in caves in New Mexico.[14] However, results obtained from this type of targeted sampling are not directly comparable to data derived from routine laboratory submission of bats.

Several findings were notable from these analyses. The crude proportion of bats with rabies was significantly higher among states in which most submissions for rabies testing were bats, compared with results from states where most rabies submissions were terrestrial carnivores. This difference was caused by the large numbers of bats without rabies in states where terrestrial rabies is the predominant form of wildlife rabies (ie, the mid-Atlantic and New England states). In the eastern United States, epizootics of rabies among raccoons (*Procyon lotor*) have been occurring since the late 1970s,[22] and raccoons have been the predominant species reported rabid since the early 1990s.[6-8] All of the eastern states were classified as having predominantly terrestrial wildlife rabies, although they also contributed most of the bats tested for rabies and analyzed in this report.[3] In states affected by rabies in raccoons, the percentage of raccoons with rabies has typically ranged from 30 to 40%,[23,24] a percentage far greater than the approximately 6% of bats with rabies. The effect of the eastern states' terrestrial pattern of wildlife rabies on the odds of a bat having rabies was apparent when little brown and big brown bats were removed from the univariate analyses. After these 2 species were removed from consideration, bats tested in a state with predominantly terrestrial rabies were actually more likely to be rabid than were bats from states with predominantly bat submissions. The risk of rabies among individuals of the 3 bat species associated with variants of rabies virus that cause most of the human rabies deaths in the United States was increased in all states regardless of the predominate wildlife reservoir for rabies virus.

The proportion of bats with rabies was higher in all seasons relative to winter, and the highest percentage (11.6%) of bats with rabies was found in autumn. However, in stratified analyses, the greatest odds of a bat in the LNPSTB or the LNPS group having rabies were in the summer. A peak in the proportion of bats with rabies in the late summer or fall has been described by several authorities,[8,12,16,25] although the significantly increased risk of silver-haired and eastern pipistrelle bats having rabies in the summer had not been described. The monthly proportion of Brazilian free-tailed bats with rabies has a bimodal distribution with an early peak between April and July and a second peak in September and October.[26] These intervals correspond to the seasonal migration of this species to and from sites within the United States.[26] The increased proportion of bats with rabies in the late summer and early autumn has been ascribed to migrational stress, disease in young bats just learning to fly, and increased contact with humans who tend to be outside more often in the summer.[11,21,26]

Bats from the Northeast region had the lowest percentage of positive results for rabies. The highest risk of a bat testing positive was seen in the Southwest, largely because of the large number of rabid Brazilian free-tailed bats identified from that region. When stratified analyses were conducted, the risk of a bat in the LNPSTB group testing positive was increased in all regions except the Southeast region, which contributed few bats. When Brazilian free-tailed bats were excluded from the group analysis, the eastern pipistrelle and silver-haired bats were less likely to test positive for rabies in the Southwest region, confirming that the high percentage of Brazilian free-tailed bats testing positive for rabies accounts for the increased risk of testing positive for rabies among bats in this region.

The types and number of bat species tested from a given state or region were generally representative of the bat species distribution patterns across the continental United States, where the greatest diversity is found in the Southwest.[19] Overall, of the 21 species of bats with individuals found to be rabid, bats from 20 of these species had been previously identified as rabid in the United States.[27] The reports of rabies in the pocketed free-tailed bat (*Nyctinomops [Tadarida] femorosaccus*) may represent a new species with regard to national surveillance of rabies in bats. Although Brass[11] indicated that rabid individuals of this species had been previously identified in the United States, the authority cited[27] did not identify them as having been reported rabid.

There are several limitations inherent to using surveillance data to infer national trends in rabies epidemiology. The data provided to the CDC by state health departments were collected by passive surveillance systems that differ from state to state, and sometimes from county to county within a state. Some states test bats (or other animals) for rabies only if the submitted animal has been involved in a potential rabies exposure to a human or a domestic animal. Other states test all animals submitted, regardless of their history. Bats submitted for rabies testing that have bitten a human have been found rabid more frequently than are bats submitted for other contacts,[28] although such find-

ings are not consistent across all bat species.[17] Because the state-specific algorithm dictating when a bat should be tested for rabies influences the probability of a positive outcome, the percentage of bats testing positive for rabies at diagnostic laboratories cannot be interpreted as a measure of the true incidence or prevalence of rabies infection in any natural population. Finally, although this report summarizes the currently available national data, the data available for analysis were not truly national. Not all states gather or report information on bat species, nor do all states report the denominator information regarding the number of animals tested. When states reported few cases of speciated bats tested for rabies (eg, Maryland, Wyoming), it is often indicative of data for bats that originated in that state but were tested and reported by a neighboring state; therefore, the national coverage is less than that indicated (Fig 1). In addition, interruptions of state efforts to speciate bats (eg, as occurred in South Carolina from 1991 to 1995[17]) have posed an ongoing challenge to collecting continuous and representative data. Our results represent an interim report on national surveillance for rabies among bats in the United States and reflect ongoing efforts to improve national coverage.

[a]PROC FREQ/CMH, SAS Institute Inc, Cary, NC.

References

1. Childs JE. Epidemiology. In: Jackson AC, Wunner WH, eds. *Rabies*. New York: Academic Press Inc, 2002;114–162.

2. Smith JS. Rabies virus epitopic variation: use in ecologic studies. *Adv Virus Res* 1989;36:215–253.

3. Krebs JW, Smith JS, Rupprecht CE, et al. Mammalian reservoirs and epidemiology of rabies diagnosed in human beings in the United States, 1981–1998. *Ann N Y Acad Sci* 2000;916: 345–353.

4. Smith JS. Monoclonal antibody studies of rabies in insectivorous bats of the United States. *Rev Infect Dis* 1988;10(suppl 4):S637–S643.

5. Smith JS. Molecular epidemiology. In: Jackson AC, Wunner WH, eds. *Rabies*. New York: Academic Press Inc, 2002;79–111.

6. Krebs JW, Strine TW, Smith JS, et al. Rabies surveillance in the United States during 1993. *J Am Vet Med Assoc* 1994;205: 1695–1709.

7. Krebs JW, Smith JS, Rupprecht CE, et al. Rabies surveillance in the United States during 1997. *J Am Vet Med Assoc* 1998;213: 1713–1728.

8. Krebs JW, Mondul AM, Rupprecht CE, et al. Rabies surveillance in the United States during 2000. *J Am Vet Med Assoc* 2001;219:1687–1699.

9. McQuiston JH, Yager PA, Smith JS, et al. Epidemiologic characteristics of rabies virus variants in dogs and cats in the United States, 1999. *J Am Vet Med Assoc* 2001;218:1939–1942.

10. Noah DL, Drenzek CL, Smith JS, et al. Epidemiology of human rabies in the United States, 1980 to 1996. *Ann Intern Med* 1998;128:922–930.

11. Brass DA. *Rabies in bats*. Ridgefield, Conn: Livia Press, 1994.

12. Baer GM, Smith JS. Rabies in nonhematophagous bats. In: Baer GM, ed. *The natural history of rabies*. Boca Raton, Fla: CRC Press, 1991;341–366.

13. Davis RB, Herreid CF, Short HL. Mexican free-tailed bats in Texas. *Ecol Monog* 1962;32:311–346.

14. Constantine DG, Tierkel ES, Kleckner MD, et al. Rabies in New Mexico cavern bats. *Public Health Rep* 1968;83:303–316.

15. Morimoto K, Patel M, Corisdeo S, et al. Characterization of a unique variant of bat rabies virus responsible for newly emerging human cases in North America. *Proc Natl Acad Sci U S A* 1996;93: 5653–5658.

16. Childs JE, Trimarchi CV, Krebs JW. The epidemiology of bat rabies in New York State, 1988–92. *Epidemiol Infect* 1994;113: 501–511.

17. Parker EK, Dowda H, Redden SE, et al. Bat rabies in South Carolina, 1970–90. *J Wildl Dis* 1999;35:557–564.

18. Burnett CD. Bat rabies in Illinois: 1965 to 1986. *J Wildl Dis* 1989;25:10–19.

19. Humphrey SR. Nursery roosts and community diversity of Nearctic bats. *J Mammal* 1975;56:321–346.

20. Messenger SL, Smith JS, Rupprecht CE. Emerging epidemiology of bat-associated cryptic cases of rabies in humans in the United States. *Clin Infect Dis* 2002;35:738–747.

21. Bigler WJ, Hoff GL, Buff EE. Chiropteran rabies in Florida: a twenty-year analysis, 1954 to 1973. *Am J Trop Med Hyg* 1975;24: 347–352.

22. Childs JE, Curns AT, Dey ME, et al. Predicting the local dynamics of epizootic rabies among raccoons in the United States. *Proc Natl Acad Sci U S A* 2000;97:13666–13671.

23. Wilson ML, Bretsky PM, Cooper GH Jr, et al. Emergence of raccoon rabies in Connecticut, 1991–1994: spatial and temporal characteristics of animal infection and human contact. *Am J Trop Med Hyg* 1997;57:457–463.

24. Torrence ME, Jenkins SR, Glickman LT. Epidemiology of raccoon rabies in Virginia, 1984 to 1989. *J Wildl Dis* 1992;28: 369–376.

25. Krebs JW, Smith JS, Rupprecht CE, et al. Rabies surveillance in the United States during 1998. *J Am Vet Med Assoc* 1999;215: 1786–1798.

26. Constantine DG. Bat rabies in the southwestern United States. *Public Health Rep* 1967;82:867–888.

27. Constantine DG. An updated list of rabies-infected bats in North America. *J Wildl Dis* 1979;15:347–349.

28. Pape WJ, Fitzsimmons TD, Hoffman RE. Risk for rabies transmission from encounters with bats, Colorado, 1977–1996. *Emerg Infect Dis* 1999;5:433–437.