ANIMAL RABIES IN MASSACHUSETTS, 1985–2006

Authors: Wang, Xingtai, Werner, Barbara G., Konomi, Raimond, Hennigan, Dennis, Fadden, David, et al.

Source: Journal of Wildlife Diseases, 45(2) : 375-387

Published By: Wildlife Disease Association

URL: https://doi.org/10.7589/0090-3558-45.2.375

Journal of Wildlife Diseases, 45(2), 2009, pp. 375–387

ANIMAL RABIES IN MASSACHUSETTS, 1985–2006

Xingtai Wang,[1,2,4] **Barbara G. Werner,**[2] **Raimond Konomi,**[2] **Dennis Hennigan,**[1] **David Fadden,**[1] **Evan Caten,**[3] **Susan Soliva,**[3] **and Alfred DeMaria**[3]

[1] Rabies Laboratory, William A. Hinton State Laboratory Institute, Massachusetts Department of Public Health, 305 South Street, Jamaica Plain, Massachusetts 02130, USA
[2] Division of Virology and Molecular Diagnostics, Bureau of Laboratory Sciences, William A. Hinton State Laboratory Institute, Massachusetts Department of Public Health, 305 South Street, Jamaica Plain, Massachusetts 02130, USA
[3] Bureau of Communicable Disease Control, William A. Hinton State Laboratory Institute, Massachusetts Department of Public Health, 305 South Street, Jamaica Plain (Boston), Massachusetts 02130, USA
[4] Corresponding author (email: xingtai.wang@state.ma.us)

ABSTRACT: In this study, we review annual rabies data from Massachusetts from 1985 to 2006, spanning the introduction of raccoon strain rabies in 1992. Of 52,034 animals tested, 9.7% (5,049/52,034) were rabid, representing 26 of over 67 species submitted. Bats were the most common rabid animals prior to 1992 (50 of 52), but raccoons (*Procyon lotor*) became the most common rabies-positive species upon arrival of raccoon strain rabies virus (38.2%, 2,728 of 7,138 tested), followed by striped skunks (*Mephitis mephitis*, 34.4%, 1,489 of 4,332), bats (5.3%, 427 of 8,053), foxes (red fox, *Vulpes vulpes*, and gray fox, *Urocyon cinereoargenteus*, 16.3%, 135 of 827), cats (0.8%, 136 of 18,050), and woodchucks (*Marmota monax*, 5.7%, 82 of 1,446). Cats were the most frequently tested animal (34.7%). Raccoon strain rabies spread from two foci of introduction with an initial epizootic phase of 4 yr, by which time most of the state was affected. In 1992, there was a transition from enzootic bat rabies, with little spillover to other animals, to terrestrial rabies associated with raccoon strain virus. Although raccoons were most affected by the raccoon strain virus, there was spillover to other species, particularly to skunks. The eastern United States raccoon rabies epizootic led to a marked increase in submissions for rabies testing and the number of positive animals detected; however, bat rabies cases remained at their previous levels. Wild animal rabies presents a significant threat to humans and domestic/companion animals and increased costs related to increased demand for rabies testing, postexposure prophylaxis as well as euthanasia of valuable domestic animals.

Key words: Animal rabies, direct fluorescent antibody test, rabies suspect exposure, raccoon, raccoon strain rabies, spillover, wildlife.

INTRODUCTION

Rabies is transmitted to humans primarily through the saliva and neurologic tissues of infected animals by direct or indirect exposure (Fishbein and Robinson, 1993; Rupprecht et al., 1996; Faber et al., 2004) and the disease is almost invariably fatal (Hattwick et al., 1972; Willoughby et al., 2005). There have been very rare reported cases of survival after the development of rabies (Centers for Disease Control [CDC], 2004). Postexposure prophylaxis (PEP) is still the only effective way to prevent rabies after exposure (Rupprecht and Gibbons, 2004).

Three major epizootics of rabies have occurred in Europe, Canada, and the United States since World War II; vectors have included the red fox (*Vulpes vulpes*), the arctic fox (*Alopex lagopus*), and raccoons (*Procyon lotor*), respectively (Real et al., 2005). The raccoon strain of rabies virus spread throughout the east coast of the United States following the importation of rabid raccoons into West Virginia from Florida in 1977 and has become a threat to human and domestic animals because of the close contact of raccoons with human habitat (Real et al., 2005). Thus far, there has been only one identified case of human rabies due to the raccoon virus variant (CDC, 2003). Raccoon strain rabies arrived in Massachusetts in September 1992. Prior to 1992, rabies was found almost exclusively in bats and “spillover” of rabies from the bat reservoir to terrestrial animals was rare (Fielding et al., 1973; Fielding and Russo, 1977). In this study, we analyzed animal rabies detection data from Massachusetts, USA from 1985 to 2006 and describe trends and distribution of affected animals.

MATERIALS AND METHODS

The Massachusetts State Laboratory Institute (MSLI) Rabies Laboratory uses the direct fluorescent antibody test (DFA) on all submitted animal brain specimens according to the procedures recommended by the CDC. This approach is used as the primary diagnostic test in the United States and has a sensitivity approaching 100% (Smith et al., 1999). Parallel tests were done with two antibody conjugates, one from Chemicon International, Inc. (now Millipore, Billerica, Massachusetts, USA) and the other from FDI Fujirebio (Fujirebio Diagnostics, Inc., Malvern, Pennsylvania, USA). Retesting was performed for discrepant results. Decomposed brain tissue or brain tissue without recognizable brain stem and cerebellum are tested, but if negative, results from poor-quality specimens are reported as "unsatisfactory for rabies testing." Positive rabies specimens were strain typed with a panel of fluorescent conjugated monoclonal antibodies (Millipore). The time from the death of an animal to rabies testing was categorized as follows: 0 day, 1–5 days, 6–14 days, greater than 2 wk, and unspecified (unknown animal death date).

Exposures to rabid or potentially rabid animals were classified as human, companion and/or domestic animal (pet), both human and animal, or unspecified/unknown. The type of the exposure was classified as bite, scratch, lick, indirect (contact with saliva or neural tissue of potentially rabid animal on another surface, such as an attacked domestic animal), and other or unspecified. The type of animal for which a specimen was submitted for diagnostic testing was classified as companion/domestic, wild, stray (unowned companion animal), and unspecified. Data were collected from test request forms and stored in a Foxpro database, which was specifically designed for the Rabies Laboratory. Chi-square tests were applied to test for frequency differences. Color mapping was performed to describe the raccoon strain rabies introduction and geographic distribution in Massachusetts. For data cleaning and statistical analyses we used the SAS statistical package version 9.1 (SAS Institute Inc., Cary, North Carolina, USA), and for mapping we used the software ArcView Version 9.1 (Environmental Systems Research Institute, Inc. [ESRI], Redmond, Washington, USA).

The G-plot procedure was used for investigation of the proportion variation among four most commonly rabid terrestrial wild animals, temporal trends in submission of bats for rabies testing and rabid bats, as well as for seasonal variations.

RESULTS

Animal rabies detection

From 1985 through 2006, 52,034 suspected rabid animals were tested; 9.7% (5,049/52,034) were confirmed rabies positive and 2.7% (1,416/52,034) were reported as unsatisfactory. Rabies test results by year are presented in Table 1. Submissions included 67 animal species, of which 26 were positive. Among submitted animals, rabies virus infection was confirmed in 38.2% (2,728/7,138) of raccoons, 34.4% (1,489/4,332) of striped skunks (*Mephitis mephitis*), 5.3% (427/8,053) of bats, 16.3% (135/827) of foxes (includes both red fox [*V. vulpes*] and gray fox [*Urocyon cinereoargenteus*]), 0.8% (136/18,050) of cats, 5.7% (82/1,446) of woodchucks (*Marmota monax*), 14.2% (15/106) of cows, 9.1% (9/99) of coyotes (*Canis latrans*), 0.1% (8/6,767) of dogs, 1.6% (3/182) of horses, 44.4% (4/9) of river otters (*Lutra canadensis*), 9.7% (3/31) of pigs, 22.2% (2/9) of bobcats (*Lynx rufus*), 6.9% (2/29) of fishers (*Martes pennanti*), 1% (1/97) of white-tailed deer (*Odocoileus virginianus*), 0.9% (1/114) of goats, 0.2% (1/568) of rabbits, 1.9% (1/54) of shrews, 0.1% (1/1,591) of squirrels and one of two chinchilla. The 10 most frequently tested animals were cats (34.7% of total), bats (15.5%), raccoons (13.7%), dogs (13.0%), striped skunks (8.3%), squirrels (3.1%), woodchucks (2.8%), opossums (*Didelphis virginiana*, 1.7%), foxes (1.6%), and rabbits (1.1%), and the six most frequent rabid animals were raccoon (54% of the positives, 2,728/5,049), striped skunk (29.5%, 1,489/5,049), bats (8.5%, 427/5,049), fox (2.7%), cat (2.7%), and woodchuck (1.6%). Bats were primarily big brown bats (*Eptesicus fuscus*, 91.3% of positive bats).

Annual trends (1985–2006)

Bats were the only rabid animals identified from 1985 to 1990. In 1991, two rabid foxes with a bat strain virus were identified. The raccoon strain of rabies

TABLE 1. Annual specimen submission, rabies-positive, and unsatisfactory specimen results in Massachusetts, 1985–2006.

Year	Number of specimens	Positive for rabies		Unsatisfactory[a]	
		No.	%	No.	%
1985	408	8	2.0	23	5.6
1986	766	7	0.9	18	2.3
1987	662	5	0.8	22	3.3
1988	430	3	0.7	17	4.0
1989	225	5	2.2	7	3.1
1990	242	10	4.1	11	4.5
1991	386	14	3.6	12	3.1
1992	1,079	57	5.3	30	2.8
1993	3,972	720	18.1	77	1.9
1994	4,532	735	16.2	95	2.1
1995	3,438	400	11.6	65	1.9
1996	3,005	115	3.8	60	2.0
1997	3,128	282	9.0	96	3.1
1998	3,938	498	12.6	100	2.5
1999	3,270	226	6.9	64	2.0
2000	3,310	276	8.3	66	2.0
2001	3,346	280	8.4	110	3.3
2002	3,137	304	9.7	116	3.7
2003	2,983	216	7.2	83	2.8
2004	3,479	327	9.4	92	2.6
2005	3,388	329	9.7	127	3.7
2006	2,910	232	8.0	125	4.3
Total	52,034	5,049	9.7	1,416	2.7

[a] If no rabies virus infection was detected and there was poor specimen quality (desiccated or decomposed brain tissue, brain tissue without recognizable brain stem and cerebellum, etc.), the result reported "unsatisfactory for rabies testing."

virus became predominant after late 1992, and there was dramatic spillover of this strain into other animals, notably striped skunks. Trends for the four most commonly rabid terrestrial wild animals from 1992 through 2006 are shown in Figure 1.

There was a significant decrease in rabies-positive raccoons ($P<0.001$) and striped skunks ($P<0.001$) from 1995 to 1996. Overall, there was a 71.3% decrease in positive specimens, with only a 12.6% decrease in submissions and no change in the proportion of unsatisfactory specimens. Rabies-positive specimens also decreased for fox, cat, bat, and woodchuck in the same period, but differences were not statistically significantly.

Seasonal trends

The proportions of rabies-positive specimens were highest in March, April, October, November, and December; in these months more than 12% of submissions tested positive. July had the highest percentage of unsatisfactory specimens (4.8%) and the lowest proportion of rabies-positive animals (6.0%; Fig. 2).

Timeliness of specimen receipt and test result

Most specimens (71.6%) were tested 1–5 days after the death of the animal and 3.7% were tested the day of death (Table 2). Delivery of the specimen later than 2 wk occurred in 0.3%, with the longest delay being 75 days. There was a significant association between unsatisfactory specimen and time between death of the animal and testing ($P<0.001$). If specimens were delivered more than 2 wk after the death of the animal, 14.5% were unsatisfactory. The unsatisfactory proportion was 4.1% for specimens with an unspecified death date. The overall unsatisfactory proportion of those

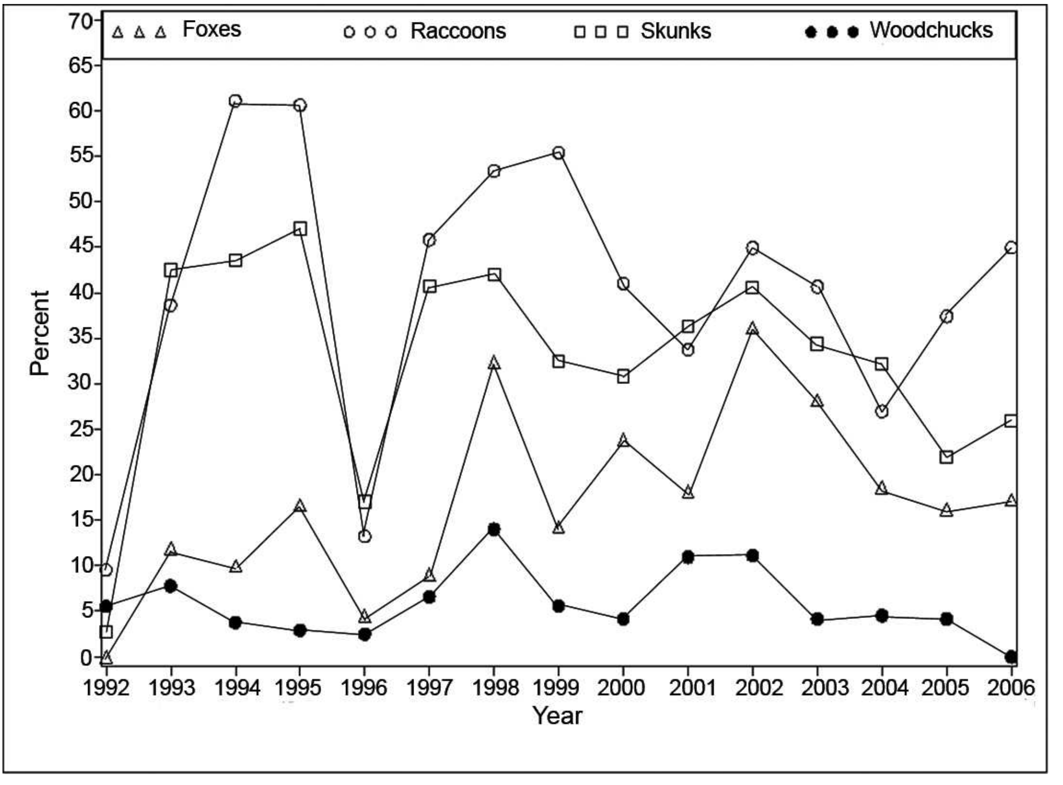

FIGURE 1. Raccoon strain rabies among the four most commonly rabid terrestrial wild animals in Massachusetts, 1992–2006.

specimens with information about death and submission date was 2.3% (958/41,119), except for frozen specimens that were part of a US Department of Agriculture (USDA) survey project.

Specimens delivered late (more than 2 wk from animal death to rabies testing) included 29.5% (49/166) of cats, 21.1% (35/166) of bats, 16.3% (27/166) of raccoons, 12% (20/166) of dogs, 9.6% (16/166) of skunks, and less than 3% of other animals. Confirmed rabid animals among late-delivered specimens included 10 bats, 8 raccoons, 3 skunks, and 1 fox.

Human/animal exposure, exposure type, and source animal of specimen

Of 52,034 animals tested, 56.9% (29,628/52,034) were associated with human exposure only, 20.1% (10,449/52,034) companion or domestic animal only, 8.3% (4,306/52,034) both, and for 14.7% (7,651/52,034) there was no exposure or no exposure information (Table 3). Active surveillance for monitoring the spread of raccoon strain rabies and evaluating an oral rabies vaccine (ORV) baiting project contributed 40.8% (3,119/7,651) of the animals without exposure or without exposure information; these submissions were mostly raccoons and skunks and 13.2% (412/3,119) were rabid. Companion/domestic animal–only exposures were associated with the highest positive proportion (24.3%), whereas human-only exposure had the lowest positive proportion for rabies (2.3%). Animals that exposed both people and animals were similar to that of animal only (19.5% positive). Specimen-unsatisfactory proportions followed a similar pattern.

There were 64,697 exposures associated with the 44,383 specimens that were submitted with exposure information (1.4

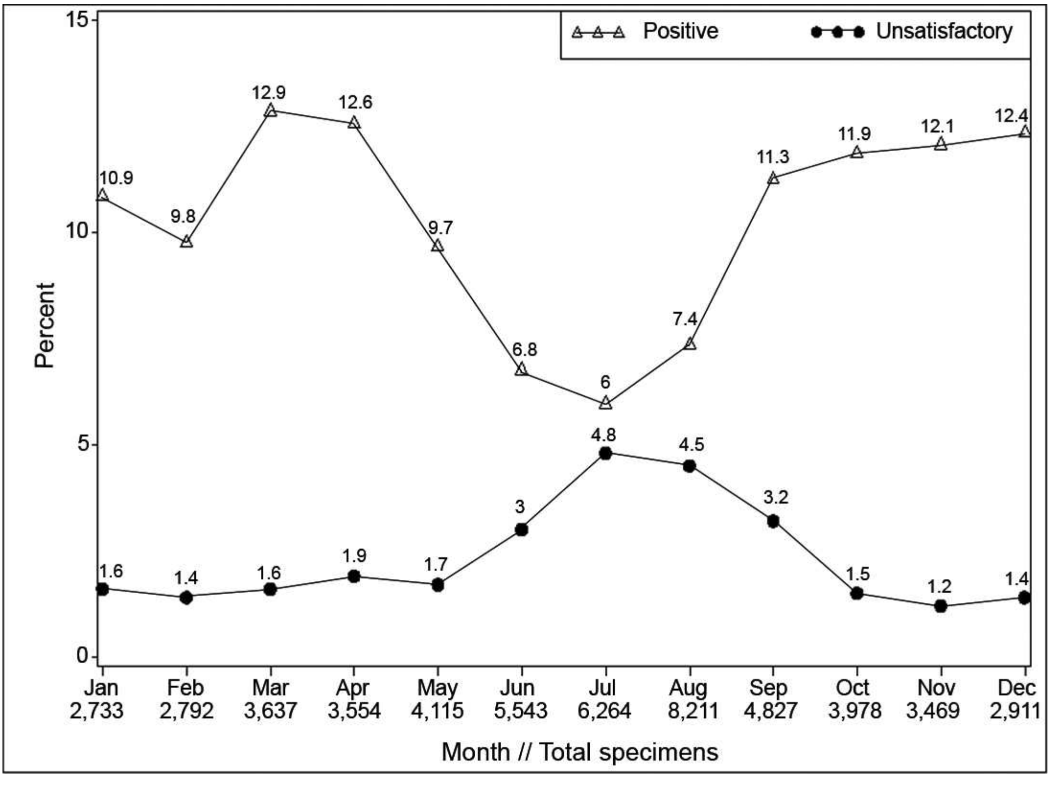

FIGURE 2. Monthly variation in percentage rabies-positive and unsatisfactory specimens submitted in Massachusetts, 1985–2006.

exposures per submission). The highest proportion of rabies positives was found in animals associated with indirect exposure (28.7%, 442/1,539) and the lowest was for scratch exposure (4.5%, 243/5,354; Table 4).

Wild animals had the highest rabies prevalence (19%), followed by unspecified (6.5%), stray (1.2%), and companion/domestic animals (0.5%). The differences between wild and either owned or stray companion/domestic animals were significant ($P<0.001$, df=3). Cats accounted for 52.8% (47/89) of rabies-positive companion/domestic animals and 76.8% (76/99) of positive stray animals. Raccoons and

TABLE 2. Specimens rabies positive and unsatisfactory with respect to time between animal death and rabies testing in Massachusetts, 1985–2006.

Category of time of death to testing	Number of specimens	Positive		Unsatisfactory	
		No.	%	No.	%
0 day	1,932	170	8.8	21	1.1
1–5 days	37,250	3,649	9.8	806	2.2
6–14 days	1,771	144	8.1	107	6.0
15–75 days	166	22	13.3	24	14.5
Unspecified	10,763	1,004	9.3	446	4.1
Frozen[a]	152	60	39.5	12	7.9
Total	52,034	5,049	9.7	1,416	2.7

[a] Tested as part of a US Department of Agriculture surveillance project.

TABLE 3. Proportions of specimens submitted for rabies testing by exposure category with specimens positive and unsatisfactory for rabies testing in Massachusetts, 1985–2006.

Category of exposure[a]	No. of specimens submitted (%)	Specimens positive for rabies		Specimens unsatisfactory	
		No.	%	No.	%
Human only	29,628 (56.9%)	686	2.3	448	1.5
Companion/domestic animal only	10,449 (20.1%)	2,538	24.3	547	5.2
Human and animal	4,306 (8.3%)	840	19.5	198	4.6
Unspecified	7,651 (14.7%)	985	12.9	223	2.9
Total	52,034	5,409	9.7	1,416	2.7

[a] Human and/or companion/domestic animal exposure.

skunks accounted for 56.7% (2,658/4,684) and 29.8% (1,397/4,684) of positive wild animals, respectively. The unsatisfactory specimen proportion was highest in wild animals (4.7%) and lowest in companion/domestic animals (0.5%), respectively ($P<0.001$, df=3).

Geographic distribution of raccoon rabies

There were two independent points of introduction of raccoon strain rabies into Massachusetts, USA. The first positive, reported in Ashby in the north-central part of the state on 16 September 1992, was followed by a broad expansion in a southeastern direction. The second introduction, reported in Monterey in the southwest corner of the state on 25 November 1992, displayed a multidirectional or circular diffusion. From these introductions, raccoon rabies rapidly spread statewide (Fig. 3). In early 2004, rabid raccoons were found in four previously unaffected towns on Cape Cod, an area that had been shielded by a successful wildlife rabies immunization project (Robbins et al., 1998). Only 15 towns out of 351 cities and towns had yet to confirm the presence of raccoon rabies by the end of 2006, and these included the seven towns on the islands of Martha's Vineyard and Nantucket. Only three of the smallest towns in the state had yet to submit a specimen for testing by the end of 2006.

Rabies in bats

Of 8,053 bats tested, 88.8% (7,151/8,053) were identified as big brown (*E. fuscus*) and 7.6% (613/8,053) little brown (*Myotis lucifugus*) bats. Keen's long-eared (*Myotis keenii*, n=95, 1.2%), red (*Lasiurus blossevillii*, n=47, 0.6%), hoary (*Lasiurus cinereus*, n=17, 0.2%), and silver-haired (*Lasionycteris noctivagans*, n=16, 0.2%) bats comprised the balance. Among 113 (1.4%) bats that were not identified to species, there were no positives. One Seychelles fruit bat (*Pter-*

TABLE 4. Category of exposure for rabies-positive and unsatisfactory specimens submitted in Massachusetts, 1985–2006.

Category of exposure	No. of exposures reported	Specimens positive for rabies		Specimens unsatisfactory	
		No.	%	No.	%
Bite	21,880	2,327	10.6	347	1.6
Scratch	5,354	243	4.5	38	0.7
Lick	2,099	238	11.3	71	3.4
Indirect	1,539	442	28.7	68	4.4
Other	12,317	2,211	18.0	567	4.6
Unspecified	21,508	2,816	13.1	781	3.6
Total	64,697	8,277	12.8	1,872	2.9

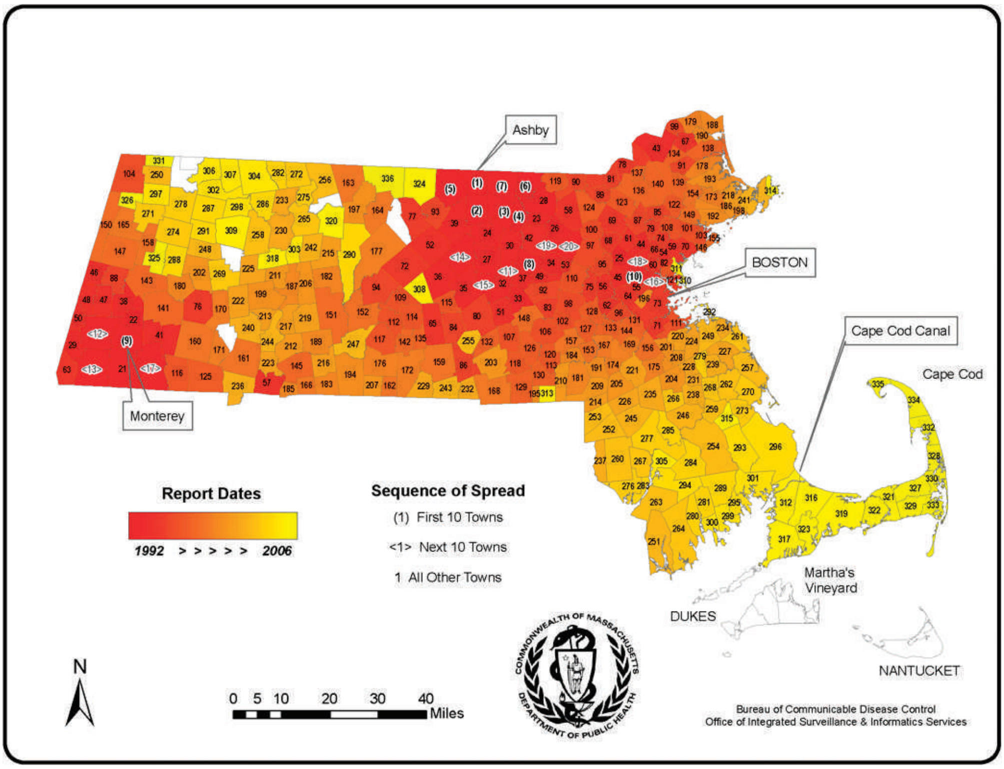

FIGURE 3. The spread of raccoon strain rabies across Massachusetts by cities and towns, 1992–2006.

opus seychellensis) was submitted by a zoo for rabies testing and was negative. Prevalence rates were similar for big brown (5.5%, n=390) and little brown bats (4.1%, n=25). Among the species with fewer numbers, positive results were observed for 23.5% (four positives) of hoary, 8.5% (four positives) of red, 6.3% (one positive) of silver-haired, and 3.2% (three positive) of Keen's long-eared bats. Among all rabies-positive bats, 91.3% were big brown, 5.9% were little brown, and 2.8% were the less common species.

For the period 1985–1991 (prior to the arrival of raccoon rabies), an average of 103 bats were submitted per year for rabies testing, with 6.9% positive. Bats accounted for 23.2% of the animals tested during this period. From 1992 through 1998, there were an average of 303 submissions per year, with 6.4% testing positive, but these accounted for only 9.2% of laboratory submissions. For the period 1999–2006, following revised recommendations associated with reports of increased risk from bat exposure without known bite or scratch (CDC and the Advisory Committee on Immunization Practices [ADIC]: Human Rabies Prevention—United States, 1999), there were an average of 651 submissions per year, with 4.7% positive; these accounted for 20.2% of submissions (Fig. 4).

DISCUSSION

The arrival of raccoon strain rabies in Massachusetts in 1992 had a dramatic impact on testing demand, species of animal submitted, types of animals positive for rabies, and circumstances surrounding specimen submission and testing. Prior to 1992, there were a small number of positive specimens annually, and they were almost exclusively bats (Fielding et al., 1973; Fielding and Russo,

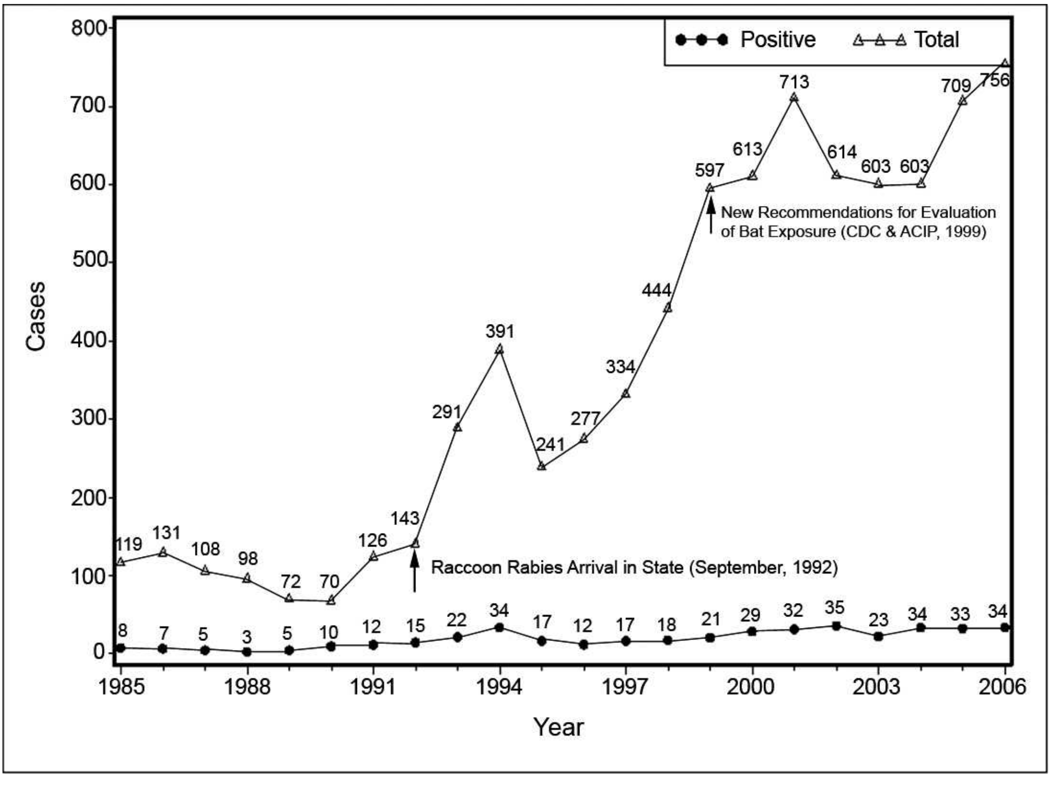

FIGURE 4. Temporal trends in submission of bats for rabies testing and bats found to be rabid in Massachusetts, 1985–2006.

1977). After 1992, specimen submissions increased to almost eightfold, and the number of positive animals increased to 45-fold. Similar to observations in other jurisdictions (Fischman et al., 1992; Krebs et al., 1994; Wilson et al., 1997; Guerra et al., 2003; Krebs et al., 2004), raccoons and skunks with the raccoon strain virus became the predominant animals positive for rabies, and the diversity of submitted and positive animals continued to increase significantly. In the period 1985–1991, bats accounted for 50/52 (96%) rabies-positive animals, with two foxes with bat strain rabies. Spillover of bat rabies into terrestrial mammals occurs, but is limited (Crawford-Miksza et al., 1999; Krebs et al., 2002; Shankar et al., 2005). After 1991, the vast majority of 4,997 positive animals identified in Massachusetts had the raccoon strain. Raccoon strain rabies is readily transmitted to a variety of terrestrial animals, most notably skunks (Fischman et al., 1992; Roscoe et al., 1998; Gordon et al., 2004).

Although raccoons, skunks, and bats were most frequently confirmed rabid, cats were the most frequently submitted animal. Cats accounted for 34.3% of submitted animals, but less than 1% of submitted cats were rabid and they accounted for only 2.7% of rabid animals. Raccoons and skunks accounted for 22.0% of submissions, but 83.5% of positives. Bats were 15.5% of submissions and 8.5% of positives. These characteristics of animal submissions and testing results mirror those observed in Connecticut (Wilson et al., 1997). The relative number of submissions and positive results relate to the transmission characteristics of raccoon rabies, the continued enzootic occurrence of bat rabies, the accessibility of animals for testing, and public awareness. Although exposures to wild animals may frequently involve an animal that is not subsequently captured or tested (especially those not affected by rabies), the potential for capturing a cat, owned or stray, probably is greater. Nonetheless, despite the availability of cats to test for rabies after human exposure and the low proportion of positives, cats consistently account for a majority of postexposure prophylaxis courses (Wyatt et al., 1999; Blanton et al., 2005).

Positive rabies specimens were most frequently detected in the spring and fall. The summer had the highest proportion of specimen submissions; prevalence was lower. Some of the increase in the number of rabies cases in the spring may be related to the emergence of susceptible yearlings and juveniles. The increased number of submissions in the summer accounts for the lower prevalence (higher denominator), and most likely relates to the likelihood of human and domestic animal encounters with wild, stray, and owned animals, rabid and otherwise. Fall is associated with fewer encounters and higher likelihood that an encounter would be with a rabid animal demonstrating abnormal behavior. Similar seasonal variation in rabies incidence in animals with the introduction of raccoon strain rabies has been observed in other areas (Jenkins et al., 1988; Fischman et al., 1992; Torrence et al., 1992; Krebs et al., 2000; Guerra et al., 2003).

Timeliness of rabies specimen delivery and testing in Massachusetts has been quite good, with the majority tested in 5 days or less, despite the large increases in demand. Annual proportion of unsatisfactory specimens ranged from 2.3 to 5.6% prior to 1992 compared to 1.9 to 4.3% in 1992 and later, when many more specimens were submitted. The reasons for specimens being unsatisfactory are several, including deterioration related to decomposition and insufficient specimen due to destruction of brain and brain stem tissue. The former underlies the correlation between unsatisfactory specimens and delays in submission, and the latter is often seen in bats damaged during capture or killing. An indicator of the role of decomposition in unsatisfactory specimens is the proportion of unsatisfactory specimens in the summer months, when there is more opportunity for heat effects before collection and breaks in consistent cold storage. Proportions of unsatisfactory specimens were least (1.5%) when there was only human exposure to a potentially rabid animal. The unsatisfactory proportions when a domestic animal, or a domestic animal and human, were exposed were 5.2% and 4.6%, respectively. The human-only exposures accounted for 56.9% of submitted animals with 2.3% positive, whereas the domestic animal and both domestic animal and human exposures contributed almost 30% of the submitted animals, with positivity of 23%. The lack of a specimen to test may result in unnecessary, expensive, uncomfortable, and inconvenient postexposure prophylaxis or euthanasia of a valued or valuable animal.

Animals that were the source of indirect human exposures (exposure of a person to an animal that was exposed to another potentially rabid animal) were most likely to be positive and scratch exposures were the least likely. The nature of the indirect exposure is usually a fight between an aggressive wild animal and a dog. This has become a common precipitant of postexposure prophylaxis for rabies in the northeast (Wyatt et al., 1999; Bretsky and Wilson, 2001). Aggressive behavior against a dog is abnormal behavior for most raccoons and skunks, so it is not surprising that these animals are likely to be rabid. Although indirect exposures lead to many instances of postexposure treatment, there is no evidence that this type of exposure has been associated with cases of human rabies (Rupprecht and Gibbons, 2004). Scratch exposures tend to involve interactions with cats, especially stray cats, and such scratches can be consistent with normal behavior. Scratch exposures led to testing over three times more frequently than indirect exposures, in part because the animals were more accessible.

Wild animals tested for rabies in Massachusetts were more likely to be rabid than domestic animals, consistent with the situation in the developed world, in which canine rabies has been controlled or eliminated (Blanton et al., 2007; CDC, 2007). More raccoons were positive than skunks, but the spillover of raccoon strain rabies into skunks is significant, and in some areas, including Massachusetts, rabid skunks with raccoon strain have outnumbered rabid raccoons, raising a concern about skunk-to-skunk transmission of the raccoon virus variant (Krebs et al., 2000). Cat rabies in the United States reflects spillover of the dominant terrestrial rabies virus where it occurs (McQuiston et al., 2001). Cats were the most frequent domestic animal positive in Massachusetts, and most of the positive cats were strays. Submitted cats are less likely to be vaccinated than dogs, even though state law requires that both dogs and cats have documentation of vaccination. This highlights the critical prevention message of having cats vaccinated and of avoiding stray cat exposure, to eliminate the risk of rabies as well as the expense associated with testing and postexposure prophylaxis. The costs associated with preventing rabies are substantial (Kreindel et al., 1998; Chang et al., 2002; Shwiff et al., 2007). Raccoon rabies spread across Massachusetts from two distinct foci of introduction in 1992, one in the north-central part of the state and one in the extreme southwestern corner, as shown in Figure 3. Increased testing allowed for an ongoing analysis of spatial trends and dynamics of the epidemic over time. During the initial 4 yr, rabies spread across the state, sparing only Cape Cod and the islands of Nantucket and Martha's Vineyard, a wildlife rabies vaccination program providing an immune barrier along the Cape Cod Canal (Robbins et al., 1998). By 1996, with the otherwise complete involvement of the state, there was a precipitous drop in animal submissions and positivity. This reflects population dynamics in the face of an epizootic of fatal disease and the exhaustion of susceptible animals to sustain the force of infectivity. This is consistent with the 48-mo period of the first epizootic phase in the predictive modeling (Childs et al., 2000) and other temporal and spatial analysis of wildlife rabies (Bögel et al., 1976; Hanlon et al., 1999; Guerra et al., 2003). Since that time, a less dramatic, approximate 5-yr cycle may be in evidence, with geotemporal hot spots of intensified activity occurring. A recent hot spot occurred on Cape Cod following the breach of the vaccine barrier in 2004. Epizootic spread and temporal–spatial clustering have been characteristic of the spread of raccoon rabies in the eastern United States (Fischman et al., 1992; Childs et al., 2000; Recuenco et al., 2007). The clusters of intensified activity in local areas also contribute to the cyclic pattern.

Bat rabies has been and continues to be a source of human rabies risk (Rupprecht et al., 2004). Bats continue to consistently test rabies positive. The bats submitted for testing and found to have rabies in Massachusetts, overwhelmingly big brown bats, are the same species as those reported previously in New York (Childs et al., 1994). The arrival of raccoon rabies was associated with a greater than twofold increase in demand for testing of bats, most likely related to increased awareness of rabies in general, with no change in the proportion of bats found rabid. Recommendations in response to the recognition that most indigenous cases of human rabies in the United States are due to bat strains of the virus, often without defined exposure (CDC and ACIP, 1999), also led to increased demand for bat testing and increased post-exposure treatment. Several limitations of this study should be noted. In particular, the primary and often the only source of information was on test request forms. In many instances, information was incomplete and inferences may have been made on the basis of the information supplied. The reliability of data provided could not be validated, but in instances of positive results, follow-up with the submitter or the exposed often supplied confirmation not available for negative submissions. Identification of East Coast raccoon rabies virus variant was made in the majority of spillover cases by testing with monoclonal antibody conjugates and in only a limited number of cases, by genomic analysis; thus, it was usually assumed that raccoons were positive for the raccoon epizootic strain. There were 52 rabies-positive specimens out of 3,119 animals, primarily raccoons and skunks, submitted by USDA for surveillance purposes and for evaluating of the oral raccoon vaccine (ORV) baiting project. These did not have human or pet exposure. Unfortunately, we are unable to differentiate the specimens by purpose. Including these submissions, the proportion of positive specimens decreased from 10.5% to 9.7%. Finally, and of some importance whenever laboratory submissions are the basis for inferences about wildlife disease, there is no information on similar interactions and events that do not lead to submission of specimens. Specimens associated with human and domestic animal exposures were targeted for testing.

The spread of raccoon strain rabies across the eastern United States since 1980 has had a large impact on public health programs, including public health laboratories, where essentially all of the public health rabies testing is done. In Massachusetts, the volume of testing rose substantially and the characteristics of animal rabies changed markedly. Prior to 1992, encounters with potentially rabid terrestrial animals were less commonly followed up with testing, and tests were rarely positive. Now, both terrestrial and bat rabies remain enzootic and a continuing challenge to public health agencies, and especially to public health laboratories.

ACKNOWLEDGMENTS

The authors express their appreciation to the staff of the Massachusetts Department of Public Health, Bureau of Laboratory Sciences, and Bureau of Communicable Disease Control, for their commitment to rabies surveillance and control, to the dedicated animal control and animal inspectors of Massachusetts cities and towns, and to the veterinarians of Massachusetts in practice in the community and at the Tufts Cummings School of Veterinary Medicine.

LITERATURE CITED

Blanton, J. D., N. Y. Bowden, M. Eidson, J. D. Wyatt, and C. A. Hanlon. 2005. Rabies postexposure prophylaxis, New York, 1995–2000. Emerging Infectious Diseases 11: 1921–1927.

———, C. A. Hanlon, and C. E. Rupprecht. 2007. Rabies surveillance in the United States during 2006. Journal of the American Veterinary Medical Association 227: 1912–1925.

Bögel, K., H. Moegle, F. Knorpp, A. Arata, K. Dietz, and P. Diethelm. 1976. Characteristics of the spread of a wildlife rabies epidemic in Europe. Bulletin of the World Health Organization 54: 433–447.

Bretsky, P. M., and M. L. Wilson. 2001. Risk factors for human exposure to raccoon rabies during an epizootic in Connecticut. Vector-Borne and Zoonotic Diseases 1: 211–217.

Centers for Disease Control and Prevention (CDC) and the Advisory Committee on Immunization Practices: Human Rabies Prevention—United States. 1999. Recommendations of the Advisory Committee on Immunization Practices (ACIP). Morbidity and Mortality Weekly Report Recommendations and Reports 48 (RR-1): 1–21.

CDC. 2003. First human death associated with raccoon rabies—Virginia. Morbidity and Mortality Weekly Report Recommendations and Reports 52: 1102–1103.

CDC. 2004. Recovery of a patient from clinical rabies—Wisconsin. Morbidity and Mortality Weekly Report Recommendations and Reports 53: 1171–1173.

CDC. 2007. *CDC announces at inaugural World Rabies Day symposium*, www.cdc.gov/2007/09/canine_rabies.html. Accessed 28 September 2007.

Chang, H. G., M. Eidson, C. Noonan-Toly, C. V. Trimarchi, R. Rudd, B. J. Wallace, P. F. Smith, and D. L. Morse. 2002. Public health impact of reemergence of rabies, New York. Emerging Infectious Diseases 8: 909–913.

Childs, J. E., A. T. Curns, M. E. Dey, L. A. Real, L. Feinstein, O. N. Bjørnstad, 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.

———, C. V. Trimarchi, and J. W. Krebs. 1994. The epidemiology of bat rabies in New York State, 1988–92. Epidemiology and Infection 113: 501–511.

Crawford-Miksza, L. K., D. A. Wadford, and D. P. Schnurr. 1999. Molecular epidemiology of enzootic rabies in California. Journal of Clinical Virology 14: 207–219.

Faber, M., R. Pulmanausahakul, K. Nagao, M. Prosniak, A. B. Rice, H. Koprowski, M. J. Schnell, and B. Dietzschold. 2004. Identification of viral genomic elements responsible for rabies virus neuroinvasiveness. Proceedings of the National Academy of Sciences of the United States of America 101: 16328–16332.

Fielding, J. E., and P. K. Russo. 1977. Massachusetts Department of Public Health. Bats, rabies and DDT. New England Journal of Medicine 297: 390–392.

Fischman, H. R., J. K. Grigor, J. T. Horman, and E. Israel. 1992. Epizootic of rabies in raccoons in Maryland from 1981 to 1987. Journal of the American Veterinary Medical Association 201: 1883–1886.

Fishbein, D. B., and L. E. Robinson. 1993. Rabies. New England Journal of Medicine 329: 1632–1638.

Gordon, E. R., A. T. Curns, J. W. Krebs, C. E. Rupprecht, L. A. Real, and J. E. Childs. 2004. Temporal dynamics of rabies in a wildlife host and the risk of cross-species transmission. Epidemiology and Infection 132: 515–524.

Guerra, M. A., A. T. Curns, C. E. Rupprecht, C. A. Hanlon, J. W. Krebs, and J. E. Childs. 2003. Skunk and raccoon rabies in the eastern United States: Temporal and spatial analysis. Emerging Infectious Diseases 9: 1143–1150.

Hanlon, C. A., J. E. Childs, and V. F. Nettles. 1999. Recommendations of a national working group on prevention and control of rabies in the United States. Article III: Rabies in wildlife. National Working Group on Rabies Prevention and Control. Journal of the American Veterinary Medical Association 215: 1612–1618.

Hattwick, M. A., T. T. Weis, C. J. Stechschulte, G. M. Baer, and M. B. Gregg. 1972. Recovery from rabies. A case report. Annals of Internal Medicine 76: 931–942.

Jenkins, S. R., B. D. Perry, and W. G. Winkler. 1988. Ecology and epidemiology of raccoon rabies. Reviews of Infectious Diseases 10 (Suppl 4): S620–S625.

Krebs, J. W., E. J. Mandel, D. L. Swerdlow, and C. E. Rupprecht. 2004. Rabies surveillance in the United States during 2003. Journal of the American Veterinary Medical Association 225: 1837–1849.

———, H. R. Noll, C. E. Rupprecht, and J. E. Childs. 2002. Rabies surveillance in the United States during 2001. Journal of the American Veterinary Medical Association 221: 1690–1701.

———, C. E. Rupprecht, and J. E. Childs. 2000. Rabies surveillance in the United States during 1999. Journal of the American Veterinary Medical Association 217: 1799–1811.

———, T. W. Strine, J. S. Smith, C. E. Rupprecht, and J. E. Childs. 1994. Rabies surveillance in the United States during 1993. Journal of the American Veterinary Medical Association 205: 1695–1709.

Kreindel, S. M., M. McGuill, M. Meltzer, C. E. Rupprecht, and A. DeMaria, Jr. 1998. The cost of rabies postexposure prophylaxis: One state's experience. Public Health Reports 113: 247–251.

McQuiston, J. H., P. A. Yager, J. S. Smith, and C. E. Rupprecht. 2001. Epidemiologic characteristics of rabies virus variants in dogs and cats in the United States, 1999. Journal of the American Veterinary Medical Association 218: 1939–1942.

Rabies in Massachusetts—Eleven years in retrospect. 1973. New England Journal of Medicine 288: 319–320.

Real, L. A., J. C. Henderson, R. Biek, J. Snaman, T. L. Jack, J. E. Childs, E. Stahl, L. Waller, R. Tinline, and S. Nadin-Davis. 2005. Unifying the spatial population dynamics and molecular evolution of epidemic rabies virus. Proceedings of the National Academy of Sciences of the United States of America 102: 12107–12111.

Recuenco, S., M. Eidson, M. Kulldorff, G. Johnson, and B. Cherry. 2007. Spatial and temporal patterns of enzootic raccoon rabies adjusted for multiple covariates. International Journal of Health Geographics 6: 14.

Robbins, A. H., M. D. Borden, B. S. Windmiller, M. Niezgoda, L. C. Marcus, S. M. O'Brien, S. M. Kreindel, M. W. McGuill, A. Demaria, Jr., C. E. Rupprecht, and S. Rowell. 1998. Prevention of the spread of rabies to wildlife by oral vaccination of raccoons in Massachusetts. Journal of the American Veterinary Medical Association 213: 1407–1412.

Roscoe, D. E., W. C. Holste, F. E. Sorhage, C. Campbell, M. Niezgoda, R. Buchannan, D. Diehl, H. S. Niu, and C. E. Rupprecht. 1998. Efficacy of an oral vaccinia-rabies glycoprotein recombinant vaccine in controlling epidemic raccoon rabies in New Jersey. Journal of Wildlife Diseases 34: 752–763.

Rupprecht, C. E., and R. V. Gibbons. 2004. Clinical practice. Prophylaxis against rabies. New England Journal of Medicine 351: 2626–2635.

———, J. S. Smith, J. Krebs, M. Niezgoda, and J. E. Childs. 1996. Current issues in rabies prevention in the United States: Health dilemmas, public coffers, private interests. Public Health Reports 111: 400–407.

SHANKAR, V., L. A. ORCIARI, C. DEMATTOS, I. V. KUZMIN, W. J. PAPE, T. J. O'SHEA, AND C. E. RUPPRECHT. 2005. Genetic divergence of rabies viruses from bat species of Colorado, USA. Vector-Borne and Zoonotic Diseases 5: 330–341.

SHWIFF, S. A., R. T. STERNER, M. T. JAY, S. PARIKH, A. BELLOMY, M. I. MELTZER, C. E. RUPPRECHT, AND D. SLATE. 2007. Direct and indirect costs of rabies exposure: A retrospective study in Southern California (1998–2002). Journal of Wildlife Diseases 43: 251–257.

SMITH, J. S. 1999. *In* P. R. Murray, E. J. Baron, M. A. Pfaller, F. C. Tenover, and R. H. Yolken (eds.). Rabies virus—Manual of clinical microbiology. 7th Edition. American Society for Microbiology, Washington, D.C., pp. 1099–1106.

TORRENCE, M. E., S. R. JENKINS, AND L. T. GLICKMAN. 1992. Epidemiology of raccoon rabies in Virginia, 1984 to 1989. Journal of Wildlife Diseases 28: 369–376.

WILLOUGHBY, R. E. JR., K. S. TIEVES, G. M. HOFFMAN, N. S. GHANAYEM, C. M. AMLIE-LEFOND, M. J. SCHWABE, M. J. CHUSID, AND C. E. RUPPRECHT. 2005. Survival after treatment of rabies with induction of coma. New England Journal of Medicine 352: 2508–2514.

WILSON, M. L., P. M. BRETSKY, G. H. COOPER, 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. The American Journal of Tropical Medicine and Hygiene 57: 457–463.

WYATT, J. D., W. H. BARKER, N. M. BENNETT, AND C. A. HANLON. 1999. Human rabies post exposure prophylaxis during a raccoon rabies epizootic in New York, 1993 and 1994. Emerging Infectious Diseases 5: 415–423.

Received for publication 26 September 2007.