

Rabies surveillance in the United States during 2022

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OBJECTIVE

To provide comprehensive epidemiological information about the distribution and occurrence of rabies during 2022 in the US, Canada, and Mexico.

METHODS

The US National Rabies Surveillance System collected 2022 animal rabies data from US state and territorial public health departments and USDA Wildlife Services. Temporal and geographic analyses were conducted to evaluate trends in animal rabies cases.

RESULTS

During 2022, 54 US jurisdictions reported 3,579 animal rabies cases, reflecting a 2.3% decline from 3,663 cases reported in 2021. Six states collectively reported > 50% of animal rabies cases: Texas (395 [11.0%]), Virginia (337 [9.4%]), Pennsylvania (329 [9.2%]), New York (267 [7.5%]), North Carolina (264 [7.4%]), and California (241 [6.7%]). Out of the total reported rabies animal cases, 3,234 (90.4%) were attributed to wildlife, with bats (1,218 [34.0%]), raccoons (1,014 [28.3%]), skunks (660 [18.4%]), and foxes (269 [7.5%]) representing the primary hosts confirmed with rabies. Rabid cats (222 [6.2%]), cattle (42 [1.2%]), and dogs (50 [1.4%]) constituted > 90% of reported domestic animal rabies cases.

CONCLUSIONS

In 2022, there was an increase in the number of animal samples submitted for rabies testing in the US and Canada. A notable geographic expansion of gray fox rabies virus variant was detected in the US. Three human rabies deaths due to vampire bat rabies infection occurred in Mexico; none were reported from the US and Canada.

CLINICAL RELEVANCE

Laboratory diagnosis of rabies in animals is critical to ensure judicious use of human rabies postexposure prophylaxis.

The annual rabies surveillance report provides the official rabies statistics for the US and an overview of rabies in Canada and Mexico during 2022. In the US, the primary hosts for rabies are bats (multiple species),

raccoons (*Procyon lotor*), skunks (primarily *Mephitis mephitis* [striped skunk]), foxes (*Vulpes lagopus* and *Urocyon cinereoargenteus*), and the small Indian mongoose (*Herpestes auro-punctatus*). Rabies virus variants (RVVs) maintained in mesocarnivores have undergone evolutionary changes within their respective host species and circulate in distinct geographic regions of the country (Figure 1).¹ An estimated 60,000 human exposures to rabies virus occur in the US each year, mainly from interactions with wildlife and unvaccinated domestic animals.² National rabies surveillance is critical to maintain an understanding of changes in RVV distributions and to identify emergent rabies threats such as introduction of novel variants, translocation of enzootic RVVs, and host-shift

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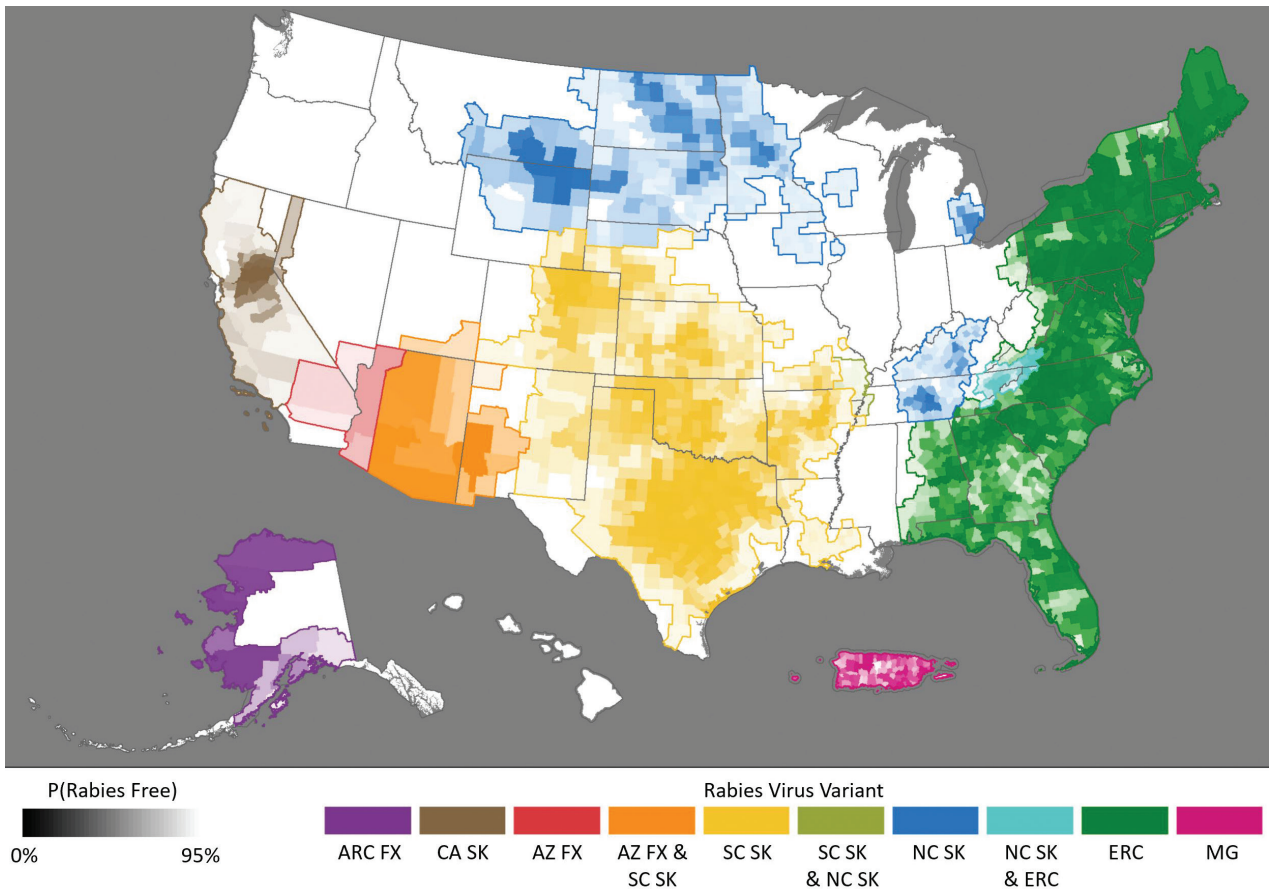


Figure 1—Distribution of major rabies virus variants (RVVs) among mesocarnivores in the US, including Puerto Rico. Lighter shading indicates a higher probability of terrestrial rabies freedom as determined by a county-level terrestrial rabies freedom model. Counties with a probability of > 95% are considered terrestrial rabies free (no color). ARC FX = Arctic fox RVV. AZ FX = Arizona fox RVV. CA SK = California skunk RVV. ERC = Eastern raccoon RVV. MG = Dog-mongoose RVV. NC SK = North central skunk RVV. SC SK = South central skunk RVV.

events. Prompt detection of changes to the known rabies epidemiology of the US is essential to protect public health, animal welfare and production, and wildlife ecosystems.

Reporting and Analysis

Approximately 130 public health, agriculture, and academic laboratories support the CDC-maintained US National Rabies Surveillance System through laboratory-based case surveillance. Laboratories perform animal rabies diagnostic tests that are accompanied by epidemiologic investigations conducted by 54 jurisdictional public health departments. Additional enhanced rabies surveillance targeting wildlife is conducted by USDA Wildlife Services as a complement to public health surveillance to monitor the geographic extent of terrestrial rabies in select areas where wildlife rabies management is conducted.

Human and animal rabies are notifiable conditions in the US. Reporting timelines, data elements, and animal rabies case definitions are detailed by the Council of State and Territorial Epidemiologists. The direct fluorescent antibody test, the direct rapid immunohistochemical test, immunohistochemistry, and the

pan-lyssavirus probe-based real-time reverse transcription PCR test are considered acceptable animal rabies diagnostic tests, and genomic and antigenic typing methods are acceptable for rabies virus characterization.³⁻⁵ During 2022, 54 jurisdictions submitted 85,691 animals for rabies testing (25.7 animals submitted/100,000 US human population), of which 83,626 (97.6%) had a conclusive (positive or negative) test result.

Analysis of trends in major rabies cases and RVV characterization are depicted in **Figure 2**. Terrestrial RVV territories were determined at the county level with historic RVV characterization data. Probability of terrestrial rabies freedom was determined as described by Kunkel et al⁶; counties with probability of rabies freedom > 95% are considered to be free of terrestrial rabies. Results in 2022 were deemed significantly different from previous results when falling outside the 95% CI established during the preceding 5-year period. The Canadian Food Inspection Agency (CFIA) Centre of Expertise for Rabies and the Centro Nacional de Programas Preventivos y Control de Enfermedades of the Secretaría de Salud (Mexican Ministry of Health) provided a summary of rabies surveillance activities during 2022 in Canada and Mexico, respectively.

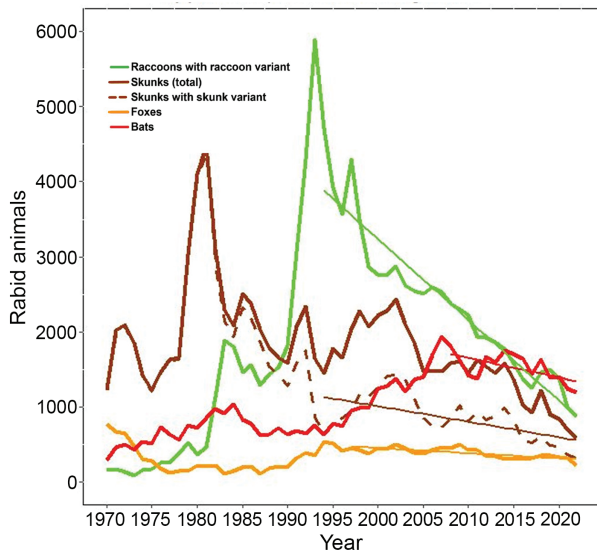


Figure 2—Cases of rabies among wildlife in the US, including Puerto Rico, by year and species, 1970 through 2022.

Rabies in Wildlife in the US

In 2022, 3,234 wildlife tested positive for rabies, representing a 3.5% decrease from the 3,352 reported wildlife rabies cases in 2021 (**Table 1**). The positivity rate of wildlife tested (7.7%) was significantly lower than the previous 5-year average (8.7%; 95% CI, 8.4% to 9.0%; **Table 2**).

Bats

In 2022, 1,218 bats tested positive for rabies, representing a 1.9% decrease compared to the 1,241 reported in 2021 (**Table 1**). The positivity rate of bats tested (5.2%) was significantly lower than the previous 5-year average (5.7%; 95% CI, 5.5% to 5.9%; **Table 2**). All jurisdictions, except Hawaii and Puerto Rico, reported rabid bats during 2022. Bats were the only animals that tested positive for rabies in 10 states (Iowa, Idaho, Illinois, Indiana, Louisiana, Mississippi, Nevada, Utah, Washington, and Wisconsin) in 2022. Six states together reported more than 50% of all reported rabid bats: California (189 [15.5%]), Texas (156 [12.8%]), Pennsylvania (100 [8.2%]), New York (85 [7.0%]), Illinois (61 [5.0%]), and Michigan (45 [3.7%]). About half (49.1%) of the bats tested for rabies in 2022 had genus and species identified and reported, which is an increase compared to 2021 (28.8%). Big brown bats (*Eptesicus fuscus*; n = 8,955; 3.9% positive) were the most frequently tested bat species, followed by Mexican free-tailed bats (*Tadarida brasiliensis*; 734; 25.7% positive; **Supplementary Table S1**). Rabies virus characterization results were reported for 28.7% of rabid bats (**Table 3**).

Raccoons

A total of 1,014 raccoons tested positive for rabies in 2022, representing a 1.6% decrease compared to the 1,030 reported in 2021 (**Table 1**). The positivity rate of raccoons tested in 2022 (9.6%) was

significantly lower than the previous 5-year average (10.8%; 95% CI, 10.1% to 11.6%; **Table 2**). The number of raccoon rabies cases peaked in 1993 at 5,912.⁷

Eastern Raccoon (ERC) RVV was enzootic in 20 states in 2022. These states (Virginia [155 {15.3%} rabid racoons], Maryland [132 {13.0%}], Pennsylvania [120 {11.8%}], North Carolina [100 {9.9%}], New Jersey [99 {9.8%}], New York [86 {8.5%}], and 14 other ERC RVV–enzootic states [299 {29.5%}]) reported 98% of all rabid raccoons in 2022. Rabies virus characterization results were reported for 160 rabid raccoons, including 141 infected with ERC RVV and 19 infected with south central skunk (SCSK) RVV (**Table 3**).

Skunks

A total of 660 skunks tested positive for rabies in 2022, representing a 4.5% decrease compared to the 691 reported in 2021 (**Table 1**). The positivity rate of skunks tested in 2022 (21.8%) was significantly lower than the previous 5-year average (23.2%; 95% CI, 21.9% to 24.5%; **Table 2**). Over 50% of rabid skunks were reported from 5 states: Texas (151 [22.9%]), Virginia (70 [10.6%]), North Carolina (67 [10.2%]), California (40 [6.1%]), and New York (36 [5.5%]). Rabies virus characterization results were reported for 328 (49.7%) rabid skunks; 184 were infected with SCSK RVV, 105 were infected with ERC RVV, 22 were infected with California skunk RVV, 13 were infected with north central skunk (NCSK) RVV, and 4 were infected with bat RVVs (**Table 3**).

Foxes

In 2022, 269 foxes tested positive for rabies, representing a 14.3% decrease compared to the 314 reported in 2021 (**Table 1**). The positivity rate of foxes tested (16.5%) was significantly lower than the previous 5-year average (19.4%; 95% CI, 18.4% to 20.3%; **Table 2**).

Over 50% of fox rabies cases were reported from Virginia (47 [17.5%]), North Carolina (46 [17.1%]), New York (31 [11.5%]), and Pennsylvania (20 [7.4%]). Rabies virus characterization results were reported for 111 (41.3%) rabid foxes: 75 were infected with ERC RVV in states where the variant was enzootic; 17 from Texas were infected with SCSK RVV; 7 from Alaska were infected with Arctic fox RVV; 6 from Arizona, California, and New Mexico were infected with Arizona gray fox (AZ GF) RVV; 5 from California were infected with bat RVVs; and 1 from California was infected with California skunk RVV (**Table 3**).

Other wild animals

In 2022, other wildlife that tested positive for rabies included 16 bobcats (*Lynx rufus*), 8 coyotes (*Canis latrans*), 8 mongooses, 5 deer, 2 Virginia opossum (*Didelphis virginiana*), 1 river otter (*Lontra canadensis*), and 1 mountain lion (*Puma concolor*). Rabies virus characterization was performed on 18 (43.9%) of 41 other wild animals, including 6 infected with ERC RVV reported from Alabama, New Jersey, North Carolina, and Virginia; 5 with mongoose RVV reported from Puerto Rico; 4 with AZ GF RVV reported from Arizona and New Mexico; 2 with SCSK RVV reported from Oklahoma and Texas; and 1 with

Table 2—Number of rabid animals reported and percentages of samples tested positive for rabies in the US, including Puerto Rico, 2017 through 2022.

Animals	2022			2017–2021			
	No. of rabid animals	No. of animals tested with positive or negative result	Percentage of samples with positive result (%)	No. of rabid animals		Samples with positive result (%)	
				Mean	95% CI	Mean	95% CI
Domestic animals							
Cats	222*	17,406	1.3	253	231–276	1.3	1.1–1.5
Cattle	42*	673	6.2*	38	35–41	4.1	3.3–4.9
Dogs	50	22,057	0.2	53	41–65	0.3	0.2–0.3
Horses and donkeys	18	556	3.2*	15	12–19	2.3	1.8–2.8
Sheep and goats	12*	553	2.2*	8	5–11	1.4	0.9–1.9
Wildlife							
Bats	1,218*	23,345	5.2*	1,419	1,308–1,530	5.7	5.5–5.9
Raccoons	1,014*	10,512	9.6*	1,350	1,188–1,513	10.8	10.1–11.6
Skunks	660*	3,034	21.8*	879	785–973	23.2	21.9–24.5
Foxes	269*	1,635	16.5*	337	319–354	19.4	18.4–20.3
Total							
Domestic animals	345	41,386	0.8	369	341–397	0.9	0.8–0.9
Wildlife	3,234*	42,240	7.7*	4,078	3,719–4,438	8.7	8.4–9.0
All animals	3,579*	83,626	4.3*	4,447	4,070–4,825	4.9	4.7–5.1

*Significantly different from mean value for 2017 through 2021.

Table 3—Rabies virus variants identified in domestic animals and wildlife in the US, including Puerto Rico, during 2022.

Variant	Domestic animals						Wildlife								
	Cats	Cattle	Dogs	Horses and donkeys	Sheep and goats	Other domestic	Raccoons	Bats	Skunks	Foxes	Other wildlife	Rodents and lagomorphs	Total	SEI*	Non-SEI
Arctic fox	0	0	0	0	0	0	0	0	0	7	0	0	7	7	0
Arizona gray fox	0	0	0	0	0	0	0	0	6	4	0	0	10	10	0
Bat	0	0	0	0	0	0	0	349	4	5	1	0	359	359	0
California skunk	1	0	1	0	0	0	0	0	22	1	0	0	25	25	0
Mongoose (Puerto Rico)	2	0	9	1	0	0	0	0	0	0	5	0	17	17	0
North central skunk	1	3	3	0	0	0	0	0	13	0	0	0	20	6	14
South central skunk	25	12	20	6	1	0	19	0	184	17	2	1	286	239	47
Raccoon	48	6	10	0	2	0	141	0	105	75	6	4	397	102	295
Variant reported	77	21	43	7	3	0	160	349	328	111	18	5	1,122	765	357
No variant reported	145	21	7	11	9	1	854	869	332	158	25	27	2,457	1,082	1,375
Total infected	222	42	50	18	12	1	1,014	1,218	660	269	41	32	3,579	1,847	1,732
Variant typed (%)	34.7	50.0	86.0	38.9	25.0	0.0	15.8	28.7	49.7	41.3	43.9	15.6	31.3	41.4	20.6
Variant typed (%), 2017–2021															
Mean (%)	28.6	49.4	54.9	50.4	27.7	83.3	21.3	30.9	45.3	38.3	27.3	21.7	32.3	41	25
95% CI	23.4–33.8	43.3–55.6	46.7–63.1	23.3–77.4	7.1–48.2	54.1–112.6	16.8–25.8	21.2–40.7	42.4–48.3	21.0–55.6	10.1–44.4	10.5–32.9	27.2–37.4	39.7–42.2	24.3–25.8

*SEI = Samples of epidemiological importance.

reported from 4 states (Pennsylvania [47 {21.2%} rabid cats], Virginia [24 {10.8%}], New Jersey [22 {9.9%}], and Georgia [20 {9.0%}]) where ERC RVV was enzootic. Variant typing results were reported for 77 (34.7%) rabid cats, including 48 infected with ERC RVV, 25 with SCSK RVV, 1 with NCSK RVV, 1 with California skunk RVV, and 2 with mongoose RVV (Table 3).

Other domestic animals

A total of 42 cattle (*Bos taurus*) tested positive for rabies in 2022, representing a 5.0% increase from 40 reported in 2021 (Table 1). The positivity rate of cattle tested (6.2%) was significantly higher than the previous 5-year average (4.1%; 95% CI, 3.3% to 4.9%; Table 2). Over 50% of rabid cattle were reported from 4 states (Texas [9 {21.4%}], Pennsylvania [6 {14.3%}], Virginia [5 {11.9%}], and North Carolina [4 {9.5%}]) where SCSK and ERC RVVs were enzootic. Other rabid domestic animals included 18 horses (*Equus caballus*), 8 goats (*Capra hircus*), 4 sheep (*Ovis aries*), and 1 llama (*Lama glama*). Rabies virus characterization was performed on 21 cattle, 7 horses, and 3 goats, all of which were infected with local terrestrial enzootic RVVs (Table 3).

National Wildlife Rabies Control Efforts in the US

The USDA Wildlife Services; the Texas Department of State Health Services; other state health, agriculture, and wildlife agencies; and the CDC lead the effort of rabies management in wildlife populations to prevent the spread of specific RVVs in mesocarnivores and eventually eliminate these RVVs. Successful wildlife rabies management requires multiagency One Health commitment to communication, coordination, enhanced rabies surveillance, management with oral rabies vaccination (ORV), program monitoring and research.⁸ It also requires an adaptive management approach to enhance efficiency and effectiveness. During 2022, a total of 7,959,921 baits (vaccinia-rabies glycoprotein recombinant vaccine baits [54%] and adenovirus-rabies glycoprotein recombinant vaccine baits [46%]) were distributed across > 125,000 km² in the eastern US. In Texas, 1,173,300 baits (100% vaccinia-rabies glycoprotein recombinant vaccine baits) were distributed across > 41,000 km² along the US-Mexico border to prevent the reintroduction of the canine-coyote RVV, last detected in the US in 2004. A field trial to evaluate the

effectiveness of the adenovirus-rabies glycoprotein recombinant vaccine baits in coyotes was initiated in 2022, with 70,288 adenovirus-rabies glycoprotein recombinant vaccine baits distributed in the northern panhandle of Texas over approximately 2,600 km².

Through the use of ORV to manage rabies in wildlife, USDA Wildlife Services and partners have successfully prevented any appreciable westward expansion of ERC RVV from its current geographic distribution and locally eliminated this RVV from specific strategic areas. In the northeastern US, the raccoon ORV zone was moved 60 km (37 miles) south of the border with Canada between 2019 and 2022 as a result of successful local rabies elimination in this region, including elimination in Quebec, Canada.⁹

Rabies in Animals in Canada and Mexico

Canada

In 2022, the CFIA laboratories tested 2,535 samples, the majority of which came from animals with a history of human exposure (72.6%).¹⁰ All other samples had only domestic animal contact (17.8%) or no documented contact with people or animals (9.5%). Samples were received from all 13 provinces and territories, with the majority (1,435 [56.5%]) submitted from the province of Ontario. One hundred thirty-six (5.4%) tested positive; of these, 29 (21.3%) were confirmatory tests on wildlife surveillance samples, initially analyzed in provincial laboratories. An additional 6 cases positive on immunohistochemistry were reported but were not submitted to the CFIA for confirmatory testing. At the CFIA, animal samples were analyzed by the direct fluorescent antibody test (n = 2,529). Nunavut, Northwest Territories, and Newfoundland and Labrador had the highest rates of positive samples with 71.4% (15/21), 40.0% (4/10), and 33.3% (10/30), respectively. Additional animal rabies testing is conducted by wildlife and agriculture agencies; however, summary data were not available.

The 2015 Ontario rabies outbreak due to ERC RVV persisted with a higher case count in 2022 (n = 25) compared to 2021 (14), and the ERC RVV outbreak in New Brunswick reemerged (2) since the last case detected in July 2019. These 2022 cases were found approximately 130 km north of the closest cases in the 2014–2019 New Brunswick outbreak. This outbreak has continued in 2023, with 6 additional cases detected.¹¹ Rabies cases due to the Arctic fox RVV increased and were widely distributed in the northern regions in comparison to 2021 (40 cases in 2022, 12 in 2021), with cases detected in Northwest Territories (4), Nunavut (15), northern Manitoba (6), northern Quebec (5) and the mainland of Newfoundland and Labrador (10). Increased detection of ERC RVV and Arctic fox RVV cases accounted for the increase in proportion of samples testing positive in 2022 (5.4% compared to 4.3% in 2021). Although most rabies cases were in wildlife species (123/135 [90.4%]), domestic species accounted for

45.7% (1,158/2,535) of specimens analyzed. Bats accounted for the highest proportion of wildlife cases in 2022 (56 [41.2%]), followed by foxes (32 [23.5%]), skunks (28 [20.6%]), and raccoons (7 [5.1%]). Among domestic animals, rabies was detected in 10 dogs, 2 horses, and 1 bovine. These cases were the result of spillover of the Arctic fox RVV in northern regions (8 dogs) and skunk RVV (NCSK RVV in the US) in western Canada (1 dog, 2 horses, and 1 bovine). An imported dog in Toronto, Ontario, was found to be infected with a Middle East canine RVV.¹² The dog had received 1 dose of a rabies vaccine that is unlicensed in the US or Canada, had a prolonged incubation period of over 7 months, and had an atypical clinical presentation. This was the second case of imported dog rabies in as many years,¹³ which influenced the decision to introduce changes in import requirements for commercial dogs from countries considered high risk for dog rabies.¹⁴

Mexico

Rabies surveillance has been maintained in Mexico through the Network of State Public Health Laboratories and the Institute for Epidemiological Diagnosis and Reference. In 2022, a total of 10,340 samples were processed, with a positivity rate of 0.6%. Animals under surveillance were dogs (9,475 [91.6%]), cats, bats, skunks, and bovines (865 [8.4%]). Out of the processed samples, 25 tested positive for rabies, including 1 domestic feline, 21 bovines, 1 equine, 1 goat, and 1 coati. Likewise, the Secretariat of Agriculture reported rabies outbreaks in cattle and confirmed 296 rabies cases during 2022.

Rabies virus characterization results were reported for 2 rabies-positive animals, including 1 coati from Quintana Roo infected with vampire bat (*Desmodus rotundus*) RVV and 1 domestic cat from Zacatecas infected with skunk RVV (SCSK RVV in the US).¹⁵ The rabid cat was a 1-month-old kitten without rabies vaccination from Monte Escobedo in the state of Zacatecas. The kitten, along with the other 3 kittens in the litter, was reported to have fought with a skunk (species not identified) a month before showing clinical signs. Regarding the other cats in the litter, 1 died the day of the fight, while the other 2 had brain samples taken after being euthanized and were found to be negative for rabies. A total of 5 people associated with this case received postexposure prophylaxis.

Rabies in humans

In 2022, no human rabies cases were reported in the US (**Supplementary Table S2**) and Canada. Four animal-transmitted human rabies cases were reported in Mexico, including 3 cases transmitted by bats and 1 case by a domestic cat. The first case occurred in a 42-year-old male resident of the state of Jalisco, who was attacked by a bat in January 2022 in the municipality of Chapala and did not receive postexposure prophylaxis, resulting in his death in April 2022. The rabies virus characterization result was vampire bat RVV; however, the bat species was not determined. In December 2022, the second human rabies case

occurred in the state of Nayarit. An unvaccinated domestic cat bit a 29-year-old female in November; the cat subsequently died and the body was cremated, making rabies diagnosis impossible. Thirty days after the bite incident, the patient began to show neurological symptoms compatible with rabies. Antirabies antibodies were found in this patient's serum and cerebrospinal fluid samples, showing titers of 3.6 IU/mL, inferred to be caused by rabies virus infection. The patient remains alive to date with autonomous breathing but is in a vegetative state without other cognitive functions. The remaining 2 cases also occurred in December 2022. A 6-year-old boy and a 7-year-old girl in the state of Oaxaca were attacked by an unidentified wild animal while they slept and did not receive postexposure prophylaxis. The diagnosis of rabies was confirmed via postmortem samples for one of the siblings, while the other case was determined by epidemiological association. The identified rabies variant was vampire bat RVV. The boy and girl died on December 28, 2022, and January 7, 2023, respectively.

Discussion

During 2022, the number of animals tested for rabies virus increased compared to 2021 in the US (85,691 in 2022; 82,366 in 2021) and Canada (2,535 in 2022; 2,441 in 2021), but the Network of State Public Health Laboratories and the Institute for Epidemiological Diagnosis and Reference in Mexico processed fewer animal samples (10,340 in 2022; 12,628 in 2021). Bats were the most reported rabid animals in the US and Canada, while rabid cattle accounted for the majority of cases in Mexico.

Rabies surveillance and virus characterizations in 2022 detected changes in fox RVV distribution. In the US, 2 foxes with AZ GF RVV were identified west of the previously recognized enzootic area. The foxes were from San Bernardino County, California, and Mohave County, Arizona, which were both previously considered to be free of terrestrial rabies. Based on the CDC's method of estimating the extent of enzootic rabies virus transmission, there is a high level of concern that the AZ GF RVV may now be spreading in parts of California, Nevada, and Utah. In Canada, the number of rabid animals infected with Arctic fox RVV continued to increase in 2022 following the outbreak detected in 2020. Similar outbreaks have been reported since 2021 in Alaska. Arctic foxes and the RVV they maintain are enzootic across their circumpolar species distribution, making surveillance and epidemiologic monitoring challenging. Furthermore, human populations in these areas often have challenges accessing public health and veterinary resources to control zoonotic diseases, such as rabies. The combination of potentially increasing rabies activity in Arctic foxes and the unique human populations that reside in the Arctic signals a need for continued epidemiologic monitoring and implementation of rabies control resources for affected communities.

During 2022, no human rabies cases were reported in the US and Canada, while Mexico reported 4 human rabies cases with 3 infected with vampire bat

RVV, emphasizing the significance of bat-mediated human rabies infections in North America. Migratory patterns of bats in nature can potentially spread bat RVVs through ecosystem expansion or cross-species transmission among bats; thus, timely bat species identification and rabies virus characterization are crucial for early detection of bat RVVs, including the vampire bat RVV. Considering there are no vaccination options for bat rabies control, continuing bat rabies surveillance, monitoring vampire bat population distribution, and raising public awareness of the risks posed by bat exposure are essential to minimize bat-mediated rabies infections in humans, pets, and domestic animals.

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Supplementary Materials

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