Rabies surveillance in the United States during 2020

Xiaoyue Ma, MPH; Sarah Bonaparte, MPH; Matthew Toro, MS; Lillian A. Oruciari, MS; Crystal M. Gigante, PhD; Jordona D. Kirby, MS; Richard B. Chipman, MS; Christine Fehlner-Gardiner, PhD; Veronica Gutiérrez Cedillo, PhD; Nidia Aréchiga-Ceballos, PhD; Agam K. Rao, MD; Brett W. Petersen, MD; Ryan M. Wallace, DVM

OBJECTIVE
To provide epidemiological information on animal and human cases of rabies in the US during 2020 and summaries of 2020 rabies surveillance for Canada and Mexico.

ANIMALS
All animals submitted for laboratory diagnosis of rabies in the US during 2020.

PROCEDURES
State and territorial public health departments and USDA Wildlife Services provided 2020 rabies surveillance data. Data were analyzed temporally and geographically to assess trends in domestic and wildlife rabies cases.

RESULTS
During 2020, 54 jurisdictions submitted 87,895 animal samples for rabies testing, of which 85,483 (97.3%) had a conclusive (positive or negative) test result. Of these, 4,479 (5.2%) tested positive for rabies, representing a 4.5% decrease from the 4,690 cases reported in 2019. Texas (n = 580 [12.9%]), Pennsylvania (371 [8.3%]), Virginia (351 [7.8%]), New York (346 [7.7%]), Maryland (256 [5.7%]), North Carolina (301 [6.7%]), New Jersey (257 [5.7%]), California (248 [5.5%]) together accounted for > 60% of all animal rabies cases reported in 2020. Of the total reported rabid animals, 4,090 (91.3%) involved wildlife, with raccoons (n = 1,403 [31.3%]), bats (1,400 [31.3%]), skunks (846 [18.9%]), and foxes (338 [7.5%]) representing the primary hosts confirmed with rabies. Rabid cats (288 [6.4%]), cattle (43 [1.0%]), and dogs (37 [0.8%]) accounted for 95% of rabies cases involving domestic animals in 2020. No human rabies cases were reported in 2020.

CONCLUSIONS AND CLINICAL RELEVANCE
For the first time since 2006, the number of samples submitted for rabies testing in the US was < 90,000; this is thought to be due to factors related to the COVID-19 pandemic, as similar decreases in sample submission were also reported by Canada and Mexico.
as these trends can dramatically threaten public health, animal welfare, and wildlife ecosystems.

**Reporting and Analysis**

The US National Rabies Surveillance System (NRSS) is a laboratory-based system consisting of approximately 130 public health, agriculture, and academic laboratories that conduct animal rabies testing. Additionally, 54 state, district, and territorial public health jurisdictions conduct epidemiological investigations. Diagnostic tests accepted by the NRSS include the direct fluorescent antibody test, direct rapid immunohistochemical test, immunohistochemistry, and the LN34 real-time reverse transcription PCR assay. Both genomic and antigenic typing methods are accepted for rabies virus characterization. The USDA Wildlife Services monitors select areas of the country to identify the geographic dispersion of rabies and to document the impacts of ongoing wildlife rabies management actions. Human and animal rabies are nationally notifiable conditions in the US, and the Council of State and Territorial Epidemiologists defines data elements, case definitions, and timelines for reporting. During 2020, 54 jurisdictions submitted 87,895 animal samples for rabies testing (26.7 animals submitted/100,000 US human population), of which 85,483 (97.3%) had a conclusive (positive or negative) test result. Samples unsatisfactory for testing or with indeterminate test results were excluded from analyses. Because rabies epidemiology in the US is well described, rabid terrestrial animals and bats without RVV typing results were assumed to have the local terrestrial enzootic RVV or bat-type RVV, respectively.

Criteria for counties to be considered free from terrestrial rabies are described in previous reports and based on an absence of case detection over a 5-year period while maintaining adequate testing levels. Summaries of 2020 rabies surveillance for Canada and Mexico were provided by the Canadian Food Inspection Agency Centre of Expertise for Rabies and the Centro Nacional de Programas Preventivos y Control de Enfermedades of the Secretaria de Salud (Mexican Ministry of Health), respectively.

**Figure 1**—Distribution of major rabies virus variants (RVVs) among mesocarnivores in the US, including Puerto Rico, from 2016 through 2020. Darker shading indicates counties with confirmed animal rabies cases in the past 5 years; lighter shading represents counties bordering enzootic counties without animal rabies cases that did not satisfy criteria for adequate surveillance. Small nonenzootic areas with no rabies cases reported in the past 15 years are shaded if they are in the vicinity of known-enzootic counties and do not satisfy criteria for adequate surveillance. ARC FX = Arctic fox RVV. AZ FX = Arizona fox RVV. CA SK = California skunk RVV. E RC = Eastern raccoon RVV. MG = Mongoose RVV. NC SK = North central skunk RVV. SC SK = South central skunk RVV.

**Figure 2**—Cases of rabies among wildlife in the US, by year and species, 1970 through 2020.
Rabies in Wildlife

During 2020, 4,090 wildlife tested positive for rabies, representing a 5.0% decrease from the 4,305 rabid wildlife reported in 2019 (Table 1). The percentage of rabid wildlife among the total tested (8.9%) was not significantly different from the previous 5-year average (9.3%; 95% CI, 8.7% to 9.9%; Supplementary Table S1).

Raccoons

A total of 1,403 raccoons tested positive in 2020 (Supplementary Figure S1), representing a 9.2% decrease from the 1,545 rabid raccoons reported in 2019 (Table 1). The percentage of rabid raccoons among the total tested (11.0%) was similar to the previous 5-year average (11.6%; 95% CI, 10.6% to 12.6%; Supplementary Table S1). The number of raccoon rabies cases peaked in 1993, at 5,912 (Figure 2).7

Twenty states, the District of Columbia, and New York City were enzootic for the eastern raccoon RVV, consistent with findings from the past 5 years. These states accounted for 98.1% of all rabid raccoons reported in 2020. Rabies virus characterization was conducted on 383 of 1,377 (27.8%) rabid raccoons from the eastern raccoon RVV area, all of which were confirmed to be infected with the eastern raccoon RVV. The remaining 26 (1.9%) rabid raccoons were reported from Arizona (n = 1) and Texas (25), where the eastern raccoon RVV is not enzootic. Twenty-four were infected with the south central skunk (SCSK) RVV (Arizona and Texas), and 2 were infected with a free-tailed bat RVV (Texas).

Table 1—Cases of animal and human rabies in the US, including Puerto Rico, during 2020.

| Location | Domestic animals | Wildlife | Other domestic* | Other wildlife | Rodents and lagomorphs | Humans | 2019 cases | Change % |
|----------|------------------|----------|----------------|---------------|-----------------------|--------|------------|----------|
| Total    |                   |          |                |               |                       |        |            |          |
|          | 4,479            | 4,090    | 288            | 43            | 37                 | 11     | 9          | 1        |
| % Pos 2020 | 100.0%          | 91.3%    | 6.4%           | 0.8%          | 0.2%                 | 0.2%   | 0.0%       | 31.3%    |
| Total 2019 | 4,600            | 3,055    | 245            | 39            | 66                  | 10     | 3          | 1,387    |
| Change % | 4.5%             | 12.0%    | 17.6%          | 10.3%         | -43.5%               | -50.0% | -10.6%     | -6.9%    |

*Other domestic includes: 1 ferret. Other wildlife includes: 1 lynx; 3 bobcats, 1 coyote, and 1 lynx; 1 cougar; 1 bobcat; 1 bobcat and 2 otters; 52 raccoons and 2 coyotes; 11 otter; 2 coyotes; 11 otter; 2 coyotes; 2 coyotes; 3 bobcats, 4 deer, and 2 fishers; 11 bobcat; 2 bobcats, 1 coyote, and 1 deer; 16 mongooses; 1 coyote; 4 bobcats and 1 coyote; and 2 bobcats and 1 otter.

**Rabbits and lagomorphs include: 2 groundhogs; 5 groundhogs; 4 groundhogs; 1 groundhog; 9 groundhogs; 5 groundhogs; 8 groundhogs; 2 groundhogs; 1 groundhog; 1 groundhog; and 2 groundhogs.

-- Not applicable. NYC = New York City. Pos = Positive.

Primary reservoir refers to the most common rabies virus variant in the locality.
**Bats**

A total of 1,400 bats tested positive in 2020, representing a 0.9% increase from the 1,387 reported in 2019 (Table 1). The percentage of rabid bats among the total tested (5.8%) was not significantly different from the previous 5-year average (6.1%; 95% CI, 5.7% to 6.5%; Supplementary Table S1).

Fifty jurisdictions reported rabid bats during 2020. No rabid bats were reported in Alaska, Hawaii, or Puerto Rico. Bats were the only rabid animals detected in 8 states (Iowa, Idaho, Illinois, Indiana, Mississippi, Oregon, Washington, and Wisconsin). Over 60% of rabid bats were reported from 10 states: Texas (n = 269 [19.2%]), California (221 [15.8%]), New York (70 [5.0%]), New Jersey (66 [4.7%]), Michigan (52 [3.7%]), Colorado (51 [3.6%]), Pennsylvania (50 [3.6%]), Ohio (39 [2.8%]), Illinois (38 [2.7%]), and Minnesota (34 [2.4%]). Rabies virus characterization results were reported for 24.9% of rabid bats, representing a significant decrease, compared with percentages for the previous 5 years (31.6%; 95% CI, 26.0% to 37.2%; Table 2). Among bats tested for rabies, 10,867 (45.0%) were described beyond the taxonomic level of order; big brown bats (Eptesicus fuscus; n = 8,137, of which 3.6% were positive) were the most commonly tested, followed by Mexican free-tailed bats (Tadarida brasiliensis; 936, of which 22% were positive) and evening bats (Nycticeius humeralis; 441, of which 2.9% were positive; Supplementary Table S2).

**Skunks**

A total of 846 skunks tested positive for rabies in 2020 (Supplementary Figure S2), representing a 7.5% decrease from the 915 rabid skunks reported in 2019 (Table 1). The percentage of rabid skunks among the total tested (21.8%) during 2020 was significantly lower than the previous 5-year average (25.2%; 95% CI, 23.1% to 27.4%; Supplementary Table S1). Over 50% of rabid skunks were reported from 5 states: Texas (n = 212 [25.1%]), North Carolina (74 [8.7%]), Virginia (72 [8.5%]), Arizona (63 [7.4%]), and Georgia (40 [4.7%]). Rabies virus characterization results were reported for 38.4% of rabid skunks; the most commonly tested was the eastern raccoon RVV, 177 with the SCSK RVV, 4 with the Texas gray fox RVV, and 1 with a big brown bat RVV (Table 2).

**Foxes**

A total of 338 foxes tested positive for rabies in 2020 (Supplementary Figure S3), representing a 6.4% decrease from the 361 reported in 2019 (Table 1). The percentage of rabid foxes among the total tested (19.7%) was significantly higher than the previous 5-year average (18.6%; 95% CI, 17.7% to 19.5%; Supplementary Table S1). Rabies virus characterization results were reported for 21 (11.6%) rabid foxes (Table 2). Ninety-nine were infected with the eastern raccoon RVV, 30 were infected with the SCSK RVV, 8 were infected with the Arizona gray fox RVV, and 3 were infected with a bat RVV (Table 2). No animals were reported infected with the Texas gray fox RVV in 2020; the last animal reported with this RVV was a cow from Texas in 2013.

**Other wild animals**

Groundhogs (Marmota monax) were the only rabid rodents reported in 2020 (n = 38). Other reported rabid wildlife included 23 bobcats (Lynx rufus), 16 mongooses from Puerto Rico, 11 coyotes (Canis latrans), 5 deer (family Cervidae), 4 otters (Lontra canadensis), 2 fishers (Martes pennanti), 1 coati (Nasua nasua), and 1 cougar (Puma concolor; Table 1). Rabies virus characterization was performed on 19 of the 65 (29.2%) other wild animals and 2 of the 38 (5.3%) groundhogs (Table 2).
North Carolina (6 [16.2%]), Puerto Rico (4 [10.8%]), and Kentucky (3 [8.1%]). Rabies virus characterization results were reported for 22 (59.5%) rabid dogs; 10 were infected with the SCSK RVV, 4 with the NCSK RVV, and 8 with the eastern raccoon RVV (Table 2).

Cats
A total of 288 cats tested positive for rabies in 2020, representing a 17.6% increase from the 245 reported in 2019 (Table 1). The percentage of rabid cats among the total tested (1.7%) was significantly higher than the previous 5-year average (1.2%; 95% CI, 1.1% to 1.2%; Table 2). Almost 70% of the rabid cats were reported from 6 states: Pennsylvania (n = 57 [19.8%]), Maryland (34 [11.8%]), New York (31 [10.8%]), Virginia (28 [9.7%]), Texas (25 [8.7%]), and New Jersey (23 [8.0%]). Rabies virus characterization results were reported for 93 (32.3%) rabid cats; 68 were infected with the eastern raccoon RVV and 25 with the SCSK RVV (Table 2).

Other domestic animals
A total of 43 cattle tested positive for rabies, representing a 10.3% increase from the 39 reported in 2019 (Table 1). The percentage of cattle that tested positive for rabies among the total tested (4.9%) was similar to the previous 5-year average (4.7%; 95% CI, 3.5% to 6.0%; Supplementary Table S1). Texas reported the highest number of rabid cattle (n = 9 [20.9%]), followed by North Carolina (7 [16.3%]), Pennsylvania (5 [11.6%]), Virginia (4 [9.3%]), Kansas (4 [9.3%]), New York (3 [7.0%]), and Oklahoma (3 [7.0%]). Other reported rabid domestic animals included 9 horses, 1 donkey, 1 mule, 9 goats and sheep, and 1 ferret. Rabies virus characterization was performed on 24 of the 64 (37.5%) other domestic animals.

Rabies in Humans
During 2020, antemortem samples from 12 human patients in 9 states and US territories (Virginia, Georgia [n = 2], Texas [2], Minnesota [2], Pennsylvania, Tennessee, Washington, Florida, and Puerto Rico) were submitted to the CDC for diagnostic testing. Postmortem samples from 3 states and US territories (Utah, Washington, and Puerto Rico) were also received. None were found to be positive.

There were 5 confirmed human rabies cases in 2021 (Table 3). Of these, 4 occurred after direct contact with a bat in the US (Minnesota, Illinois, Idaho, and Texas), and 1 occurred after a bite from a dog in the Philippines (New York). Median age was 66 years (range, 7 to 87 years); all were male. All 5 persons died. Postexposure prophylaxis (PEP) was not sought in 4 of the 5 cases; the Minnesota case was classified as a breakthrough infection (ie, rabies illness despite administration of PEP). This patient’s poor antibody response after PEP was attributed to a previously unrecognized immunocompromising condition. The most common reason that patients did not receive PEP was not knowing that bats can transmit rabies.

National Rabies Control Efforts
Primary rabies prevention efforts in the US are led by local and state health departments. Jurisdictions employ preventative measures such as encouraging pet vaccination (to prevent secondary rabies exposure from wildlife reservoirs); providing animal control services to respond to sick, nuisance, and unwanted animals; providing risk assessments and laboratory diagnosis of animals for residents suspected to have a rabies exposure; and assisting with access to rabies PEP for persons confirmed or suspected to have been exposed to rabies. Rabies management in wildlife populations to prevent the spread and eventually eliminate specific RVVs in mesocarnivores is a collaborative effort led by the USDA Wildlife Services, the Texas Department of State Health Services, other state agencies, and the CDC. These landscape-scale programs use oral rabies vaccination (ORV) as the primary rabies control strategy targeting wild carnivore populations. Oral rabies vaccination is used to prevent specific RVVs from gaining a larger geographic footprint, lessen impacts to human and animal health, and reduce the substantial costs associated with rabies prevention and control.

During 2020, the USDA maintained an ORV zone to prevent the spread of the eastern raccoon RVV in 13 states. The zone was located near the US-Canada border in parts of Maine, New Hampshire, New York, and Vermont and then from Lake Erie at the New York-Ohio-Pennsylvania border south through the Appalachia region (Virginia and West Virginia) to the Alabama-Georgia-North Carolina-Tennessee border. An ORV zone in Massachusetts to prevent recurrence of eastern raccoon RVV cases on peninsular Cape Cod was also maintained. Additionally, state and county collaborators conducted ORV programs in local jurisdictional areas of Florida, Maryland, and New Jersey. In total, 8,367,970 baits (vaccinia-rabies glycoprotein recombinant vaccine baits [62%] and adenovirus-rabies glycoprotein recombinant vaccine baits [38%]) were distributed across > 124,000 km². Additionally, 1,180,200 baits (vaccinia-rabies glycoprotein recombinant vaccine baits) were distributed across > 41,000 km² along the US-Mexico border in Texas to prevent the reintroduction of the canine coyote RVV.

Rabies in Canada and Mexico
Canada
During 2020, the Canadian Food Inspection Agency received 2,675 samples, of which 2,670 were from animals (7.1 animals tested/100,000 Canada human population). There was a 20.5% decrease in the number of animal samples submitted, compared with 2019 (n = 3,360), attributable to abnormally high numbers of bat samples submitted during the 3 months following detection of a human case in July 2019, and a decrease in samples during March through May 2020, most likely due to a reduction in surveillance activities during these early months of the COVID-19 pandemic.
| Date of onset | Date of death | Reporting state | Age (y) | Sex | Exposure* | Rabies virus variant† |
|--------------|---------------|-----------------|--------|-----|-----------|----------------------|
| 13 Sep 00    | 20 Sep 00     | CA              | 49     | M   | Contact   | Bat, Tb              |
| 26 Sep 00    | 9 Oct 00      | NY              | 54     | M   | Bite, Ghana| Dog, African         |
| 3 Oct 00     | 10 Oct 00     | GA              | 26     | M   | Contact   | Bat, Tb              |
| 8 Oct 00     | 25 Oct 00     | MN              | 47     | M   | Contact   | Bat, Ln/Ps           |
| 12 Oct 00    | 1 Nov 00      | WI              | 69     | M   | Contact   | Bat, Ln/Ps           |
| 19 Jan 01    | 4 Feb 01      | CA              | 72     | M   | Unknown   | Dog, Philippines      |
| 18 Mar 02    | 31 Mar 02     | CA              | 28     | M   | Unknown   | Bat, Tb              |
| 21 Aug 02    | 31 Aug 02     | TN              | 13     | M   | Contact   | Bat, Ln/Ps           |
| 14 Sep 02    | 28 Sep 02     | IA              | 20     | M   | Unknown   | Bat, Ln/Ps           |
| 10 Feb 03    | 10 Mar 03     | VA              | 25     | M   | Unknown   | Raccoon, eastern US  |
| 28 May 03    | 5 Jun 03      | PR              | 64     | M   | Bite, Puerto Rico| Dog/mongoose, Caribbean |
| 23 Aug 03    | 1 Sep 03      | CA              | 66     | M   | Bite, Hs   | Dog, Hs              |
| 9 Feb 04     | 15 Feb 04     | FL              | 41     | M   | Bite, Ghana| Dog, Hs              |
| 27 Apr 04    | 3 May 04      | AR              | 20     | M   | Bite (organ donor) | Bat, Tb     |
| 27 May 04    | 31 May 04     | OK              | 53     | M   | Transplant, liver | Bat, Tb     |
| 27 May 04    | 21 Jun 04     | TX              | 18     | M   | Transplant, kidney | Bat, Tb     |
| 29 May 04    | 9 Jun 04      | TX              | 50     | F   | Transplant, kidney | Bat, Tb     |
| 2 Jan 04     | 10 Jun 04     | TX              | 55     | F   | Transplant, artery | Bat, Tb     |
| 12 Oct 04    | Survived      | WI              | 15     | F   | Bite       | Bat, unknown         |
| 19 Oct 02    | 26 Oct 04     | CA              | 22     | M   | Unknown, El Salvador| Dog, El Salvador |
| 27 Sep 05    | 27 Sep 05     | MS              | 10     | M   | Contact   | Bat, unknown         |
| 4 May 06     | 12 May 06     | TX              | 16     | M   | Contact   | Bat, Tb              |
| 30 Sep 06    | 2 Nov 06      | IN              | 10     | F   | Bite       | Bat, Ln              |
| 15 Nov 06    | 14 Dec 06     | CA              | 11     | M   | Bite, Philippines | Dog, Philippines |
| 19 Sep 07    | 20 Oct 07     | MN              | 46     | M   | Bite       | Bat, unknown         |
| 16 Mar 08    | 18 Mar 08     | CA              | 16     | M   | Bite, Mexico| Fox, Tb related      |
| 19 Nov 08    | 30 Nov 08     | MO              | 55     | M   | Bite       | Bat, Ln              |
| 25 Feb 09    | Survived      | TX              | 17     | F   | Contact    | Bat, unknown         |
| 5 Oct 09     | 20 Oct 09     | IN              | 43     | M   | Unknown    | Bat, Ps              |
| 20 Oct 09    | 11 Nov 09     | MI              | 55     | M   | Unknown    | Bat, Ln              |
| 23 Oct 09    | 20 Nov 09     | VA              | 42     | M   | Contact, India| Dog, India          |
| 2 Aug 10     | 21 Aug 10     | LA              | 19     | M   | Bite, Mexico| Bat, Dr              |
| 24 Dec 10    | 10 Jan 11     | WI              | 70     | M   | Unknown    | Bat, Tb              |
| 30 Apr 11    | Survived      | CA              | 8      | F   | Unknown    | Unknown              |
| 30 Jun 11    | 20 Jul 11     | NJ              | 73     | F   | Bite, Haiti| Dog, Haiti           |
| 14 Aug 11    | 31 Aug 11     | NY              | 25     | M   | Contact, Afghanistan| Dog, Afghanistan |
| 21 Aug 11    | 22 Jan 21     | NC              | 20     | M   | Bite (organ donor) | Dog, eastern US     |
| 1 Sep 11     | 1 Sep 11      | MA              | 40     | M   | Contact, Brazil | Dog, Brazil         |
| 3 Dec 11     | 19 Dec 11     | SC              | 46     | F   | Unknown    | Bat, Tb              |
| 22 Dec 11    | 23 Jan 12     | MA              | 63     | M   | Contact   | Bat, My sp           |
| 6 Jul 12     | 31 Jun 12     | CA              | 34     | M   | Bite       | Bat, Tb              |
| 31 Jan 13    | 27 Feb 13     | MD              | 49     | M   | Transplant, kidney | Raccoon, eastern US |
| 16 May 13    | 11 Jun 13     | TX              | 28     | M   | Unknown, Guatemala | Dog, Guatemala |
| 12 Sep 14    | 26 Sep 14     | MO              | 52     | M   | Unknown    | Bat, Ps              |
| 30 Jul 15    | 24 Aug 15     | MA              | 65     | M   | Bite, Philippines | Dog, Philippines |
| 17 Sep 15    | 3 Oct 15      | WY              | 77     | F   | Contact    | Bat, Ln              |
| 25 Nov 15    | 1 Dec 15      | PR              | 54     | M   | Bite       | Dog/mongoose, Puerto Rico |
| 5 May 17     | 21 May 17     | VA              | 65     | F   | Bite       | Dog, India           |
| 6 Oct 17     | 21 Oct 17     | FL              | 56     | F   | Bite       | Bat, Tb              |
| 28 Dec 17    | 14 Jan 18     | FL              | 6      | M   | Bite       | Bat, Tb              |
| 15 Jul 18    | 23 Aug 18     | DE              | 69     | F   | Unknown    | Raccoon, eastern US  |
| 16 Oct 18    | 4 Nov 18      | UT              | 55     | M   | Contact    | Bat, Tb              |
| 7 Jan 19     | 22 Jan 21     | MN              | 84     | M   | Bite       | Dog, Philippines     |
| 11 Feb 21    | 12 Mar 21     | NY              | 59     | M   | Bite       | Dog, Philippines     |
| 8 Sep 21     | 20 Sep 21     | IL              | 87     | M   | Contact    | Bat, Ln              |
| 10 Oct 21    | 28 Oct 21     | ID              | 66     | M   | Contact    | Bat, Ln              |
| 19 Oct 21    | 10 Nov 21     | TX              | 7      | M   | Bite       | Bat, Tb              |

*Data for exposure history are reported when plausible information was reported directly by the patient (if lucid or credible) or when a reliable account of an incident consistent with rabies virus exposure (eg, dog bite) was reported by an independent witness (usually a family member). Exposure histories are categorized as bite, contact but no known bite was acknowledged (eg, waking to find bat on exposed skin), or unknown (eg, no known contact with an animal was elicited during case investigation).†Rabies virus variants associated with terrestrial animals in the US and Puerto Rico are identified with the names of the reservoir animal (eg, dog or raccoon), followed by the name of the most definitive geographic entity (usually the country) from which the variant has been identified. Rabies virus variants associated with bats are identified with the names of the species of bats in which they have been found to be circulating. Because information regarding the location of the exposure and the identity of the exposing animal is almost always retrospective and much information is frequently unavailable, the location of the exposure and the identity of the animal responsible for the infection are often limited to deduction. Infection was not identified until 2013, when an organ recipient developed rabies.§The patient had received rabies immune globulin and 4 doses of rabies vaccine.

Dr = Desmodus rotundus. Ln = Lasionycteris noctivagans. My sp = Myotis spp. Ps = Perimyotis subflavus. Tb = Tadarida brasiliensis.
Direct fluorescent antibody testing found 104 (3.9%) of these animal samples to be positive, with most (n = 71 [68.3%]) detected during June through September. As in past years, the province of Ontario submitted the most samples (n = 1,501 [56.2%]), followed by Alberta (339 [12.7%]), British Columbia (253 [9.5%]), and Saskatchewan (220 [8.2%]). However, the highest rates of case detection were observed for the provinces of Manitoba (10.9%); 7 skunks and 4 domestic animals), Quebec (7.9%); 6 bats), and British Columbia (6.7%); 17 bats). Antemortem samples (nuchal skin biopsy, saliva, and CSF) from 5 human suspect cases tested by direct fluorescent antibody testing, and/or a quantitative reverse transcription PCR assay, were negative.

Most animal samples were submitted because of potential human exposure (n = 1,885 [70.6%]). A smaller number (n = 543 [20.3%]) were submitted owing to contact with domestic animals only, whereas 35 (1.3%) samples had no contact noted on the submission form and 207 (7.8%) were submitted by wildlife surveillance testing programs (either contracted testing [148] or confirmatory testing on samples that were positive or inconclusive in direct rapid immunohistochemical tests or immunohistochemistry tests at other laboratories [59]). In addition to these samples, 3 immunohistochemistry-positive bats were reported to the Canadian Food Inspection Agency but not submitted for confirmatory testing. The largest proportion of rabies cases was found in bats (n = 75 [72.1%]), followed by skunks (15 [14.4%]) and raccoons (4 [3.8%]). Two red foxes and 1 arctic fox also tested positive. Domestic animal cases were detected in cattle (n = 3), dogs (3), and 1 cat.

Antigenic variant typing with a discriminatory panel of monoclonal antibodies verified that 3 raccoons from Ontario were infected with the eastern raccoon RVV, the arctic fox from Nunavut and the red foxes from Northwest Territories were infected with the arctic fox RVV, and skunks (n = 7) from Manitoba were infected with the NCSK RVV. Cross-species transmission during 2020 was detected in the 3 bovids, 1 cat, and 1 dog from Manitoba, as well as 1 dog from Saskatchewan, infected with the NCSK RVV; in 7 rabid skunks in Ontario, 6 infected with the eastern raccoon RVV and 1 with a bat RVV associated with *E. fuscus*; and in 1 dog from Northwest Territories infected with the arctic fox RVV. This dog had been moved from Nunavut 3 days before developing clinical signs.

The Nunavut and Northwest Territories cases from 2020 were a harbinger of a new northern outbreak, with 15 cases due to the arctic fox RVV diagnosed in foxes and dogs from Northwest Territories, Nunavut, and northern Quebec in 2021. In the south of the country, Ontario saw a 59% reduction in the number of cases due to the eastern raccoon RVV (n = 9), compared with 2019 (22), and detected no cases associated with the fox variant, with over 3,300 samples from the enhanced surveillance zones tested with the direct rapid immunohistochemical test.11

### Mexico

Mexico has not detected a DMRVV (antigenic RVV V1) human rabies case since 2006. However, reports of human deaths due to other variants still occur, such as the fatal case registered in March 2020 of a male in the state of Veracruz bitten by a bat. This case had laboratory confirmation (direct fluorescent antibody technique), although the antigenic and genetic characterization was not done because the sample did not meet the testing conditions, preventing the determination of the species of the rabies-transmitting bat.

In domestic animals, a case involving a 7-year-old cat and another involving a 6-month-old puppy were registered. Both animals were owned by residents of rural areas of the state of Veracruz and Yucatan but had not been vaccinated. In the feline case, the V8 antigenic variant (SCSK RVV in the US) was determined and confirmed to be transmitted by a vampire bat (*Desmodus rotundus*), whereas the canine case corresponded to an atypical antigenic RVV from wildlife thought to be transmitted by skunks.12

Regarding wildlife, 4 bat cases were registered in the states of Baja California Sur, Jalisco, and Guerrero. Furthermore, the Agriculture Department reported an outbreak of 233 cases of cattle paralytic rabies transmitted by vampire bats.

During the COVID-19 pandemic, rabies surveillance was affected, as the health services of the 32 states submitted fewer samples to the public health state laboratories and to the Institute of Diagnosis and Epidemiological Reference. In 2020, a total of 11,643 samples were tested for rabies, of which 90.3% (n = 10,519) were from dogs and the other 9.7% (1,127) were from cats, cattle, and bats. From these, 24 samples were found positive: 18 in bovids, 4 in bats, 1 in a cat, and 1 in a dog. This represented a per capita testing rate of 9.0/100,000 human population.

In addition to surveillance, the intensive, massive, and free-of-charge rabies vaccination campaigns implemented yearly, with an annual average of 18 million vaccine doses administered to dogs and cats, and the prompt medical attention given to people attacked by animals contributed to maintaining the recognition given by the World Health Organization in 2019 to Mexico as the first country to have eliminated dog-transmitted human rabies cases.

### Discussion

The NRSS relies on state and local jurisdictions to operate frontline rabies surveillance and management programs and share notifiable data with the CDC, in accordance with Council of State and Territorial Epidemiologists recommendations. This system has operated in the US since its inception in 1944. Although approximately 100,000 animals have been submitted for rabies testing annually in the US, only 87,895 were submitted in 2020. Compared with 2019, there were fewer samples submitted for testing each month of 2020 except for June, and there were > 20% decreases in the number of submissions...
in April, October, and November, which correlated with peaks observed in COVID-19 case reports. The 10.2% decline in US testing was consistent with COVID-related rabies testing declines reported from Canada and Mexico. The COVID-19 pandemic has overwhelmed public health systems, and stay-at-home orders may have resulted in reduced human-animal interactions. Despite a notable decrease in submissions, rabies case detection rates decreased by only a small amount, which may indicate that pandemic-associated impacts on testing were more prominent among lower-risk exposures.

The NRSS has consistently evaluated the enzootic terrestrial rabies status of counties since 2008 to infer rabies risks to people and animals. The methods described in this report are applied to every US county annually. In 2020, the number of counties in which terrestrial rabies was enzootic increased by 2% (1,335 vs 1,308), with increases occurring primarily in regions where the arctic fox RVV and California skunk RVV were enzootic. Despite not having active wildlife management programs, the number of enzootic counties in areas where the SCSK RVV and NCSK RVV were enzootic decreased by 4.3% and 7.1%, respectively. These decreases could have been due to natural epidemiological changes resulting from host-virus-ecological factors. Alternatively, limited testing and surveillance in this more sparsely populated region of the US could mask underlying enzootic cycles. The methodology used by the NRSS to determine the presence or absence of enzootic terrestrial rabies has been used for > 10 years; an evaluation of the accuracy of this definition across reservoir territories is warranted to ensure accurate public health guidance is being maintained.

The DMRVV was eliminated from the US after a decades-long campaigns of dog vaccination and population management programs. Maintenance of this DMRVV-free status requires regulations to moderate the importation of dogs from high-risk countries as well as systematic and actionable surveillance systems for dogs in which rabies is diagnosed in the US. The NRSS has a goal of variant typing all rabid dogs in the US. In 2020, virus characterization of rabid dogs was significantly improved, but still only 60% of dog cases had the RVV reported to the NRSS. Fortunately, all dogs with virus characterization results had RVVs consistent with local epidemiological expectations, supporting both epidemiological and diagnostic evidence that the US DMRVV-free status was maintained.

Over the past 5 years, Puerto Rico has reported the greatest number of rabid dogs among all reporting jurisdictions, a consequence of their enzootic mongoose RVV and a relatively high proportion of free-roaming dogs. The decrease in rabid dogs in 2020 was most evident in Puerto Rico, which saw the number of rabid dogs decrease from 23 in 2019 to just 4. It is unclear whether this reduction reflects reduced surveillance during the pandemic or a true decline in cross-species transmission of the local mongoose RVV. Since 2018, 2 dogs infected with the mongoose RVV were translocated to the continental US (Maryland and Virginia). The movement of dogs within the US poses a risk for translocating nonenzootic variants. The mongoose RVV resulted from a host shift of the virus from dogs into mongooses, making this variant of greater concern to reestablish itself within susceptible canid populations. Ensuring strong vaccination and surveillance programs in Puerto Rico has direct benefits for the national program.

Rabies virus characterization is becoming a more important tool to understand the epidemiology of rabies and effects of public health and wildlife management actions. However, determining the variant of a rabies-positive sample constitutes an added cost to health departments and may not provide actionable information. The NRSS has developed criteria to determine which samples should be prioritized for virus characterization and defined these as samples of epidemiological importance (SEIs). Given that not all samples are of equal value to rabies management, the NRSS now evaluates improvements in variant typing solely on the basis of changes in viral characterization rates for SEIs. In 2020, only 40% of SEIs had a variant result submitted to the NRSS, marking the first time since tracking that this value has decreased. This could be the result of COVID-19 pandemic effects, a reduced state capacity for testing, or a decrease in the number of jurisdictions that included this information in their notifications to the NRSS.

Acknowledgments

This is a written work prepared by employees of the Federal Government as part of their official duties and, under the United States Copyright Act, is a “work of the United States Government” for which copyright protection under Title 17 of the United States Code is not available. Copyright does not extend to the contributions of employees of the Federal Government.

The authors declare that there were no conflicts of interest. Use of trade names and commercial sources is for identification only and does not imply endorsement by the US Department of Health and Human Services. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the CDC.

The authors thank the state and territorial public health and agriculture departments and laboratories for their contributions of rabies surveillance data and human case investigations. The authors also thank Rene Edgar Condori, Yu Li, Pamela Yager, Subbian Satheshkumar Panayampalli, and other staff of the CDC Poxvirus and Rabies Branch for their help and support.

References

1. Ma X, Monroe BP, Wallace RM, et al. Rabies surveillance in the United States during 2019. J Am Vet Med Assoc. 2021;258(11):1205–1220. doi:10.2460/javma.258.11.1205
2. Velasco-Villa A, Reeder SA, Orciari LA, et al. Enzootic rabies elimination from dogs and reemergence in wild terrestrial carnivores in the United States. Emerg Infect Dis. 2008;14(12):1849–1854
3. CDC. Rabies testing. Accessed February 1, 2022. https://www.cdc.gov/laboratory/specimen-submission/detail.html?CDCTestCode=CDC-10397
4. Council of State and Territorial Epidemiologists. Public health reporting and national notification for animal ra-
bies. 09-ID-12. Accessed January 28, 2022. cdn.ymaws.com/www.cste.org/resource/resmgr/PS/09-ID-12.pdf
5. Council of State and Territorial Epidemiologists. Revision of the surveillance case definition for human rabies. 10-ID-16. Accessed January 28, 2022. cdn.ymaws.com/www.cste.org/resource/resmgr/PS/10-ID-16.pdf
6. Wallace RM, Gilbert A, Slate D, et al. Right place, wrong species: a 20-year review of rabies virus cross species transmission among terrestrial mammals in the United States. PLoS One. 2014;9(10):e107559. doi:10.1371/journal.pone.0107559
7. Krebs JW, Strine TW, Smith JS, Rupprecht CE, Childs JE. Rabies surveillance in the United States during 1993. J Am Vet Med Assoc. 1994;205(12):1695–1709.
8. Dyer JL, Yager P, Orciari LA, et al. Rabies surveillance in the United States during 2013. J Am Vet Med Assoc. 2014;245(10):1111–1123.
9. Kunkel A, Minhaj FS, Whitehill F, et al. Notes from the field: three human rabies deaths attributed to bat exposures—United States, August 2021. MMWR Morb Mortal Wkly Rep. 2022;71(1):31–32. doi:10.15585/mmwr.mm7101a5
10. Canadian Food Inspection Agency. Archived—rabies cases in Canada 2020. Accessed February 10, 2022. https://inspection.canada.ca/animal-health/terrestrial-animals/diseases/reportable/rabies/rabies-cases-in-canada-2020-eng/1584479348956/1584479349378
11. Government of Ontario. Wildlife rabies outbreaks and control operations. Accessed February 10, 2022. https://www.ontario.ca/page/wildlife-rabies-outbreaks-and-control-operations
12. García-Ayala F, Aréchiga-Ceballos N, Ortiz-Alcántara JM, et al. Molecular characterization of atypical antigenic variants of canine rabies virus reveals its reintroduction by wildlife vectors in southeastern Mexico. Arch Virol. 2017;162(12):3629–3637. doi:10.1007/s00705-017-3529-4
13. CDC. Provisional mortality data—United States, 2020. Accessed February 1, 2022. https://www.cdc.gov/mmwr/volumes/70/wr/mm7014e1.htm
14. Kintziger KW, Stone KW, Jagger MA, Horney JA. The impact of the COVID-19 response on the provision of other public health services in the US: a cross sectional study. PLoS One. 2021;16(10):e0255844. doi:10.1371/journal.pone.0255844
15. Pieracci EG, Pearson CM, Wallace RM, et al. Vital signs: trends in human rabies deaths and exposures—United States, 1938–2018. MMWR Morb Mortal Wkly Rep. 2019;68(23):524–528.
16. CDC. Bringing an animal into the United States. Accessed February 1, 2022. https://www.cdc.gov/importation/bringing-an-animal-into-the-united-states/index.html
17. CDC. High-risk countries for dog rabies. Accessed February 1, 2022. https://www.cdc.gov/importation/bringing-an-animal-into-the-united-states/high-risk.html
18. Pieracci EG, Chipman RB, Morgan CN, et al. Evaluation of rabies virus characterization to enhance early detection of important rabies epizootic events in the United States. J Am Vet Med Assoc. 2020;256(1):66–76.
19. Pieracci EG, Brown JA, Bergman DL, et al. Evaluation of species identification and rabies virus characterization among bat rabies cases in the United States. J Am Vet Med Assoc. 2020;256(1):77–84.

Supplementary Materials
Supplementary materials are posted online at the journal website: avmajournals.avma.org