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RABIES IN RODENTS AND LAGOMORPHS IN THE USA, 2011–20

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ABSTRACT: Rabies is an acute progressive encephalitis caused by infection with rabies viruses, with reservoirs among bats and mesocarnivores, but all mammals are susceptible. Despite its distribution and abundance, cases of rabies are much less common in rodents and lagomorphs. Familiarity with current rabies prevalence data is important for informed decisions on human postexposure prophylaxis after rodent and lagomorph bites. This study is an update of rabies cases reported in rodents and lagomorphs in the US from 2011 to 2020. Rabies reports were collected passively from laboratory testing agencies in the US and Puerto Rico from 2011 to 2020. Descriptive analysis was conducted to determine the percent positivity of rabies cases by species. A total of 401 cases of rabies in rodents and lagomorphs were reported from 2011 to 2020. Most reported cases were in groundhogs (*Marmota monax*), representing >90% of cases, and the trend closely aligned with rabies in raccoons (*Procyon lotor*). In any given year, the percent positivity of rabies in rodents and lagomorphs was <2.5%, and the trend of percent positivity from 2011 to 2020 was stable. Groundhog and North American beaver (*Castor canadensis*) percent positivity was significantly higher than the rest of the rodents and lagomorphs. Most rabies cases occurred during the months of May–September. Documented cases of rabies in rodents and lagomorphs are generally rare, but with variation between species. Groundhogs and North American beavers had rabies percent positivity similar to high-risk species, such as bats and raccoons, and constituted 97% of all rodent and lagomorph positive cases. Since 1993, the trend in rabies cases in groundhogs has significantly declined. These results can be used to help inform public health officials on rodent and lagomorph prevention and control efforts, as well as rabies postexposure prophylaxis.

Key words: Animal bites, lagomorphs, rabies, rodents.

INTRODUCTION

Rodents and lagomorphs are associated with multiple zoonoses, including hantavirus infections, leptospirosis, and tularemia (Grange et al. 2021; CDC 2023). All mammals are susceptible to infection, typically through a bite, with rabies virus (RV; *Rabies lyssavirus*), which causes an acute, progressive encephalitis (Walker et al. 2022). Once manifested clinically, the infection is almost universally fatal (Jackson et al. 2003). Lyssaviruses perpetuate in discrete populations of conspecifics, known as reservoir species. In the US, there are major reservoirs in wild mesocarnivores, including raccoons (*Procyon lotor*), skunks (family Mephitidae), foxes (*Vulpes* spp. and *Urocyon cinereoargenteus*), and the small Indian mongoose (*Urva auropunctata*). These taxa maintain distinct RV variants (RVVs), including the Arctic fox RVV, Arizona fox RVV, California skunk RVV, dog-mongoose RVV, north-central skunk RVV, south-central skunk RVV, and raccoon RVV. In addition, there are multiple RVVs associated with bats (Ma et al. 2022). Rodents and lagomorphs are not RV reservoirs in the US (Gilbert 2018).

A rabid mammal exposure at risk for transmitting RV usually consists of a bite, although transmission is possible via infected saliva through open skin from scratches or abrasions (CDC 2019c). Postexposure prophylaxis (PEP) in those not previously vaccinated against rabies, consisting of wound care, administration of rabies immune globulin (RIG), and a series of vaccines, is crucial to prevent disease after exposure. In those who have been properly vaccinated, wound care and repeat vaccination are recommend, but administration of RIG is not (Rupprecht et al. 2010). When indicated, public health efforts focus on the importance of timely and appropriate PEP. Despite numerous reports of rodent and lagomorph bites in rabies-enzootic countries, no human rabies deaths have ever been associated with rodents and lagomorphs in the US. Although uncommon, pets can also become exposed to RV when they encounter wildlife, which is concerning due to frequent contact with humans (CDC 2019b). In the US, certain pets vaccinated against rabies, such as cats (*Felis catus*), dogs (*Canis familiaris*), and ferrets (*Mustela furo*), need to be monitored after possible exposure to RV, while all other RV-exposed pets require euthanasia (Brown et al. 2016).

In contrast to bats and mesocarnivores, rabies is much less commonly documented in rodents and lagomorphs (Ma et al. 2021). Infections in wild rodents and lagomorphs are probably from cross-species transmission (CST), such as a bite from a bat or mesocarnivore (Fitzpatrick et al. 2014). Most data on animal rabies in the US are from state public health agencies. Reports to these agencies reflect passive case detection systems, which initiate investigations when there is concern a rabid mammal bites a human. Clinically significant bites (leading to emergency room visits) involving rodents and lagomorphs occur over 10,000 times annually in the US (Hareza et al. 2020). The magnitude of rodent and lagomorph bites highlights the importance of routine surveillance and accurate reporting of rabies in these animals. The highest rabies positivity rates in rodents and lagomorphs in the US historically have been found in some of the largest-bodied of these animals, such as the groundhog, also known as woodchuck (*Marmota monax*; Childs et al. 1997; Fitzpatrick et al. 2014). Explanations for this association include the following: the comparative size (i.e., larger rodents are more likely to survive bites via rabid mesocarnivores, remain alive to develop a productive viral infection, and be successfully captured for euthanasia and testing); ecologic relationships with mammalian reservoirs for CST events; and species-specific susceptibility to RV (Winkler et al. 1972). Reports of such CST have been described with the raccoon RVV infecting rodents in the eastern US, where the raccoon RVV predominates (Morgan et al. 2015).

Given the large number of rodent and lagomorph bites and the case fatality rate of rabies, public health officials receive numerous inquiries about PEP after such events. Both the Centers for Disease Control and Prevention (CDC) and the National Association of State Public Health Veterinarians acknowledge the low risk of rabies associated with rodent and lagomorph bites. As such, current recommendations suggest consideration of rodent and lagomorph bites on a case-by-case basis, depending on local epidemiology and the circumstances of the encounter (CDC 2021). Although highly safe and effective, PEP has associated financial and temporal costs to the previously unvaccinated individual. This involves a 2-wk vaccine regimen and RIG administration, causing a substantial burden to patients and health systems. Thus, it is important to understand the epidemiology of rabies in all mammals to make informed decisions after bites occur. Our study aimed to provide an update on rabies epidemiology in rodents and lagomorphs in the US.

MATERIALS AND METHODS

Rabies reports were collected passively from laboratory testing agencies in the US and Puerto Rico from 2011 to 2020. Rabies was confirmed in animals postmortem by using one of the gold standard assays described by the Council of State and Territorial Epidemiologists (2009). Since 1944, these data have been submitted by public health jurisdictions annually to the CDC for inclusion in the National Rabies Surveillance System report (Blanton et al. 2012; Dyer et al. 2013, 2014; Monroe et al. 2016; Birhane et al. 2017; Ma, Monroe, Cleaton, Orciari, Li et al. 2018; Ma, Monroe, Cleaton, Orciari, Yager et al. 2018; Ma et al. 2020, 2021, 2022). Data on rodents and lagomorphs from these publications were used for analysis. Information collected included species name (American Society of Mammalogists 2023), time of year (month), year, and state.

Data from the years 1985–94 (Childs et al. 1997) and 1995–2010 (Fitzpatrick et al. 2014) were obtained from previous publications on this topic for further analysis of trends. Total tested samples by species were not routinely reported to the CDC prior to 1992. For the years 1985–1991, the forecast.linear function in Excel version 2208 (Microsoft 2023) was used to estimate the number tested based on the observed testing data from 1992 to 1996. Descriptive analysis was conducted to determine the percent positivity of rabies cases by species, annual and monthly trends in case reports, and annual trends in percent positivity. The *segmented* package in Rstudio version 4.0.0 (R Core Team 2020) was used to determine when the annual trend in the cases or percent positivity significantly changed, as well as if the predicted linear trend line was significantly different from "no change." Trends in rodents and lagomorphs were compared with trends in raccoons over the same time period for the purpose of assessing if trends were similar to those observed during the raccoon rabies outbreak (1985–98) and subsequent control (1998–2020) time periods.

To visualize spatial distribution of rabid rodents and lagomorphs in the US from 2011 to 2020, the *usmap* package in RStudio version 4.2.0 (R Core Team 2022) was used to create a map of reported rabies cases in rodents and lagomorphs by state. The number of rodents and lagomorphs tested for rabies by state from 2011 to 2020 was used to represent the rabies surveillance effort.

RESULTS

A total of 401 cases (40 mean annual cases) of rabies in rodents and lagomorphs was reported by public health agencies from 2011 to 2020, among 21,925 tested (1.8% positive; 95% confidence interval [CI], 1.6–2.0%; Table 1). The groundhog was the most common rodent or lagomorph associated with rabies during this time frame, with 368 of 9,084 cases (4.1%) testing positive (37 mean annual cases and 92% of rabid rodent and lagomorph cases). North American beavers (*Castor canadensis*) were the second most reported rodent or lagomorph with rabies, with 21 of 283 (7.4%) testing positive (a mean of two annual cases from 2011 to 2020). Other rodents or lagomorphs with rabies included the eastern cottontail rabbit (*Sylvilagus floridanus*; 8 of 1,364), Alaska marmot (*Marmota broweri*; 2 of 109), and eastern grey squirrel (*Sciurus carolinensis*; 2 of 6,195). For comparison, from 2011 to 2020, there were 16,172 rabies confirmed raccoons among 123,704 tested (13.1% positive).

The risk ratio for a sample to test positive, compared with raccoons, was highly variable between rodent and lagomorph species. Larger rodent species had a low, but not insignificant, risk ratio of 0.3 (groundhog) and 0.6 (North American beaver). The eastern cottontail rabbits and smaller rodents had a drastically lower risk of testing positive if submitted (eastern cottontail rabbit risk ratio=0.04, other rodent or lagomorph risk ratio=0.004). There were no rabid rats (*Rattus* spp.), house mice (*Mus musculus*), or eastern chipmunks (*Tamias striatus*) from 2011 to 2020.

When comparing trends in rabies in rodents and lagomorphs since 1985, trends differed based on the rodent or lagomorph species. Cases of rabies in North American beavers and eastern cottontail rabbits had no significant annual change (P=0.32 and P=0.18, respectively; Fig. 1). Groundhogs had a significant decline in rabies cases, starting in 1993 and continuing through 2020 at a rate of −0.71 cases per year (P=0.002). Other rodents and lagomorphs also had a significant decline from 1985 to 2020, although at a very modest rate of −0.06 cases per year (P=0.011). The trend in raccoon rabies cases was shown to have a similar trend to groundhogs, with a significant decline in cases beginning in 1993 and continuing through 2020 (decline of 109 cases per year, P<0.001). When comparing percent positivity, there was no significant change over the study period among all rodents and lagomorphs (Table 2).

Rabies cases in rodents and lagomorphs were most common in the northeastern and mid-Atlantic region (Fig. 2), where the raccoon RVV is present in 99.3% of mesocarnivore cases (Wallace et al. 2014). Cases in rodents and lagomorphs (primarily represented by groundhogs) emerged in March, with cases

TABLE 1. Rabies in rodents and lagomorphs in the USA and Puerto Rico, 2011–20.

Rodent or lagomorph	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total positive	Total tested	% positive
Groundhog (*Marmota monax*)	45	42	37	43	25	44	33	23	38	38	368	9,084	4.1
North American beaver (*Castor canadensis*)	3	4	0	2	2	5	0	4	1	0	21	283	7.4
Eastern cottontail rabbit (*Sylvilagus floridanus*)	0	0	1	0	7	0	0	0	0	0	8	1,364	0.6
Marmot (*Marmota broweri*)	0	0	2	0	0	0	0	0	0	0	2	109	1.8
Eastern grey squirrel (*Sciurus carolinensis*)	0	0	0	0	1	0	0	0	1	0	2	6,195	0.0
Rat (*Rattus* spp.)	0	0	0	0	0	0	0	0	0	0	0	1,052	0.0
House mouse (*Mus musculus*)	0	0	0	0	0	0	0	0	0	0	0	840	0.0
Muskrat (*Ondatra zibethicus*)	0	0	0	0	0	0	0	0	0	0	0	835	0.0
Eastern chipmunk (*Tamias striatus*)	0	0	0	0	0	0	0	0	0	0	0	658	0.0
All others[a]	0	0	0	0	0	0	0	0	0	0	0	1,505	0.0
Total	48	46	40	45	35	49	33	27	40	38	401	21,925	1.8
All tested	2,516	2,504	2,243	2,309	2,273	2,168	2,090	2,090	1,904	1,828	21,925		
% positive	1.9%	1.8%	1.8%	1.9%	1.5%	2.3%	1.6%	1.3%	2.1%	2.1%	1.8%		

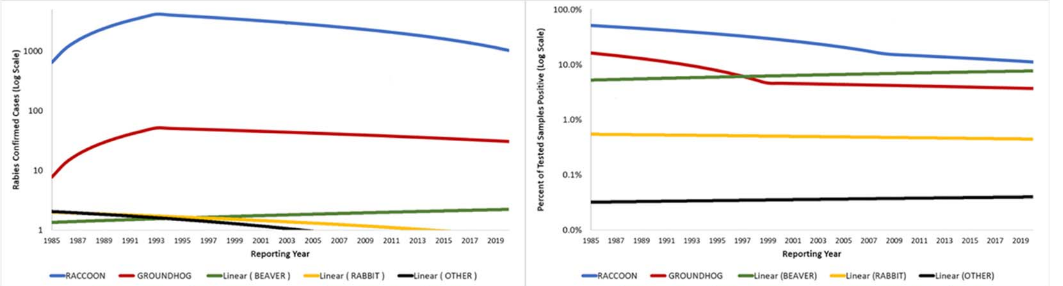
[a] All others: moles (e.g., subfamily Scalopinae) and shrews (e.g., family Soricidae); note that surveillance records are usually applied with common names only.

peaking in July (Fig. 3). Cases were documented through December, although a steep decline was noted from the summer to winter months.

DISCUSSION

Rabies in rodents and lagomorphs is rare and tends to occur in the eastern US. However, over 10,000 clinically relevant rodent and lagomorph bites occur annually in the US. Our study found a decreasing trend in the number of rabid rodents and lagomorphs from 2011 to 2020. In previous studies conducted since the 1980s, there were 368 total rabid rodents and lagomorphs from 1985 to 1994 (37 per year; Childs et al. 1997) and 737 rabid rodents and lagomorphs between 1995 and 2010 (46 per year; Fitzpatrick et al. 2014). Our study reports a similar mean annual number of 40 rodent and lagomorph rabies cases per year (401 total from 2011 to 2020) obtained from data provided by testing agencies in the US and reported to the CDC. Including data from previous publications for the 1985 to 2020 time period, the overall trend of rabies cases in all rodents and lagomorphs rose until 1993 and has since decreased, resulting in an overall flat trend.

From 2011 to 2020, most cases of rabid rodents and lagomorphs occurred in relatively large species (>90% of cases are from groundhogs and North American beavers). In previous studies, reported rabies cases in groundhogs rose during the 1980s and 1990s, concomitant with the rise in raccoon rabies cases (CDC 2020). During the period of our study, rabies cases in groundhogs trended downward, also concomitant with previously reported data, indicating a fall in raccoon rabies cases from 2011 to 2020 (Ma et al. 2022). Furthermore, most rodent and lagomorph rabies cases in our study were associated with the raccoon RVV from the eastern US (Fig. 2), suggesting that raccoons are the primary source of CST. This association is believed to be related to competition for dens, which may increase the likelihood of exposure and CST (Childs et al. 1997).



	CoEfficient	Trend Shift	Trend P-value	Trend
Raccoon	(109.00)	1993	<0.001	Decline
Groundhog	(0.71)	1993	0.002	Decline
Beaver	0.025	-	0.320	No Change
Rabbit	(0.034)	-	0.180	No Change
Other	(0.055)	-	0.011	Decline

	CoEfficient	Trend Shift	Trend P-value	Trend
Raccoon	(0.004)	2008	0.040	Decline
Groundhog	(0.350)	1998	0.200	No Change
Beaver	(0.000)	-	0.880	No Change
Rabbit	(0.000)	-	0.420	No Change
Other	-	-	0.470	No Change

FIGURE 1. Trends in rabies cases and percent positivity among rodents and lagomorphs, compared with a predominant reservoir species, the raccoon (*Procyon lotor*) in the USA and Puerto Rico from 2011 to 2020.

Even though the other rodents and lagomorphs also overlap geographically with groundhogs in the territory of the raccoon RVV, the cases do not align as closely with raccoon cases compared with groundhogs (Fig. 1). This may again be related to exposures of groundhogs occurring over competition for dens, as raccoons are known to occupy groundhog dens to forage for prey and raise litters (Grizzell 1955). Given the high energy expenditure needed to construct a den, groundhogs typically aggressively defend them (Grizzell 1955). The relatively larger size of groundhogs compared with other rodents and lagomorphs increases the likelihood of surviving such an encounter and developing an RV infection in the event the raccoon was infected. Such interactions with the other rodents and lagomorphs are less likely due to temporal, seasonal, ecologic, and size limitations.

The majority of rabies cases in groundhogs occurred during the summer (Fig. 3). Considering the incubation time after exposure, this suggests that RV exposures occur after the groundhogs become active posthibernation. This observation can inform efforts regarding seasonal prevention of bites, as there were virtually no cases of rabies in groundhogs during January–March. The potential impacts of climate change and further encroachment of human development into wildlife habitats necessitate further future monitoring of these epidemiologic relationships.

Access to current rabies epidemiologic trends is important to better inform public health decisions on PEP. Although there are no documented cases of rabies in humans from exposure to rodents and lagomorphs in the US, rabies virus may be excreted in saliva (Childs et al. 1997). Modern pre-exposure prophylaxis for individuals at risk of exposure and PEP with proper wound care prevent infection in virtually all cases of RV exposure (World Health Organization 2018). However, PEP should be used within the appropriate epidemiologic context, as costs are high and adverse reactions are documented (Mattner et al. 2007). Public health expenditures on surveillance, diagnostics, prevention, and control of rabies range from US $245 to US$510 million annually, and a single course of PEP may exceed US$3,800 (CDC 2019a). Accurate information on disease prevalence is warranted for proper risk assessments, a cost-effective approach to PEP implementation, and relevant prevention and control of wildlife.

As our study demonstrates, consistent with previous data, rabies in rodents and lagomorphs is rare (1.8%; 95% CI, 1.6–2.0%). The overall percent positivity is significantly lower ($P<0.05$) than the annual percent positivity in all wildlife (10.0%; 95% CI, 9.2–10.8%), but certain species of rodents and lagomorphs have a higher risk associated with rabies than others. As shown in Table 1, the percent

Table 2. Rabies percent positivity in rodents, lagomorphs, and raccoons (*Procyon lotor*) in the USA and Puerto Rico from 1985 to 2020.

Time span	Raccoon (*Procyon lotor*)			Groundhog (*Marmota monax*)			North American beaver (*Castor canadensis*)			Eastern cottontail rabbit (*Sylvilagus floridanus*)			Other rodents and lagomorphs[a]			All rodents and lagomorphs[b]		
	Tested	Positive	% positive	Tested	Positive	% positive	Tested	Positive	% positive	Tested	Positive	% positive	Tested	Positive	% positive	Tested	Positive	% positive
1985–94	122,394	27,284	22.29	5,985	327	5.46	206	12	5.82	3,380	17	0.50	52,266	19	0.04	61,837	375	0.61
1995–2010	202,426	46,637	23.04	14,051	663	4.72	551	31	5.63	5,502	25	0.45	53,571	16	0.03	73,675	735	1.00
2011–20	123,704	16,172	13.07	9,084	368	4.05	283	21	7.42	1,364	8	0.59	11,194	4	0.04	21,925	401	1.83
Total	448,524	90,093	20.09	29,120	1,358	4.66	1,040	64	6.15	10,246	50	0.49	117,031	39	0.03	157,437	1,511	0.96

[a] Other rodents and lagomorphs: marmot (*Marmota broweri*); eastern grey squirrel (*Sciurus carolinensis*); rat (*Rattus* spp.); house mouse (*Mus musculus*); muskrat (*Ondatra zibethicus*); eastern chipmunk (*Tamias striatus*), and all others.

[b] All rodents and lagomorphs: groundhog; North American beaver; eastern cottontail rabbit; marmot; eastern grey squirrel; rat; house mouse; muskrat; eastern chipmunk; and all others.

positivity of rabies in rodents and lagomorphs is overall exceedingly low, with annual percent positivity being <2.5% from 2011 to 2020; certain rodents or lagomorphs (e.g., rats, house mice, muskrats, and eastern chipmunks) had no identified cases of rabies from 2011 to 2020. Yet, groundhog and North American beaver percent positivity (4.1% and 7.4%, respectively) was closer to that of higher risk rabies reservoirs, such as bats (5.9%) and raccoons (11.7%), as described (Ma et al. 2022). The risk ratio for rabies comparing North American beavers to bats is 1.25 (95% CI, 0.83–1.9; P=0.28), indicating the similarity, while the risk ratio of rodents and lagomorphs other than groundhogs and North American beavers to North American beavers is 0.013 (95% CI, 0.006–0.026; P<0.001). Thus, human exposures to larger bodied rodents, such as groundhogs and North American beavers, should be investigated thoroughly, similar to investigations following exposures to wild mammals more commonly associated with rabies. However, the other rodents and lagomorphs in Table 1 have a much smaller risk for rabies, so further evaluations and interventions such as PEP may not be required. Overall, evaluations for rabies should be approached on a case-by-case basis, accounting for the species, the availability for diagnostic testing, local epidemiology, the type of exposure, and the animal's behavior.

This study has several limitations. Data collection by the various testing agencies throughout the US and Puerto Rico is conducted passively. Existing surveillance does not enable accurate determination of the incidence of rabies among wildlife such as rodents and lagomorphs. Passive surveillance may lead to larger types of mammals being tested disproportionally, as they may be more easily observed and captured. Animals with strange behaviors may also be tested disproportionately, skewing results toward more positive cases. A more active strategy involving random samples of rodents and lagomorphs, or enhanced surveillance among suspect animals, would be an alternative approach, but such a scheme would

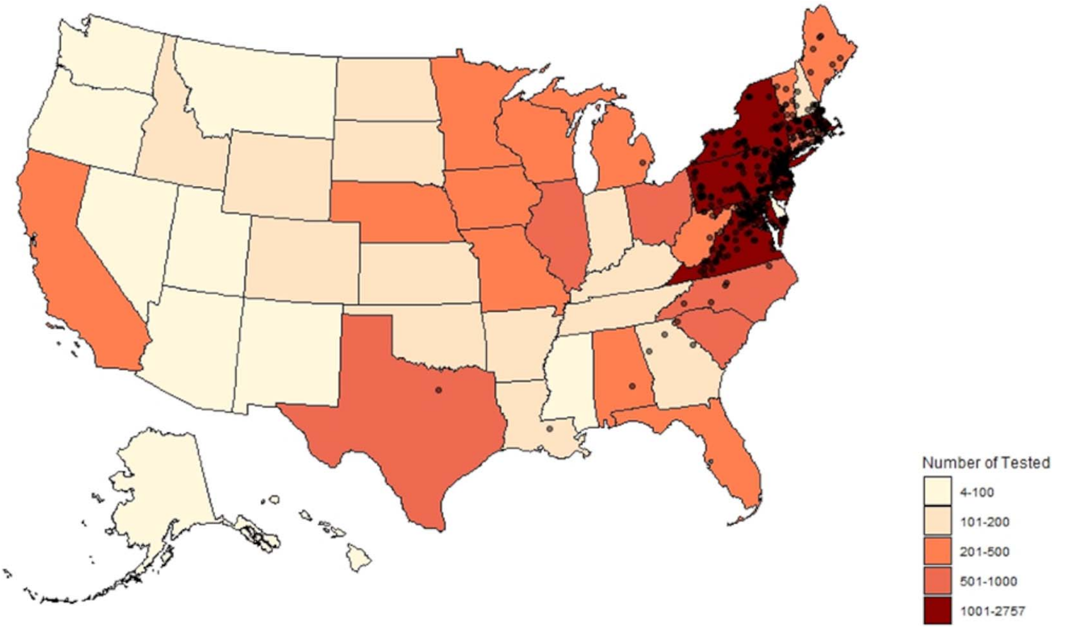


FIGURE 2. Number of rodents and lagomorphs tested for rabies (shading) and distribution of rabid rodents and lagomorphs reported (circles) by state in the USA from 2011 to 2020.

be expensive, ethically questionable, and by inference from other studies, would not be anticipated to generate more meaningful epidemiologic conclusions. Various jurisdictions also may have different ways of collecting and reporting information, which may make these data difficult to compare. For example, some states do not test for rabies in rodents and lagomorphs, while other states have higher areas of population density with higher contact with commensal rodents and lagomorphs.

A One Health approach to animal rabies prevention is crucial. This needs to be an interdisciplinary approach that considers host, pathogen, and environmental factors (Nadal et al. 2022). Globally, a One Health approach

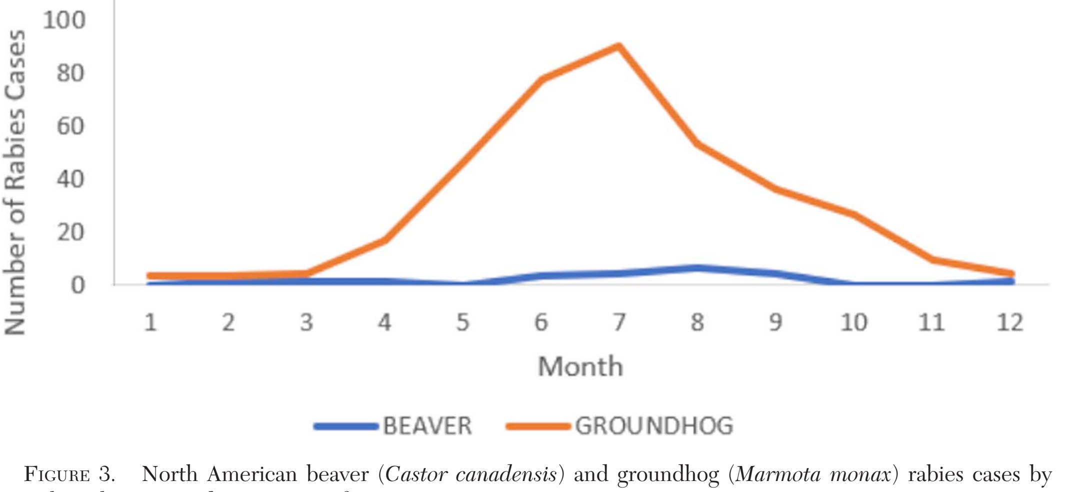


FIGURE 3. North American beaver (*Castor canadensis*) and groundhog (*Marmota monax*) rabies cases by month in the USA and Puerto Rico from 2011 to 2020.

has involved vaccination campaigns with a focus on dogs, as well as education and awareness initiatives that adapt to local cultural practices (Lavan et al. 2017). The oral vaccination of mesocarnivores, such as raccoons, would be expected to minimize the CST to larger bodied rodents, such as groundhogs and North American beavers, by breaking the chain of RV transmission from raccoons to these rodents (Slate et al. 2009). It is critical to ensure that people in rabies-endemic areas are educated about the need to avoid exposures and are aware of the need to quickly seek medical attention after such events (Lavan et al. 2017).

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