U.S. National Plan for Wildlife Rabies Management

2023-2027

All front cover photos are by the United States Department of Agriculture Wildlife Services (USDA WS).

A USDA-led collaboration with 52 agencies and organizations

More than 100 individuals representing 52 agencies/organizations attended a virtual meeting and contributed to the development of this US National Plan for Wildlife Rabies Management. *USDA WS photo.*

Contributors to the Plan

The 106 individuals below, representing 52 agencies/organizations, attended the Wildlife Services (WS) National Rabies Management Program (NRMP) cooperators meeting in September 2021 and were assigned to one of five theme teams (Coordination and Communication, Rabies Surveillance, oral rabies vaccination (ORV) Management, ORV Monitoring, and Research) described in the Development of the Current USNP section. They provided direct input on the objectives and strategies outlined in this plan. The names marked with an asterisk were members of a 17-person volunteer group that further refined the final plan.

Last Name	First Name	Organization Name
State/Local Agriculture Agencies		
*dePersio	Suzette	Arizona Dept. of Agriculture
Elchos	Brigid	Mississippi Board of Animal Health
Fiske	Rachael	Maine Dept. of Agriculture, Conservation and Forestry
Schalow	Michelle	Michigan Dept. of Agriculture and Rural Development
*Walsh	Michele	Maine Dept. of Agriculture, Conservation and Forestry
State/Local Fish & Wildlife Agencies		
Casey	Christine	Kentucky Dept. of Fish and Wildlife Resources
Cooley	Tomas	Michigan Dept. of Natural Resources
Cunningham	Mark	Florida Fish and Wildlife Conservation Commission
Flynt	Ricky	Mississippi Dept. of Wildlife, Fisheries & Parks
Hudson	Marianne	Alabama Dept. of Conservation and Natural Resources
Justice-Allen	Anne	Arizona Game and Fish Dept.
Melotti	Julie	Michigan Dept. of Natural Resources
Womack	Brent	Georgia Dept. of Natural Resources
State/Local Public Health Agencies		
Appler	Kim	New York State Dept. of Health
*Brown	Katie	Massachusetts Dept. of Public health
Burja	Tom	Anne Arundel County Dept. of Health (MD)
Clark	Stephanie	New Hampshire Dept. of Health and Human Services
Darby	Brandy	Virginia Dept. of Health
Davis	April	New York State Dept. of Health
Dotseth	Eric	West Virginia Dept. of Health and Human Resources
Fill	Mary-Margaret	Tennessee Dept. of Health
Fonken	Eric	Texas Dept. of State Health Services
Giesbrecht	Kelly	Kentucky Dept. for Public Health
Goonewardene	Dilani	Tennessee Dept. of Health
Hirsbrunner	Andrew	New York State Dept. of Health
Horman	Joe	Anne Arundel County Dept. of Health (MD)
Horowitz	Lori	Allegheny County Health Dept. (PA)
Jarvis	Jodie	New York State Dept. of Health

Jones	Dee	Alabama Dept. of Public Health
Kwit	Natalie	Vermont Dept. of Health
Mathewson	Abby	New Hampshire Dept. of Health and Human Services
Murphy	Julia	Virginia Dept. of Health
Newman	Andie	New York State Dept. of Health
Parker	Kathy	Texas Dept. of State Health Services
Rollo	Susan	Texas Dept. of State Health Services
Signs	Kimberly	Michigan Dept. of Health and Human Services
Singh	Amber	Ohio Dept. of Health
Slavinski	Sally	New York City Dept. of Health and Mental Hygiene (NY)
Stanek	Danielle	Florida Dept. of Health
Tracy	Clay	Georgia Dept. of Public Health
Williams	Carl	North Carolina Dept. of Health and Human Services
University/Research Organizations		
Bender	Scott	Dine College (Navajo Nation)
*Bigler	Laura	Cornell University (New York)
Davis	Rolan	Kansas State University
Dharmarajan	Guha	University of Georgia
*Grove	Daniel	University of Tennessee
*Murdoch	Jed	University of Vermont
Needle	David	University of New Hampshire
*Rhodes	Gene	University of Georgia
Industry Organizations		
Boyd	Frank	Artemis Technologies Inc.
Donald	Matt	Dynamic Aviation Group Inc.
Ensley	Doug	Boehringer Ingelheim Animal Health USA Inc.
Lyness	Margie	Boehringer Ingelheim Animal Health USA Inc.
*Maki	Joanne	Boehringer Ingelheim Animal Health USA Inc.
*Moore	Susan	Compass Rabies Consulting LLC
Rupprecht	Charles	Lyssa LLC
Vos	Ad	Ceva Sante´ Animale, S.A.
Federal Animal Health		
Buss	Linda	USDA/Veterinary Services
Harper	Vanessa	USDA/Veterinary Services
Srinivas	Geetha	USDA/Veterinary Services
Federal Public Health		
Gigante	Crystal	Centers for Disease Control and Prevention
Lowe	David	Centers for Disease Control and Prevention
*Panayampalli	Sathesh	Centers for Disease Control and Prevention
*Wallace	Ryan	Centers for Disease Control and Prevention

Federal Wildlife		
Allaben	David	USDA/Wildlife Services (NH/VT)
Berentsen	Are	USDA/Wildlife Services (NWRC)
Bergman	Dave	USDA/Wildlife Services (AZ)
Bodenchuk	Mike	USDA/Wildlife Services (TX)
*Chipman	Rich	USDA/Wildlife Services (NRMP)
Cromwell	Jennifer	USDA/Wildlife Services (VA)
Davis	Amy	USDA/Wildlife Services (NWRC)
Duffiney	Tony	USDA/Wildlife Services (MI)
Dunlap	Brett	USDA/Wildlife Services (TN/KY)
Dyer	Robin	USDA/Wildlife Services (ME)
Forbes	John	USDA/Wildlife Services (WV)
*Gilbert	Amy	USDA/Wildlife Services (NWRC)
Glass	Harris	USDA/Wildlife Services (PA)
Gosser	Allen	USDA/Wildlife Services (NY)
Gruver	Ken	USDA/Wildlife Services (AL/PR/USVI)
Hale	Bob	USDA/Wildlife Services (NRMP)
Haley	Betsy	USDA/Wildlife Services (NRMP)
Hall	Parker	USDA/Wildlife Services (FL)
Hicks	Bradley	USDA/Wildlife Services (NRMP)
Hopken	Matt	USDA/Wildlife Services (NWRC)
Johnson	Shylo	USDA/Wildlife Services (NWRC)
Kabert	Beth	USDA/Wildlife Services (NEPA)
*Kirby	Jordona	USDA/Wildlife Services (NRMP)
Leddon	Jonathan	USDA/Wildlife Services (MS)
Leland	Bruce	USDA/Wildlife Services (TX)
Montoney	Andy	USDA/Wildlife Services (OH)
*Nelson	Kathy	USDA/Wildlife Services (NRMP)
Smith	Steve	USDA/Wildlife Services (NC)
Stephens	Odin	USDA/Wildlife Services (GA)
*Thurber	Christine	USDA/Wildlife Services (NRMP)
Wilda	Don	USDA/Wildlife Services (MA/CT/RI)
Wilmoth	Bill	USDA/Wildlife Services (NY)
Federal Other		
Espinosa	Tanya	USDA/Legislative and Public Affairs
*Lecuona	Luis	USDA/International Services (MEX)
International Agencies/Organizations		
Buchanan	Tore	Ontario Ministry of Natural Resources & Forestry
Fehlner-Gardiner	Christine	Canadian Food Inspection Agency
Gagnier	Marianne	Quebec Ministry of Forests, Fauna and Parks
Home	Colleen	New Brunswick Dept. of Agriculture, Aquaculture & Fisheries

Leighton	Patrick	University of Montreal (Quebec)
Masse	Ariane	Quebec Ministry of Forests, Fauna and Parks
Nituch	Larissa	Ontario Ministry of Natural Resources & Forestry

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Introduction and Background

The United States National Plan for Wildlife Rabies Management (USNP) is a 5-year framework for collaborative management of wildlife rabies in the United States (US) developed by a coalition of experts representing multiple agencies and disciplines dedicated to wildlife rabies management. The USNP outlines goals, objectives and strategies that incorporate what has been learned to date, addresses current issues, and anticipates future challenges. The purpose of the plan is to provide clear direction toward achieving wildlife rabies management goals, help prioritize management actions, and track progress toward meeting strategic goals. The scope of the plan primarily addresses management of rabies in raccoons, coyotes, and gray foxes in the US through ORV, and to a lesser degree skunks, Arctic foxes, free-ranging dogs, and mongoose. In addition, the plan addresses surveillance of vampire bats, as oral rabies vaccines are not currently available for managing rabies in bats.

Wildlife rabies management is complex and requires a shared strategic vision and diverse professional knowledge. North America benefits from a wide array of talents and expertise from a variety of sources that is integral to the overall team-centered approach to rabies prevention and control across many borders. These subject matter experts form the basis of a coalition providing necessary support for meeting the demands of a large-scale wildlife disease management program that impacts both human and animal health. Rabies management success depends heavily on the ability of an interdisciplinary partnership to function cooperatively and collaboratively to avoid redundancy of effort, and to maximize the use of limited resources to achieve rabies management goals including the elimination of terrestrial rabies from North America. Such an accomplishment could in turn serve as a model for rabies elimination around the globe.

Figure 1. Rabies control in the US is a complex system involving many agencies under the umbrella of One Health. *Image used with permission from the CDC.*

Rabies Overview

Rabies is a viral disease of mammals, usually transmitted from the bite of a rabid animal and direct contact with saliva or brain/nervous tissue from the infected animal. It has the highest case fatality rate of any known disease (~100%), globally killing >59,000 people annually, primarily in developing countries where dog rabies

Read More About It!

When you see this box, go to the Relevant Literature section for:

- Hampson 2015
- Held 1967
- Ma 2023

has not been controlled. Prior to compulsory pet vaccination laws and mass vaccination campaigns, rabies was responsible for hundreds of human deaths each year in the US. By 1970, most human rabies cases were due to rabid wildlife exposures rather than dogs and by the late 1970s, enzootic canine rabies virus variant (RVV) transmission had been eliminated.

Rabies can be effectively prevented by vaccination in humans and domestic animals but remains a significant wildlife management and public health challenge in the US. Nearly 100,000 animals are tested annually through a laboratory-based surveillance system (Fig. 1) representing 53 jurisdictions (50 states, Puerto Rico, New York City, and Washington, D.C.) across 130 public health, agriculture, and academic laboratories. Approximately 4,000 animals test positive for rabies in the US each year and >90% of those are wildlife, primarily raccoons, bats, skunks, and foxes. Four million Americans report being bitten or scratched by animals each year and 60,000 receive post-exposure prophylaxis (PEP) to prevent rabies by the suspect animal. The estimated cost of rabies prevention and control in the US is high and growing to >$600 million per year. Despite these staggering numbers, human rabies is rare in the US, averaging only three cases annually since 2000, thanks in large part to the robust nationwide One Health approach that involves a network of animal, human, and wildlife health officials working together to manage this deadly disease.

Wildlife Rabies and Management in the US

Rabies virus variants in terrestrial wildlife evolved after successful host shift events from either a rabid dog (canine variant) or bat (bat variant). Presently in the US, there are seven RVVs that are enzootic in small to midsized carnivores (meso-carnivores) with varying host species and regions of distribution: Arctic fox (Alaska only), Arizona fox, California skunk, eastern raccoon, mongoose (Puerto Rico only), north central skunk, and south central skunk (Fig. 2).

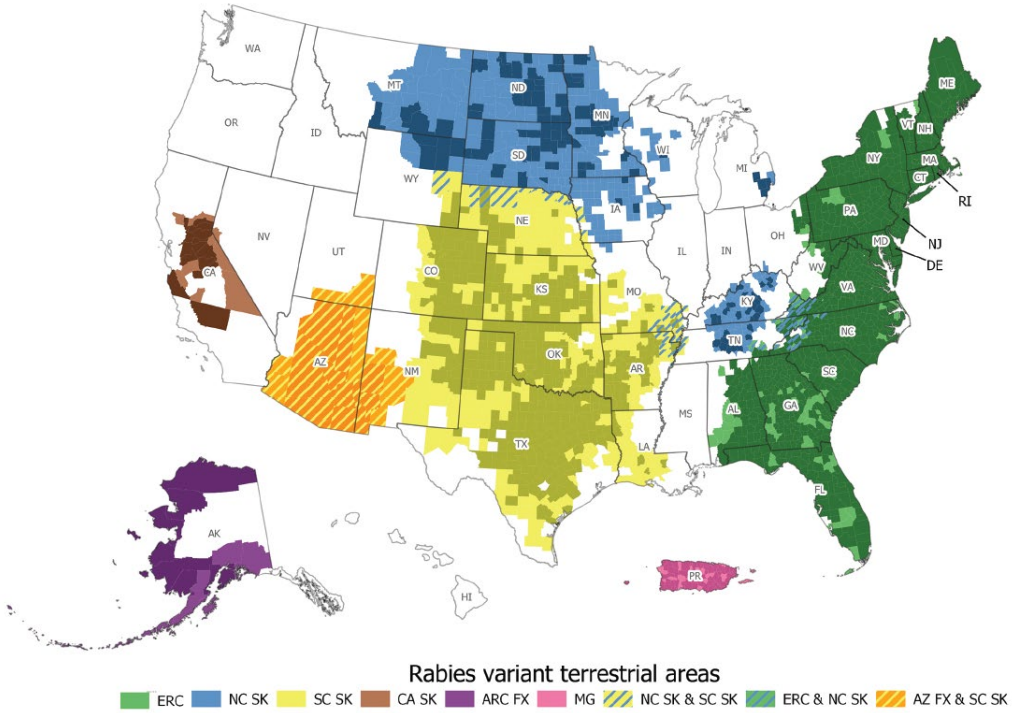


Figure 2. Distribution of terrestrial rabies virus variants (RVVs) in the US, including Puerto Rico, for 2017-2021. Darker shading indicates counties with confirmed animal rabies cases in the past 5 years; lighter shading represents counties bordering enzootic counties without animal rabies cases that did not satisfy criteria for adequate surveillance. Small non-enzootic 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; ERC = Eastern raccoon RVV; MG = Dog-mongoose RVV; NC SK = North central skunk RVV; SC SK = South central skunk RVV. *Figure used with permission from Ma et al. 2023 and the CDC.*

Contemporary management of rabies in terrestrial wildlife in the US, Canada, and Europe involves ORV, the distribution of rabies vaccine baits targeting various wildlife species and associated variants. Two oral rabies vaccines are currently used in the US: RABORAL V-RG® (V-RG; Boehringer Ingelheim Animal Health USA Inc., Duluth, Georgia, USA) and ONRAB (Artemis Technologies Inc., an indirect, wholly-owned subsidiary of Ceva Sante´ Animale, S.A., Guelph, Ontario, Canada). V-RG is a licensed product that has been used in the US since 1990, whereas ONRAB is experimental and has been used since 2011. Between the two vaccines, 8-10 million doses (baits) are distributed annually in the US. Most ORV efforts (90%) target raccoons and the raccoon RVV in the eastern US, while baiting is conducted in Texas to prevent reemergence of the dog-coyote RVV and the Texas gray fox RVV (Fig. 3).

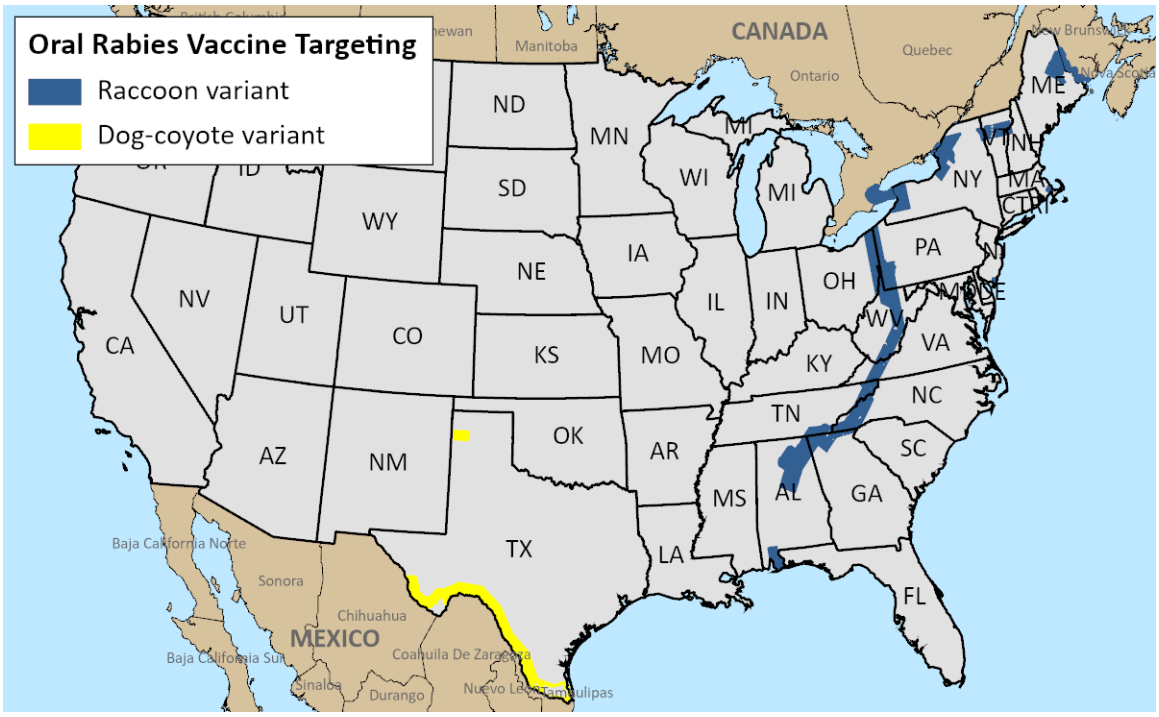


Figure 3. Distribution of oral rabies vaccine in North America targeting raccoon and dog-coyote rabies virus variants in 2022. *Canada data used with permission from the Ontario Ministry of Natural Resources and Forestry and the New Brunswick Department of Agriculture, Aquaculture & Fisheries.*

Eastern Raccoon RVV

Epidemiologic data indicate that the raccoon RVV was not documented prior to the 1940s and was possibly the result of a host shift from a skunk or bat first described in Florida in the late 1940s. The variant spread slowly into neighboring states for 30 years until it was unintentionally introduced >400 miles (>640 km) north into eastern West Virginia on the Virginia border in 1977 because of an intentional translocation event. Hunters had been legally moving raccoons from the southeastern US into this area of Appalachia for years to replenish populations. Movement of rabid raccoons from Florida to a North Carolina hunting club had been documented and later genetic characterization showed the West Virginia/Virginia outbreak was similar to raccoon rabies in the deep south. After the translocation event, raccoon rabies spread rapidly north and south over the next two decades and reached Ontario, Canada in 1999 (Fig. 4). The variant has been responsible for four human deaths and today is contiguous from southwest Alabama into southeastern Canada, extending west to eastern Ohio (Fig. 2). In 2022, ORV targeting this variant occurred in 15 eastern states, as well as New Brunswick and Ontario, Canada (Fig. 3). Since large-scale ORV programs began in 1997, cases of raccoons with raccoon RVV have decreased in the US (Fig. 5) and the westward spread of the variant has been slowed or stopped.

Raccoon
- Anderson 2014a
- Biek 2007
- Davis 2019
- Jenkins 1988
- Rosatte 2001

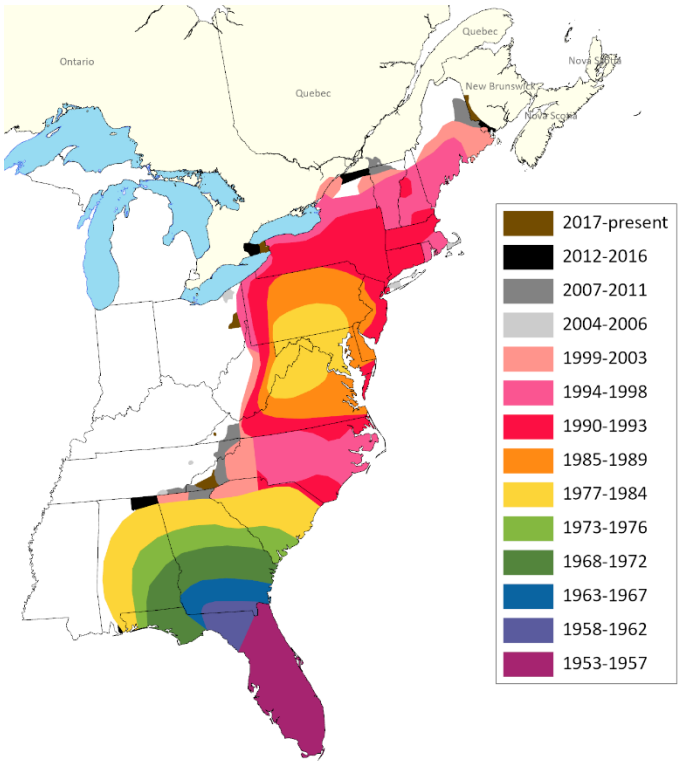


Figure 4. Distribution of raccoon rabies virus variant over time. The variant was first described in Florida, then after a significant translocation event in the late 1970s, spread quickly through the northeastern US reaching Canada in 1999. *This map was created by USDA but adapted from an early map created by Merial Limited, Inc (now Boehringer Ingelheim).*

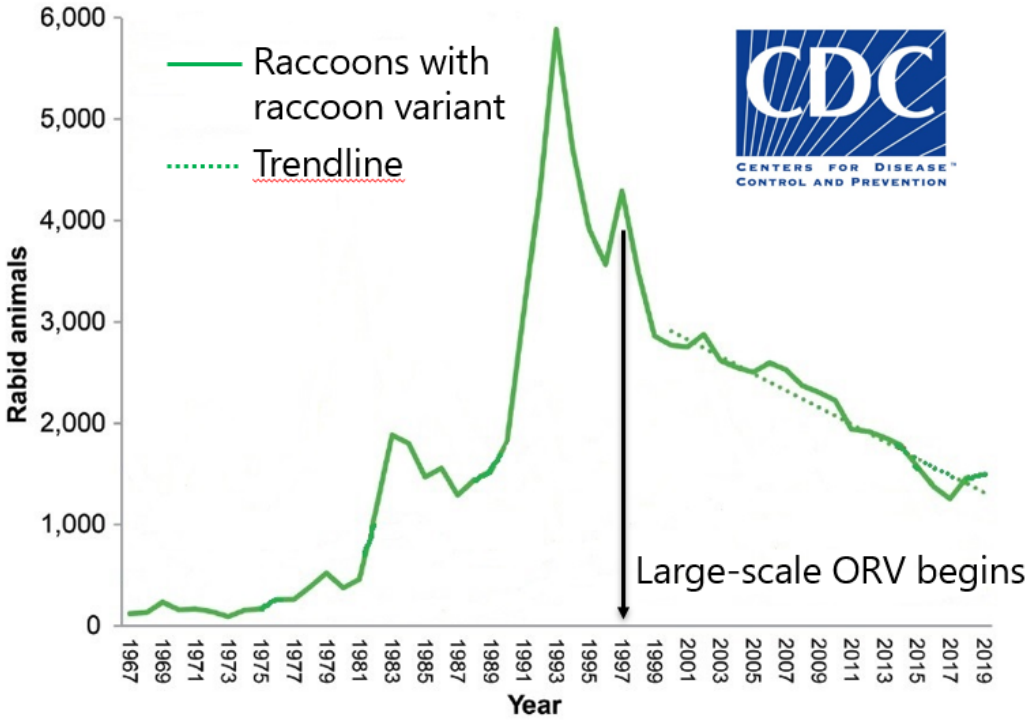


Figure 5. The number of raccoons with raccoon rabies virus variant has declined since large-scale oral rabies vaccination (ORV) efforts began in the US in 1997. *Image used with permission from the CDC. (Source: adapted from https://www.cdc.gov/rabies/location/usa/surveillance/wild_animals.html).*

Dog-Coyote RVV

Dog rabies was eliminated from the US in the late 1970s, but in 1988, a Mexican dog RVV became established in coyotes along the US-Mexico border in south Texas. This variant was readily transmitted from coyotes to domestic dogs and subsequently between domestic dogs. By 1994, this variant had advanced 158 miles (255 km) north of the US-Mexico border and had been associated with two human deaths. This dog-coyote RVV epizootic resulted in over 3,000 human rabies PEP treatments. Coordinated ORV began in 1995 targeting coyotes and the last case of dog-coyote RVV was documented in 2004, thus canine rabies was eliminated for a second time in the US. V-RG was very effective against this RVV with an average annual post-bait antibody response of 57% in coyotes from 1995-2021 (n=2,827). Today, nearly 1 million ORV baits continue to be distributed annually along the Texas-Mexico border as a maintenance zone to prevent the reemergence of canine rabies in the US (Fig. 3).

TX Coyote/ Gray Fox
- Fearneyhough 1998
- Maki 2017
- Sidwa 2005
- Velasco-Villa 2008

Texas Gray Fox RVV

During the late 1980s, another dog-associated RVV was detected in Texas gray foxes (i.e., the Texas gray fox RVV) and in 1996, ORV began targeting this variant in west-central Texas. The last case was documented in 2013 and this variant is considered eliminated from the US. V-RG is also very effective at vaccinating gray foxes, with an average annual post-bait antibody response of 76% from 1996-2021 (n=2,458).

Arctic Fox RVV

The Arctic fox RVV circulates among Arctic foxes and has a broad circumpolar distribution throughout North America, Europe, and Asia, but in the US, it is confirmed only in Alaska. There, rabies outbreaks routinely occur during winter and the number of red foxes with this variant has increased over the past decade. This observation along with modeling, suggests regional warming trends may be associated with increased contact rates and transmission between Arctic and red foxes. At present, no ORV programs exist in the US targeting Arctic foxes due in part to the remote geographic area this variant encompasses, challenges associated with host ecology (e.g., Arctic foxes have large territories, travel great distances, and have different behavior between summer and winter), and challenges with consistent delivery of oral vaccines in freezing temperatures.

Arctic Fox
- Follmann 2011
- Kuzmin 2008

Arizona Fox RVV

The Arizona fox RVV is enzootic in gray foxes throughout most of Arizona, in southwestern New Mexico, and southern Utah (Fig. 2). Although V-RG is effective in gray foxes, all US ORV programs remain focused on raccoon RVV and maintaining the US canine variant free which has not allowed for expansion of ORV programs targeting the Arizona fox RVV at this time.

Mongoose RVV

The mongoose RVV is enzootic on four Caribbean islands including Puerto Rico and is closely related to canine RVV. There is some concern that the mongoose variant may be capable of limited dog-to-dog transmission which presents a public health concern in Puerto Rico where dog vaccination rates are low. No ORV programs currently exist in Puerto Rico targeting mongoose, but numerous research studies have been conducted over the last two decades by industry and government including vaccine, bait and biomarker development, and ecological investigations to assist with developing baiting strategies for mongooses.

The V-RG vaccine is not efficacious in mongoose through direct oral installation, but SPBN GASGAS (Ceva Sante´ Animale, Libourne, France) produces an immune response in mongooses. This led to a placebo bait trial that

Mongoose
- Berentsen 2020
- Blanton 2006
- Vos 2013

Figure 6. Ceva egg flavored bait targeting mongoose. *USDA WS photo.*

was conducted in the fall of 2016 and spring of 2017 in southwestern Puerto Rico using an egg flavored Ceva bait with no vaccine (Fig. 6), but with an iophenoxic acid (IPA) biomarker that can be detected in sera. Baits were distributed at 200/km^2 and 74% (133/179) of unique mongooses were positive for IPA biomarker, indicating bait consumption during either the fall, spring, or both trials. These results are promising and may prove ORV for mongooses on Puerto Rico could be effective (i.e., able to reach >60% of the target population that would likely be required for RVV elimination in a variety of island habitats). It is expected that a live vaccine field trial will occur during the timeframe of this national plan.

Skunk RVVs

The California and north central skunk variants represent host shifts of canine lineages, whereas the south central skunk variant is more closely related to bat rabies. Skunks were responsible for most reported wildlife rabies cases prior to the expansion of raccoon rabies in the 1980s. Today, skunks remain a significant source of rabies cases and their variants comprise the broadest geographic area of any terrestrial RVVs in the US.

ORV for skunks is challenging as vaccines that show efficacy by direct oral installation often prove less effective when delivered in baits in the field. During 2012-2017, the Texas Department of State Health Services (TDSHS) had an ORV program specifically targeting skunks. More than 4.2 million V-RG baits were distributed, but the average annual post-bait positive antibody response in skunks was only 34% (n=580). The TDSHS discontinued the program and presently, there are no ORV programs targeting skunks in the US.

Bat RVVs

In addition to the terrestrial variants, 29 known bat reservoirs exist in the Americas and about half of those are in North America. Forty-five species of bats are found in the continental US, and rabid bats have been reported from every state except Hawaii. Most human rabies deaths in the US since 2000 are attributed to exposures to bat RVVs. Cases in humans are frequently due to a failure to seek medical advice following a bat bite, or in some cases, a failure to detect the bite or recognize the presence of a bat.

Bats pose unique challenges to oral vaccination when compared to carnivores. Most bats eat insects, fruit, nectar, or pollen and spend very little time on the ground. Thus, developing an attractive bait that can deliver a large enough dose of oral vaccine to be protective, and distributing it in such a way to be effective for volant (aerial) animals remains difficult and has safety concerns. However, many bats often live in colonies and practice social grooming, so much of the oral rabies vaccine research conducted in the last two decades has capitalized on the notion of vaccinating a few bats, allowing for wider vaccination through their behavior. Several vaccines have proven immunogenic and efficacious in preventing rabies in bats, but more research is needed to have a commercially available oral rabies vaccine for wide distribution.

As such, bat rabies risk reduction strategies include public information and education campaigns to increase awareness of bats, bat rabies, and the need to capture and test bats involved in possible exposure situations. In addition, other strategies include the humane exclusion of bats from houses and public buildings, etc. to prevent direct contact with humans.

Common Vampire Bat RVV: Only three bats in the world feed on blood and only one feeds on mammalian blood, the common vampire bat. Common vampire bats primarily feed on cattle, but also horses, goats, pigs, and a variety of wildlife species. The common vampire bat is host to a unique RVV and its bite can be damaging to cattle (e.g., damaged hides, weight loss, decreased milk production). In some parts of Mexico, vampire bat RVV kills up to 20% of unvaccinated cattle and results in millions of dollars of economic loss annually.

The common vampire bat has a considerable range in Mexico and has been documented within 31 mi (50 km) of the US border in south Texas. Modeling results suggest natural range expansion into Texas or south Florida and possibly Arizona and Louisiana may occur. One study estimated the economic impact of vampire bats spreading into south Texas at $7-9M annually.

Skunk

- Brown 2014
- Fehlner-Gardiner 2012
- Gilbert 2018
- Grosenbaugh 2007
- Mainguy 2012
- Pedersen 2019
- Rupprecht 1995
- Slate 2009
- Slate 2014
- Tolson 1987
- Wohlers 2018

Bat

- Acha 1988
- Aguilar 2002
- Almeida 2008
- Anderson 2014b
- Anderson 2014c
- Baggaley 2017
- Bakker 2019
- Bodenchuk 2020
- Cardenas-Canales 2022
- Delpietro 2021
- Gilbert 2020
- Hayes 2018
- Johnson 2014
- Kunkel 2022
- Mistry 2009
- Stading 2017
- Van de Vuurst 2022
- Worsley-Tonks 2020
- Zarza et al. 2017

Since 2016, surveillance activities have been implemented in Arizona, New Mexico, Texas, and Florida for early detection of vampire bats and vampire bat RVV. Primary activities include: surveying cattle (>500,000 to date) at livestock sales, dairy farms, feedlots (Fig. 7), and ranches for evidence of vampire bat bite wounds (no bites found); and educating ranchers, livestock owners/producers, and cattlemen on what to look for related to vampire bats and their bites via >1,800 DVDs distributed on both sides of the US-Mexico border. This surveillance will continue as more research is needed on modeling range expansion and the further development of science-based strategies for oral vaccination of vampire bats to reduce rabies risk. Additionally, federal partners have been working with states to improve bat identification when reporting rabies cases, and citizen science apps (e.g., iNaturalist) are being monitored; both tactics provide additional surveillance for detecting common vampire bats in the US.

Figure 7. Cattle at a feedlot are surveyed for signs of vampire bat bites. *USDA WS photo.*

Significant RVV Spillover Events

Spillover
- Kuzmin 2012
- Leslie 2006
- McCollum 2012
- Wallace 2014

Cross species transmission (or spillover) is not uncommon and occurs when a RVV causes disease in non-reservoir species, but rarely initiates sustained transmission in the non-reservoir. However, in 2001 an outbreak of big brown bat RVV was documented in 19 striped skunks in Flagstaff, Arizona indicating transmission and maintenance among skunks. Similar host shifts of big brown bat RVV occurred again in 2004-2005 (in 6 striped skunks and 2 gray foxes), 2009 (in 23 gray foxes, 6 striped skunks, and a ringtail), and 2021-2022 (in 20 striped skunks). All cross species transmission events occurred in the Flagstaff area and trap-vaccinate-release (TVR) was used to control the skunk outbreaks given the limitations of ORV in skunks. ORV targeting gray fox was successfully used in 2009-2011 (~130,000 V-RG baits each year).

Roles and Responsibilities

Federal, tribal, state, county and municipal government agencies, universities, private organizations, industry, and bordering countries all play essential roles in rabies prevention and control in the US. The challenge of successful rabies elimination involves cooperation by numerous states, land managers, and neighboring countries. Single states within any large RVV enzootic area cannot succeed long term with control or elimination programs in isolation. To minimize the risk of

rabies spreading back into areas where RVV has been locally eliminated requires a coordinated effort among government agencies and key stakeholders to implement a robust surveillance system and cooperative ORV project planning at the regional and national level.

Federal

The major federal agencies involved in wildlife rabies management are the US Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Wildlife Services (WS) program and the Centers for Disease Control and Prevention (CDC).

WS is authorized to conduct rabies control under its enabling legislation, the Acts of March 2, 1931 (46 Stat. 1468-69, 7 U.S.C. §§ 8351-8352), as amended, and December 22, 1987 (Public Law No. 100-202, § 101[k], 101 Stat. 1329-331, 7 U.S.C. § 8353) and has done so through the WS National Rabies Management Program (NRMP) since 1997. The WS NRMP's major responsibilities (and the pillars of any wildlife rabies management program) are to (see call out box on right): coordinate and communicate among all partners, collaborators and stakeholders, including a diverse group of government agencies in the US, Canada, and Mexico; conduct enhanced rabies surveillance (ERS) and test non-exposure animal brainstem samples for rabies antigen via the direct rapid immunohistochemical test (DRIT; Fig. 8); distribute ORV baits; conduct post-ORV monitoring through target species sampling to determine rabies antibody response and bait uptake levels; and conduct research to increase scientific knowledge and better inform rabies management strategies.

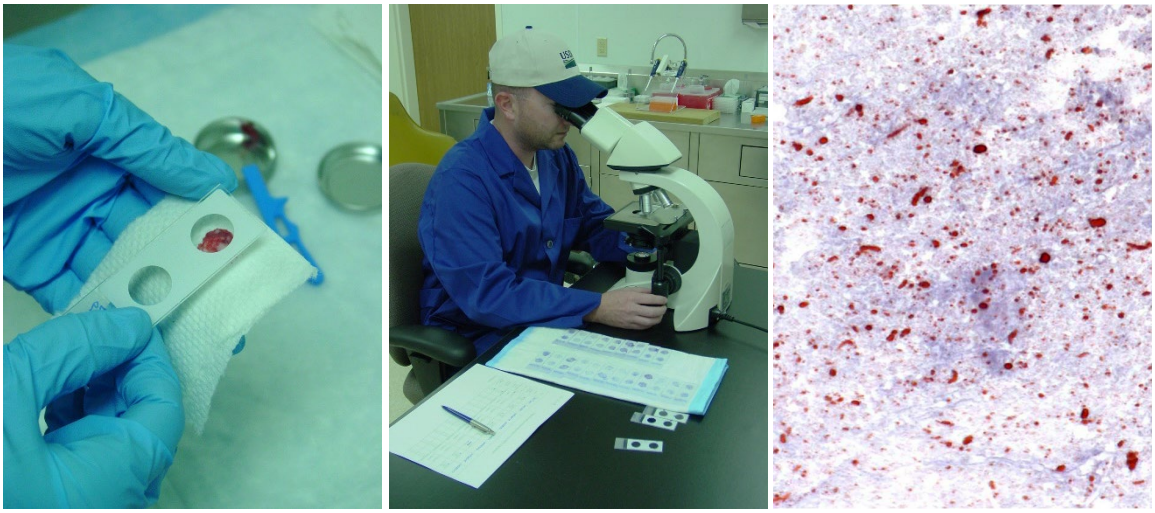


Figure 8. As part of enhanced rabies surveillance, the direct rapid immunohistochemical test is conducted to diagnose rabies. Several steps are involved including touch impressions of animal brain (left), reviewing slides by light microscope (center), and determining positive samples via red viral inclusions (right). *USDA WS photos.*

The CDC serves as the National Rabies Reference Laboratory and National Rabies Surveillance System, as well as representing the US in several critical international designations including a World Health Organization (WHO) Collaborating Center for Rabies and World Organization for Animal Health (WOAH, formerly OIE: Office International des Epizooties) Reference Laboratory for Rabies. Rabies in humans and animals was declared a federally notifiable disease to the CDC in 1941, and the CDC has maintained national rabies surveillance data for over 80 years. The Council of State and Territorial Epidemiologists (CSTE), in collaboration with CDC, state, and local public health officials develop Position Statements, which are standardized surveillance case definitions, maintain the Nationally Notifiable Condition List, and address policy issues that could affect state or local law, rules or regulations. Rabies Position Statements for Human (2009) and Animal (2022) rabies represent the framework for public health surveillance, testing, and reporting systems in the US (see call out box on right). CDC is a leading institution on the research of new vaccine technologies, novel diagnostic techniques, and molecular epidemiology.

Wildlife Rabies Management Pillars

Referred to as major responsibilities, pillars, and themes, these components make up any scientifically sound wildlife rabies management program and can be found throughout this plan by following the colors below:

- Communication
- Surveillance
- Management
- Monitoring
- Research

WS/CDC

- Ma 2023
- Patrick 2019
- Tobin 2012

Position Statements

Human #09-ID-70
https://cdn.ymaws.com/www.cste.org/resource/resmgr/PS/09-ID-70.pdf

Animal #22-ID-06
https://cdn.ymaws.com/www.cste.org/resource/resmgr/ps/ps2022/22-ID-06_Animal_Rabies.pdf

Other cooperating federal agencies involved in wildlife rabies management include (but are not limited to) the: USDA, APHIS, Veterinary Services; USDA, APHIS, International Services; National Park Service; US Fish and Wildlife Service; US Forest Service; Bureau of Land Management; Bureau of Indian Affairs; Department of Defense; Army Corps of Engineers; Homeland Security; US Coast Guard; National Aeronautics and Space Administration; and Federal Bureau of Investigation.

Tribal

All tribes have the ability to conduct passive rabies surveillance through their respective public health systems. The tribes currently involved in wildlife rabies management and ERS are the: MOWA Band of Choctaw Indians (in Alabama); Houlton Band of Maliseet Indians, Penobscot Nation, and Aroostook Band of Micmac (in Maine); Seneca and Tuscarora Nations (in New York), and Eastern Band of Cherokee Indians (in North Carolina). These nations collaborate to allow bait distribution targeting raccoons, and on some lands, post-bait sampling (trapping) on their properties. Several also provide samples for ERS and testing including the Navajo and Hopi Nations (in Arizona). The Navajo Nation has been a longtime key partner on researching ORV for dogs (Fig. 9).

Figure 9. Several studies have been conducted on the Navajo Nation involving oral rabies vaccination for dogs (handout models). *USDA WS photo.*

Navajo
- Bender 2009
- Bender 2017
- Berentsen 2014
- Berentsen 2016
- Bergman 2008

State/Territory

All states/territories conduct passive rabies surveillance through their respective public health systems. In each of these states/territories the health departments' primary responsibilities in support of wildlife rabies management include testing samples for rabies virus antigen via the direct fluorescent antibody (DFA) test that have been involved in a human or domestic animal exposure. In addition, health departments take the lead on exposure investigations and make determinations for PEP (in humans) and/or quarantines (in animals).

Each state's agriculture department's primary responsibilities in terms of supporting wildlife rabies management programs include developing and enforcing domestic animal vaccination laws and, in some locales, testing samples for rabies virus antigen via the DFA test. The state wildlife departments support broader wildlife rabies control efforts through conservation and management of furbearer species populations (raccoons, skunks, foxes, coyotes, etc.), enforcing wildlife relocation laws (if they exist), managing wildlife rehabilitation permits, and permitting to trap furbearers. Other cooperating state/territorial agencies involved in wildlife rabies management include (but are not limited to): forests, parks, environmental conservation, and transportation departments.

The states/territories currently cooperating in US wildlife rabies management and ERS are Alabama, Arizona, Florida, Georgia, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Mississippi, New Hampshire, New Jersey, New Mexico, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Texas, Vermont, Virginia, West Virginia, and Puerto Rico. While state agency support for ERS primarily involves assisting WS with sample collection, in some locales (New York, Texas and Vermont), the state health departments routinely test ERS samples. Additionally, cooperating state wildlife departments assist WS by granting permits specifically for pre- and post-bait monitoring (trapping).

Local ORV
- Bigler 2021a/b
- Horman 2012
- Roscoe 1998
- Slavinski 2012

County/Municipal

Many counties and municipalities have their own health departments, some with similar responsibilities as mentioned for state health departments. Currently, Anne Arundel County in Maryland, Cape May County in New Jersey, and New York City in New York conduct ORV programs

within their political boundaries. While these programs are not directly tied to nationally coordinated efforts focused on the elimination of raccoon RVV, they are important to rabies prevention and control at the local level.

Universities, Private Organizations, Industry

At least 27 universities are collaborating with the federal government on wildlife rabies related research. These cooperative studies involve several objectives to improve wildlife rabies management, surveillance, monitoring, and planning: enhancing field diagnostic tools; refining and evaluating novel wildlife rabies vaccines, baits, and biomarkers; understanding target and nontarget species ecology, behavior, and population biology; understanding host population and landscape genetics to define population connectivity across important areas; evaluating ORV strategies targeting free-ranging wildlife; developing and evaluating engineered tools and/or technology to improve the logistics, efficiency, and mechanics of bait delivery; modeling and assessing risk to improve the prevention, control and elimination of wildlife rabies; and assessing risk and surveillance for bat RVVs.

Current Collaborating Universities:

Auburn University; Colorado State University; Cornell University; Kansas State University; National Chiayi University; Ross University; Southern Illinois University; Tulane University; Universidad Andres Bello; Universidad de Zaragoza; University of British Columbia; University of Colorado; University of Georgia; University of Glasgow; University of Minnesota; University of Missouri; University of Montreal; University of New Hampshire; University of Oklahoma; University of Puerto Rico; University of Richmond; University of Saskatchewan; University of Tasmania; University of Vermont; University of Wisconsin; University of Wyoming; and Washington State University

Many individuals and non-governmental organizations (NGO; e.g., wildlife rehabilitators, nuisance wildlife control operators, furbearer trappers' associations, landowners' associations, etc.) have important roles in support of wildlife rabies management, for example: educating the public on the threats posed by potentially rabid animals; understanding the importance of not moving potentially rabid animals across the landscape; providing samples for ERS and testing; and allowing access to properties for bait distribution and post-bait sampling (trapping).

Industry partners also play critical roles in wildlife rabies management by manufacturing oral rabies vaccine baits (Artemis Technologies, Inc.; Boehringer Ingelheim Animal Health USA, Inc.; Ceva Sante´ Animale), providing contracted air services for bait distribution (Dynamic Aviation [Bridgewater, Virginia, USA]), and producing recombinant monoclonal antibody conjugate that will be evaluated for use in the DRIT and potentially determining scalability for commercial production (Absolute Antibody [Boston, Massachusetts, USA]).

Canada and Mexico

Having eliminated dog rabies decades ago like the US, Canada has been focused on wildlife rabies management since the mid-1980s in certain provinces and currently conducts ORV and ERS in Ontario and New Brunswick and ERS in Quebec (last ORV in 2020). All other provinces conduct rabies surveillance through their respective public health systems. At the federal level, the Canadian Food Inspection Agency plays a similar role as the US CDC by serving as a reference laboratory, testing samples involved in exposures, and summarizing provincial rabies case data. In contrast to the US, wildlife rabies control programs are led by provincial governments (wildlife ministries in Ontario and Quebec and the agriculture department in New Brunswick) but are well coordinated and involve a great deal of communication and collaboration among provinces and across the international border with the WS NRMP and states through a "Management Without Borders" initiative. Recognizing that wildlife and wildlife RVVs don't stop at political boundaries, Canada has donated >3.9 million US dollars' worth of ORV baits to WS since 1997 under the umbrella of the North American Rabies Management Plan (NARMP).

In 2019, Mexico obtained WHO validation for eliminating dog-mediated human rabies and became the first country to do so under a new official validation process. Since 1990, they have

Canada/ Mexico

- Acheson 2023
- Arechiga Ceballos 2022
- Fehlner-Gardiner 2018

distributed >450 million doses of parenteral rabies vaccine to dogs and reduced the number of rabid dogs and humans due to canine RVV to zero (from 3,049 and 60 in 1990, respectively). Mexico is now experiencing some of the same challenges as other countries looking toward the management of rabies in free-ranging wildlife. Mexico continues to control localized outbreaks of vampire bat rabies through vampire bat population control (vampiricide) and human cases of rabies in Mexico are now due to wildlife, mostly bats and skunks. The Mexico ministries of health (SALUD), agriculture (SAGARPA) and natural resources/wildlife (SEMARNET) have been important partners in the NARMP for over a decade. As a result of country-wide success with canine-mediated human rabies elimination and a shift in focus to terrestrial wildlife rabies management, Mexico has begun discussions with US agencies on ERS, ORV and TVR strategies and post-bait monitoring. Additionally, CDC has provided support to Mexico to improve diagnostic capacities and sharing of surveillance data.

Planning Process

History and Development of Previous USNPs

Federally funded wildlife rabies management through ORV began in 1995 in the US. Prior to the first USNP (2008-2012), several foundational documents served as an unofficial national plan for wildlife rabies management in the US and facilitated rabies management decision-making. Those documents included: national working group recommendations; WS wildlife rabies control business plans; and WS National Environmental Policy Act (NEPA) analyses including environmental assessments of oral vaccination, Decisions/Findings of No Significant Impact, and supplemental environmental assessments.

From 1999-2008, the WS NRMP hosted annual national rabies management team meetings (known as "cooperators meetings") where >100 professionals from local, state, federal and international governments including health, agriculture, and fish and wildlife departments as well as universities and industry participated (Fig. 10). Meeting goals were to: 1) conduct strategic planning for wildlife rabies control; 2) exchange scientific and program information on nationally coordinated rabies management; and 3) ensure interdisciplinary input into ORV decision-making. Meetings were structured around 10 teams that focused on specific aspects of managing wildlife rabies in North America: ORV Evaluation, Surveillance/Laboratory Support, Vaccine/Bait/Biomarker, Rabies Management Strategies, Contingency Action Planning, Aviation Support, Communications Planning, Economic Analysis, NEPA Compliance, and Research Prioritization.

Foundational Documents
- Hanlon 1999
- Slate 2005
- USDA 2001
- USDA 2002
- USDA 2003
- USDA 2004
- USDA 2008a

Figure 10. USDA Wildlife Services hosted a national rabies management team ("cooperators meeting") in San Antonio, Texas, 2007. *USDA WS photo.*

The first USNP was based on scoping exercises conducted at the 2007 and 2008 cooperator meetings in San Antonio, Texas and Mobile, Alabama, respectively. There was no meeting in 2009, but at the 2010 meeting in Nashville, Tennessee, many of the strategies in the plan were revised by the group, resulting in the final USNP for 2008-2012.

The second USNP from 2016-2021 involved a nine-person committee representing state departments of health (MA and TX), the federal government (WS NRMP and CDC), and industry

(vaccine manufacturer). Special attention was given, as before, to rabies monitoring and surveillance, vaccine and bait development, legal questions such as those arising through NEPA, and partnerships development. A draft revised plan was distributed to cooperators in all states involved in the WS NRMP cooperative wildlife rabies control program at that time for review and comment. The final USNP for 2016-2021 was produced and provided to stakeholders in August 2016.

Development of the Current USNP

Development of the current plan (2023-2027) began in September 2021, with the WS NRMP hosting the first cooperators meeting since 2014. Due to the global COVID-19 pandemic, it was a 3-day virtual Zoom meeting with over 100 participants representing more than 50 agencies, institutions, and vendors (see Contributors to the Plan section). The first day provided a series of updates since the last meeting including: messages from WS headquarters, the WS National Wildlife Research Center, and the WS NRMP; the CDC One Health Office; a panel of experts from federal and state agencies outlining current partnerships in wildlife rabies management with case examples; and background presentations for five themes (called teams here) focused on planning input: Coordination and Communication, Rabies Surveillance, ORV Management, ORV Monitoring, and Research. Days two and three of the meeting involved breakout group exercises focused on these five themes. Attendees were assigned to one of the five theme teams and then broke into smaller sub-groups of 5, 10 and 20 people for four exercises before getting back together (100+ people) for two final exercises. The smaller group exercises focused on revising, removing, or adding new objectives and strategies from the 2016-2021 USNP, while the large group exercises focused on theme reporting and brainstorming for future opportunities and challenges through an interactive online polling software that provided immediate feedback as participants answered questions. At the conclusion of the meeting, each theme team had updated or created new draft objectives and strategies for inclusion in the 2023-2027 USNP.

The next phase involved creating a group of 17 volunteers who had attended the September meeting (see names with asterisk in Contributors to the Plan section). These volunteers were tasked with additional writing, editing, and refining the final draft plan. This group had representation from USDA, CDC, universities, state agriculture, state health, and industry. Over the course of eight weeks, six 1-hour Microsoft Teams calls, and shared documents on a Microsoft SharePoint site, the group worked to finalize the draft objectives and strategies for each theme and provided input for updating the introduction and background; mission, goals, and measures of success; and relevant literature sections of the plan. The remainder of the plan was finalized by three WS NRMP employees and sent to three reviewers for final comment. Then by protocol, a final policy review by WS leadership and clearance by CDC was conducted. The plan was completed and distributed to stakeholders in September 2023.

North American Rabies Management Planning Process

NARMP
- USDA 2008b

The USNP integrates into the NARMP along with national rabies management plans developed by Canada and Mexico. In 2006, the WS NRMP began an effort with other agencies in the US, Canada, Mexico, and the Navajo Nation to develop the NARMP to facilitate effective cross-border rabies control efforts. The NARMP identified four primary areas for international collaboration: information transfer, prevention and control, surveillance and monitoring, and research. The NARMP was reviewed by administrative entities in each country and was formally signed at a ceremony in October 2008. The plan is available at: https://www.aphis.usda.gov/wildlife_damage/oral_rabies/downloads/Final%20NARMP%209-30-2008%20(ENGLISH).pdf

Strategic Framework Definitions

In the context of this USNP, these strategic framework definitions apply.

Mission: The guiding purpose that provides the broad logic, overall intention, and foundation for how wildlife rabies should be managed in the US. The mission statement serves to communicate purpose and direction outlined in this national plan.

Goals: Broadly defined strategic ideas that help bridge the gap of where cooperative wildlife rabies management programs are currently and where they should be in five years.

Measures of Success: Standards or benchmarks by which wildlife rabies management programs can measure progress in achieving their goals.

Themes: Broad emphasis areas that are integral to supporting and achieving the mission. In this plan, the objectives and strategies are presented under five major themes.

Objectives: Measurable statements or milestones that lead to the accomplishment of a wildlife rabies management program's goals. Along with the measures of success, objectives provide short and long-term indicators of progress.

Strategies: Clear statements of purpose, actions, or steps for successfully achieving objectives in support of goals outlined in this national plan. Strategies also can demonstrate how activities and available resources could be prioritized to accomplish objectives.

An Anne Arundel County Police Department helicopter is used to distribute oral rabies vaccine baits throughout Anne Arundel County, Maryland. *Anne Arundel County Department of Health photo.*

Mission, Goals, and Measures of Success

The wildlife rabies management goals for the US are shaped by a low human mortality rate from rabies and high social and financial costs associated with coexistence with specific RVVs. Accomplishing rabies management goals is also dependent on the availability of safe and effective oral vaccines for wildlife and funding to implement rabies control efforts. Containment of the raccoon RVV and elimination of the dog-coyote and Texas gray fox RVVs has proven that ORV programs are effective in the US. The implementation of this USNP will help advance efforts to further reduce the impacts of rabies on human and animal health while promoting wildlife management and conservation.

Mission

The mission of a collaborative program to manage wildlife rabies in the US is to implement a coordinated, cost-effective, science-based program to control and eventually eliminate specific variants of rabies in wildlife to reduce costs and associated impacts to human health, domestic animals, and wildlife for the benefit of the public.

Goals

The primary goals for wildlife rabies management in the US are to:

1) enhance coordination of wildlife rabies surveillance, management, monitoring, research, and communication among government agencies, universities, and other organizations;
2) prevent the spread of specific RVVs in the US (Phase I); and
3) eliminate specific RVVs among carnivores at the local, regional, and national level (Phase II).

Coated sachets are the most common oral rabies vaccine bait distributed in the US. *Boehringer Ingelheim Animal Health USA photo.*

Measures of Success

Success of a cooperative wildlife rabies management program will be measured by:

- continued public support and increased awareness of goals and current wildlife rabies management programs to protect human and animal health and to reduce financial and social costs of rabies (*Coordination and Communication*);
- annual reduction of RVV cases (incidence) among targeted wildlife within ORV zones, assuming adequate surveillance (*Rabies Surveillance*);
- no sustained spread of raccoon RVV outside of or within ORV zones, and elimination of raccoon RVV in defined geographic areas (*ORV Management*);
- no reintroductions/outbreaks of the dog-coyote or Texas gray fox RVVs (*ORV Management*);
- science-based evidence of rabies immune response and biomarkers (where applicable) due to vaccination in targeted geographical areas and populations of rabies reservoir species (*ORV Monitoring*); and
- new methods developed, implemented, and evaluated for improved management of rabies in wildlife (*Research*).

During wildlife rabies management program monitoring, target animals are released at the point of capture after recovery from immobilization and sampling. *Vermont Air National Guard photo.*

Themes, Objectives, and Strategies

This USNP is focused on five thematic areas that are the pillars of wildlife rabies management in the US:

- Coordination and Communication
- Rabies Surveillance
- ORV Management
- ORV Monitoring
- Research

Under each theme are several objectives, and strategies to meet those objectives in the next five years. At the end of each strategy is a "subtopic" (in gray text) that guides development of strategies within that theme.

Beechcraft King Air 90 planes (contracted by Dynamic Aviation) get fueled for the night after a day of distributing oral rabies vaccine baits in Texas. *Texas Department of State Health Services photo.*

Coordination and Communication

Extensive interagency involvement has occurred in the development of national wildlife rabies management objectives and strategies for decades, as described earlier in the History and Development of Previous USNPs section. Federal and state public affairs professionals collaborate annually to prepare rabies communication plans, develop public outreach materials, and respond to media requests. Education and communication campaigns have been implemented targeting both the public and cooperating agencies, increasing wildlife rabies awareness and wildlife rabies management programs occurring in the US. These activities have included developing, producing, and distributing products such as videos and brochures explaining ERS and DRIT, ORV management (baiting operations), ORV monitoring (post-bait trapping and sampling), and rabies related research. In addition, rabies related presentations, geared toward the public and the scientific community, have been given by wildlife, public health, and agriculture professionals in states with ORV programs to highlight rabies management goals and accomplishments. The development and distribution of press releases, scientific manuscripts, public facing dashboards with online mapping, and the use of social media (e.g., Facebook, Twitter) have been significant and important components of wildlife rabies management coordination and communication. In the future, cooperatively developed communication methods and materials will be focused on promoting the goals, objectives, and strategies outlined in this plan and will continue providing timely information, education, and media announcements informing the public about annual ORV bait distribution activities and accomplishments.

Objective 1.1: Enhance the coordination and cooperative management of wildlife rabies within the US and its territories, Canada, Mexico, and other countries in the Americas by maintaining and building partnerships and coalitions among stakeholders including government and NGOs, tribal nations, academia, and the private sector.

Strategies

- Increase awareness among key stakeholders regarding the impact that an international, national, and regional approach to wildlife rabies management has in reducing rabies incidence. *Communication in Support of ORV Activities*
- Prepare inclusive multilingual multimedia tools, outreach materials, and public notifications to promote and market the goals, objectives, and strategies outlined in the USNP. *Communication in Support of ORV Activities*
- Enhance communication with Puerto Rico and other Caribbean entities regarding the current strategies for surveillance and management of rabies in wildlife populations. *Communication in Support of ORV Activities*
- Collaborate with local, state, federal, and NGO partners to better communicate wildlife rabies management objectives and actions while encouraging positive messaging regarding conservation and management of bats and other wildlife. *Information Sharing*
- Enhance communication and outreach targeting veterinary medical associations, state agriculture veterinarians, state public health veterinarians, and mixed practice veterinarians to improve detection and surveillance for vampire bats in the US. *Information Sharing*
- Develop outreach materials for vampire bat identification based on physical and morphological characteristics for state rabies laboratories conducting rabies testing on bat species found along the border with Mexico. *Information Sharing*
- Continue to explore opportunities to partner with NGOs and the United Against Rabies Forum to enhance communication associated with wildlife rabies prevention and management in concert with global dog rabies elimination efforts. *Information Sharing*

- Improve and refine operational programs, continue to build, and enhance relationships among partners involved in wildlife rabies management to facilitate the timely and confidential sharing of evaluation and rabies surveillance data. *Information Sharing*

Objective 1.2: Enhance and strengthen communication strategies for wildlife rabies prevention, management, and research by developing effective messages and outreach materials for dissemination across multimedia platforms. Develop timely strategies that are inclusive in scope and focus on reaching critical geographic areas for dissemination to target audiences.

Strategies

- Encourage and facilitate communication among stakeholders and management agency communication specialists to ensure that timely, accurate and engaging stories about ORV activities are shared with the media and the public. *Communication in Support of ORV Activities*
- Produce a US risk communications plan containing high profile scenarios associated with cooperative ORV programs and other wildlife rabies management issues. *Communication in Support of ORV Activities*
- Identify and support local and regional wildlife rabies communication needs to enhance effective delivery to targeted audiences. *Communication in Support of ORV Activities*
- Develop and cultivate relationships with local and national media outlets and other interested stakeholders to improve the delivery of coordinated, accurate, and timely information to the public regarding wildlife rabies management. *Communication in Support of ORV Activities*
- Create a web-based resource room to maintain a clearinghouse of local, state, and federal outreach materials. *Communication in Support of ORV Activities*
- Develop targeted messages and multilingual outreach products to enhance public awareness of the negative impacts and risks associated with wildlife translocation. *Communication in Support of ORV Activities*
- Engage partner organizations such as the CSTE and the National Association of State Public Health Veterinarians to advocate for appropriate, state-supported approaches to data collection and sharing to refine and improve wildlife rabies management. *Communication in Support of ORV Activities*
- Develop a communication strategy that outlines risks to the public and domestic animals associated with range expansion of vampire bats (and vampire bat rabies) into the US and what management strategies might be implemented at the state level once first detection is confirmed. *Communication in Support of ORV Activities*
- Use a collaborative approach to develop inclusive outreach and multilingual products for targeted audiences (including underserved communities) to enhance awareness and educate the public about wildlife rabies management programs. *Communication in Support of ORV Activities*

Objective 1.3: Develop communication and outreach strategies to enhance awareness of the impact and economic benefits of wildlife rabies prevention and control to encourage advocacy for wildlife rabies management programs and to diversify and increase funding streams.

Strategies

- Develop approaches to communicate results of economic studies to highlight the benefits of wildlife rabies management. *Information Sharing*

- Support and promote efforts by wildlife rabies management programs to publish in peer-reviewed journals to enhance science-based improvement of current management strategies and the development of novel methods for wildlife rabies prevention and control. *Information Sharing*
- Continue to support and promote activities associated with World Rabies Day. *Information Sharing*

Objective 1.4: Develop communication and outreach strategies to enhance documentation of vaccine bait contacts and wildlife rabies management actions to improve transparency and continue to comply with federal and state regulatory requirements.

Strategies

- Continue to comply with statutory and regulatory requirements including NEPA to better assess impacts of federal actions related to wildlife rabies management goals and objectives, while averting potential conflicts through transparency and regular communication with national and internal partners and stakeholders. *Regulatory and Environmental Compliance*
- Review and improve existing communication strategies and explore novel approaches for creative methods to enhance the identification and tracking of vaccine bait contacts to include federal, state, and local wildlife rabies management programs. *ORV Bait Contacts*
- Continue to work with vaccine producers, public health partners and others to improve the national surveillance and reporting system for contact with vaccine baits by nontarget species, specifically humans and companion animals, in a timely manner that provides actionable information which complies with vaccine manufacturers' regulatory requirements. Support the development of a national web-based platform for submitting standardized data on ORV bait and vaccine contacts. *ORV Bait Contacts*

Coordination and communication are integral components of any wildlife rabies management program. Here, a USDA Wildlife Services employee teaches youth at Camp Colton in Flagstaff, Arizona about raccoons. *USDA WS photo.*

Rabies Surveillance

Surveillance is the cornerstone for effective wildlife disease management, since knowing exactly when and where cases occur is vital to formulate prevention, control, and elimination strategies. To halt the spread of specific RVVs and eventually eliminate terrestrial rabies in carnivores in the US, rabies surveillance through conventional public health networks should be complemented with strategic application of ERS programs. Public health surveillance, often referred to as passive surveillance, implies rabies detection without an active effort targeting a specific area or species to search for the disease. This system is effective in protecting human and domestic animal health but may not adequately characterize the spatial-temporal distribution of rabies in real-time for effective intervention. ERS (also referred to as active rabies surveillance) is targeted, preferably based on risk factors, and is typically initiated with a designed sampling scheme to meet specific disease management needs. ERS includes the collection and testing of strange acting, found dead, road killed, lethally removed, and nuisance animals with no known involvement in a human or domestic animal exposure. Testing of ERS samples is usually conducted by trained wildlife biologists using the DRIT, although some state public health laboratories have the capacity to test non-exposure based ERS samples. Enhanced and public health rabies surveillance is critical for determining the incidence and geographic and temporal distribution of specific RVVs in wildlife populations, which is essential for meeting national rabies management goals and objectives.

Objective 2.1: Better understand rabies epizootiology by improving public health (i.e., passive) and enhanced (i.e., active) surveillance of wildlife rabies throughout the US using nationally accepted and validated laboratory methods, particularly in areas where management using ORV is occurring and along the borders with Canada and Mexico.

Strategies

- Champion initiatives to develop and improve local, state, national, and international mechanisms for rabies surveillance data sharing. *Data Sharing*
- Continue to evaluate and optimize the WS NRMP ERS Initiative Best Management Practices and Implementation Plan to ensure that ERS is cost-efficient, timely and sensitive for ORV decision-making. *Epidemiology: Public Health and ERS*
- Continue ERS with CSTE-approved diagnostic methods and assays (e.g., DRIT, DFA, real-time reverse transcription-polymerase chain reaction) where there is a need, and the techniques are supported by cooperating agencies. *Laboratory Support: Rabies Antigen Diagnostics (DFA/DRIT)*
- Continue to support decentralized yet standardized diagnostic testing by providing field personnel with training on test methodologies and associated activities such as sample collection and shipping techniques to ensure compliance with current regulations and protocols. *Laboratory Support: Rabies Antigen Diagnostics (DFA/DRIT)*
- Continue to encourage and support diagnostic training modules provided by the CDC, the National Laboratory Training Network, and regional laboratories in support of the National Rabies Surveillance System. *Laboratory Support: Rabies Antigen Diagnostics (DFA/DRIT)*
- Continue to require all persons performing rabies diagnostic tests to participate in and pass an accredited national proficiency testing (PT) program. If an accredited PT program is not available, using an informal or internal PT is sufficient, especially where retraining is necessary. *Laboratory Support: Rabies Antigen Diagnostics (DFA/DRIT)*
- Continue to develop and evaluate novel antigenic and molecular diagnostic methods that can be implemented for more timely, efficient, and cost-effective rabies surveillance. *Laboratory Support: Rabies Antigen Diagnostics (DFA/DRIT)*

- Explore and evaluate new and updated methods for animal euthanasia and rabies surveillance sample collection. *Laboratory Support: Rabies Antigen Diagnostics (DFA/DRIT)*

Objective 2.2: Establish surveillance criteria based on scientific data for different environments (e.g., urban vs. rural) and rabies reservoirs, and develop action points (parameters) for identifying rabies outbreaks.

Strategies

- Support the establishment and implementation of a national, standards-based, electronic laboratory reporting system of animal rabies cases and the development of web-based platforms for timely sharing of rabies surveillance data with local, state, federal, and international partners to support real-time program management. *Data Sharing*
- Encourage laboratories, epidemiologists, and cooperators to identify the species of all animals (especially bats) submitted for rabies diagnostic testing by using regional taxonomic keys and consultation with experts where appropriate. Support and enhance cooperator training activities for species identification. *Epidemiology: Public Health and ERS*
- Improve and support characterization of RVVs and timely data sharing in the US to better understand the epizootiology of rabies, identify boundaries of current RVV areas and to inform wildlife rabies management especially along international borders. *Epidemiology: Public Health and ERS*
- Continue analyses of pre- and post-baiting surveillance data to provide input on ORV effectiveness (i.e., reduction of rabies cases in management areas), and to support other analytic methods such as predictive modeling or sensitivity analyses of surveillance methods. *Epidemiology: Public Health and ERS*
- Improve rabies surveillance and suspect animal collection in epidemiologically relevant areas where surveillance may be inadequate, including rural environments and in underserved communities. *Epidemiology: Public Health and ERS*
- Maintain surveillance activities in AZ, FL, NM, and TX by conducting cattle surveys to assess for evidence of vampire bat bites as an early-warning system for their emergence in the US. *Epidemiology: Public Health and ERS*
- Develop surveillance criteria to establish "rabies freedom" definitions associated with RVVs for public health at appropriate spatial scales, based on US regulation and WHO and WOAH recommendations. *Epidemiology: Public Health and ERS*
- Define, standardize, and communicate surveillance and elimination criteria used for ORV zone movements and disease management. *Epidemiology: Public Health and ERS*
- Maintain genetic tissue archives (e.g., ear tips, brain tissue, viral RNA: ribonucleic acid) to support surveillance and research of host population structure and characterization of the rabies virus. *Epidemiology: Public Health and ERS*

Rabies surveillance involves collecting road killed (left) and strange acting (right) animals, often seen with porcupine quills. *USDA WS photos.*

ORV Management

Several wildlife rabies control alternatives have been used in the US historically: wildlife exclusion and habitat management; modifying human behavior (i.e., stop feeding wildlife); removal of suspect animals; population suppression through culling; and TVR, but only ORV can be done at the landscape level on a geographic and species scale. ORV management may be affected by numerous variables including, but not limited to: bait densities relative to target and nontarget population densities; bait distribution patterns; timing and frequency of baiting; vaccine bait field effectiveness; bait types and attractants; bait distribution methods (fixed wing/rotary wing aircraft, hand/vehicle, bait stations); landscape/habitat factors; treatment area size; elevation; and latitude. To be successful, ORV management requires: 1) sensitive surveillance (public health, complemented by ERS); 2) coordination among counties, states, and international cooperators; 3) integration of natural and human-made landscape features (as barriers) into ORV zones to reduce costs; 4) host population density and habitat effects; and 5) contingency action support to address emergencies. During emergency rabies outbreaks, contingency actions are employed that often incorporate several steps: conduct a risk assessment for the area; increase ERS immediately; localized population reduction and testing of reservoir hosts; TVR; and ORV at higher bait densities and greater frequencies. More than 20 contingency actions have taken place in the US in response to actual emergencies or high risk rabies situations since 1999. The suite of confounding variables that may affect successful rabies management through ORV requires continued collaboration and coordination among multiple disciplines on WS NRMP program priorities which is integral to achieving wildlife rabies management objectives in the next five years and long-term.

Objective 3.1: Implement a cooperative, science-based wildlife rabies management program in the US with an immediate focus on control and elimination of rabies in raccoons in the eastern US and to maintain rabies elimination in coyotes/gray foxes in Texas. As resources permit, secondary foci will include mongoose in Puerto Rico, skunks in the US, and early variant detection in common vampire bats along the US-Mexico border. This program will be implemented through ERS, ORV, TVR, Trap-And-Test (TAT), and the strategic use of natural barriers.

Strategies

- Limit potential negative impacts from ORV (e.g., adverse events) by evaluating bait stations, habitat baiting, and other novel approaches (e.g., combination of ground baiting strategies) to decrease nontarget species uptake and human and domestic animal exposures to vaccine baits in developed areas. *Management Strategies*
- Evaluate timing (seasons) of bait distribution and refine strategies to increase target species acceptance in high-risk areas for rabies spread (e.g., developed areas) while considering target species ecology and nontarget bait competition. *Management Strategies*
- Work with industry and researchers to improve bait delivery equipment, navigation systems, and bait counting/geocoding on aircraft and vehicles. *Distribution Methods*
- Continue the evaluation of bait application strategies (e.g., one or combination of methods) and timing relative to target species and distribution densities to support cost-conscious and effective product use. *Distribution Methods*
- Refine bait distribution methods and strategies to reduce labor, costs, and enhance efficiencies while maintaining effectiveness (e.g., convert ground baiting areas to rotary wing distribution where appropriate). *Distribution Methods*
- Continue to improve standard operating and safety guidelines to address planning and logistical considerations for ORV management, including adaptive strategies and timelines (e.g., adjust distribution in response to weather and climate changes). *Planning and Logistics*

- Enhance and maintain communication regarding ORV planning and logistical activities among cooperating agencies and vendors. *Planning and Logistics*
- Identify and communicate knowledge transfer within ORV management programs to ensure continuity of implementation (e.g., planning and logistics of vaccine distribution, vaccine bait contact surveillance, etc.). *Planning and Logistics*
- Continue to explore options for using alternative types of aircraft (i.e., make, model, engine configuration) for ORV bait distribution that also meet aircraft safety guidelines and policy, including unmanned aircraft. *Aviation Support*
- Explore opportunities for additional aviation vendors that can provide appropriate aircraft and qualified pilots. *Aviation Support*
- Work with research entities to develop and test new ORV bait distribution machines for aircraft that are less staff intensive (e.g., automated) and more bait friendly (e.g., protected from heat). *Aviation Support*

Objective 3.2: Document and assess current management methods (e.g., ORV, ERS, TVR, TAT) and strategies, and collaborate to develop new management methods and strategies for skunk, mongoose, Arctic fox, and vampire bat RVVs as they exist or emerge in the US.

Strategies

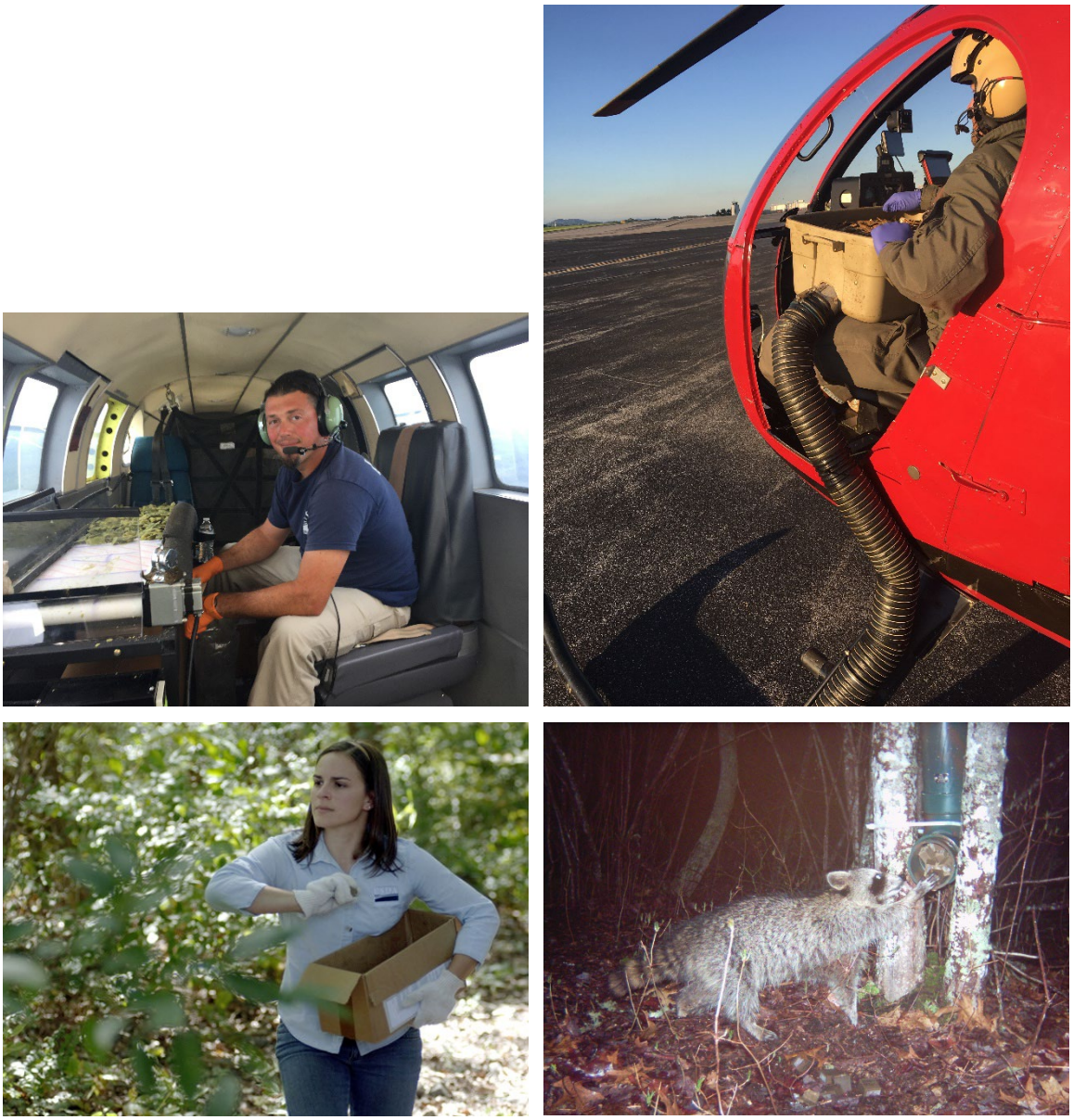
- Support continued field evaluation and research on more extensive use of bait stations, remote delivery, rotary wing aircraft, and ground baiting strategies for developed areas. *Distribution Methods*
- Continue to explore industry and university interest, commercial availability, regulatory restrictions, and potential use of oral rabies vaccines which have been registered for wildlife in other countries. *Vaccine/Bait/Biomarker*

Objective 3.3: Conduct risk assessments and implement contingency actions as necessary, as part of a comprehensive wildlife rabies management program.

Strategies

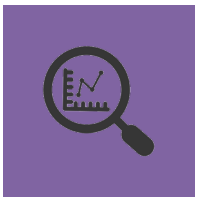
- Continue to refine an adaptive management strategy for contingency actions that involves rabies testing, monitoring, and incorporation of new knowledge into coordinated emergency response activities. *Contingency Actions*
- When practical, utilize aspects of the Incident Command System or National Incident Management System framework during contingency actions to ensure safe, standardized, and efficient responses. *Contingency Actions*
- Assess data gaps and improve processes to capture costs, identify equipment needs, establish timelines, and implement strategies associated with contingency actions. *Contingency Actions*
- Continue to refine interagency contingency action procedures and response plans, including cooperator contact lists and initial actions to implement when rabies has been documented within or beyond established ORV zones. *Contingency Actions*
- Continue to support the development of integrated wildlife population management strategies where applicable, including habitat management, public education, and the implementation of nonlethal and/or lethal tools. *Contingency Actions*
- Take a proactive approach to contingency action planning in advance of emergencies by updating and maintaining contact networks, landowner permissions, permits and state approval letters for operational needs. *Contingency Actions*

- Explore options for procuring, stocking, and maintaining a contingency action response trailer equipped with necessary inventory (e.g., traps, scalpels, syringes, needles, personal protective equipment, etc.) that can be deployed quickly to an area implementing a contingency action. *Contingency Actions*
- Identify options and apply for emergency funding if necessary to implement contingency actions to prevent loss of investments already made in ORV operational areas. *Contingency Actions*
- Develop risk assessments and investigation protocols for addressing contingency response triggers (i.e., index case) to document potential translocation events and inform best practices for ERS and management. *Contingency Actions*



Management with oral rabies vaccine involves distributing baits by fixed-wing aircraft (top left), helicopter (top right), hand/vehicle (bottom left) and bait stations (bottom right). *USDA WS photos.*

ORV Monitoring



Wildlife rabies management program effectiveness is measured by two primary metrics: surveillance (presence and absence of specific RVV cases) and serology (percent of rabies virus neutralizing antibodies [RVNA] in target populations after baiting [post-ORV]). The serology metric (along with bait uptake via biomarkers) is often referred to as ORV monitoring. Historically, monitoring included a measurement of bait uptake by testing teeth collected from target animals for the presence of a tetracycline biomarker; however, 99% of all baits distributed in the US today no longer contain a biomarker, thus, serology has become the standard monitoring method in ORV programs (alongside surveillance). In the raccoon rabies management program, serology monitoring involves collecting blood from live-trapped, immobilized raccoons beginning at least four weeks after ORV bait distribution, centrifuging the blood into sera aliquots, and testing those sera by virus neutralization assays. The presence of RVNA above a specified cutoff provides an overall index to population immunity. Laboratory support for vaccine bait uptake diagnostics (serology and biomarker, when available in baits) is a major collaborative component to successful ORV monitoring. Timely turnaround of results and cooperative data sharing are critical for informed decision making and meeting the objectives of this 5-year plan.

Objective 4.1: Apply conventional and novel science-based approaches for monitoring wildlife populations in ORV baited areas (both current and future) to better understand rabies immune response and bait uptake (via biomarker) in target and select nontarget species.

Strategies

- Collaborate to use relevant data to evaluate and mitigate nontarget competition for ORV baits. *Data Sharing, Epidemiology, and Modeling*
- Conduct data analyses of naturally existing rabies antibodies in pre-epizootic and enzootic raccoon populations to better understand the epizootiology of the raccoon RRV. *Data Sharing, Epidemiology, and Modeling*
- Establish protocols for the use of sensitive and efficient WOAH-approved or accepted laboratory methods for RVNA testing in wildlife (as the primary method); and develop and initiate secondary methods (e.g., ELISAs: enzyme-linked immunosorbent assays) to detect and measure rabies antibodies. *Laboratory Support: Vaccine bait Uptake Diagnostics (Serology/Biomarker)*
- Explore options for biomarkers in ORV baits to aid in understanding bait uptake and identify vendors to provide diagnostic services to support monitoring metrics (e.g., biomarker, serology, age, etc.). *Laboratory Support: Vaccine bait Uptake Diagnostics (Serology/Biomarker)*
- Continue to engage with the WS led Interagency Committee (formerly "Blue Ribbon Panel") on Wildlife Serology in Support of ORV to develop best practices for assessing herd immunity in target populations to monitor ORV programs and promote cross-laboratory evaluations and timely information exchange in support of science-based decision-making. *Laboratory Support: Vaccine bait Uptake Diagnostics (Serology/Biomarker)*
- Establish additional expert committees (as needed) to develop and interpret the application of field and laboratory standard practices. *Laboratory Support: Vaccine bait Uptake Diagnostics (Serology/Biomarker)*
- Develop and initiate a formalized mechanism for the committees to communicate their findings within and between committees to optimize procedures and standards. *Laboratory Support: Vaccine bait Uptake Diagnostics (Serology/Biomarker)*
- Develop and maintain sera archives of target species sampled for ORV monitoring. *Laboratory Support: Vaccine bait Uptake Diagnostics (Serology/Biomarker)*

- Proactively develop a strategic storage of critical laboratory reagents (e.g., challenge virus standard, immunoglobulin standards, etc.) as needed for retrospective analysis of quality assurance and control. *Laboratory Support: Vaccine bait Uptake Diagnostics (Serology/Biomarker)*

Objective 4.2: Evaluate quantitative relationships between bait uptake, antibody seroprevalence, and rabies case rates, to better measure the effectiveness of ORV distribution.

Strategies

- Conduct analyses of post-ORV monitoring data to provide input on vaccine field effectiveness and program evaluation, and to support other analytic methods such as predictive modeling. *Data Sharing, Epidemiology, and Modeling*
- Determine age- and sex-related vaccination rates in target populations using available data and evaluate the relationship between vaccination rates and rabies case incidence across meso-carnivore populations. *Data Sharing, Epidemiology, and Modeling*

Objective 4.3: Engage ORV programs (e.g., federal, state, county, municipal, etc.) to promote and share standardized approaches for ORV monitoring (e.g., sample collection, vaccine bait uptake diagnostics, etc.).

Strategies

- Explore existing technologies and continue to refine mechanisms for all cooperators to share their program's ORV monitoring data (e.g., target species sampling locations and serology results via standard queries, reports, maps, etc.) with each other to facilitate a collaborative approach and improve ORV monitoring and evaluation. *Data Sharing, Epidemiology, and Modeling*
- Collaborate with researchers to identify and standardize the data needed for disease modeling (e.g., target species densities, habitat, etc.). *Data Sharing, Epidemiology, and Modeling*
- Encourage collaboration among wildlife agencies to facilitate sharing of wildlife population data (e.g., density, mortality events, etc.) in support of rabies management in meso-carnivores. *Data Sharing, Epidemiology, and Modeling*
- Develop, promote, and share standardized protocols for data collection, sample collection and submission (e.g., blood, teeth, etc.), including minimum target sample size, timing and locations of collection, post-bait evaluation procedures according to species, population densities, and ORV zone size and vaccine type. *Sample Collection*

Trapping raccoons (left) and collecting blood (right) after baiting are critical to program monitoring. *USDA WS photos.*

Research

Implicit in a cooperative, science-based wildlife rabies management program is the need for research aimed at increasing the scientific knowledge base to close critical data gaps, integrate contemporary scientific findings into applied management practices, and collaborate on research to improve programs and ensure sound rabies management decisions. In recent years, research priorities have changed to focus more on vaccines, baits, baiting strategies, and delivery systems. There is a need to better understand the ecology, abundance, and behavior of wildlife reservoir species. Impacts of nontarget competition on ORV baits remains a priority as well. It is critical that programs adopt and increase the use of new technologies that allow managers to model many variables influencing ORV effectiveness (e.g., bait density, flight line spacing, distribution method, etc.) and predict those with the most impact to improve baiting strategies, particularly in human developed habitats. Identifying and assessing high-risk corridors for rabies spread through modeling is of significant interest along international borders where the raccoon and dog-coyote RVVs have been eliminated. Using genetics to characterize host populations and evaluate the geographic relatedness of RVVs can aid in contingency action planning and help document potential translocation events within or beyond ORV zones. There remains a need to further evaluate the economics of wildlife rabies management and enhance communication, collaboration, and coordination with a diversity of institutions to promote program benefits and work toward achieving short-and long-term research goals and objectives.

Objective 5.1: Ensure adequate research support and an improved framework of networking among academic, government and industry groups to better understand and share information about ecology, epidemiology, and community dynamics of the rabies virus and its host and reservoir species.

Strategies

- Continue to cooperatively establish national and international wildlife rabies research priorities in association with the cooperators meetings hosted by the WS NRMP. *Enhanced Communication, Collaboration and Coordination*
- Dedicate support to review and synthesize literature and best practices on rabies diagnostic testing to stay at the forefront of technologies and costs. Conduct comparative evaluations of current and novel diagnostic assays to establish the most efficient, effective, timely and economical tests for field and laboratory applications. *Enhanced Communication, Collaboration and Coordination*
- Host and collaborate with existing bat working groups to compile information on current issues, discuss research priorities, and encourage morphological identification, ecological studies (including vampire bats) and spillover of bat rabies as part of the cooperators meetings hosted by the WS NRMP. *Enhanced Communication, Collaboration and Coordination*

Objective 5.2: Engage academia and enhance outreach programming to improve diversity of research recruitment, collaborations, and transdisciplinary training of the next generation of wildlife health researchers.

Strategies

- Continue to enhance international collaboration on wildlife rabies research and wildlife rabies management programs. *Enhanced Communication, Collaboration and Coordination*

Objective 5.3: Create mechanisms for internal and external communications about rabies research outcomes to stakeholders, professional groups, citizen scientists, and the public by incorporating One Health and human dimensions in research proposals to increase funding for rabies research.

Strategies

- Facilitate greater dissemination of information through research briefs, forums, and meetings to bring together North American scientists for idea exchange on basic and applied research for wildlife rabies control. *Enhanced Communication, Collaboration and Coordination*
- Continue collaborations to seek alternate sources of funding for research on wildlife rabies and vaccine development, such as Small Business Innovative Research, National Institutes of Health, National Science Foundation, and other public and foundation grants. Take advantage of new and existing opportunities for centers for excellence and collaboration on applied research on wildlife zoonoses. *Enhanced Communication, Collaboration and Coordination*
- Enhance communication and coordination among industry, government agencies, and universities involved in wildlife rabies management to promote research collaborations on method development for increasing efficiency and effectiveness of oral rabies vaccine distribution strategies. *Enhanced Communication, Collaboration and Coordination*
- Support and encourage the timely dissemination of wildlife rabies management research findings at scientific meetings including the Rabies in the Americas conference, US Animal Health Association conference, The Wildlife Society conference, state fish and wildlife meetings, REDIPRA (the meeting of the Directors of National Programs for Rabies Control in Latin America), and other venues. *Enhanced Communication, Collaboration and Coordination*

Objective 5.4: Continue applied research on the development and refinement of baits, vaccines, baiting strategies, and distribution methods to enhance rabies management and future variant elimination.

Strategies

- Continue to optimize current bait acceptance and vaccine effectiveness in reservoir species (e.g., raccoons, skunks, foxes, mongooses, vampire bats, free-ranging dogs) in representative habitats. *Vaccines, Baits, Baiting Strategies, and Delivery Systems*
- Continue to develop and improve baits and vaccine delivery systems to enhance field performance and ORV effectiveness among reservoir hosts in diverse environments, especially in developed areas. *Vaccines, Baits, Baiting Strategies, and Delivery Systems*
- Support the development of novel biomarkers to aid in ORV program evaluation and assess the effectiveness of current vaccines in rabies vectors. *Vaccines, Baits, Baiting Strategies, and Delivery Systems*
- Support research efforts to further facilitate off-label use and field application of experimental oral rabies vaccines across North America targeting meso-carnivore reservoirs. *Vaccines, Baits, Baiting Strategies, and Delivery Systems*
- Support efforts to improve efficiency and maximize utility of vaccines, baits, and biomarkers, including development of non-toxic, biodegradable, and environmentally friendly options (e.g., antibiotic-free biomarkers, plastic-free/biodegradable packaging for baits/bait stations). *Vaccines, Baits, Baiting Strategies, and Delivery Systems*

- Evaluate the effectiveness of TVR as a stand-alone strategy or in combination with other strategies, especially in developed areas. *Vaccines, Baits, Baiting Strategies, and Delivery Systems*
- Develop standardized criteria to guide the evaluation of new oral rabies vaccine candidates under pen and field conditions. *Vaccines, Baits, Baiting Strategies, and Delivery Systems*
- Support comparative testing of existing and new rabies vaccines and baits under a variety of conditions through laboratory, pen, and field trials. *Vaccines, Baits, Baiting Strategies, and Delivery Systems*

Objective 5.5: Develop and refine new and current short- and long-term methods to evaluate and assess risk of rabies spread using current and historical data.

Strategies

- Develop and refine methods of program evaluation driven by data collected from ERS and ORV monitoring. Continue to foster studies that analyze long-term data sets. Develop consistent criteria for establishing high-risk corridors for rabies virus emergence, perpetuation, and spread. *Risk Assessment, Contingency Response, and Program Evaluation (Surveillance and Monitoring)*
- Develop methods to investigate the relationship between serology and case incidence and reduction or elimination of rabies cases for specific variants in diverse environments. *Risk Assessment, Contingency Response, and Program Evaluation (Surveillance and Monitoring)*
- Continue to develop and use models and experiments to address the population level impacts of TAT contingency response activities and population management for rabies virus spillover, spread, and the effectiveness of control. *Risk Assessment, Contingency Response, and Program Evaluation (Surveillance and Monitoring)*
- Develop a standard process for collaborative sharing of rabies virus sequencing data and archived positive tissues. *Risk Assessment, Contingency Response, and Program Evaluation (Surveillance and Monitoring)*
- Develop a modeling approach to assess patterns of rabies spread in the future given climate change and landscape development trends. *Risk Assessment, Contingency Response, and Program Evaluation (Surveillance and Monitoring)*

Objective 5.6: Better understand the economic dynamics associated with rabies management in wildlife including economic forecasting for planning purposes and economic benchmarks to help measure success.

Strategies

- Standardize economic data needs and produce practical data collection protocols for efficient and timely data collection during rabies control operations. *Economics*
- Evaluate the benefits of national reporting of rabies exposures detailed by species and PEP to evaluate the cost-effectiveness of rabies management actions. *Economics*

Objective 5.7: Advance understanding of the ecology, abundance, and behavior of wildlife rabies vector species, ORV target and important nontarget species, and the ecology of RVVs in the US.

Strategies

- Continue to conduct studies to document movements, distribution, and dispersal of meso-carnivores in areas prioritized for rabies management. *Ecology*
- Continue to study the ecology and movements of small Indian mongoose, as well as density of nontarget hosts (e.g., rats, cats, etc.), on islands in the Caribbean to support the design of ORV programs to control and eliminate mongoose rabies on affected islands. *Ecology*
- Continue to study the ecology and impact of important nontarget species on competition for rabies vaccine baits, including opossums and invertebrate communities (e.g., fire ants, slugs, etc.). *Ecology*
- Continue to study meso-carnivore and bat community ecology in developed areas and high-risk corridors for rabies virus spread. *Ecology*

Rabies related research may involve studying host ecology via radio telemetry (top left), invertebrate impacts on vaccine baits (top right), engineering bait distribution equipment for helicopters (bottom left), and using camera traps to monitor bait disappearance by target and nontarget species (bottom right). *USDA WS and Colorado State University photos.*

Acronyms and Abbreviations

APHIS	Animal and Plant Health Inspection Service
CDC	Centers for Disease Control and Prevention
CSTE	Council of State and Territorial Epidemiologists
DFA	direct fluorescent antibody
DRIT	direct rapid immunohistochemical test
ERS	enhanced rabies surveillance
IPA	iophenoxic acid
NARMP	North American Rabies Management Plan
NEPA	National Environmental Policy Act
NGO	non-governmental organization
NRMP	National Rabies Management Program (USDA, APHIS, WS)
ONRAB	Ontario rabies bait (human adeno-rabies glycoprotein recombinant vaccine)
ORV	oral rabies vaccination
PEP	post-exposure prophylaxis
PT	proficiency testing
RVNA	rabies virus neutralizing antibodies
RVV	rabies virus variant
SPBN GASGAS	modified live recombinant rabies vaccine
TAT	trap-and-test
TDSHS	Texas Department of State Health Services
TVR	trap-vaccinate-release
US/USA	United States/United States of America
USDA	United States Department of Agriculture
USNP	United States National Plan for Wildlife Rabies Management
V-RG	Vaccinia-rabies glycoprotein recombinant vaccine
WHO	World Health Organization
WOAH	World Organization for Animal Health
WS	Wildlife Services

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