

# Forecasting the spread of raccoon rabies using a purpose-specific group decision-making process

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**Abstract:** The Centers for Disease Control (CDC) and USDA Wildlife Services (WS) have been involved in an oral rabies vaccination (ORV) program for raccoons (*Procyon lotor*) that has slowed the westward spread of raccoon rabies. The objective of this study was to forecast the spread of the disease if an ORV zone was not maintained. A group decision-making process was designed to address the forecasting problem and was implemented using a group of 15 experts and 4 support personnel at a meeting at the USDA National Wildlife Research Center. Ten expansion regions were constructed that described the spread of disease at 2-year intervals. This forecast may provide for more accurate cost-benefit analysis of the ORV barrier.

**Key words:** forecast, human–wildlife conflict, oral rabies vaccination, *Procyon lotor*, raccoon, rabies, United States, zoonotic disease

**WORLDWIDE**, >55,000 PEOPLE are estimated to die from rabies each year (World Health Organization 2013). Most of these deaths occur in Africa and Asia where canine rabies virus variants have not been controlled (World Health Organization 2004). However, in the United States, canine rabies virus variant

transmission has been eliminated, and wildlife are now the primary reservoir of rabies. In 2010, wildlife accounted for approximately 92% of all reported rabid animals in the United States (Blanton et al. 2011). The raccoon (*Procyon lotor*; Figure 1) rabies virus variant is responsible for significant spillover infection into dogs



**Figure 1.** Raccoon in crabapple tree. (Photo by B. Buchanan, courtesy U.S. Fish and Wildlife Service)

and cats, as well as wildlife (McQuiston et al. 2001, Blanton et al. 2011). Rabid raccoons also present a significant threat to humans because this species is well-adapted to life in urban and suburban areas (Uhaa et al. 1992)

Raccoon rabies was first recognized in central Florida during 1947 (Scatterday et al. 1960, Kappus et al. 1970). Over the next 3 decades, the disease spread slowly northward from the initial focus, reaching South Carolina by the early 1970s (Childs et al. 2001). However, between 1977 and 1991 >3,500 raccoons were translocated from Florida to southwest Virginia (Nettles et al. 1979). These translocations are believed to have led to the introduction of the raccoon rabies virus variant in the area. By 1977, an outbreak of raccoon rabies was detected at the West Virginia-Virginia border (Jenkins et al. 1998). Once established in the Mid-Atlantic region, raccoon rabies spread north through a naïve population at approximately 40 km per year, faster than the spread of the original southern focus of the disease (Centers for Disease Control 2000). By 1995, the Mid-Atlantic and southern epizootics had converged in North Carolina. By 1997, raccoon rabies had spread west through Pennsylvania and reached northeastern Ohio, and by 1999, the Mid-Atlantic epizootic had reached Ontario, Canada (Wandeler and Salsberg 1999). Raccoon rabies is now enzootic throughout the eastern United States (Blanton et al. 2011).

Although the spread of raccoon rabies beyond the eastern U.S. was slowed in part by geographical features (e.g., the Appalachian Mountains, the Great Lakes, large rivers), an extensive collaborative oral rabies vaccination (ORV) program has assisted in preventing its westward spread to date. Following a successful evaluation of a vaccinia-rabies glycoprotein (VRG) recombinant ORV in 1990, a larger scale ORV field trial was conducted in 1992 to determine if the spread of rabies onto the Cape May peninsula in New Jersey could be prevented (Hanlon and Rupprecht 1998, APHIS 2007). This program continued as an operational program, and in 1994, it was followed by a small operational program in Massachusetts to prevent the spread of raccoon rabies onto Cape Cod (Algeo et al. 2008). In 1997, USDA Wildlife Services (WS) cooperated to implement ORV programs in Ohio and Vermont to prevent the westward spread of raccoon rabies. Since that time, WS's National Rabies Management Program continued to grow, and the ORV program now operates in 15 states that encompass the western edge of the raccoon rabies enzootic area. From federal year (FY) 2006 to FY2010, >38 million vaccine-laden baits were distributed to prevent the westward spread of raccoon rabies (Figure 2; APHIS 2011).

The benefits of maintaining the ORV zone are significant to several public health, agricultural, and wildlife management objectives as it helps prevent raccoon rabies from continuing to spread. Specific benefits include reductions in human post-exposure prophylaxis (PEP), reduced livestock and pet losses, and protection of wildlife resources. One example of the repercussions of this disease was an estimated 40-fold increase in the use of PEP when the mid-Atlantic raccoon rabies epizootic entered New York state during 1990 (Wyatt et al. 1999). Thereafter, PEP has declined from the peak of the epizootic, but Christian et al. (2009) estimated that approximately 15,000 people receive PEP each year in the raccoon rabies enzootic area in the United States.

At a mean indirect and direct cost of \$5,500 (dollar amounts are expressed in 2010 dollars) per person, PEP is a major financial burden associated with raccoon rabies (Shwiff et al.



**Figure 2.** Raccoon oral rabies vaccination areas within the United States (2010).

2007). If raccoon rabies were to spread beyond its current range, the costs for PEP in newly affected areas would likely increase, as it has in the current area. To date, Kemere et al. (2002) completed the only comprehensive assessment of the benefits of a large scale raccoon ORV program and estimated the net present value of benefits to be \$138 million to \$628 million. However, estimates of benefits are highly dependent on the assumed rate and pattern of spread in the absence of an ORV-created zone. Kemere et al. (2002) applied 2 rates of spread: 40 km/year and 120 km/year that began from and mimicked the current westward edge of raccoon rabies. However, difference in the spread and rate of raccoon rabies in relation to environmental factors has been shown, and no attempt was made to tailor the rate of spread to differences in geography, climate, or land use (Childs et al. 2001).

The objective of this study was to construct a more realistic forecast of the spread of raccoon rabies in the absence of ORV that would

improve the quality and accuracy of any cost-benefit analysis of the barrier. At the time of this study, no suitable epizootiologic model was available to forecast the westward spread of raccoon rabies throughout the rest of the United States from the existing western edge of the current distribution of the disease. In the absence of such a model, we explored options that could be used in real time. One alternative was to assume, similar to Kemere et al. (2002), that raccoon rabies would spread at a constant rate, based on the rate of the mid-Atlantic epizootic. However, that approach would not allow for the incorporation of variation in spread that may be expected in relation to topography, elevation, habitat quality, land use, raccoon population density, and other factors. Using expert opinion became the preferred alternative, given that linear spatiotemporal spread is not expected for raccoon rabies in the absence of intervention and that no suitable predictive models were available

to produce the spread scenarios within the time constraints imposed to inform economic models that will be applied to evaluate benefits and costs.

## Methods

To construct a forecast, a group decision-making process (or opinion capture technique) was designed specifically to address the unique nature of our raccoon rabies problem and its potential spread westward. Fifteen experts and 4 support personnel from 3 relevant disciplines (rabies modeling, rabies management, and economics) were assembled at the National Wildlife Research Center (NWRC), Fort Collins, Colorado. Four support personnel also were present, including the meeting facilitator, a note taker, and 2 additional experts to provide support to the facilitator (Table 1).

The decision-making process consisted of multiple steps:

**Table 1.** List of all individuals attending meeting, the organization they represented, field of expertise, and assigned subgroup. (APHIS = Animal and Plant Health Inspection Service; CDC = Centers for Disease Control; CF = consensus forming; HHS = Health and Human Services ; NWRC = National Wildlife Research Center; USDA = United States Department of Agriculture; WS = Wildlife Services.)

Experts	Organization	Field	Subgroup
Aaron Anderson, Ph.D.	NWRC-USDA	Economics	1
Todd Atwood, Ph.D.	NWRC-USDA	Disease modeling and ecology	1
Jesse Blanton, M.P.H.	HHS-CDC	Epidemiology	2, CF
Rebekah Borse, Ph.D.	HHS-CDC	Economics	2
Richard Chipman, M.S., M.B.A.	WS-USDA	Disease ecology	3
Tyler Cozzens	NWRC-USDA	Economics	2
Frank Fillo, Ph.D.	APHIS-USDA	Economics	1
Robert Hale	WS-USDA	GIS	3
Joanne Maki, D.V.M., Ph.D.	Merial Ltd.	ORV	3, CF
Sergio Recuenco, M.D., Ph.D.	HHS-CDC	Disease ecology	3, CF
Erin Rees, Ph.D.	University of Montreal	Disease ecology	2, CF
Charles Rupprecht, D.V.M., Ph.D.	HHS-CDC	Disease and raccoon ecology	1, CF
Dennis Slate, Ph.D.	WS-USDA	Disease and raccoon ecology	1
Rowland Tinline, Ph.D.	Queen's University	Disease modeling and ecology	1, CF
Kurt Vercauteren, Ph.D.	NWRC-USDA	Ecology	3
Meeting staff members			
Michael Fraidenburg, M.S.	The Cooperation Company	Group decision making	
Stephanie Shwiff, Ph.D.	NWRC-USDA	Economics	
Gene Rhodes, Ph.D.	NWRC-USDA	Disease and raccoon ecology	
Samantha Tracht, M.S.	University of Tennessee	Note taking	

1. discussing specific questions relating to the problem via the internet prior to in-person meeting (i.e., what are the likely raccoon rabies spread scenarios in the absence of intervention, and what are viable strategies for forming a consensus answer to the first question?);
  2. defining the forecasting problem followed by unstructured discussion;
  3. ranking determinants of the spread of raccoon rabies using the nominal group technique;
  4. developing forecasts in subgroups using unstructured discussion within each subgroup;
  5. presenting each group's forecast, along with reasoning, to the entire group of experts;
  6. generating a forecast by a group consisting of 1 elected member from each subgroup;
  7. presenting the consensus forecast, along with rationale, to all participants; and
  8. approving the consensus forecast by all participants.
- The in-person meeting at the NWRC began by explicitly defining the forecasting problem. Experts were informed that a 20-year forecast was desired. The time period was limited to 20 years due to the increasing uncertainty as the forecast is extended into the future, as well as error compounding from early years in the forecast as it is extended. To make forming a

consensus opinion more likely, the group was told that the forecast would involve defining the expansion of the raccoon rabies enzootic area in 2-year increments, thus, reducing expansion regions to be determined from 20 regions to ten. For mapping ease, expansion regions were to be defined along county boundaries. After defining the forecasting problem, an unstructured discussion was allowed to identify and communicate factors deemed important to producing an accurate forecast.

The next step in the meeting used the nominal group technique to decide what factors would determine the speed and extent of the spread of raccoon rabies. The nominal group technique is an approach in which experts are assembled at a single location. Individuals are then asked to silently and independently generate their ideas on a problem or a task in writing. This is followed by a presentation of each individual's ideas to the group. Ideas were summarized and listed, and a voting procedure was used to rank the ideas. The group decision is the pooled outcome of individual votes (Van de Ven and Delbecq 1974, Murnighan 1981).

Participants were asked to list factors that they believed relevant to the westward spread of raccoon rabies. The responses were assembled into a comprehensive list. A multi-voting procedure was then used that gave each participant 3 votes that could be used, however participants deemed appropriate, including using all votes on a single factor. The purpose of this part of the meeting was to reach consensus on what factors should drive the subsequent forecast.

Following the multi-voting procedure, the group was split randomly into 3 subgroups (Table 1). Each subgroup was tasked with producing a unique forecast of the spread of raccoon rabies over a 20-year period in 2-year increments. The complexity of the forecasting problem explains the decision to break the group into only 3 subgroups. More than 3 preliminary forecasts would make constructing a consensus forecast prohibitively difficult. After constructing their forecasts, each subgroup presented its forecast and reasoning for it to the entire group of experts. This step of the decision-making process concluded by allowing unstructured discussion among all group members.

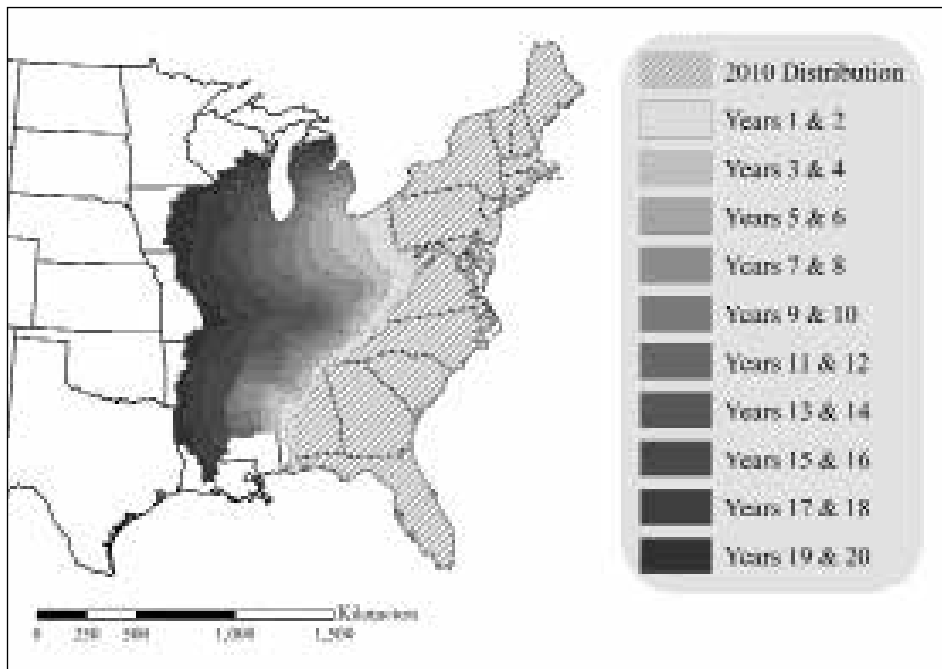
A consensus forecast was formed by having each subgroup elect 2 members to represent that subgroup within the consensus-forming subgroup. Thus, the consensus-forming subgroup consisted of 6 experts—2 from each group (Table 1). The size of this group was kept small because of the complexity of its task, and the consensus forecast was formed by considering the similarities and differences in the preliminary forecasts. Unstructured discussion was used to manage the differences in the preliminary forecasts and incorporate diverse views into a single forecast. The consensus forecast was then presented to the entire group. All group members agreed that this was the best consensus forecast that could be produced, given the experts present and information available.

## Results

The consensus forecast covers a 20-year period and consists of 10 raccoon rabies spread-expansion regions (Figure 3). Thus, each region represents a 2-year time frame, so that the first (easternmost) expansion region represents the spatial status of raccoon rabies 2 years after the ORV zone ceases to exist. The combined 10 regions show the extent raccoon rabies is projected to spread after a 20-year period without ORV intervention.

The consensus forecast was constructed by first agreeing on 3 rates of spread: low (15 km/year), medium (30 km/year), and high (60 km/year). The specific rates were chosen based on both the combined inputs of the experts in the consensus-forming group and the historic rates of spread as raccoon rabies spread from the mid-Atlantic focus in the eastern United States. The results of the multi-voting exercise provided the guidance to assign the appropriate rate of spread to the different regions. Specifically, spread rate was assigned based on land-cover type, presence and directional flow of large rivers, presence of large urban areas, elevation, and climate.

A high rate of spread was assigned to areas where data from other studies (Wilson et al. 1997, Russell et al. 2005) and population monitoring (Slate et al. 2008) that suggest high densities of raccoons, including agriculture-forest mixed land use (especially corn agriculture; Beasley et al. 2007), and significant



**Figure 3.** Map of the potential spread of raccoon rabies based on the consensus forecast.

urban–rural interface areas (Prange et al. 2003). Based on firsthand knowledge of meeting personnel and an examination of agricultural production data from the National Agricultural Statistics Service, areas assigned a high rate of spread included much of Ohio, Indiana, and Illinois. Medium rates of spread were assigned to upper Michigan, many agricultural areas in the South, and the Mississippi Delta. Upper Michigan has a cool climate, which minimizes winter movement of raccoons, potentially slowing the spread of rabies. In the South, a high proportion of agricultural areas contain managed pine forests, pasture, and soybean and rice production. These types of land use generally provide poor raccoon habitat, and it is believed that they support lower raccoon densities (Chamberlain et al. 2002, Zaveloff 2002, Arjo et al. 2008). The same is projected for the Mississippi Delta due to poor raccoon habitat. Finally, low spread rates are mostly confined to the higher elevation areas in north Alabama, east Tennessee, and parts of Kentucky. Forested habitats at higher elevations in combination with harsher winters and the absence of agriculture often support lower raccoon abundance (Slate et al. 2005).

Additional consideration was given to the

Mississippi River itself due to its length, width, infrequent bridges, and north-south orientation. The river would pose a barrier, slowing the spread in varying degrees, depending on the location. Below St. Louis, where the river is wide and there is a relative scarcity of bridges, the spread of raccoon rabies is expected to stall, as it will take more time to cross. Above St. Louis, a stall is also expected, though it is expected to be shorter, as ice cover may provide a bridge across the river. Arbitrary stall times of 2 years for below St. Louis and 1 year above were chosen by consensus. Finally, it was decided that an area extending from southern Louisiana to southern Alabama would remain raccoon rabies-free over this time horizon, based on recent and historic observations in Alabama that raccoon rabies has not spread beyond the Alabama River. Additionally, some of this area has poor raccoon habitat and relatively low raccoon densities (Arjo 2008).

Over the 20-year horizon, spread would extend as far west as the Texas border and western Iowa. However, over a longer time period, the spread would likely continue to the Rocky Mountains, where it may finally be stopped due to harsh winters and unsuitable habitat.

## Discussion

The results of this study project the substantial spread of raccoon rabies over a 20-year horizon in absence of the current ORV zone. In the eastern United States, where raccoon rabies is enzootic, the burden of rabies is high. For example, rates of human post-exposure prophylaxis are much higher than in other parts of the United States, and risk of exposure and death to domestic animals, including livestock, is greater (Christian et al. 2009, Blanton et al. 2011). By forecasting the spread of raccoon rabies in absence of the existing ORV zone, the benefits of intervention designed to prevent spread can be measured more accurately.

We believe that our forecast of the spread of raccoon rabies is an improvement over that used in Kemere et al. (2002), and, therefore, a cost-benefit analysis using this forecast would also be an improvement. First, more conservative rates of spread were used than the 40 km/year and 120 km/year ones used by Kemere et al. (2002). While 40 km/year may be justified, based on known spread rates in eastern states, there is less justification for assuming a rate of spread of 120 km/year. Thus, the rates of spread used here were generally lower and more consistent with previous studies (Rupprecht and Smith 1994, Hanlon and Rupprecht 1998, Centers for Disease Control 2000, Childs et al. 2001). Second, while Kemere et al. (2002) used a range of spread rates, they were used to construct 2 separate forecasts. No attempt was made to tailor the rate of spread to specific areas. Alternatively, the forecast presented logically applied knowledge relative to land use, locations of large rivers, urban areas, elevation, and climate to project the spread of raccoon rabies.

The primary limitation in our forecasting approach is that it is potentially biased by subjective judgment. In addition, group members may have relied on incorrect information or failed to consider known and relevant information. In addition, some group members may have dominated discussions within subgroups due to force of personality or by a perception of other members that their level of expertise was greater. Despite these potential shortcomings, the method developed here was designed to limit these problems and was considered appropriate for the forecasting

problem given both the lack of other suitable models and management time constraints.

## Management implications

The methodology applied in this study, including the integration of several methods to reach consensus of expert opinions, as well as the results of this study, could be used in several ways. The methodology, perhaps with some modification, could be used in complicated forecasting problems for which no models are immediately available. Applications are potentially broad and could include forecasting problems related to animal and human disease spread, the spread of agricultural pests and invasive species, political geography, or other problems where the forecast must be more complex than a number or on which relevant information for a quantitative forecasting model is lacking. The results themselves are useful for understanding the benefits of the raccoon rabies ORV-created zone of immunity and developing additional economic models to determine cost-benefits of maintaining ORV. The forecast and consensus on relevant factors associated with predicting raccoon spread of rabies may also be important for developing research related to ORV and management practices. Overall, it is clear that without the ORV program, the spread would be fast and extensive and would likely result in a significant economic impact.

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