Background

Rabies in North America

- Rabies maintained enzootically in the wild among terrestrial carnivore species: raccoon, skunk, fox, coyote (bats-nonterrestrial)

- Each species strongly associated with a genetically distinct variant

- Each variant and its associated species occur in geographically distinct areas
Spatial Distribution of Major Variants of Rabies Virus in Terrestrial Carnivores in the United States
Dynamics of Rabies Virus

- When epizootics of rabies occur in a reservoir species, spillover of rabies can occur into other species.
- Adaptation of the virus to a new host species may occur over time.
- No documented evidence of rabies variant becoming established in another species.
Raccoon Rabies Epizootics
mid-Atlantic states
1981                    2000
Pattern of epizootics observed in majority of counties with epizootics in both species

Fairfield County, CT

Number of cases

Time (months)
Pattern of Epizootics
Skunk rabies cases > raccoon rabies cases in areas of Massachusetts and Rhode Island

Norfolk County, MA

Number of cases

Time (months)

CDC
Objectives

study dynamics of rabies in skunks and raccoons

- Describe characteristics of rabies epizootics in skunks vs. raccoons
- Determine if rabies in skunks and raccoons are temporally and spatially associated
- Assess evidence of spillover of rabies vs. independent cycling
Materials and Methods

- **Database**: Passive surveillance data collected by state health departments and compiled by CDC yearly.

- **States**: Connecticut, Delaware, Massachusetts, Maryland, North Carolina, New Jersey, New York, Pennsylvania, Rhode Island, Virginia, West Virginia.

- **Time period**: First case of raccoon or skunk rabies reported (1981 – 2000) by county.

- **Unit of analysis**: Number of laboratory-confirmed rabid raccoons and skunks reported monthly at the county level.
Descriptive Analysis
Are skunk and raccoon epizootics similar?

- Comparison of number of rabid animals, duration of epizootics (Wilcoxon rank sum test)
- Epizootic- definition
  - starts when # of rabid animals reported by month > county’s monthly median for 2 consecutive months
  - ends when the number < the county median for 2 consecutive months
  - minimum duration of 5 months
### Epizootic Characteristics
#### Skunks vs. Raccoons

#### Characteristics of Raccoon and Skunk Epizootics Restricted to 12+ Counties

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of counties with epizootics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raccoon</td>
<td>32</td>
<td>22</td>
<td>10</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Skunk</td>
<td>31</td>
<td>19</td>
<td>12</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td><strong>Length (months)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raccoon</td>
<td>18.5 (6, 26)</td>
<td>8.5 (5, 23)</td>
<td>8 (6, 12)</td>
<td>11.5 (11, 12)</td>
<td>-</td>
</tr>
<tr>
<td>Skunk</td>
<td>8 (5, 24)*</td>
<td>8 (5, 10)</td>
<td>6 (5, 10)**</td>
<td>8 (5, 13)</td>
<td>7.5 (5, 10)</td>
</tr>
<tr>
<td><strong>Size (# of rabid animals)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Raccoon</td>
<td>125.5 (9, 494)</td>
<td>18.5 (5,138)</td>
<td>18.5 (9, 43)</td>
<td>53 (28, 78)</td>
<td>-</td>
</tr>
<tr>
<td>Skunk</td>
<td>16 (4, 85)*</td>
<td>18 (5, 39)</td>
<td>13 (4, 32)**</td>
<td>18 (6, 37)</td>
<td>13 (12, 14)</td>
</tr>
</tbody>
</table>

Comparison between raccoon and skunk (Wilcoxon Rank-Sum test)

* \( p < 0.0001 \)

** \( 0.01 < p < 0.05 \).
Spatial Analysis
Are epizootics associated in space through time?

- Determined mean center and standard deviational ellipse of counties positive by year for raccoons and skunks
- County considered positive when first epizootic of rabies for each species occurred

1990

Raccoon

Skunk
Epizootics
Mean Center and Standard Deviational Ellipse
1991

Raccoon

Skunk
Epizootics
Mean Center and Standard Deviational Ellipse
1992

Raccoon

Skunk
Epizootics
Mean Center and Standard Deviational Ellipse
1993

Raccoon

Skunk
Epizootics
Mean Center and Standard Deviational Ellipse
1994

Raccoon

Skunk
Epizootics
Mean Center and Standard Deviational Ellipse

1995

Raccoon

Skunk
Epizootics
Mean Center and Standard Deviational Ellipse
1996

Raccoon

Skunk
Epizootics
Mean Center and Standard Deviational Ellipse
1997

Raccoon

Skunk
Epizootics
Mean Center and Standard Deviational Ellipse

1998

Raccoon

Skunk
Epizootics
Mean Center and Standard Deviational Ellipse
1999

Raccoon
Skunk
Epizootics
Mean Center and Standard Deviational Ellipse

2000

Raccoon

Skunk
Are epizootics moving in the same direction?

Vectors

- Calculation of direction (0-360º) and distance (km) for each epizootic by year and species
- Calculation of directional mean and variance for each epizootic (Crimestat, DOJ)
- Comparison of angle of rotation between epizootics (Watson-Williams test)
Spatial Analysis Results

- Directional mean and distance of epizootics:
  - Skunk: 42.06° ± 0.23°, 339.28 km
  - Raccoon: 47.76° ± 0.28°, 368.18 km

- No significant difference between angles of rotation of epizootics:
  \( F_{1,18;0.05} = 0.11 (<4.41, \text{n.s.}) \)
Temporal Analysis
Are raccoon and skunk rabies associated over time?

- 32 counties selected for analysis
- Criteria - ≥ 12 rabid skunks in first year
- Corresponded to 90th percentile of counties at least 1 rabid skunk
Temporal Analysis

- Poisson regression analysis
  - Variables that describe count data
  - When events occur randomly in space or time
  - Poisson distribution parameter- average count/unit time
- Outcome- # of rabid skunks
- Predictors- # of rabid raccoons, time (continuous, 1-140 months), month, county
- Regression equation:

\[
\log(\text{SKUNK}) = 0.2835 + 0.0262(\text{RACCOON}_{t-1}) - 0.0021(\text{time}) + 0.0020(\text{RACCOON}_{t-1} \times \text{time}) + B_i(\text{county}_i) + B_j(\text{month}_j)
\]
Poisson regression model

- # of rabid raccoons (lag of 1 month) significant predictor of # of rabid skunks (p=0.0054)
- Effect of # of raccoons on # of skunks increased over time (p=0.0037)
- # of skunks – strong seasonal component (p=0.0049)
Percent of Rabies Cases by Month

- **Raccoon**
- **Skunk**

*Fall peak*
Summary

- Spillover of rabies from raccoon to skunk population
- After initial epizootic, size and duration of skunk and raccoon epizootics similar
- Directional and magnitude of epizootic spread does not differ between species
- Number of skunk and raccoon rabies cases are temporally associated - with a lag time of 1 month (rabies incubation period – 3-8 weeks)
- Increased number of rabid skunks in the fall months when dispersion of juveniles occurs
Future Research

At present, no evidence of independent maintenance of rabies in skunk population where raccoon-associated variant is enzootic

Further investigations needed to assess changes in the dynamics of rabies:

- periodicity of epizootics – long cycles
- influence of environmental factors
- changes in genetics of regional rabies variants
Acknowledgements

- John Krebs
- Meghan Dey
- Wade Ivy III
- State and county health departments
- PDI Images