Epidemiology of Raccoon and Skunk Rabies in the Eastern United States

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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

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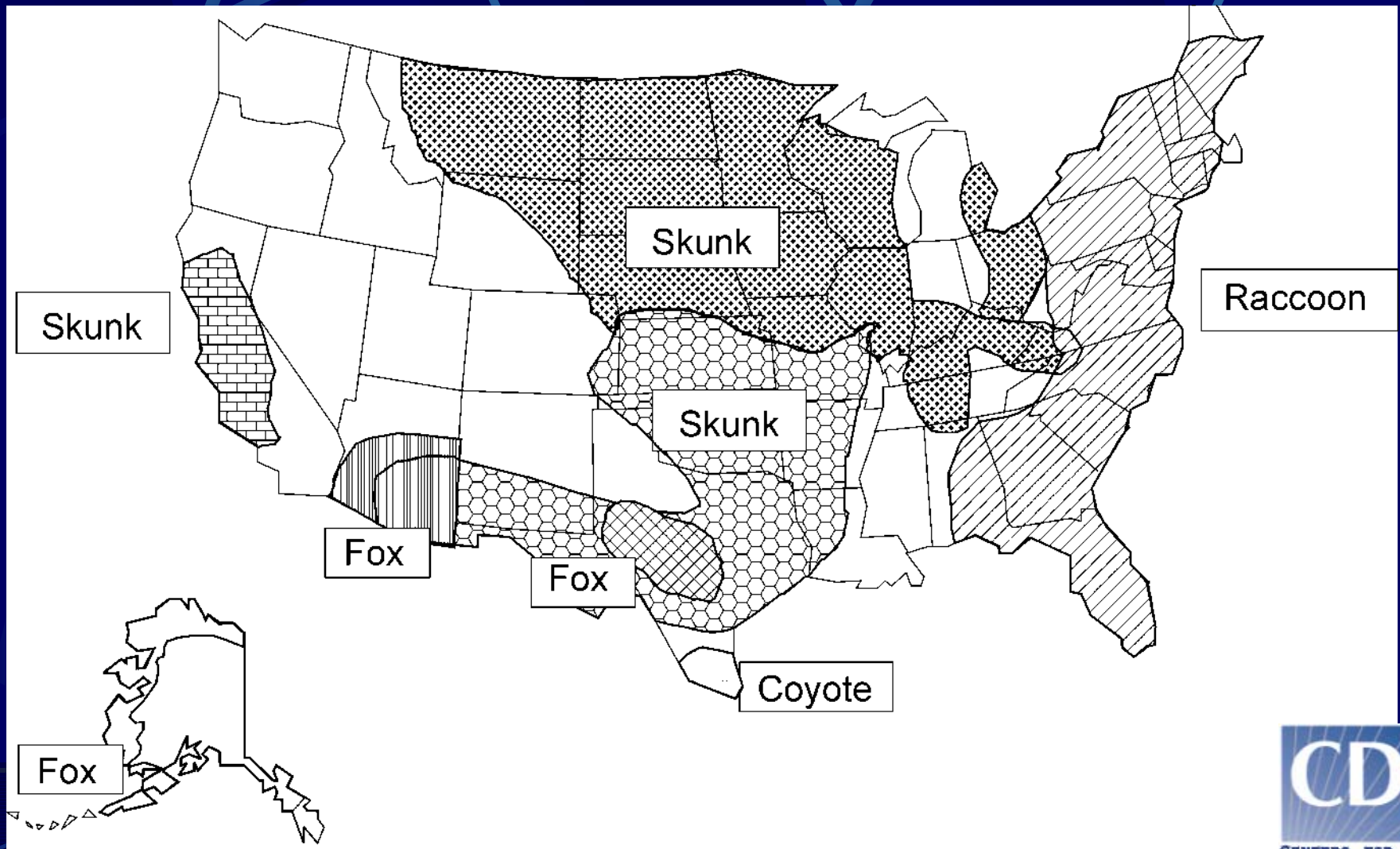
Spatial Distribution of Major Variants of Rabies Virus in Terrestrial Carnivores in the United States



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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

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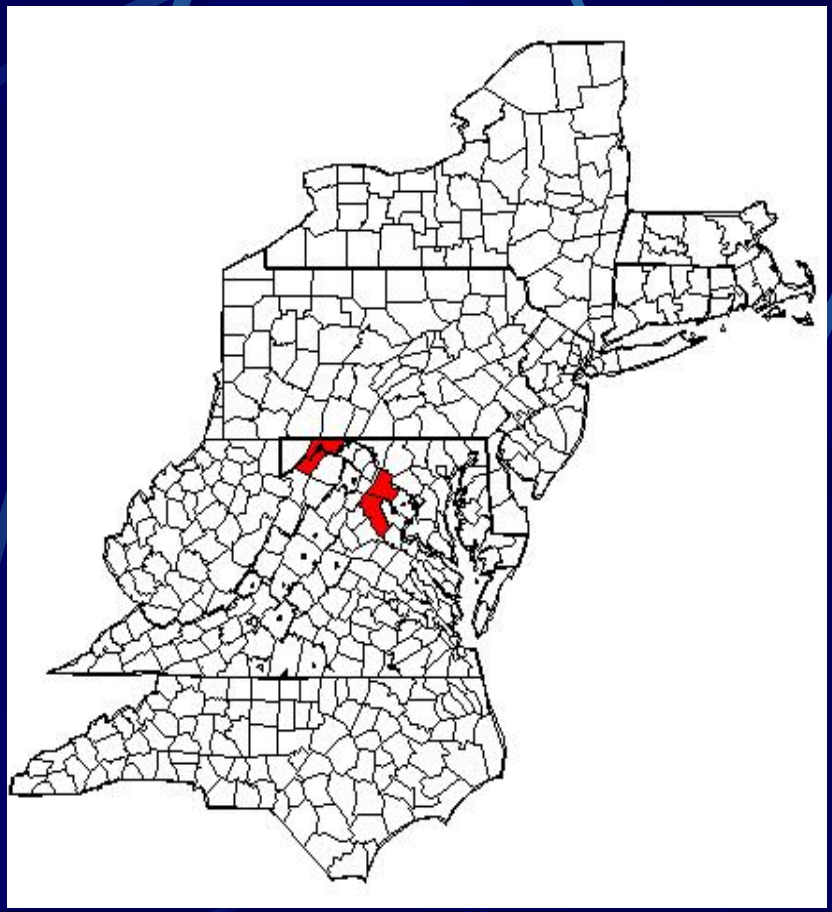
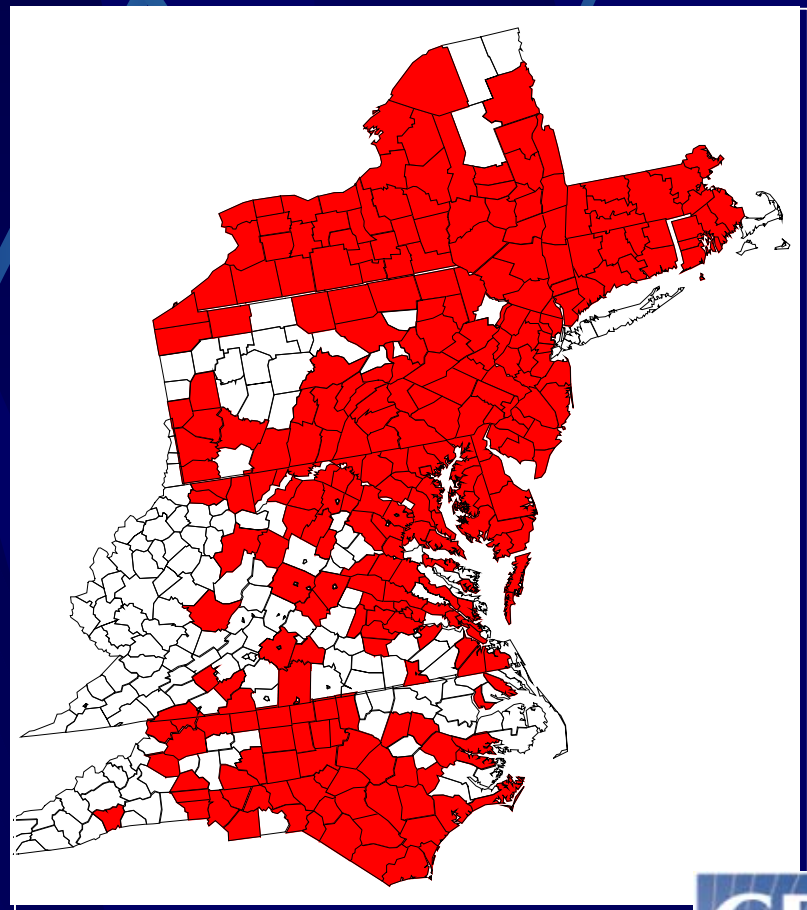
Raccoon Rabies Epizootics

mid-Atlantic states

1981



2000



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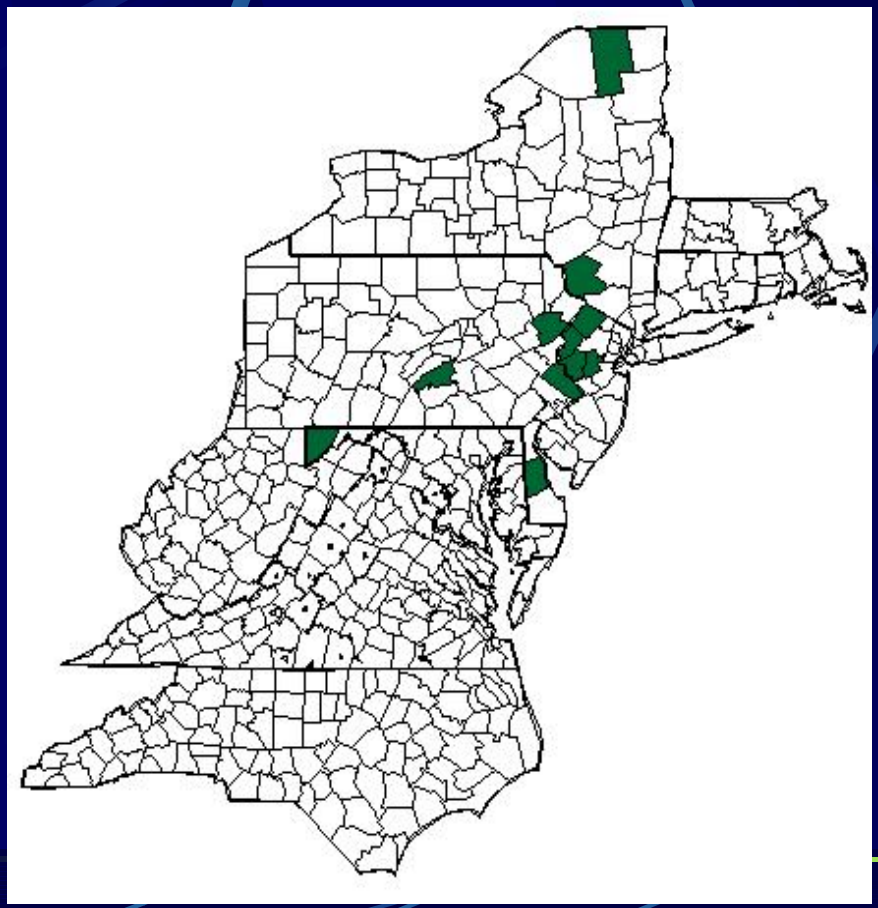
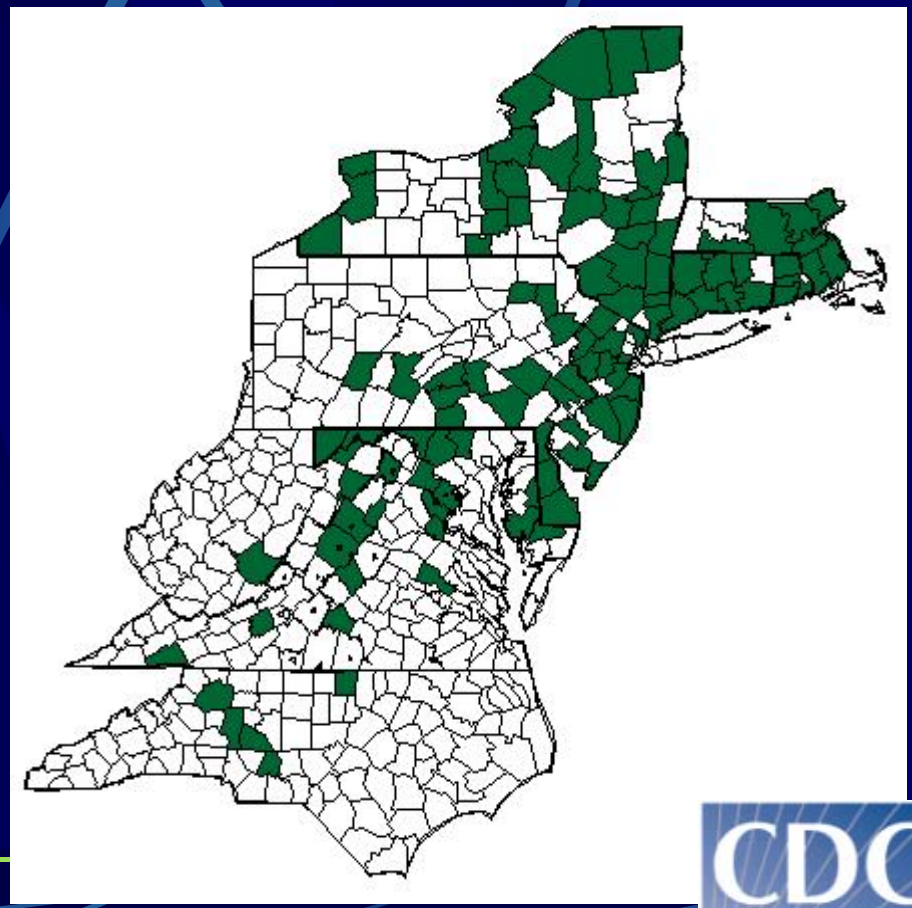
Emergence of Epizootics of Skunk Rabies

mid-Atlantic states

1990



2000



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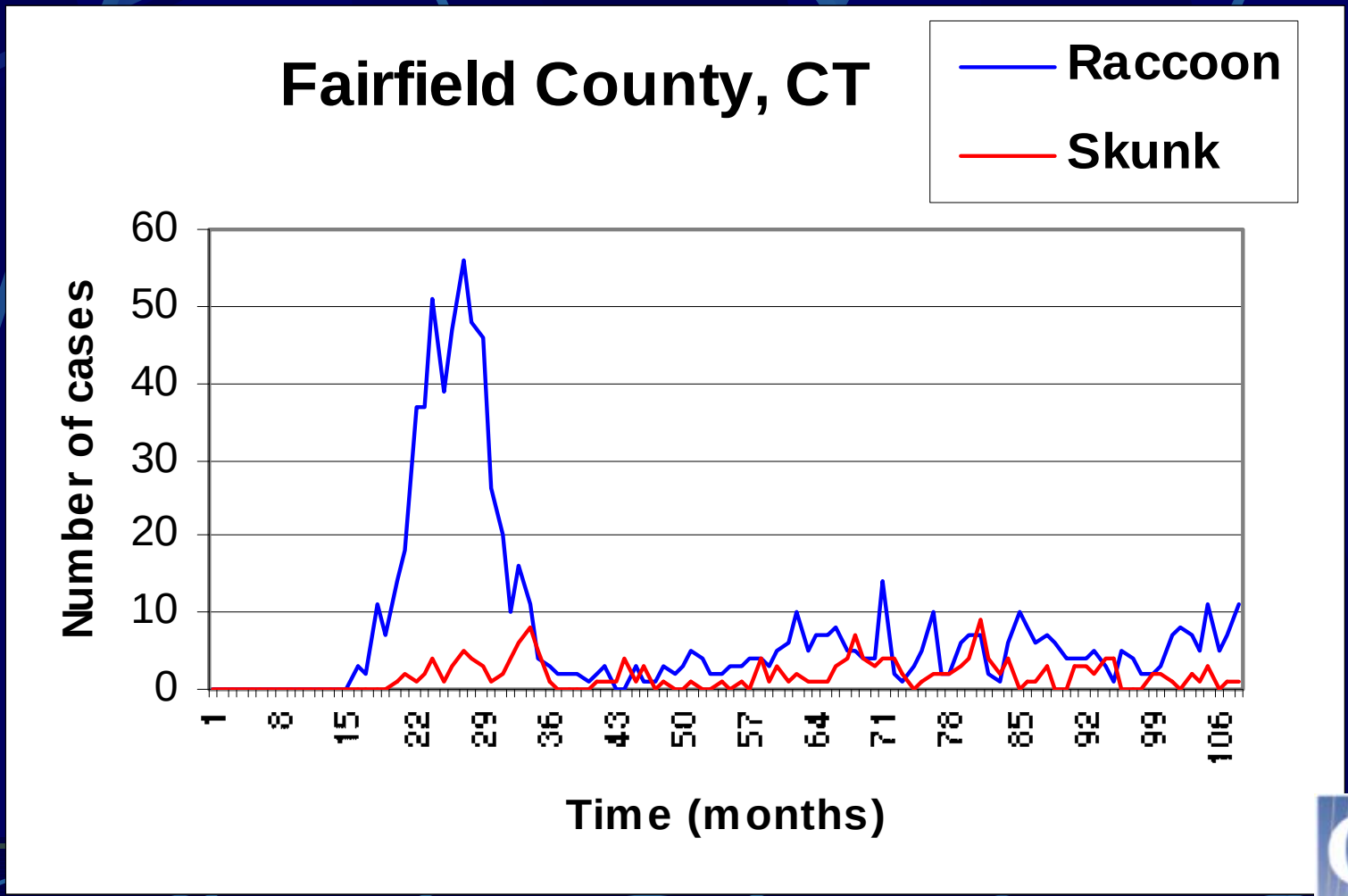
Pattern of Epizootics

observed in majority of counties with epizootics in both species



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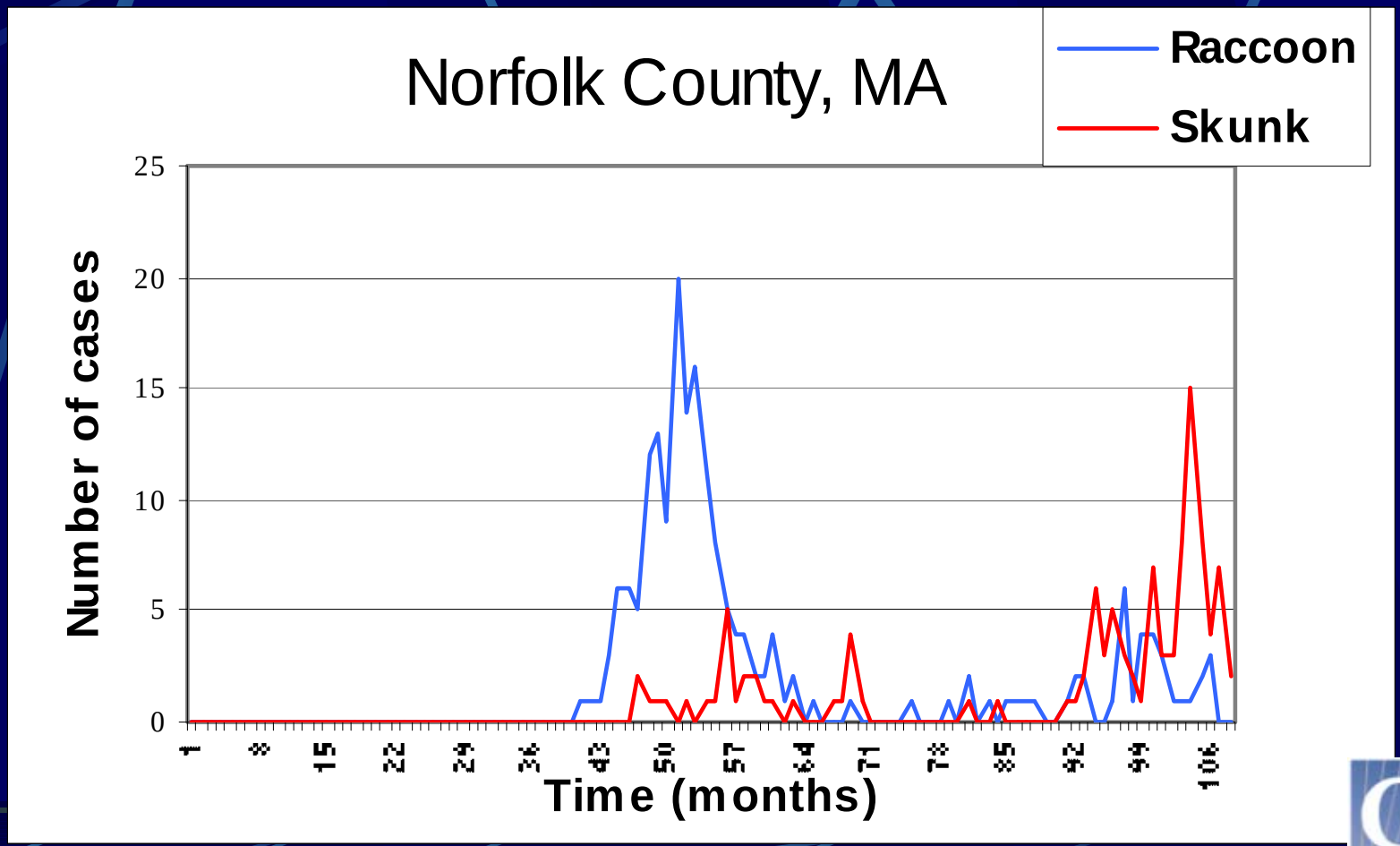
Pattern of Epizootics

Skunk rabies cases > raccoon rabies cases in areas of Massachusetts and Rhode Island



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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

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Materials and Methods

- Database- passive surveillance data collected by state health depts. 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

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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

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Epizootic Characteristics
Skunks vs. Raccoons

Characteristics of Raccoon and Skunk Epizootics Restricted to 12+ Counties						
		Epizootic Number				
Characteristic		1	2	3	4	5
Number of counties with epizootics						
Raccoon		32	22	10	2	0
Skunk		31	19	12	6	2
Length (months)			Median (min, max)			
Raccoon		18.5 (6, 26)	8.5 (5, 23)	8 (6, 12)	11.5 (11, 12)	-
Skunk		8 (5, 24)*	8 (5, 10)	6 (5, 10)**	8 (5, 13)	7.5 (5, 10)
Size (# of rabid animals)			Median (min, max)			
Raccoon		125.5 (9, 494)	18.5 (5,138)	18.5 (9, 43)	53 (28, 78)	-
Skunk		16 (4, 85)*	18 (5, 39)	13 (4, 32)**	18 (6, 37)	13 (12, 14)
Comparison between raccoon and skunk (Wilcoxon Rank-Sum test)						
* p < 0.0001						
**0.01 < p < 0.05.						

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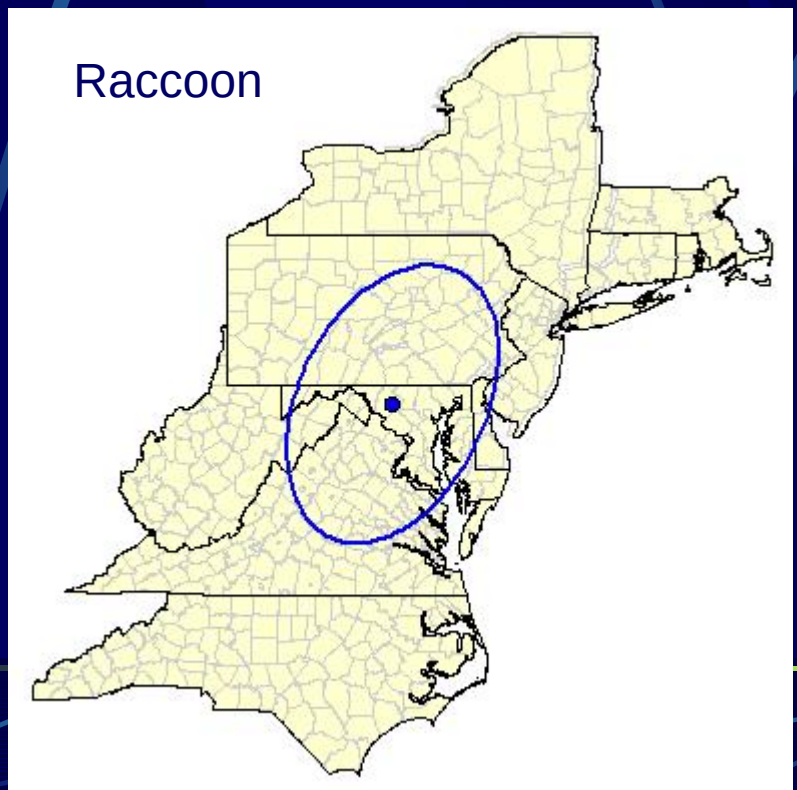
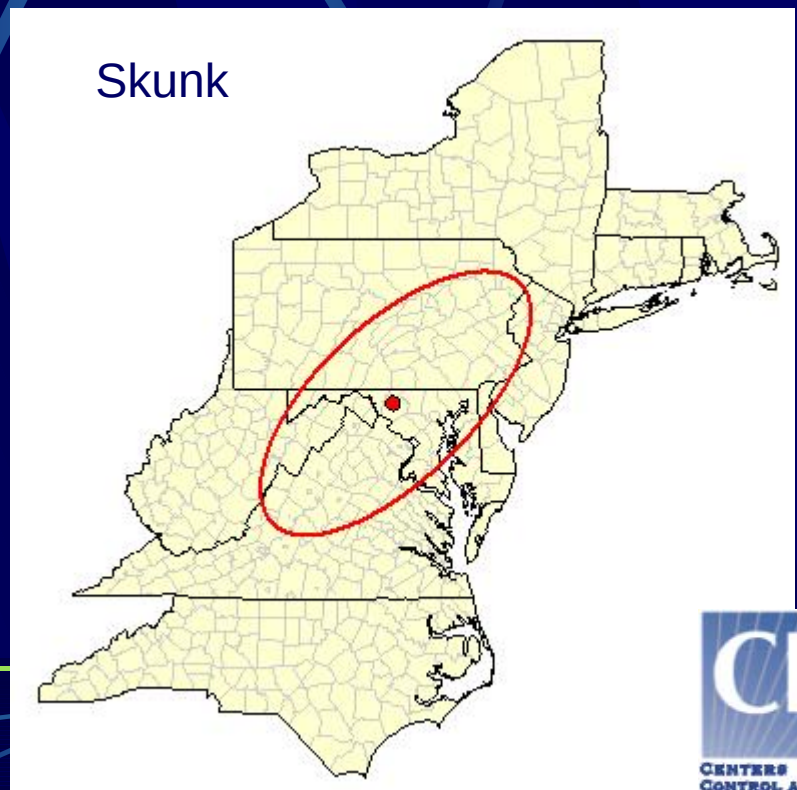
Spatial Analysis

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





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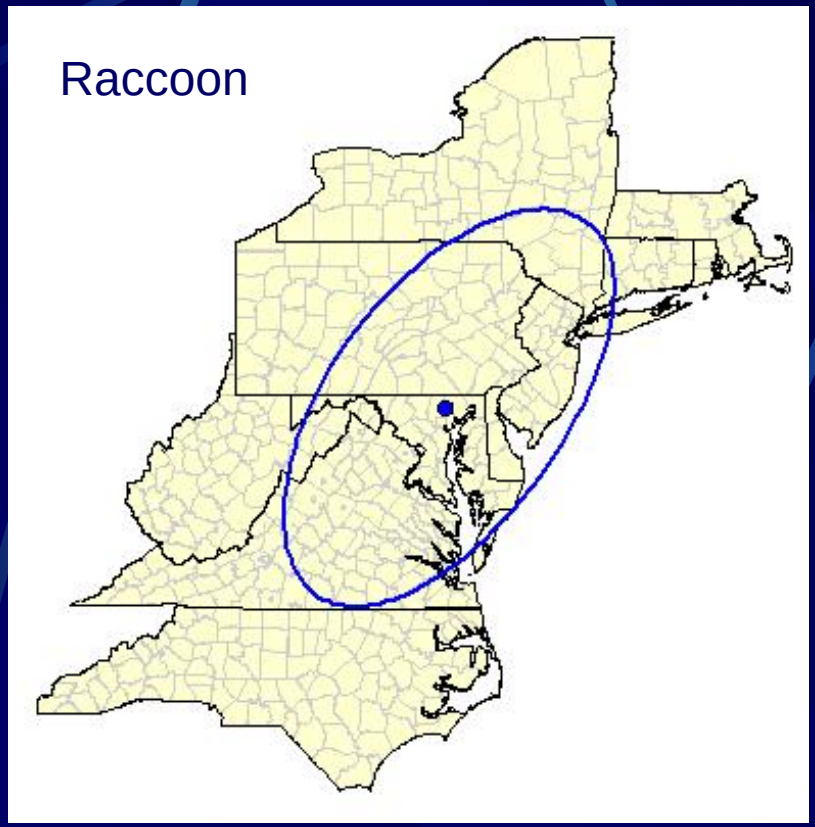
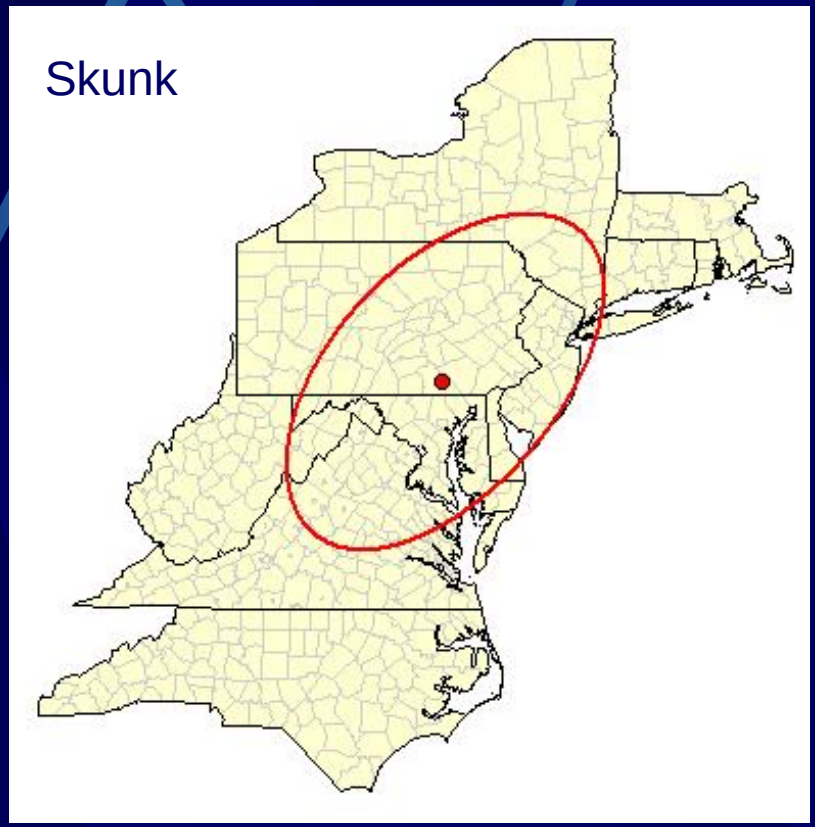
Epizootics

Mean Center and Standard Deviational Ellipse

1991





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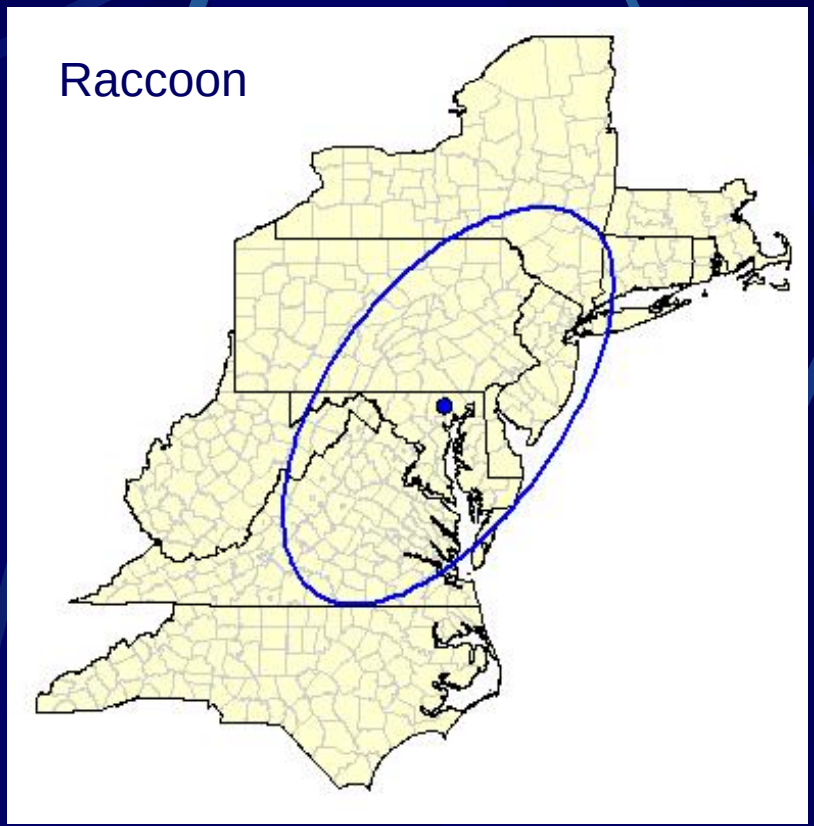
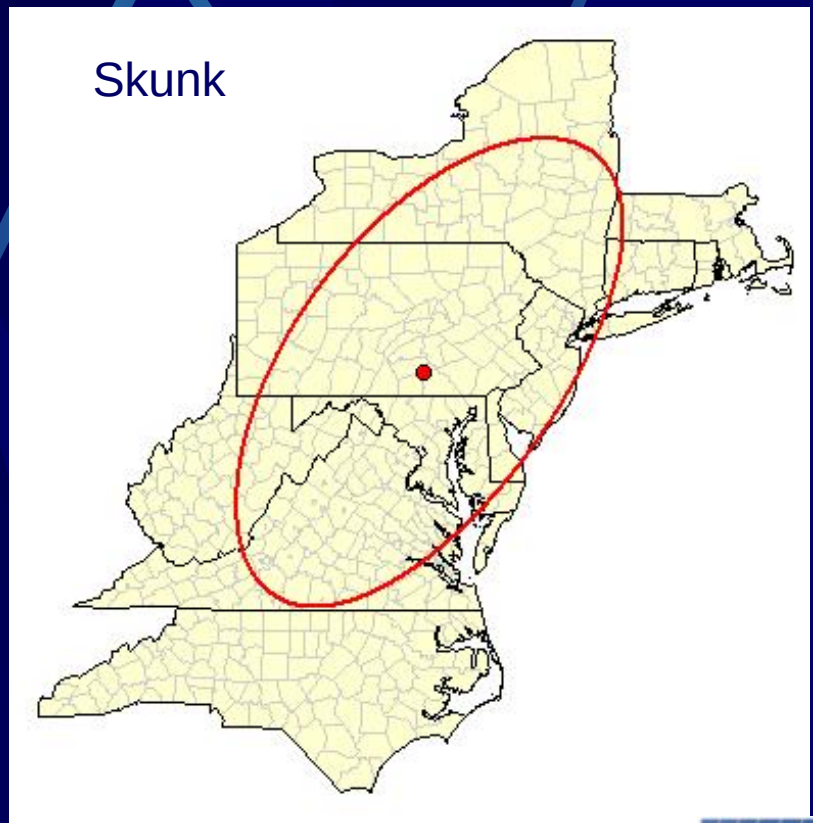
Mean Center and Standard Deviational Ellipse

1992





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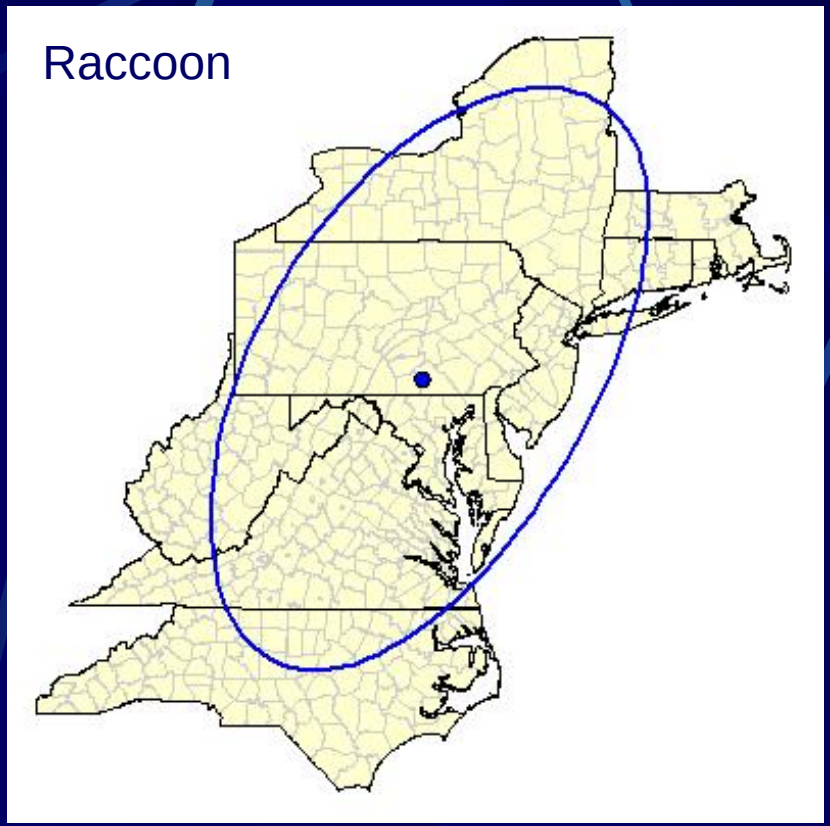
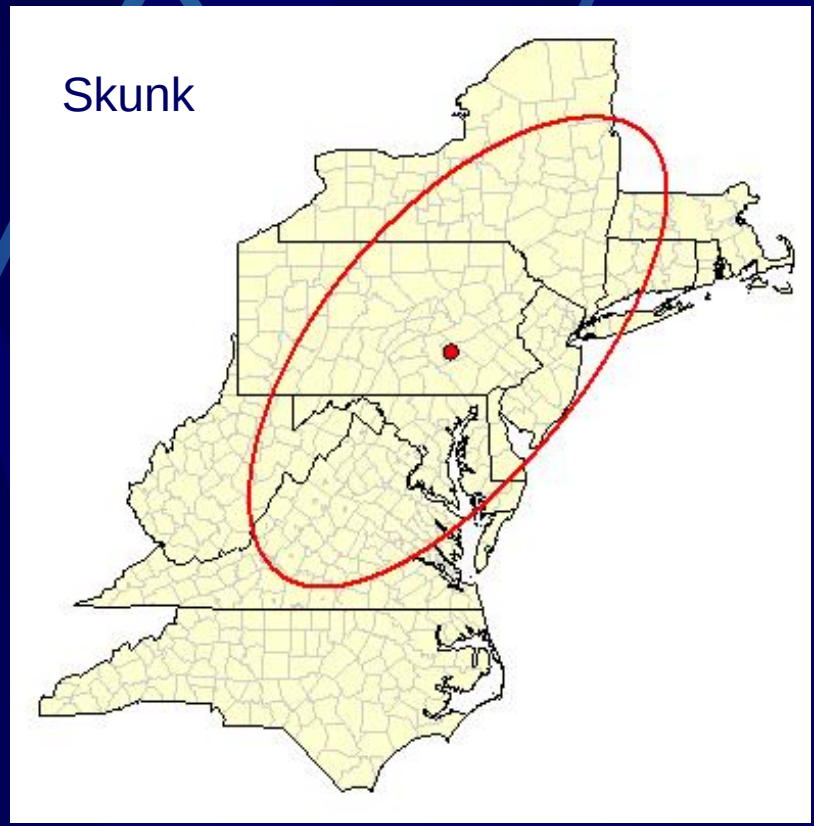
1993





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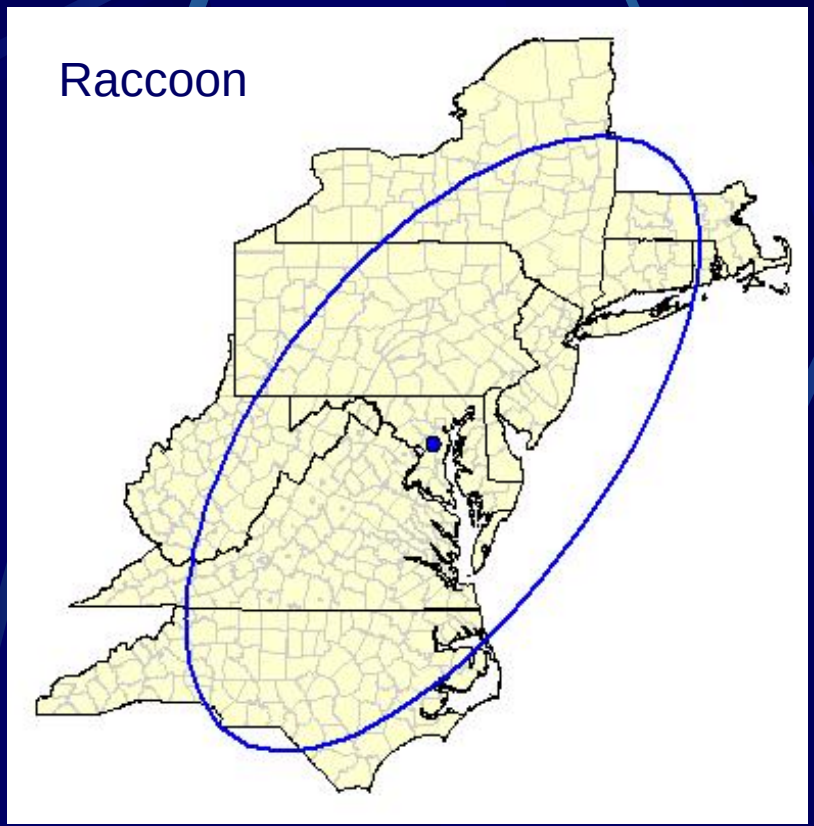
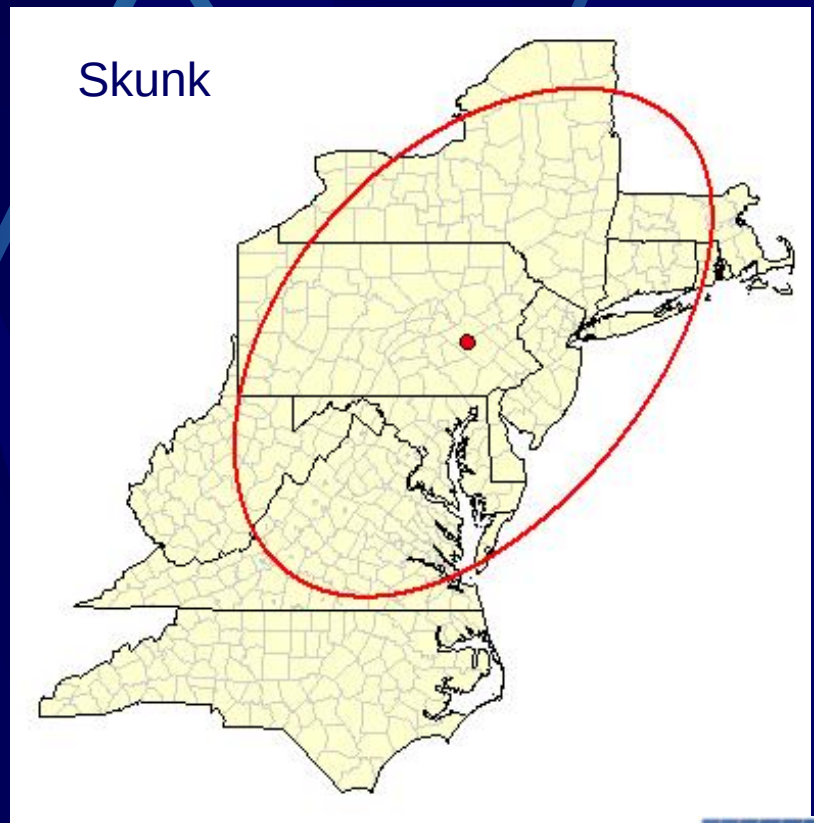
Mean Center and Standard Deviational Ellipse

1994





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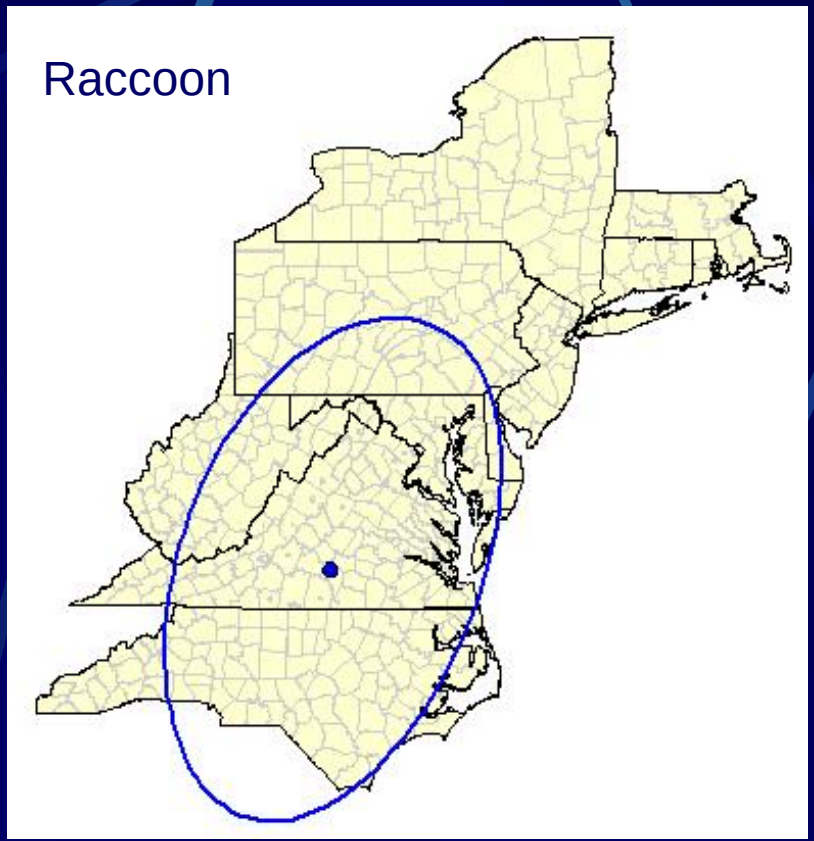
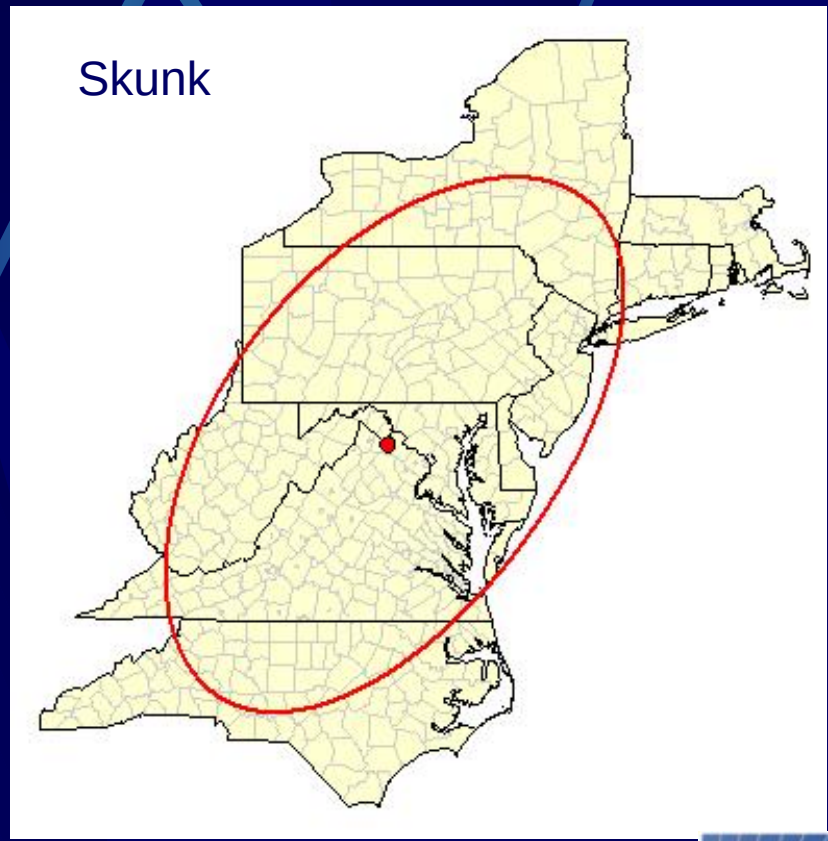
1995





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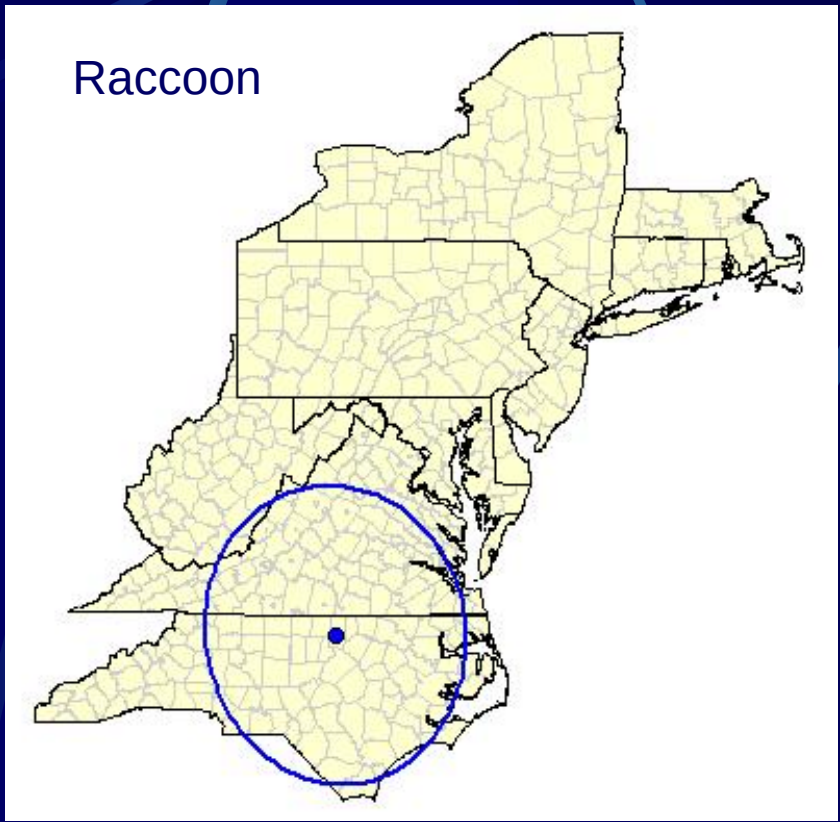
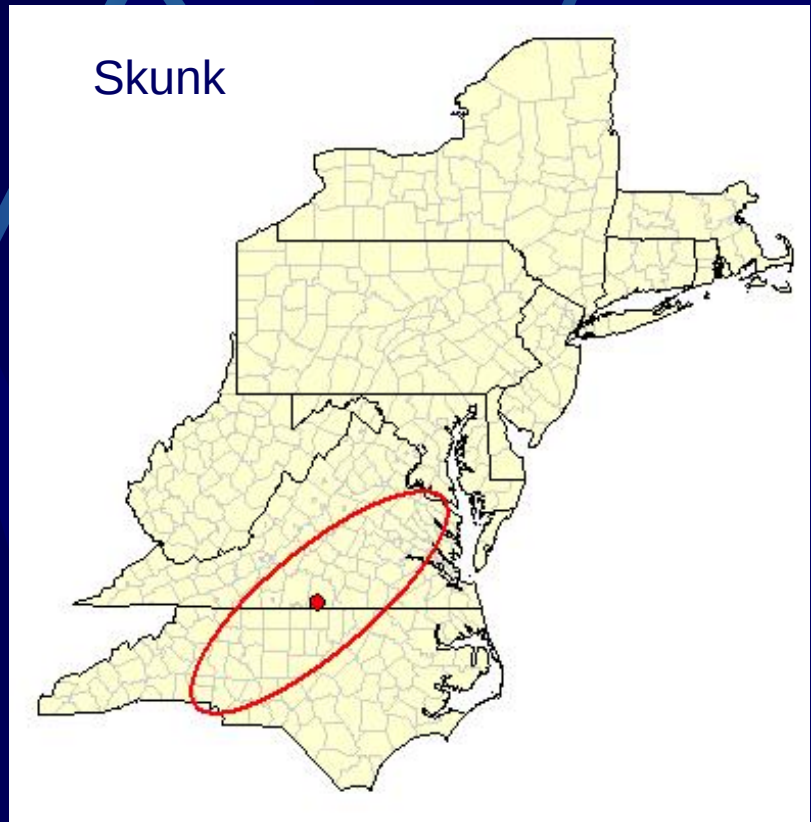
Mean Center and Standard Deviational Ellipse

1996





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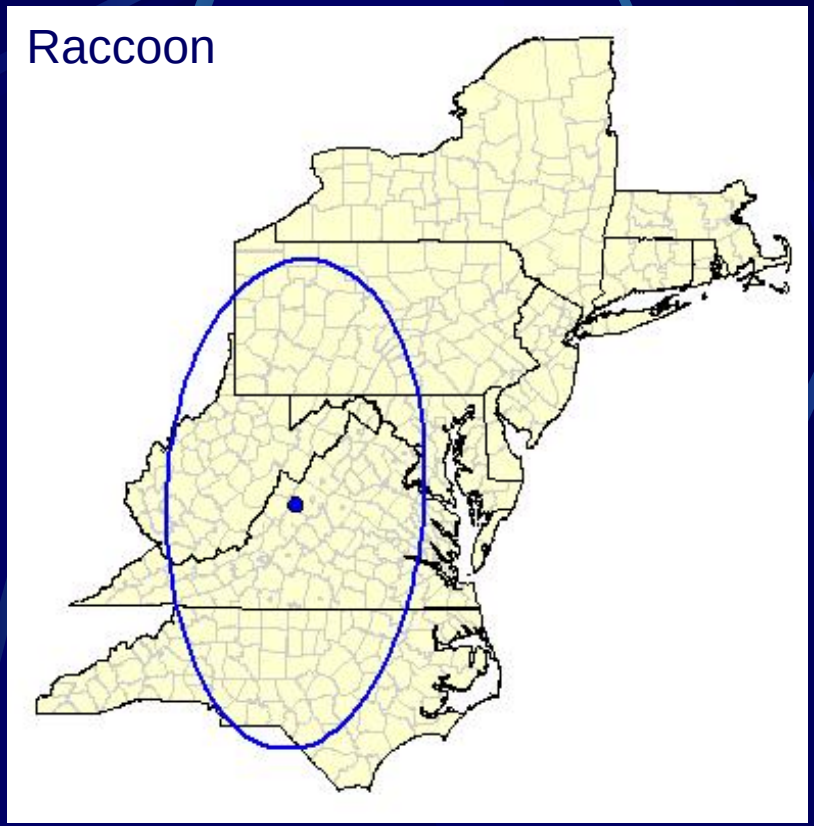
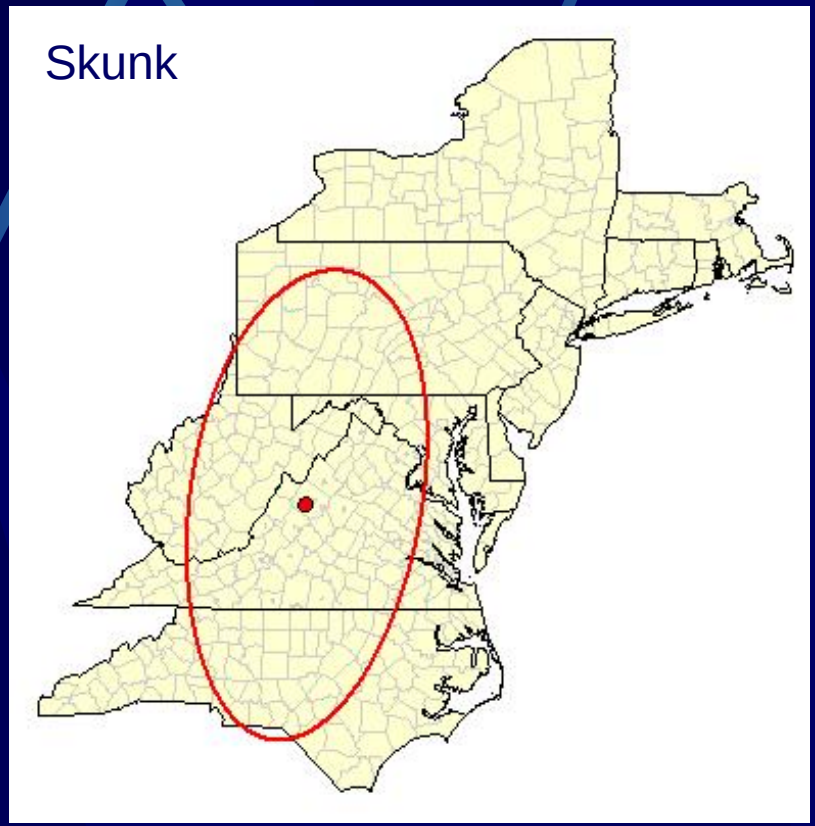
1997





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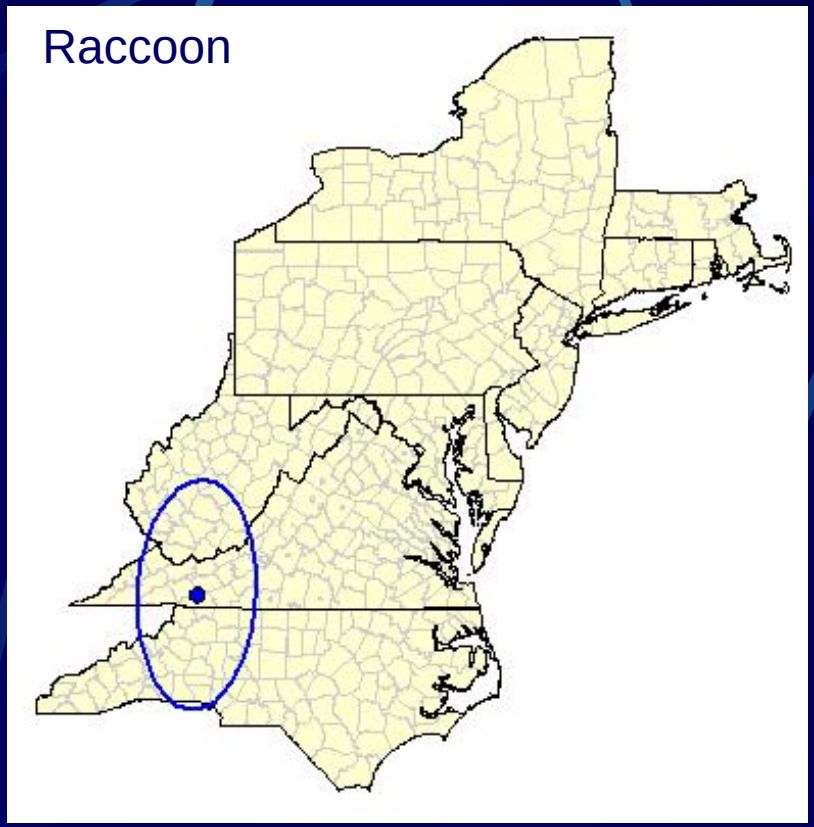
Mean Center and Standard Deviational Ellipse

1998



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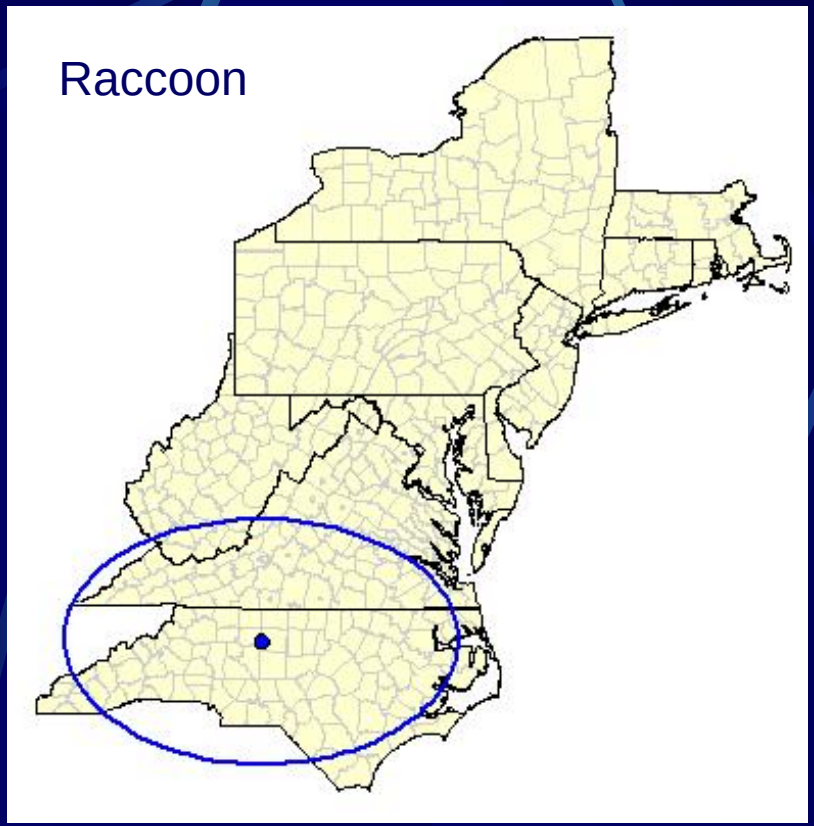
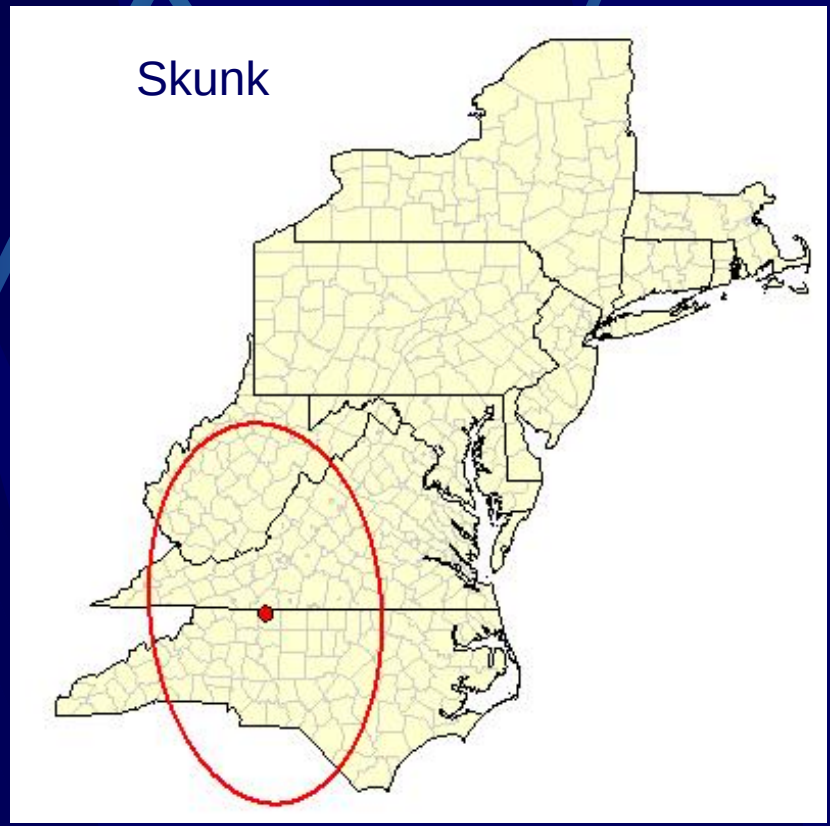
Mean Center and Standard Deviational Ellipse

1999





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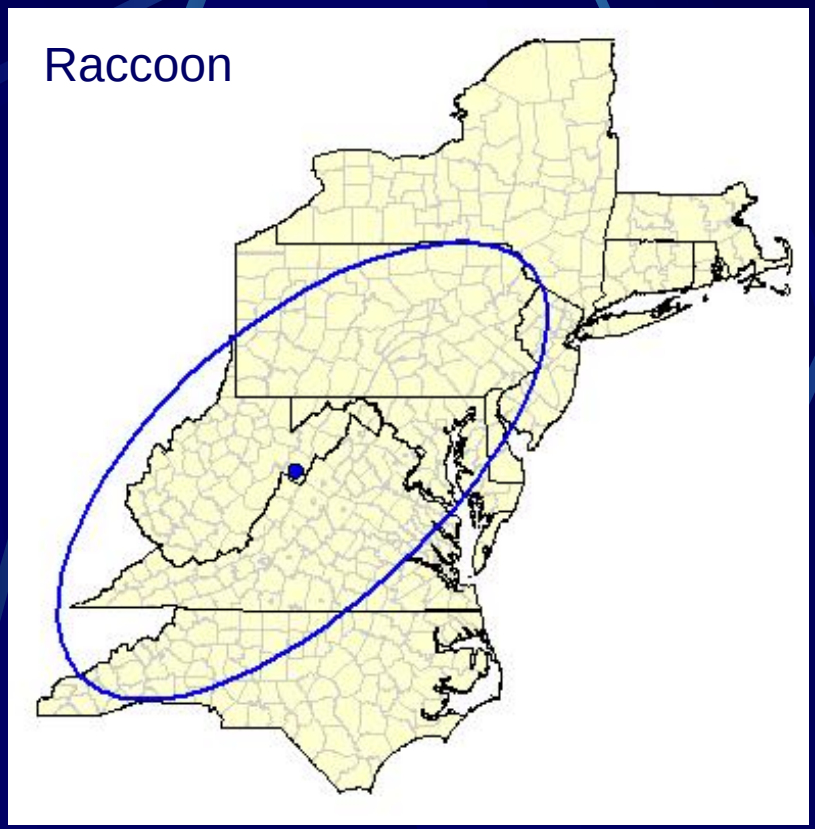
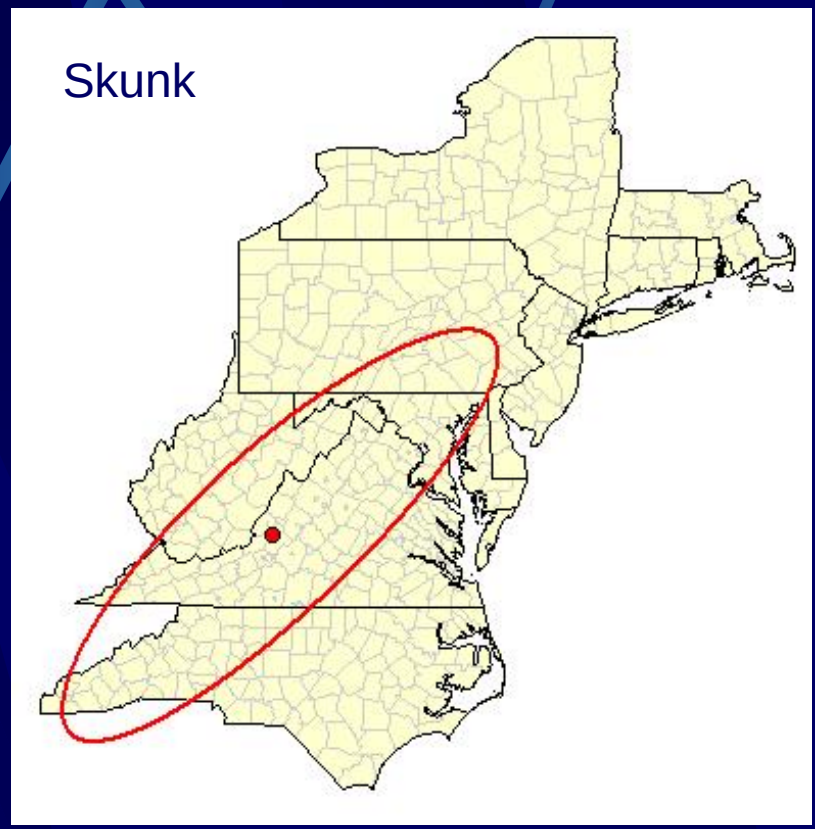
Mean Center and Standard Deviational Ellipse

2000





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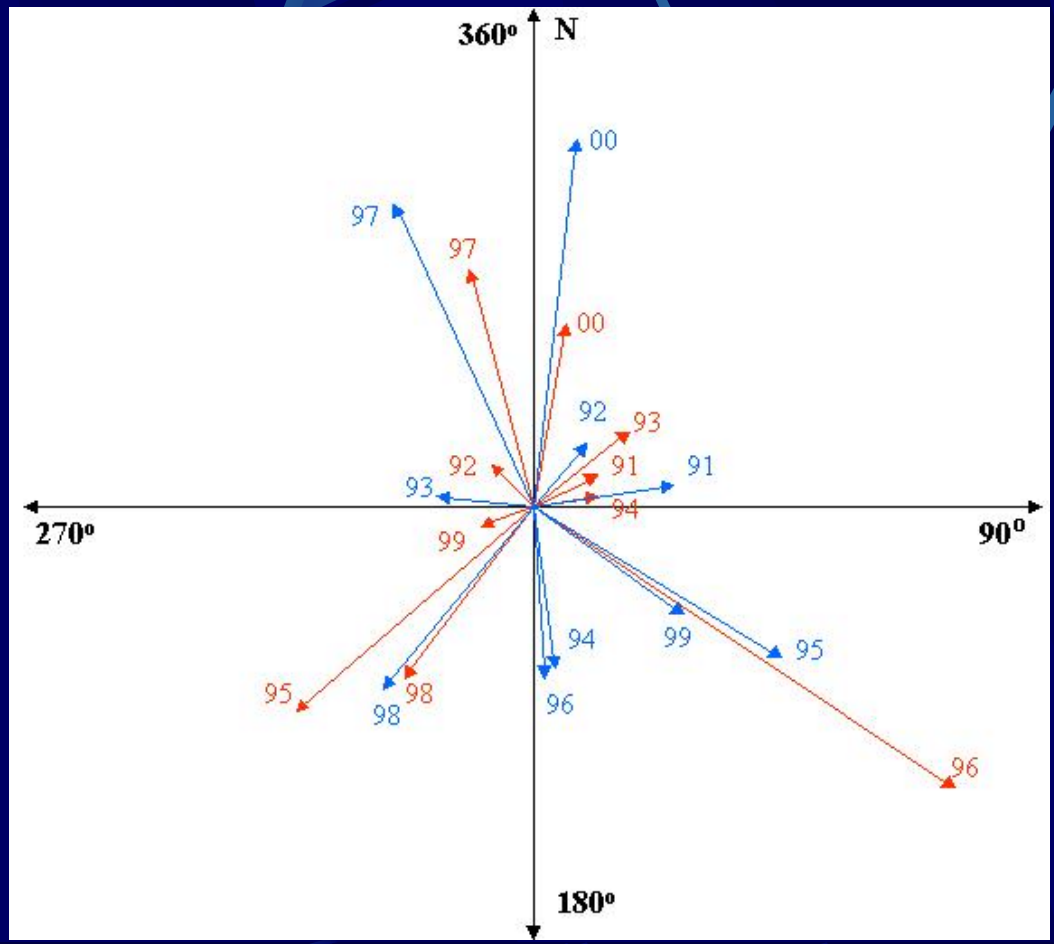
Are epizootics moving in the same direction?

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)

Raccoon Skunk 100 km

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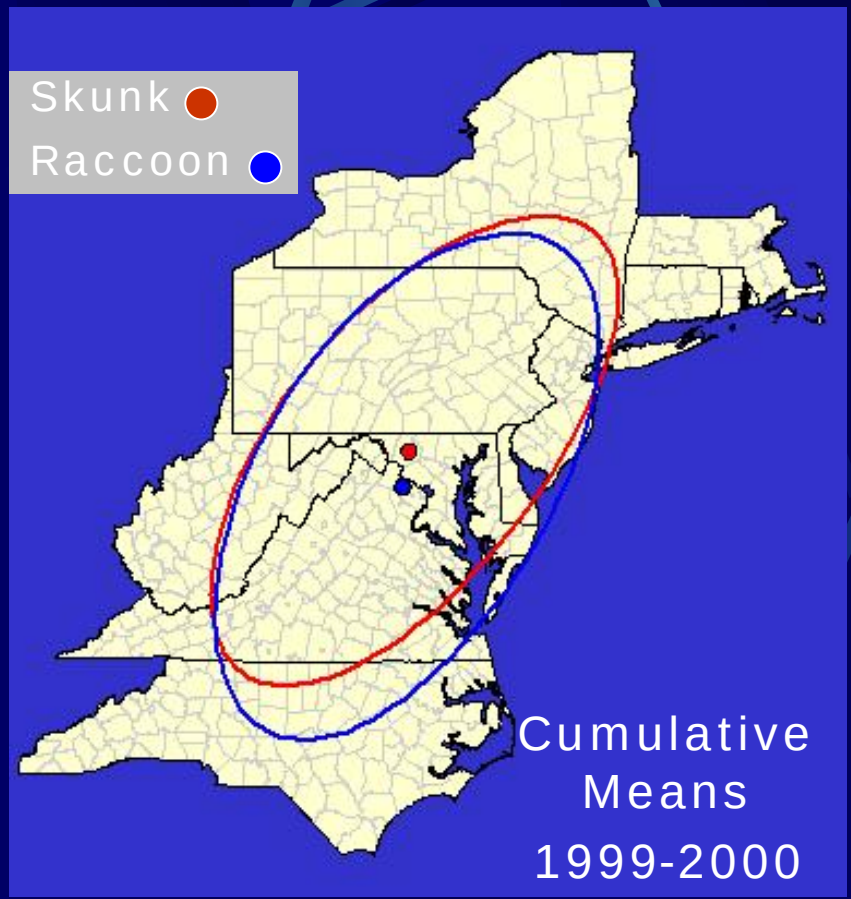
Spatial Analysis Results



- Directional mean and distance of epizootics:

  Skunk - 42.06+/-0.23 degrees
  339.28 kilometers

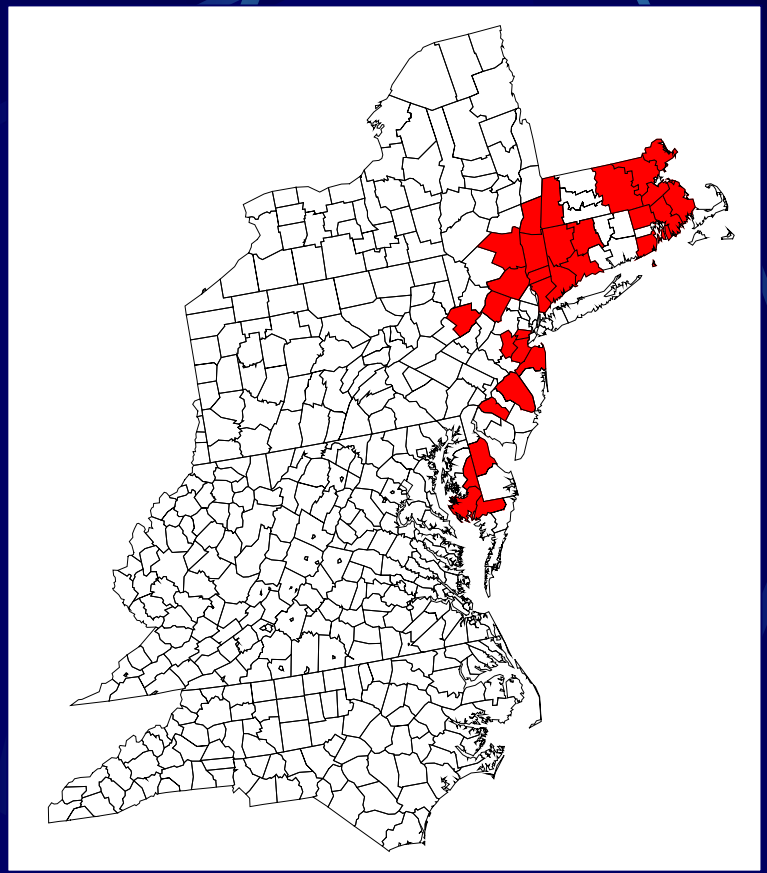
  Raccoon - 47.76+/-0.28 degrees
  368.18 kilometers

- No significant difference between angles of rotation of epizootics

  $F_{1,18;0.05} = 0.11$ (<4.41, n.s.)

Temporal Analysis

Are raccoon and skunk rabies associated over time?



- 32 counties selected for analysis
- Criteria- $\geq$ 12 rabid skunks in first year
- Corresponded to 90th percentile of counties at least 1 rabid skunk

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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:

$$\mathbf{Log(SKUNK) = 0.2835 + 0.0262(RACCOON_{t-1}) - 0.0021(time) + 0.0020(RACCOON_{t-1}*time) + B_i(county_i) + B_j(month_j)}$$

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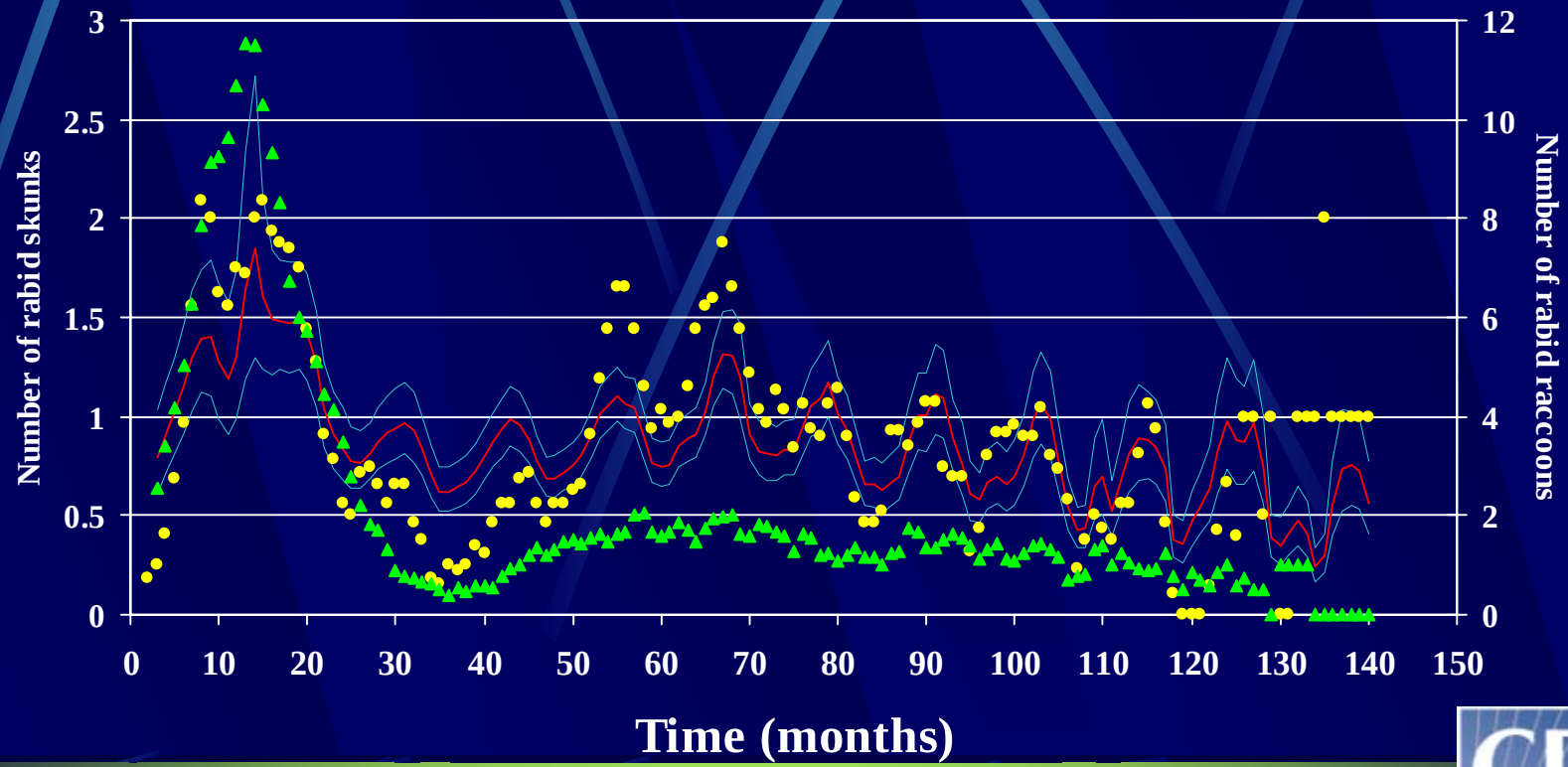
Poisson regression model

- # 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)



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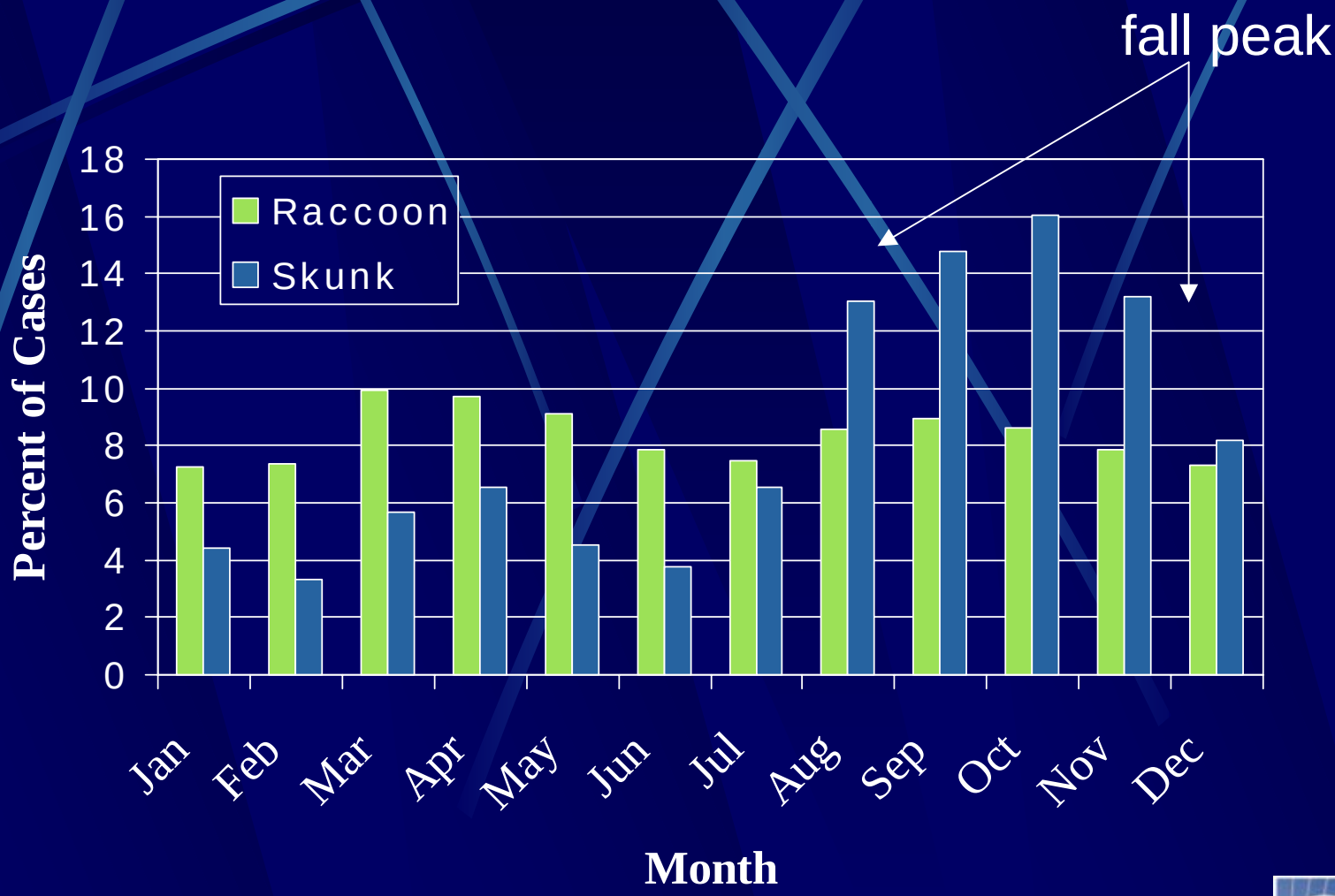
Percent of Rabies Cases by Month



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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

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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

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Acknowledgements

- John Krebs
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- Wade Ivy III
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- PDI Images

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