Soil and climactic predictors of canine coccidioidomycosis seroprevalence in Washington

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Outline

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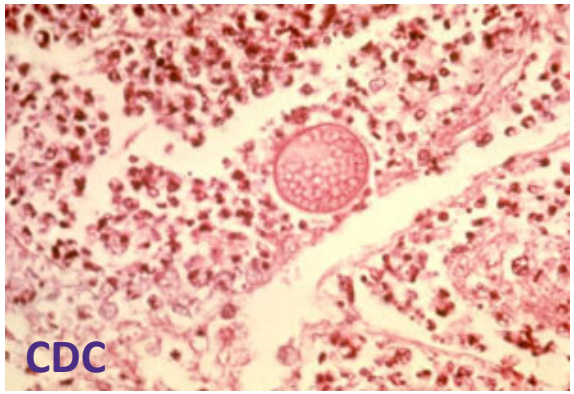
Background



- "Valley Fever", "cocci"
  - Fungal pathogen: *Coccidioides immitis*, *C. posadasii*
- 2010: locally-acquired human cases
  - Franklin, Walla Walla, Yakima, Benton
- Saprophytic; poor competitor
  - Inhalation
  - 60% subclinical, 1% fatal pulmonary or disseminated disease
  - Dust exposure in dry months after periods of heavy rain
- Positive soil samples: Yakima, Benton

Motivation

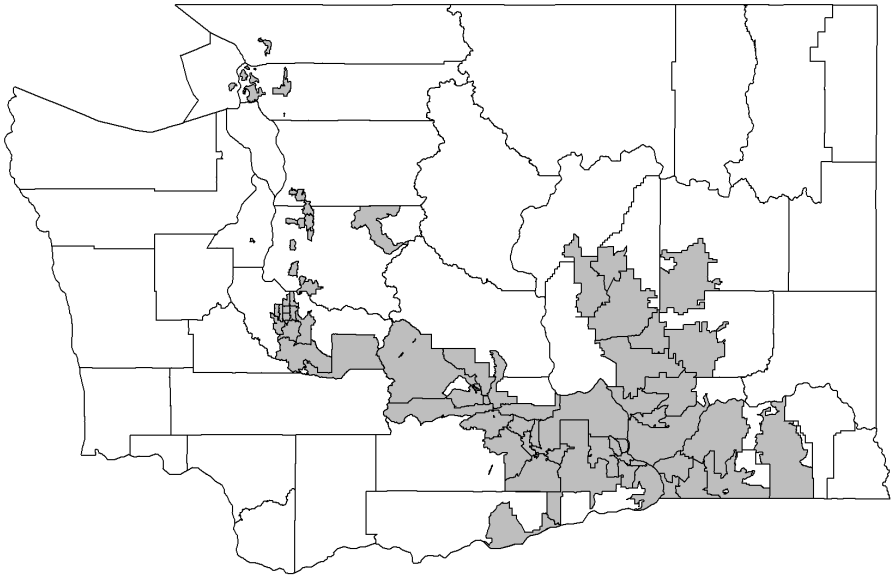
- Positive soil isolation challenging
- 2007: ecological niche map developed for Southwestern US and Mexico
- Goal: ecological niche map for Washington State
- 2015: Canine serosurvey conducted by Washington Department of Health to inform this map
  - "Animal sentinel" for human risk

Motivation

- Why dogs?
  - Susceptibility, latency
  - Lower cost
  - Higher exposure
  - Companion species
  - Reduced exposure misclassification
  - Informs veterinary practice

Design

- Cross-sectional ecological study
- Level = zip code tabulation area (ZCTA)
- Urban, suburban, and rural communities in western, south-central, and eastern Washington



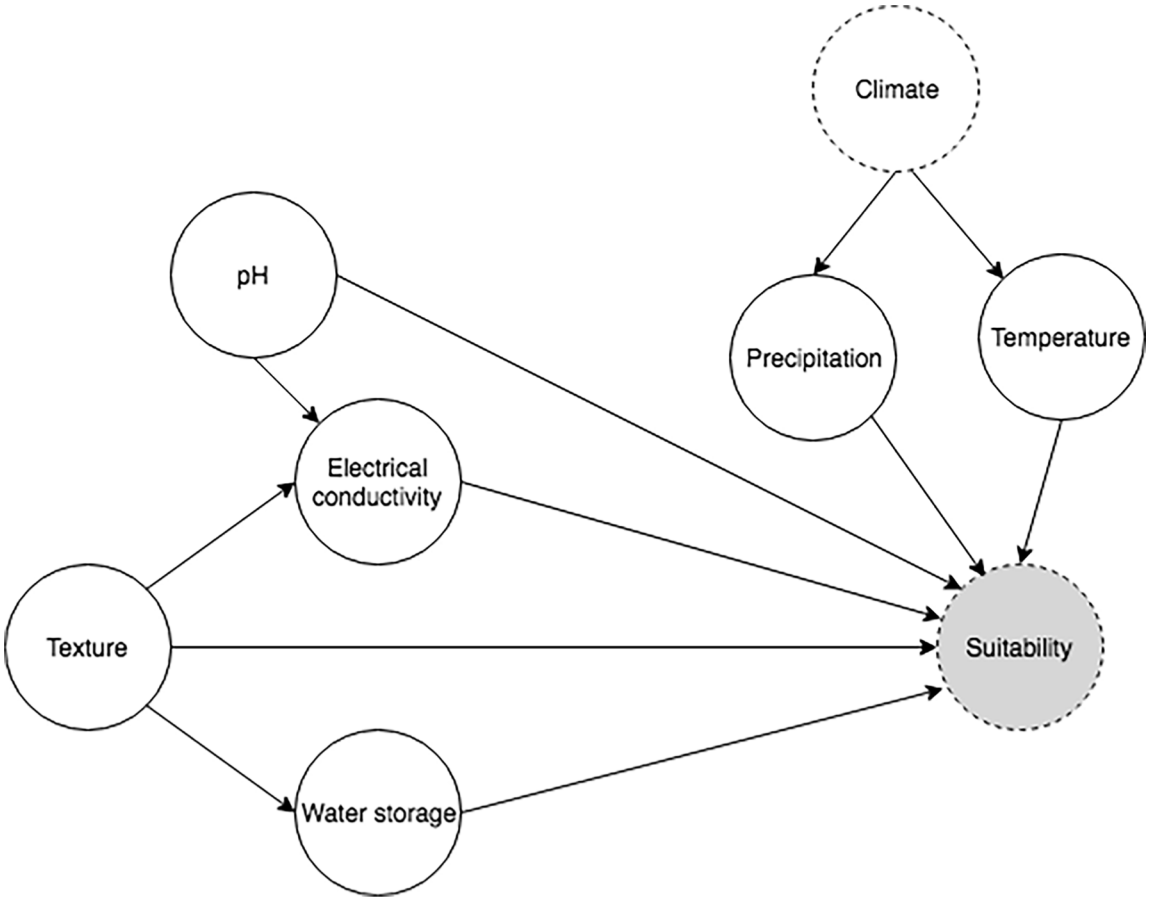
Geographic extent of study area within WA

Design

- **Exposure:**
  - **USDA Soil Survey Geographic Database (SSURGO)**
  - **December 2013-September 2017**
  - **Soil variables: texture, electrical conductivity, water storage, pH**
  - **Climactic variables: air temperature, precipitation**
- **Outcome:**
  - **Canine serology**
  - **All dogs presenting for venipuncture to participating veterinary clinics**
    - **6 “exposed” counties (eastern and south-central WA)**
    - **2 “control” counties (western WA)**
- **Linkage: ZCTA of residence**

Design

Hypothesized relationships between the exposure variables



Analysis

- **Prevalence:** $p_i = \frac{Total\ positive\ dogs\ in\ ZCTA_i}{Total\ tested\ dogs\ in\ ZCTA_i}$
- **Five analytic models fit:**
  - **Model 1: texture only**
  - **Model 2: electrical conductivity, adjusted for pH and texture**
  - **Model 3: water storage, adjusted for texture**
  - **Model 4: pH only**
  - **Model 5: temperature, precipitation, temperature*precipitation interaction**
- **Model:** $\text{logit}(p_i) = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_k x_{ki} + e_i$
- **Missingness: complete case**

Analysis

- **Sequence of models fit for Models 1-5**
- **Non-smoothing models**
  - **Logistic regression:** $var(Y_i) = p_i(1 - p_i)$
  - **Quasi-likelihood model:** $var(Y_i) = \kappa p_i(1 - p_i)$
  - **Fit with and without de-trending**
  - **Moran's I on residuals (clustering)**
- **Smoothing models**
  - **Binomial logit-normal Bayesian hierarchical non-spatial smoothing model:** $e_i|\sigma_e^2 \sim_{iid} N(0, \sigma_e^2)$
  - **Binomial logit-normal Bayesian hierarchical spatial smoothing model:** $e_i = S_i + \epsilon_i$
    - $\epsilon_i\ |\sigma_\epsilon^2 \sim_{iid} N(0, \sigma_\epsilon^2)$
    - $\boldsymbol{S}|\sigma_s^2 \sim ICAR(\sigma_s^2)$

Findings

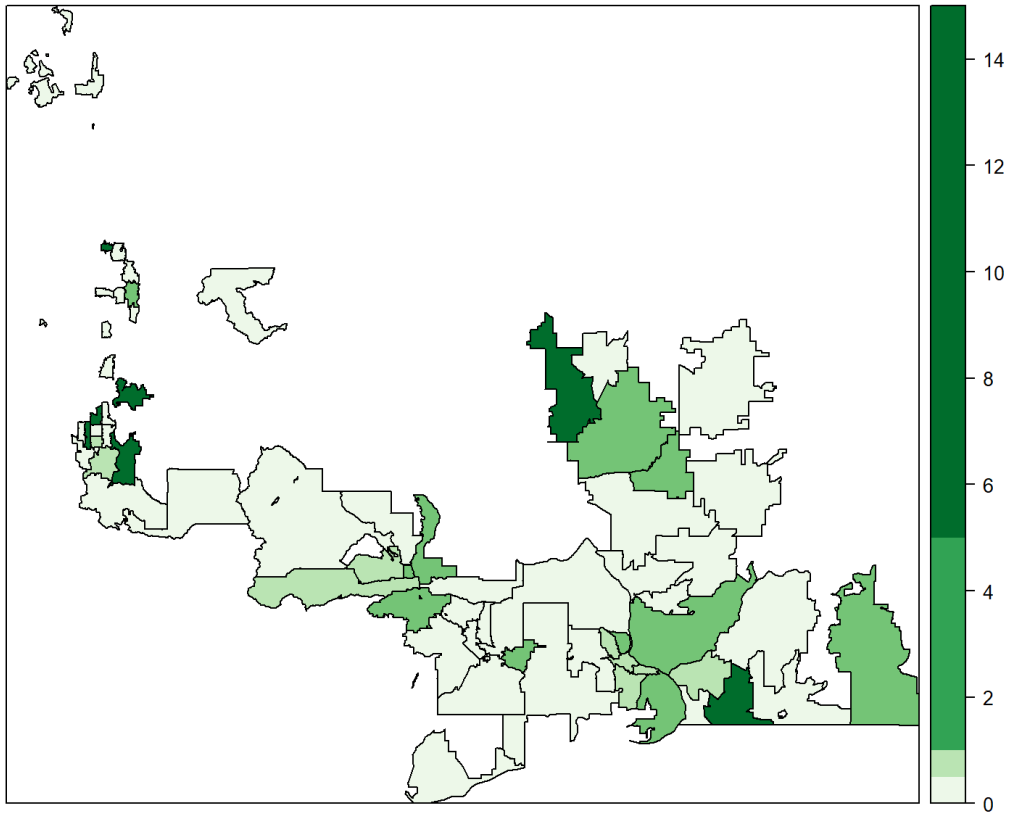
> 1,013 dogs, 72 ZCTAs

Variable	Mean	SD	Range
Cases	0.96	2.31	0-17
Tested dogs	14.1	30.5	1-213
Seroprevalence (%)	9	20	0-1
Clay (%)	12.5	5.66	5.7-27.5
Silt (%)	46.0	12.2	25.5-70.4
Sand (%)	41.4	14.0	9.6-65.7
Water storage (volume fraction)	19.7	5.47	11.6-31.7
Air temperature (Celsius)	9.63	1.25	5.7-11.0
Precipitation (millimeters)	672	650	190-2275
Electrical conductivity (dS/m)	0.37	0.34	0-2
pH	7.11	0.83	5.6-8.0

Data are provided at the ZCTA level. Cases: seropositive dogs

Findings

> Higher prevalence in central and eastern ZCTAs



Prevalence ratios

Findings

- No evidence for temperature*precipitation interaction
- No evidence of clustering or overdispersion → can interpret logistic model

Findings

Parameter	Logistic		Quasi-likelihood		Non-spatial smoothing	Spatial smoothing
	No detrend	Detrend	No detrend	Detrend		
Clay	9.48 (0.37, 242)	7.75 (0.30, 199)	9.48 (0.37, 242)	7.75 (0.30, 199)	1.00 (0.995, 1.006)	1.00 (0.995, 1.007)
Silt	9.85 (0.38, 255)	8.02 (0.31, 209)	9.85 (0.38, 255)	8.02 (0.31, 209)	1.00 (0.998, 1.002)	1.00 (0.998, 1.002)
Sand	9.90 (0.38, 257)	8.05 (0.31, 211)	9.90 (0.38, 257)	8.05 (0.31, 211)	1.00 (0.999, 1.002)	1.00 (0.999, 1.003)
EC	0.62 (0.10, 3.71)	0.63 (0.11, 3.79)	0.62 (0.10, 3.71)	0.63 (0.11, 3.79)	0.96 (0.84, 1.10)	0.96 (0.83, 1.11)
pH	1.05 (0.76, 1.45)	1.06 (0.78, 1.44)	1.05 (0.76, 1.450	1.06 (0.78, 1.44)	1.00 (0.988, 1.020)	1.00 (0.988, 1.020)
WS	0.98 (0.88, 1.09)	0.98 (0.89, 1.09)	0.98 (0.88, 1.09)	0.98 (0.89, 1.09)	1.00 (0.987, 1.005)	0.995 (0.985, 1.006)
Temp	1.70 (0.96, 3.02)	1.73 (0.99, 3.02)	1.70 (0.96, 3.02)	1.73 (0.99, 3.02)	1.00 (0.996, 1.014)	1.004 (0.99, 1.02)
Precip	1.001 (1.00, 1.002)	1.001 (0.9998, 1.002)	1.001 (1.00, 1.002)	1.001 (1.00, 1.002)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)

Prevalence odds ratio (95% CI). For the smoothing models, these estimates refer to the posterior median and 95% credible interval. No detrend: model fit without latitude and longitude of ZCTA centroids; detrend: model fit with latitude and longitude of centroids. Clay: %; silt: %; sand: %; EC: electrical conductivity in dS/m; WS: water storage; Temp: mean annual air temperature in degrees Celsius; Precip: mean annual liquid precipitation in millimeters.

Findings

- No significant findings
  - Texture: strong positive but non-significant effect
  - Temperature: possible modest positive association
  - Electrical conductivity: moderate negative association
  - pH: slight positive association
  - Soil water storage, annual precipitation: no evidence of association

Implications

- **Limitations:**
  - **Few positive cases**
  - **Canine seroprevalence ≠ soil suitability (true outcome of interest)**
  - **Cross-sectional study, ecological design**
  - **Pure specification bias due to aggregation of SSURGO data**
  - **Modelling assumptions made: linear terms, relationships between variables**
  - **No animal-level data: travel history, age, breed, indoor vs. outdoor, owner SES**
  - **Selection bias**

Implications

- Future models in Washington:
  - Include temperature, soil texture, electrical conductivity, and soil pH
  - Use flexible forms when possible
- Motivates need to collect rich animal-level covariate data, as done in the current canine seroprevalence study
- Demonstrates the utility of collecting veterinary data for an environmental pathogen of One Health concern

Acknowledgments

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  - Wayne Clifford
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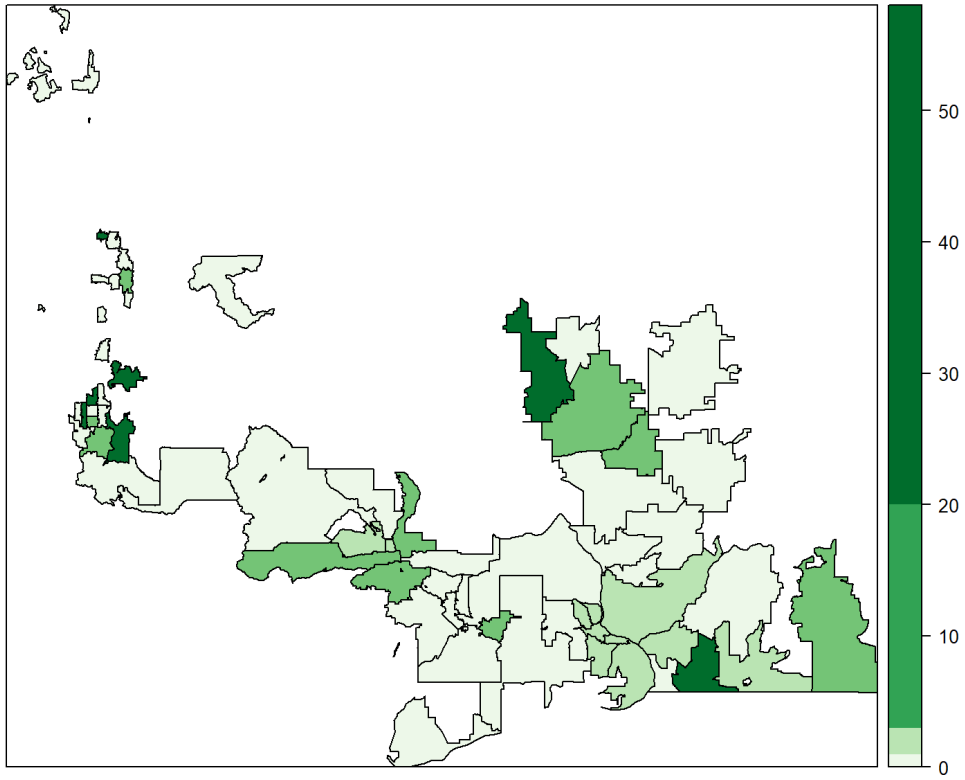
- Center for One Health Research, University of Washington:
  - Dr. Peter Rabinowitz

Thank you!

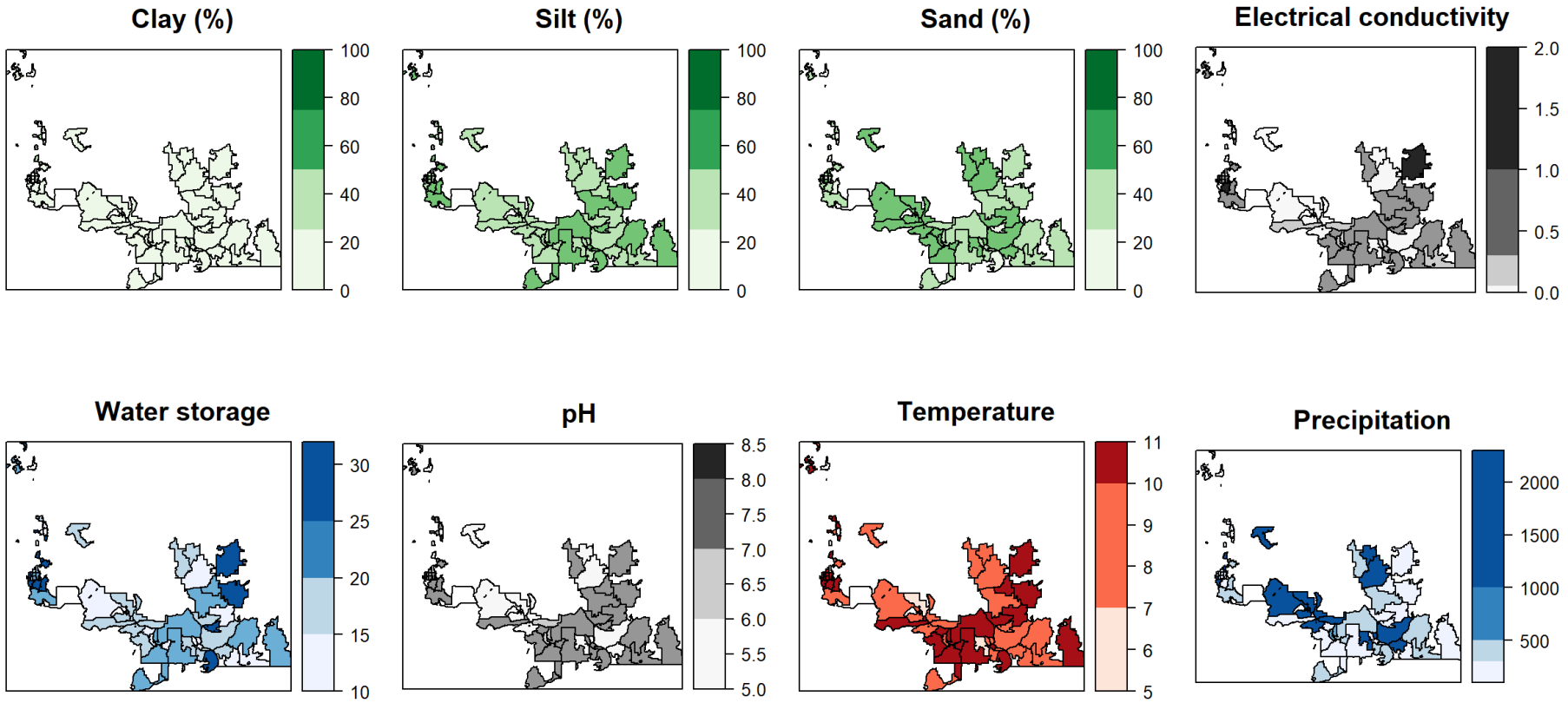
> Questions?

Supplementary slides



Estimated PRs, width of 95% CI

Supplementary slides



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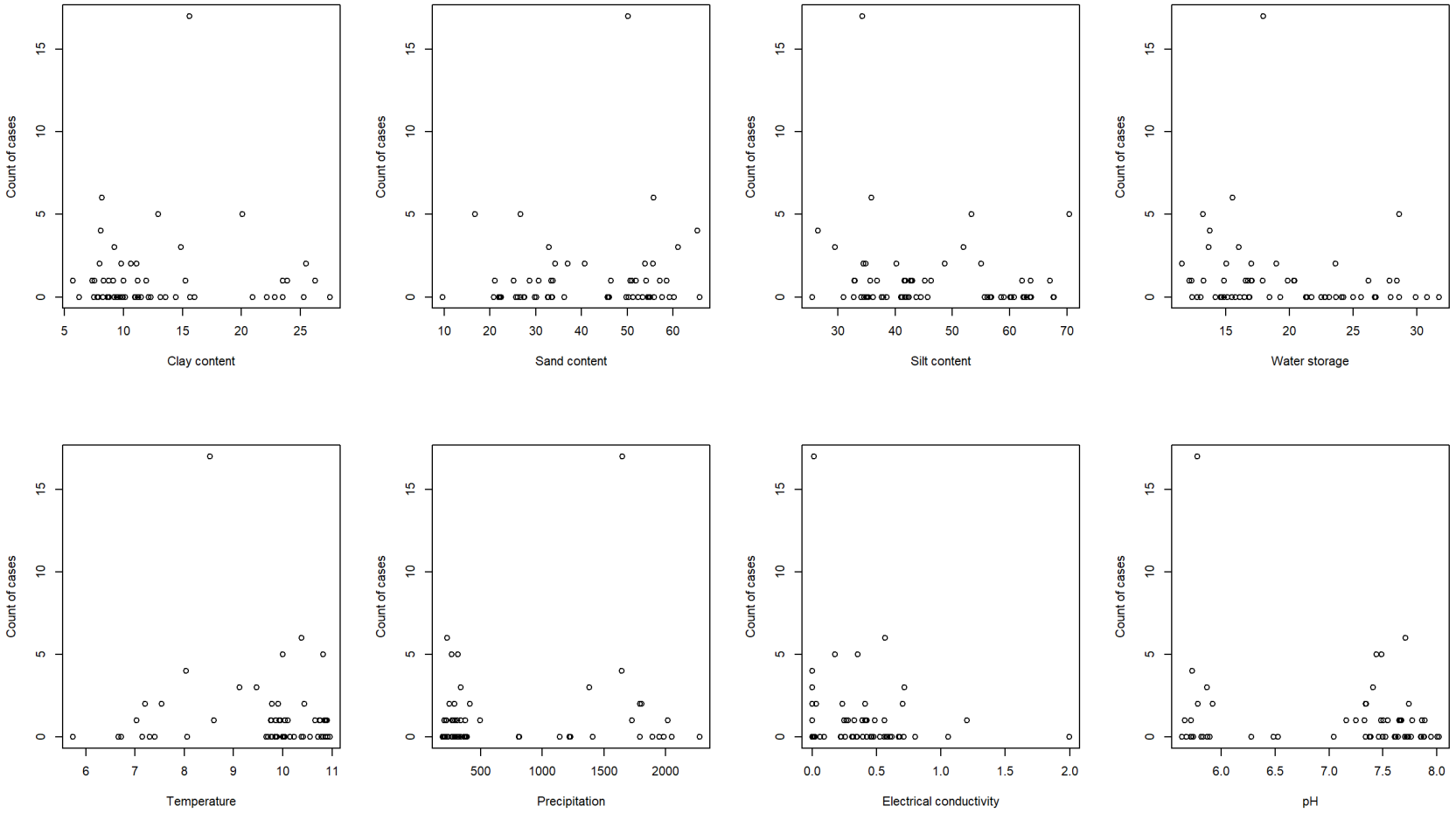
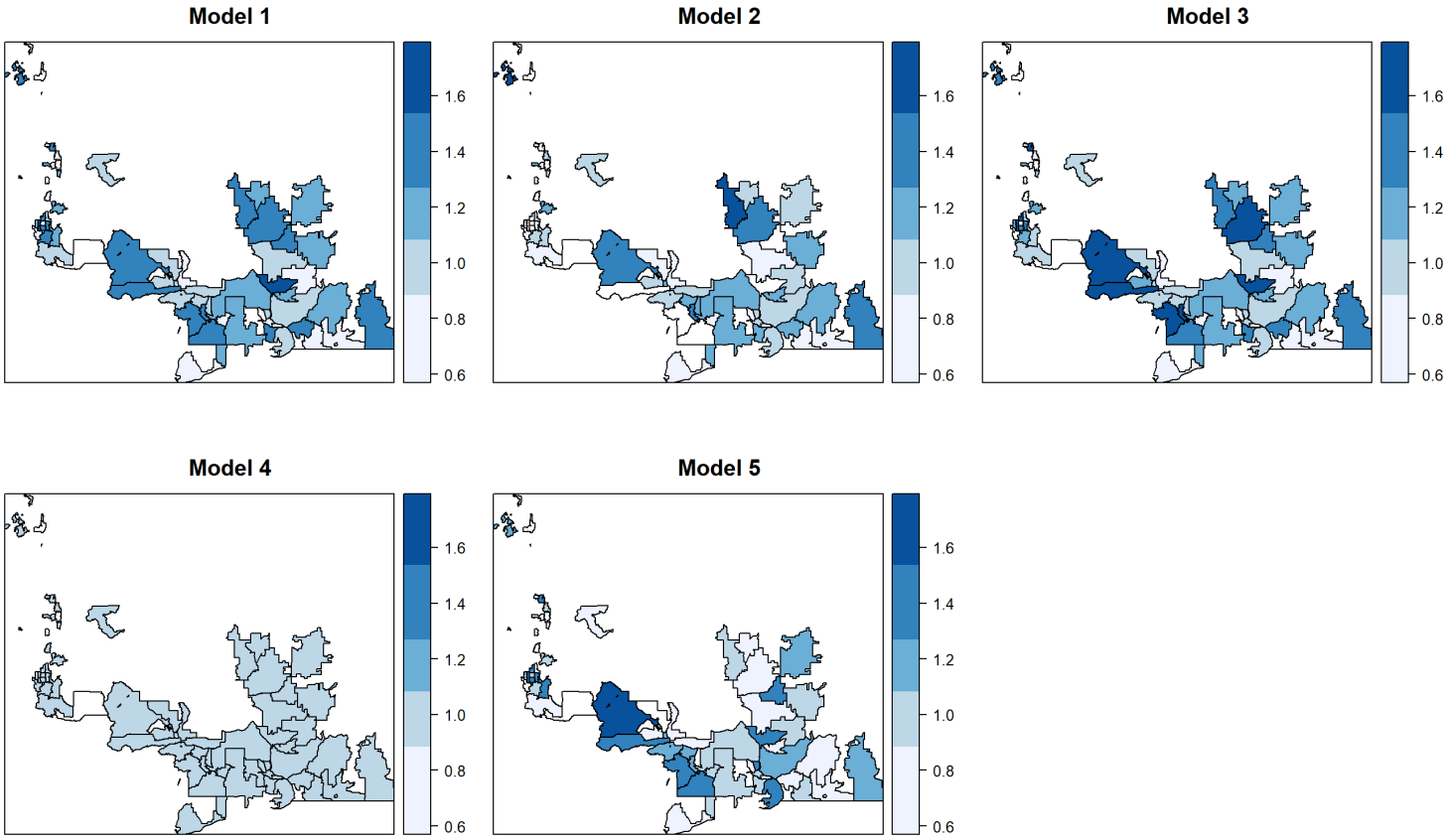


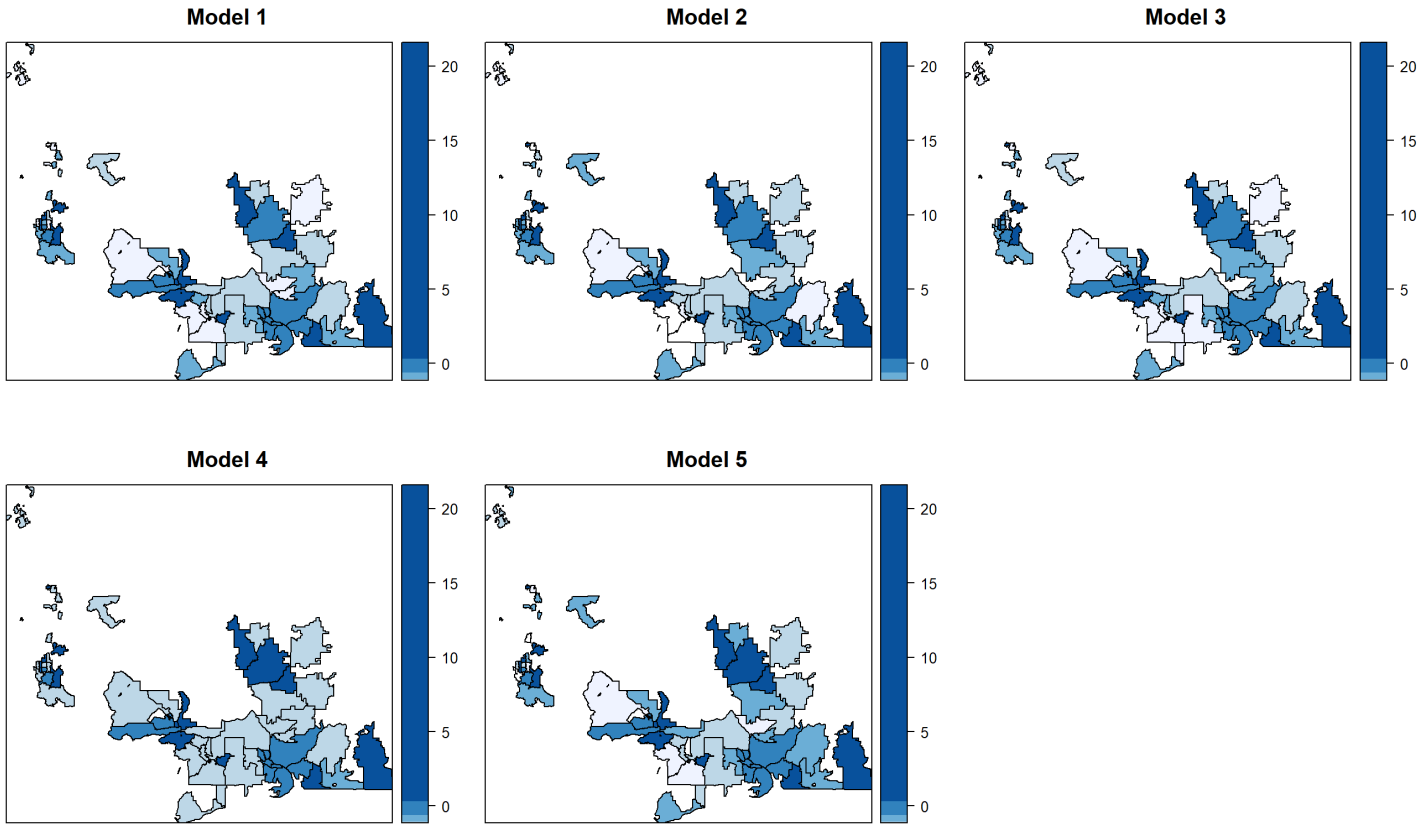
Case counts vs. predictors

Supplementary slides



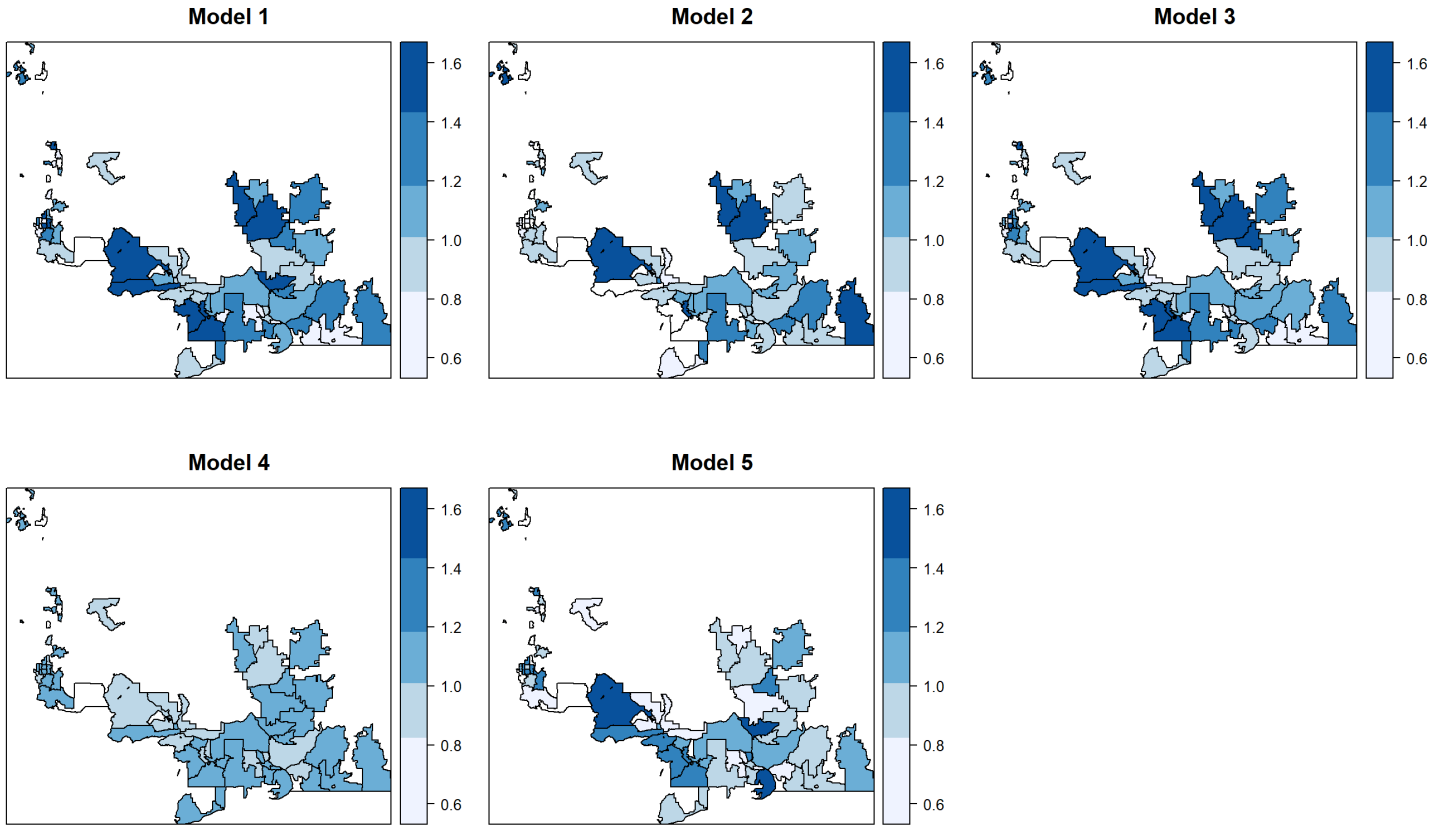
Predicted PORs, logistic model, no de-trending

Supplementary slides



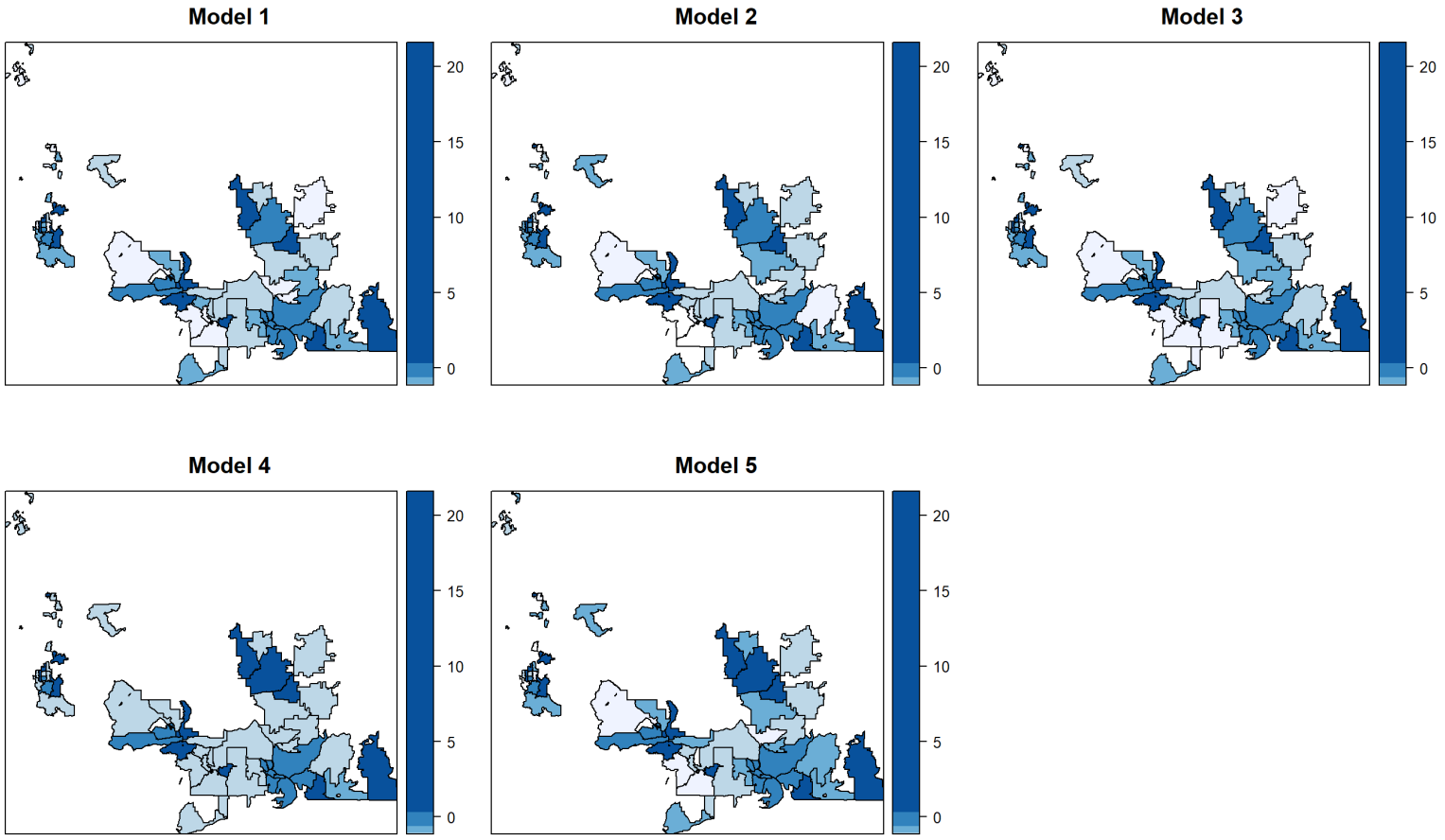
Model residuals, logistic model, no de-trending

Supplementary slides



Predicted PORs, quasi-likelihood model, no de-trending

Supplementary slides



Model residuals, quasi-likelihood model, no de-trending

Supplementary slides

Random effects estimates, smoothing models

Parameter	Model 1	Model 2	Model 3	Model 4	Model 5
$\hat{\sigma_e}$ (non-spatial model)	0.008 (0.004, 0.023)	0.008 (0.004, 0.024)	0.008 (0.004, 0.023)	0.008 (0.004, 0.023)	0.008 (0.004, 0.023)
$\hat{\sigma_e}$ (spatial model)	0.008 (0.004, 0.022)	0.008 (0.004, 0.023)	0.008 (0.004, 0.024)	0.007 (0.003, 0.018)	0.008 (0.004, 0.024)
$\hat{\sigma_s}$	0.008 (0.004, 0.023)	0.008 (0.004, 0.024)	0.0083 (0.004, 0.025)	0.007 (0.003, 0.019)	0.008 (0.004, 0.023)

Posterior median (95% credible interval). $\hat{\sigma_e}$: independent random effects; $\hat{\sigma_s}$: spatial random effects.