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Empirical Strategies for Coupling the Analysis of Social and Physical Systems

Christa Brelsford

Liane Russell Fellow

Oak Ridge National Laboratory

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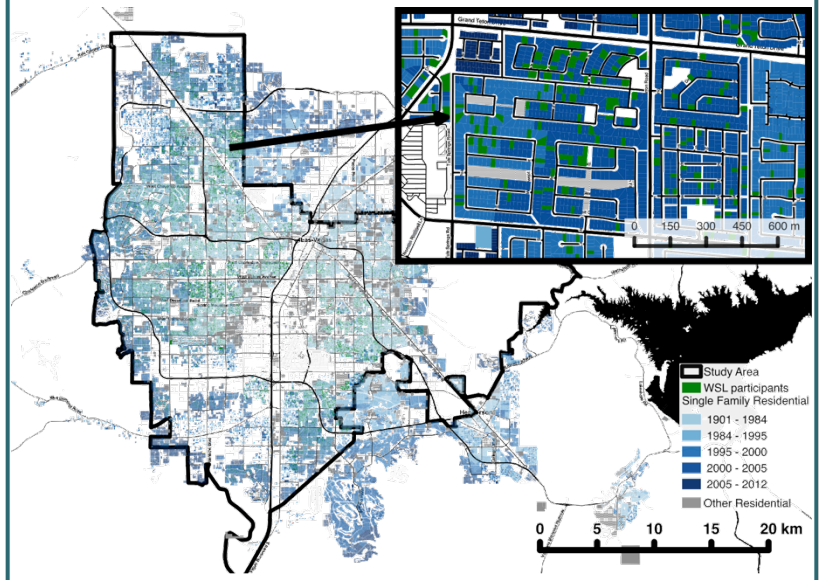
U.S. DEPARTMENT OF ENERGY

Individuals

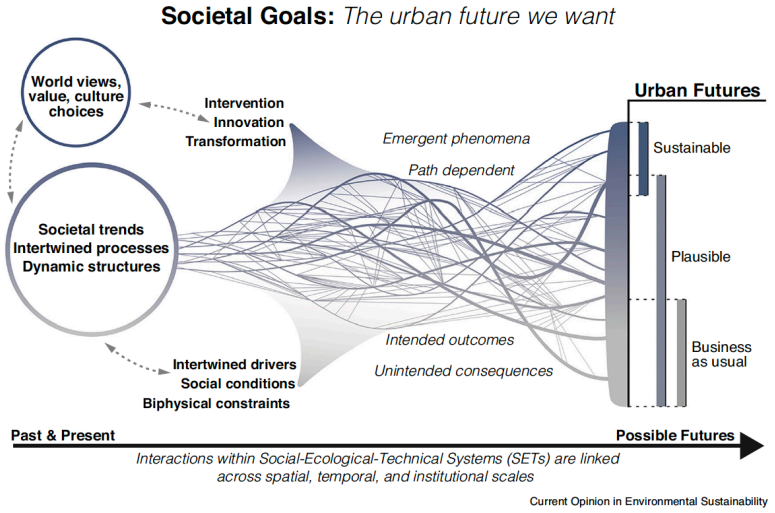
Probabilistic, Empirical or Agent Based Models



Brelsford & De Bacco. NETS (2018)

Cities

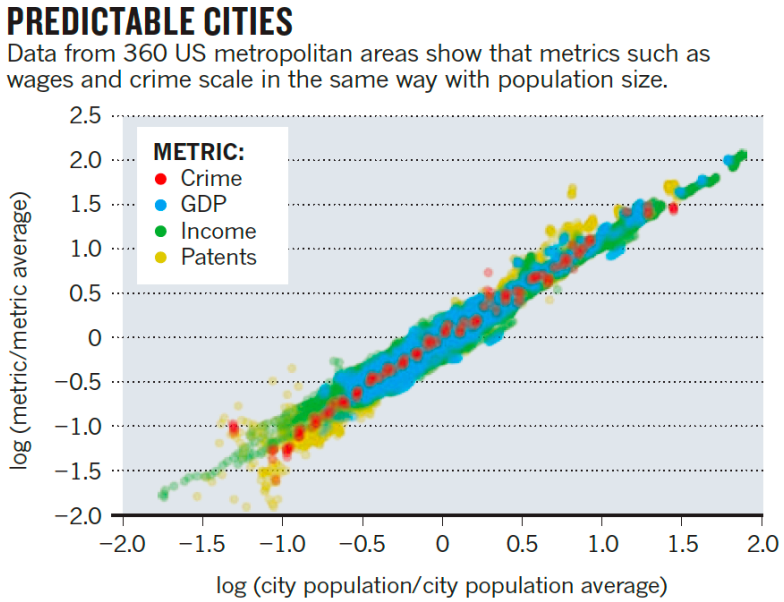
Urban Analysis and Stakeholder Engagement



McPhearson, Iwaniec, & Bai. Crnt. Opn. in Envi. Sust. (2016)

Nations

Urban Scaling Theory



Bettencourt & West. Nature (2010)

Individual Neighborhood City Region Nation

Social Scale

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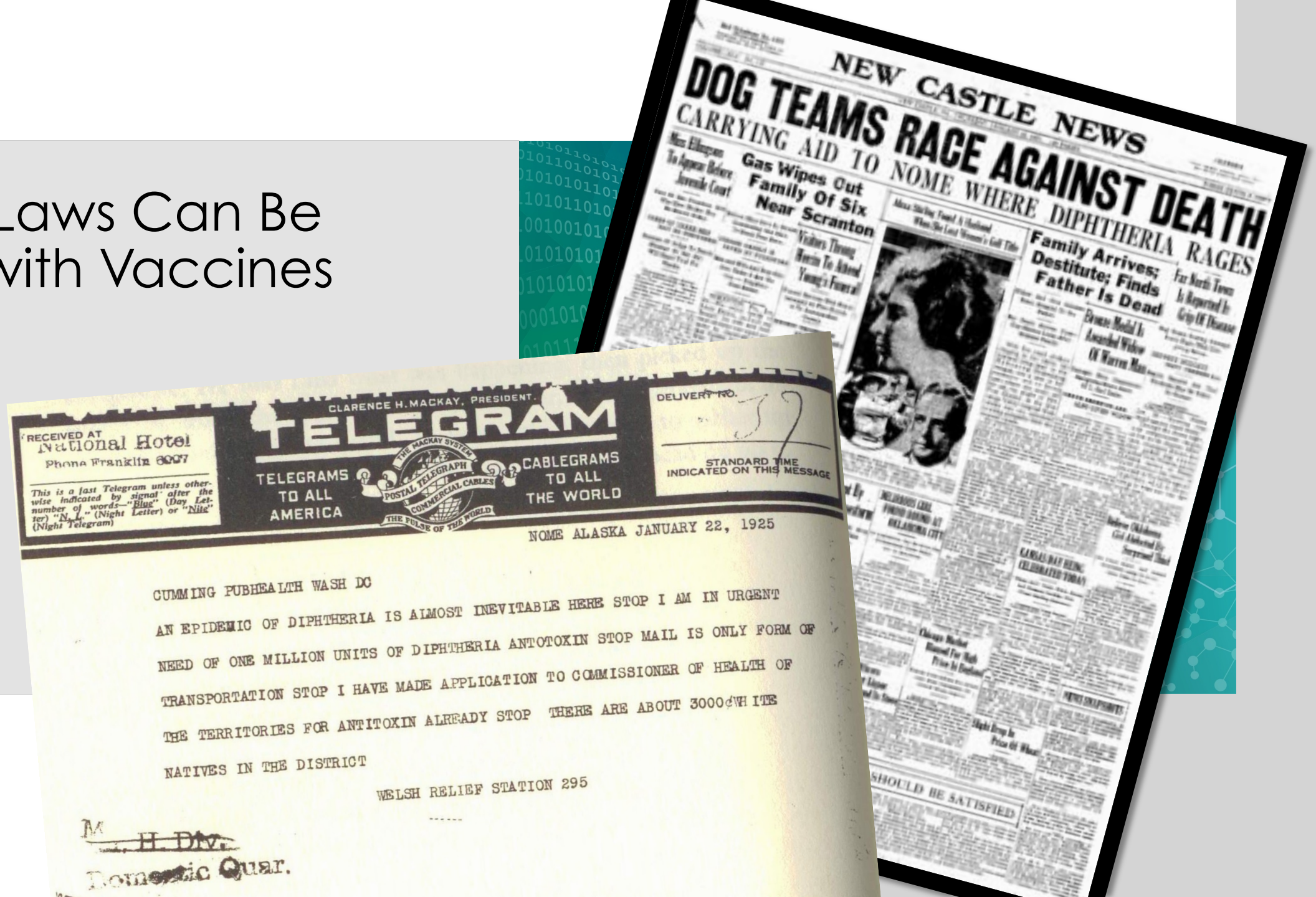
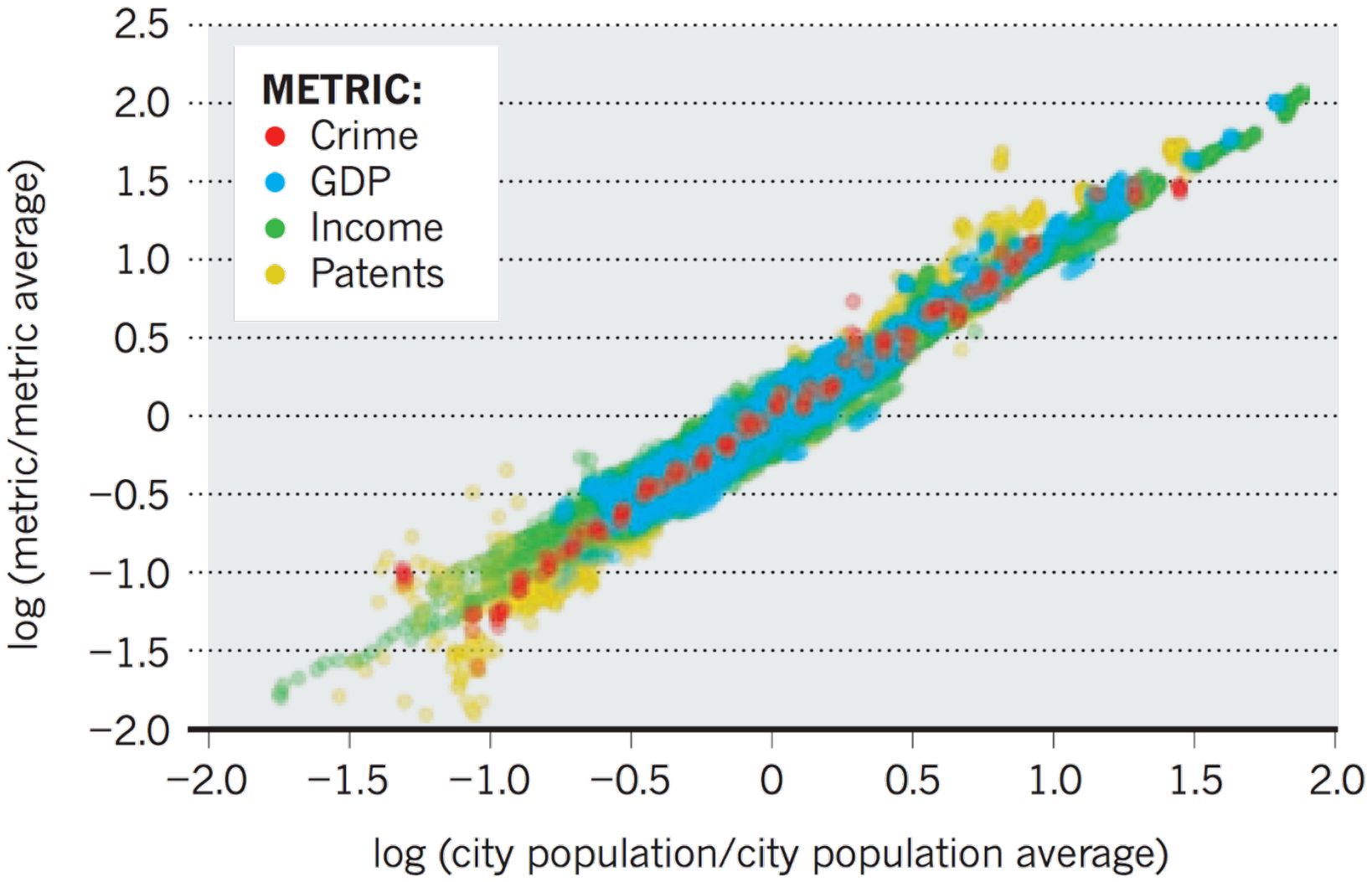
Scaling Laws Can Be Broken with Vaccines



Benoist, 1805 via wikipedia

PREDICTABLE CITIES

Data from 360 US metropolitan areas show that metrics such as wages and crime scale in the same way with population size.



$$Y_j(N) = Y_0 N_j^{\beta} e^{\varepsilon_j},$$

$$\ln Y_i = \ln Y_0 + \beta \ln N_i + \varepsilon_i$$

Bettencourt & West, Nature 2010

Urban Infrastructure scales sub-linearly
Socio-economic output scales super-linearly

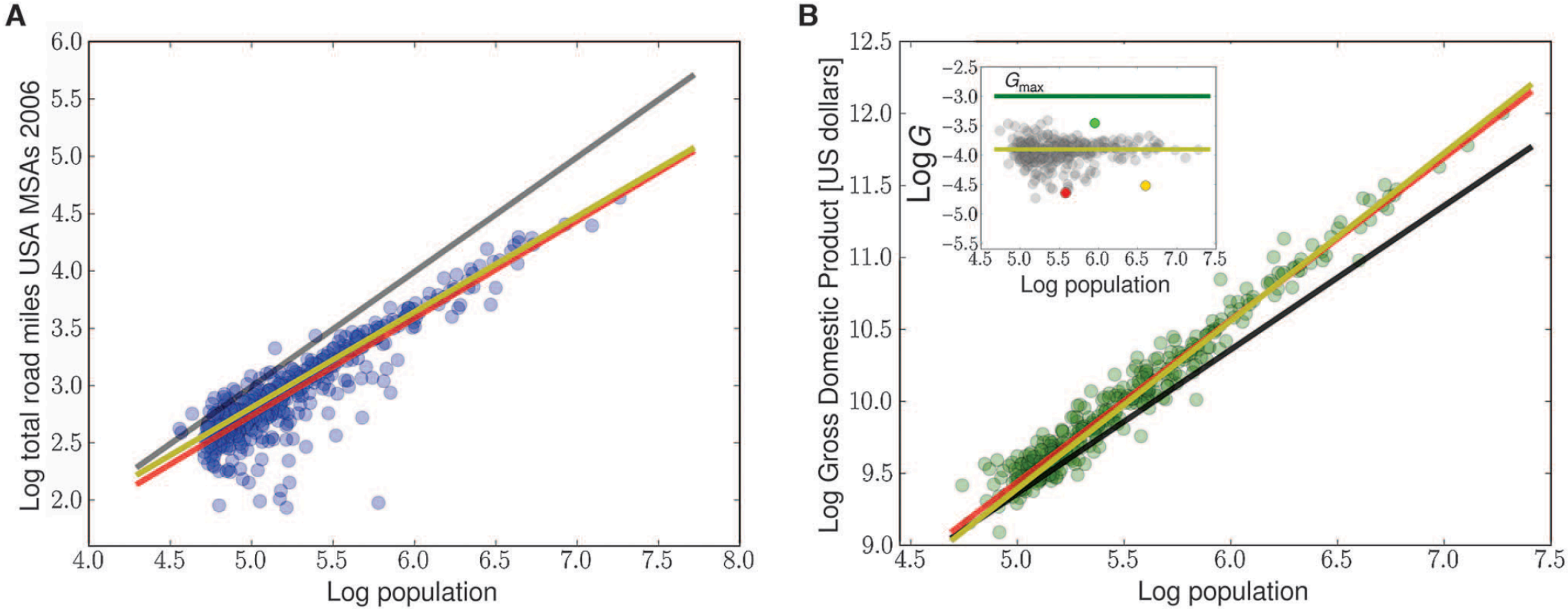
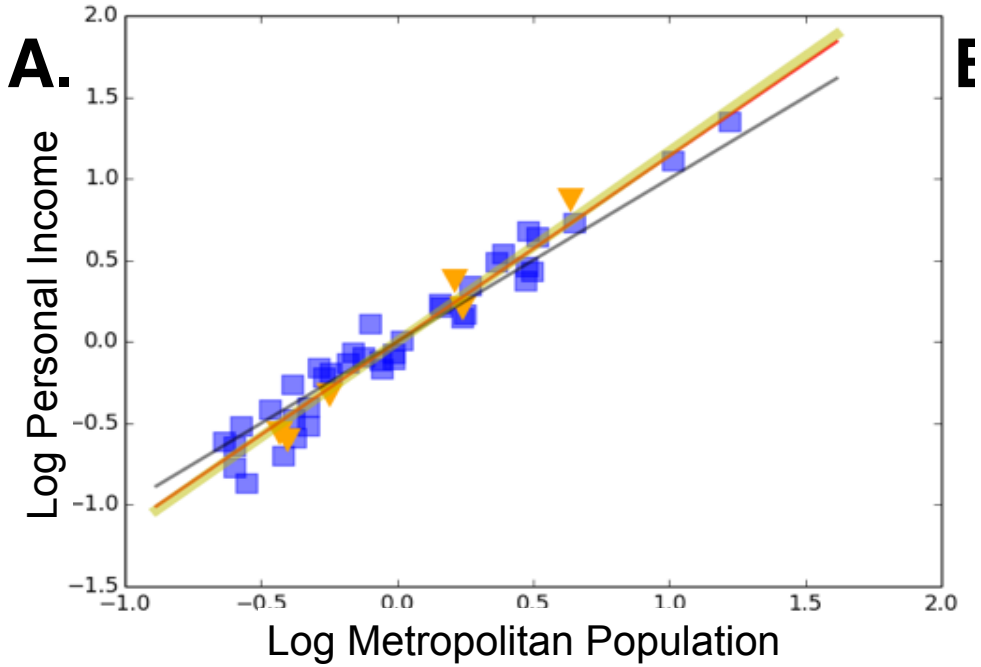


Fig 1 in Bettencourt, Science 2013

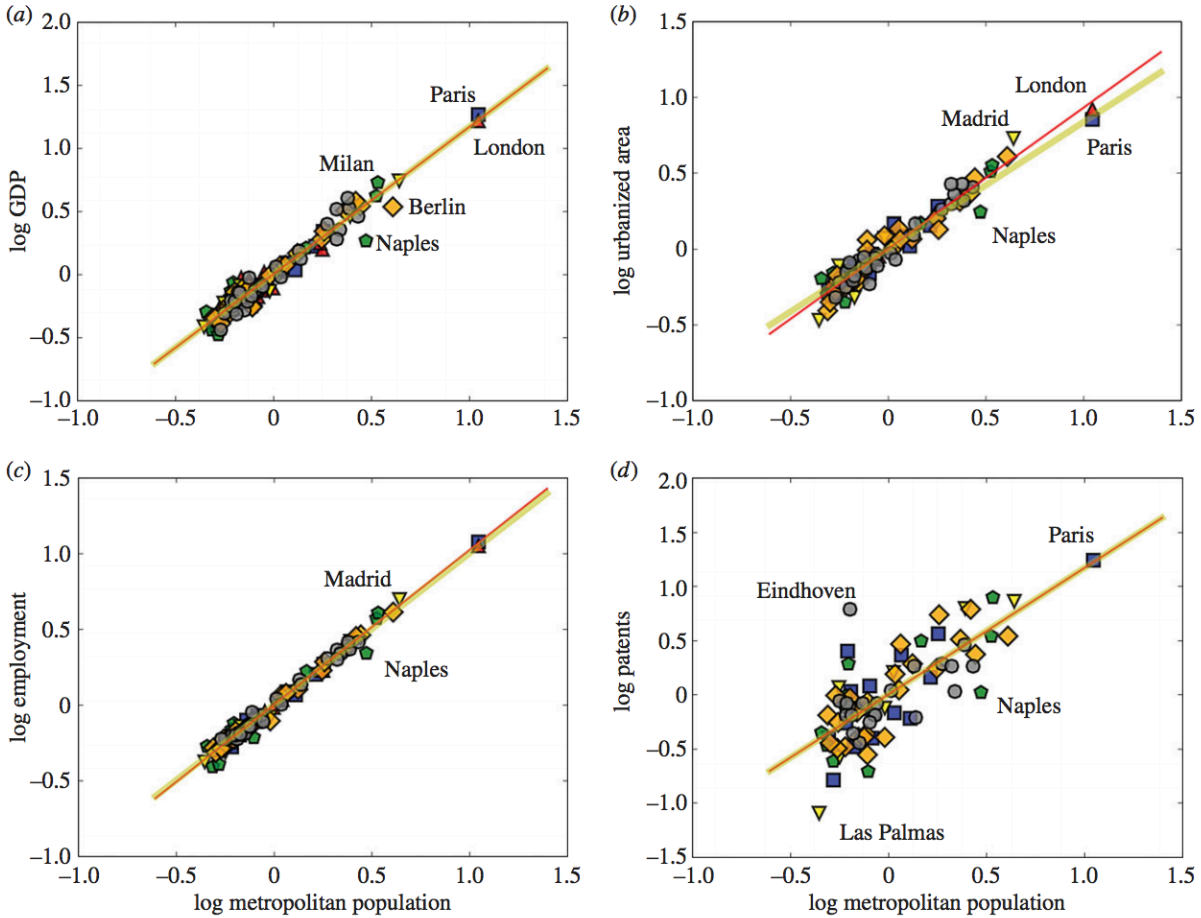
Scaling Results show up around the world.

South Africa (Orange) Brazil (Purple)



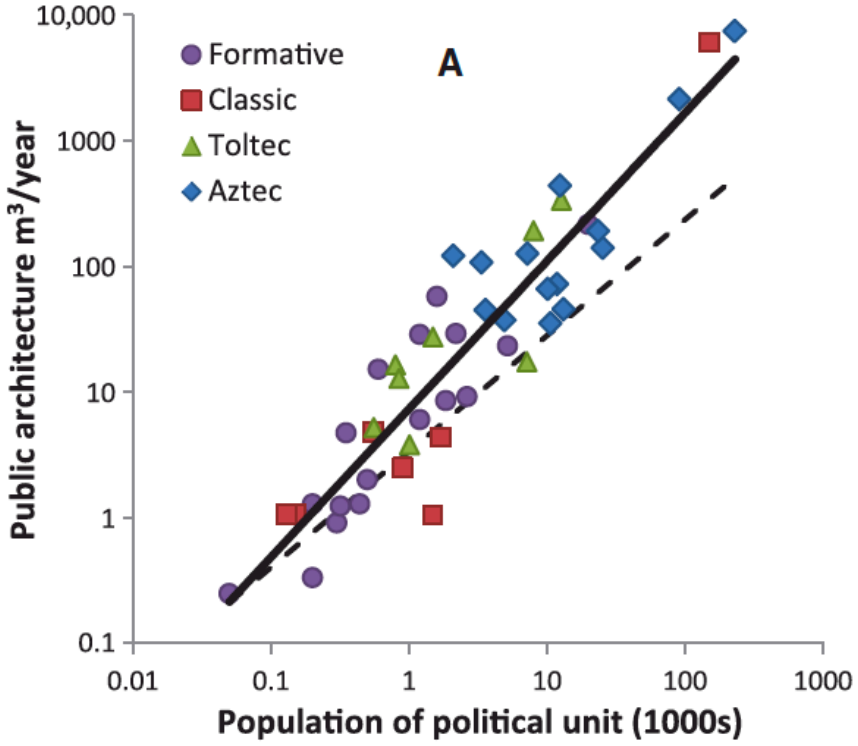
Brelsford, Lobo, Hand, Bettencourt. PNAS 2017

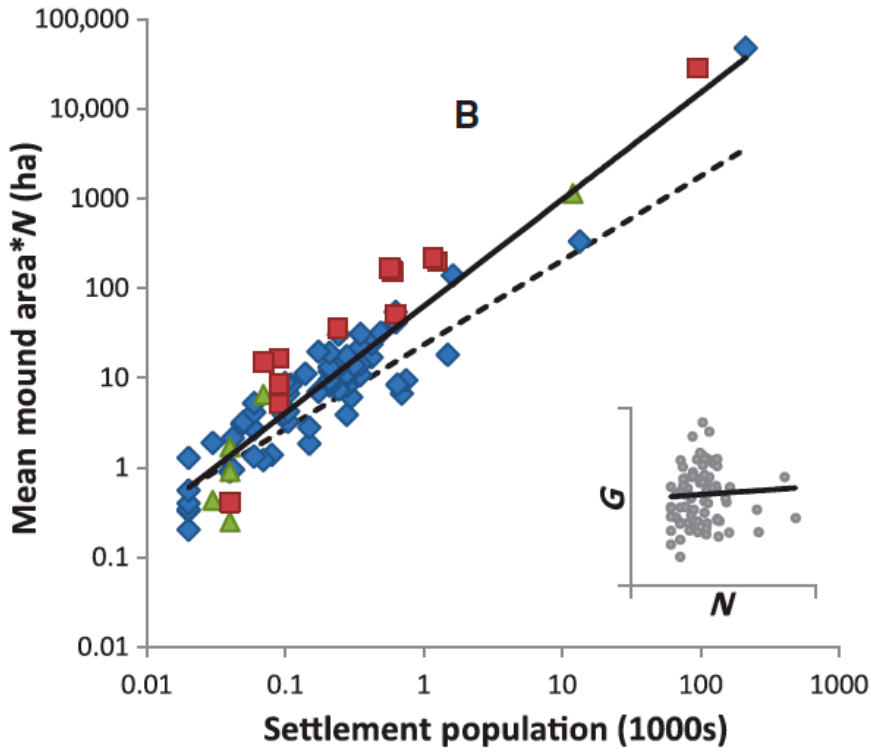
European Cities



Bettencourt & Lobo. RSIF 2016

And throughout history.





Ortman, Cabaniss, Sturm & Bettencourt, Science Advances 2015

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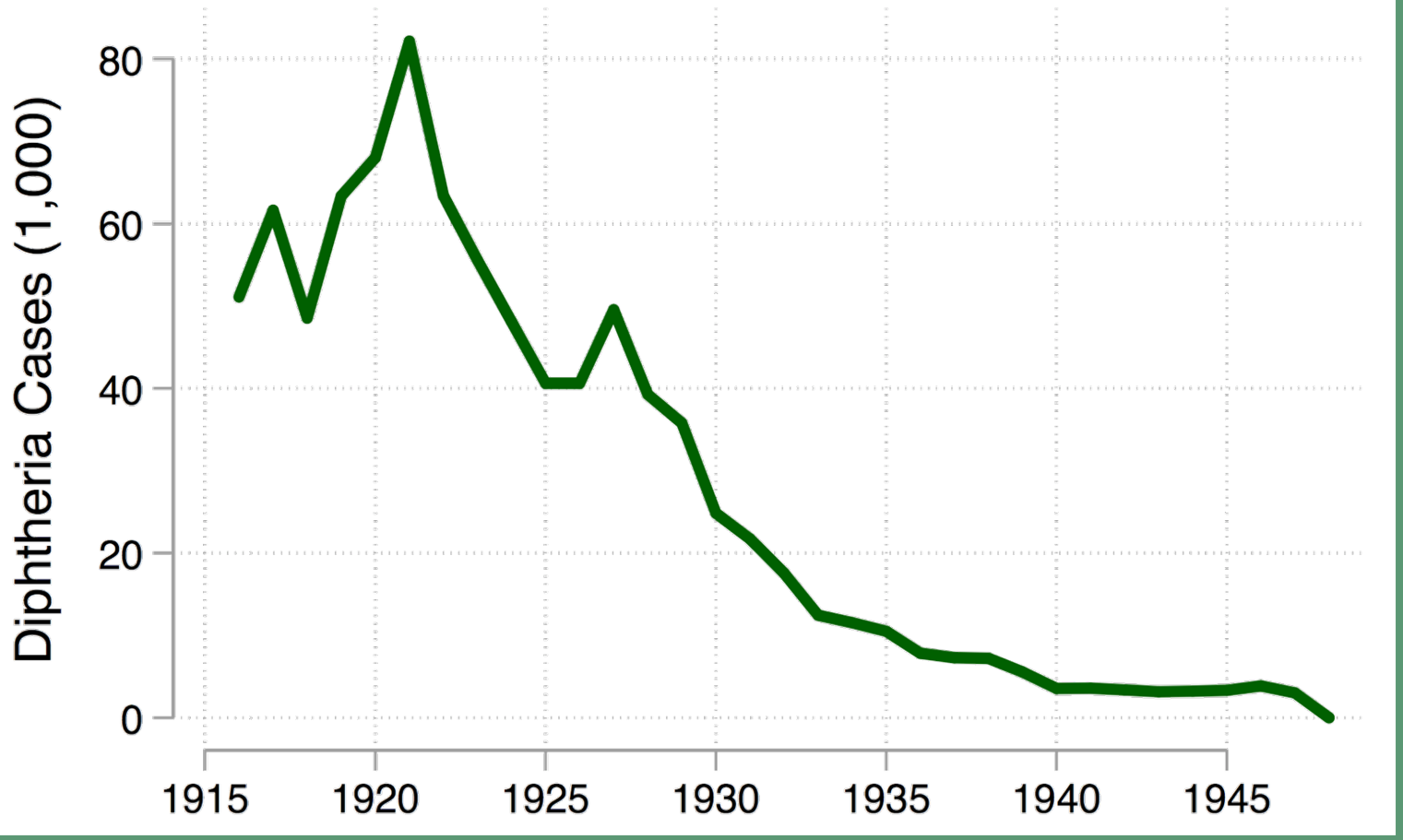
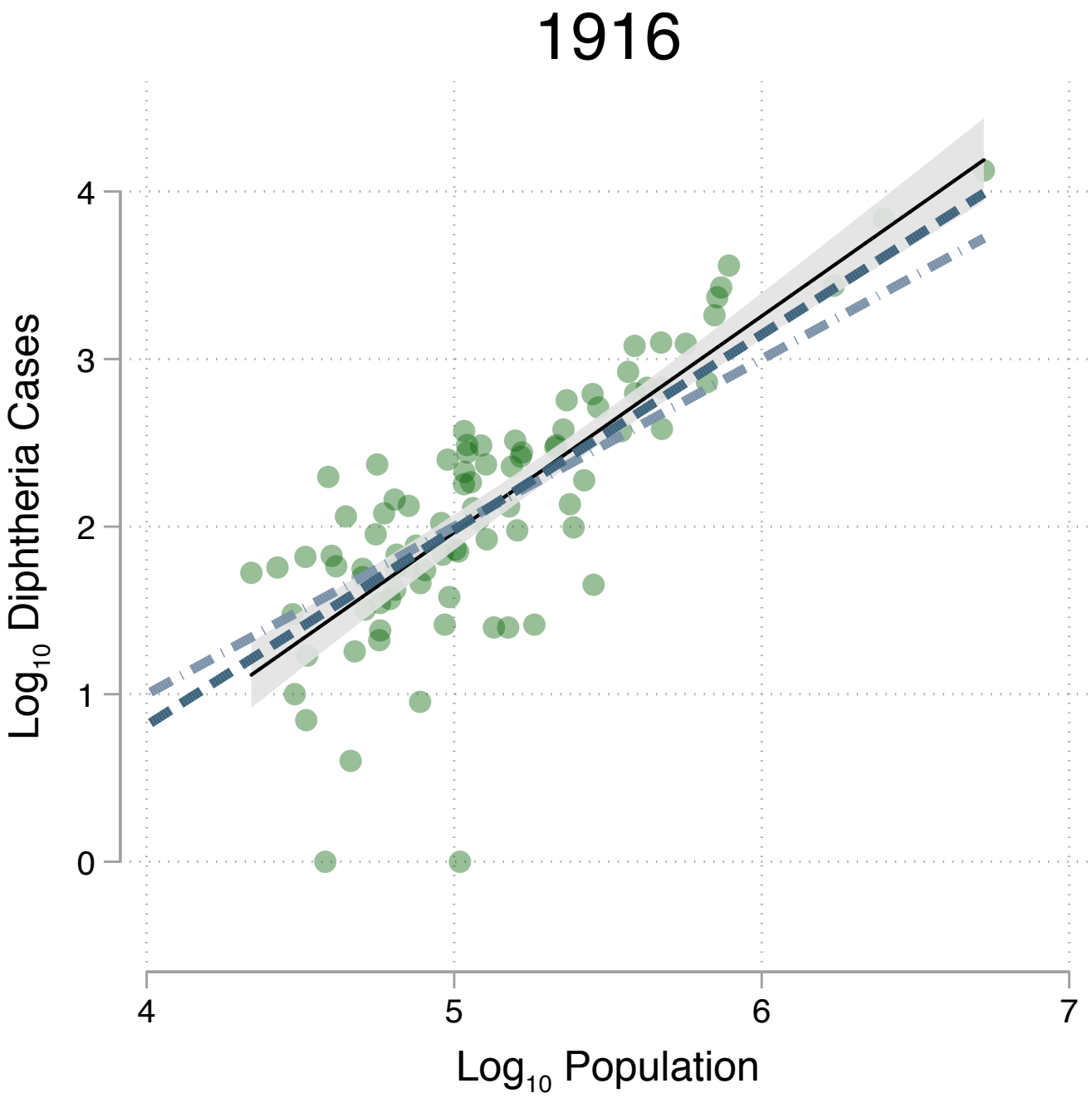
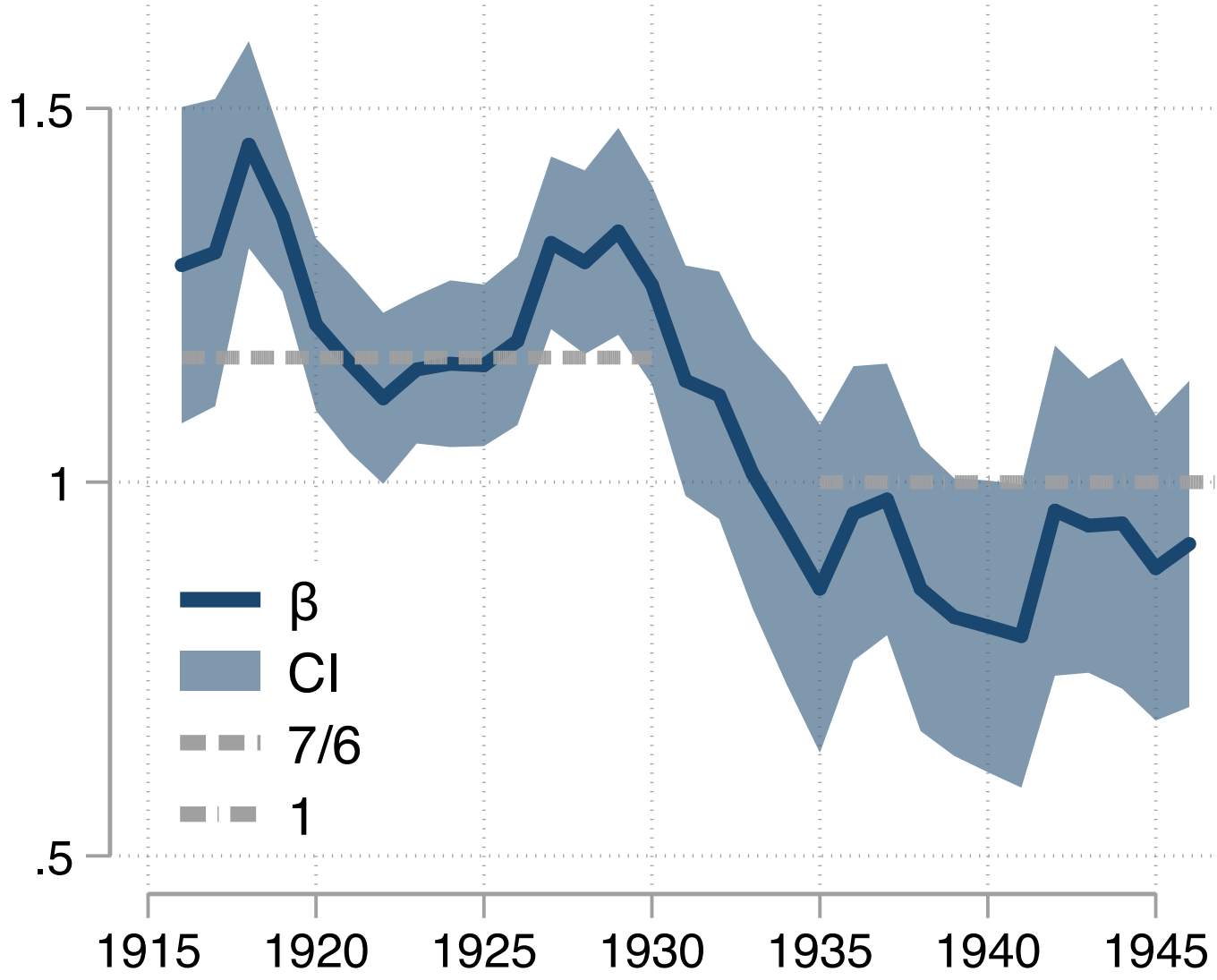
US Diphtheria Cases

- 1923 Diphtheria Toxiod Invented
- 1926 Diphtheria Toxiod + Adjuvant invented
- 1930s Widespread Use
- 1940s Routine Use

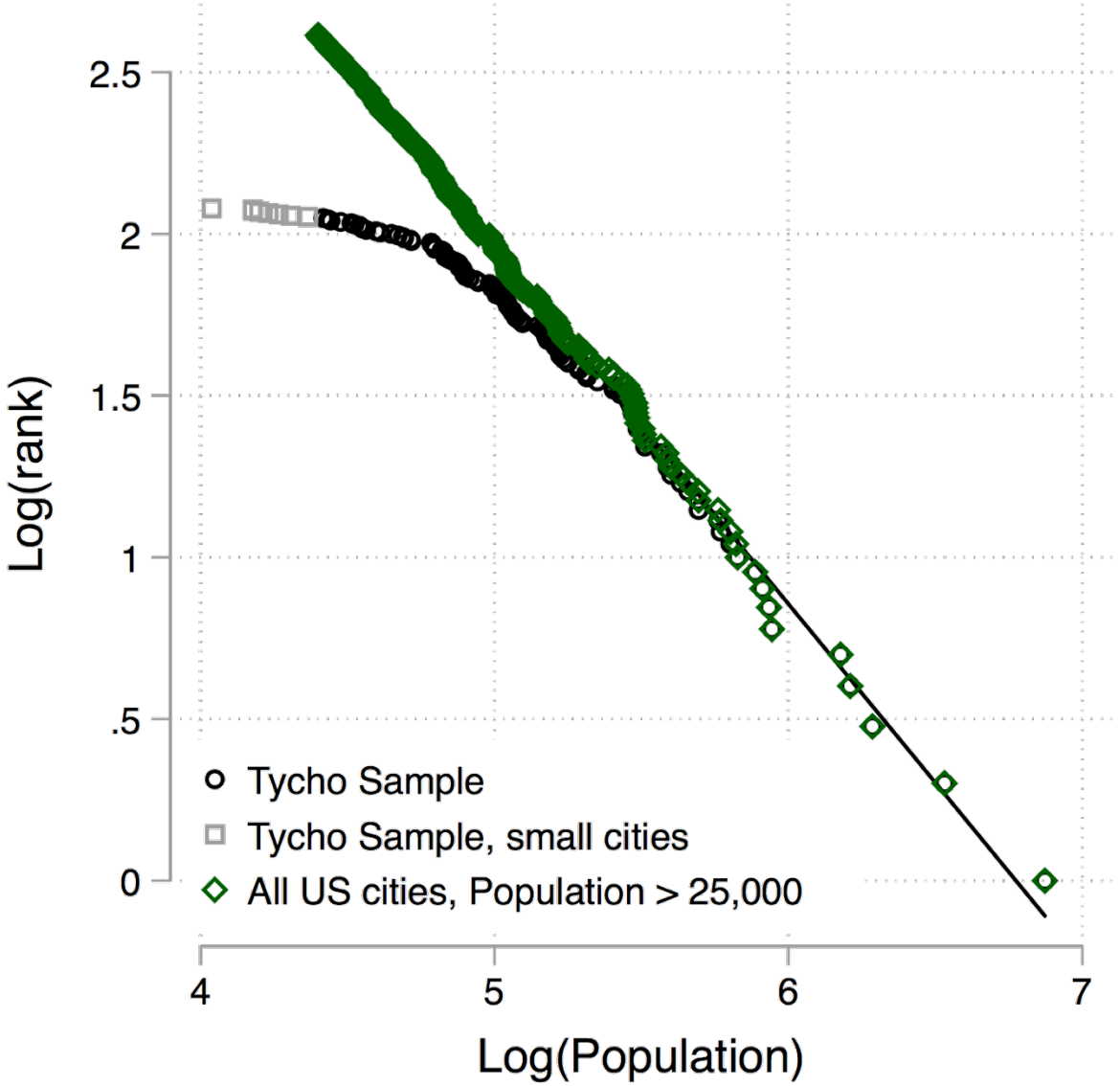



1916
Log10 Diphtheria Cases
0
1
2
3
4
4
5
6
7
Log10 Population

1916


1.5
1
.5
β
CI
7/6
1
1915
1920
1925
1930
1935
1940
1945

The Sample of Cities is Biased.



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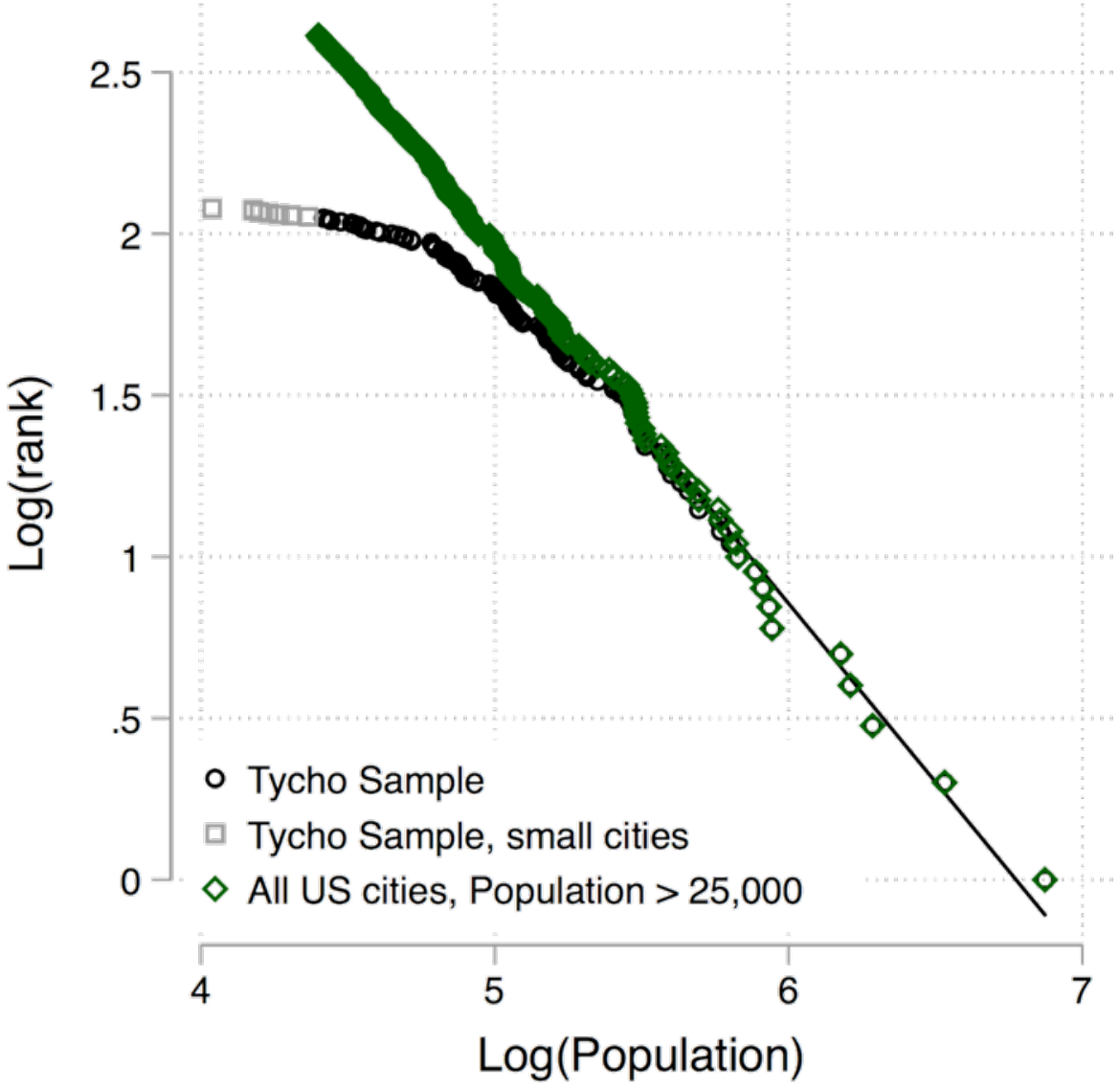

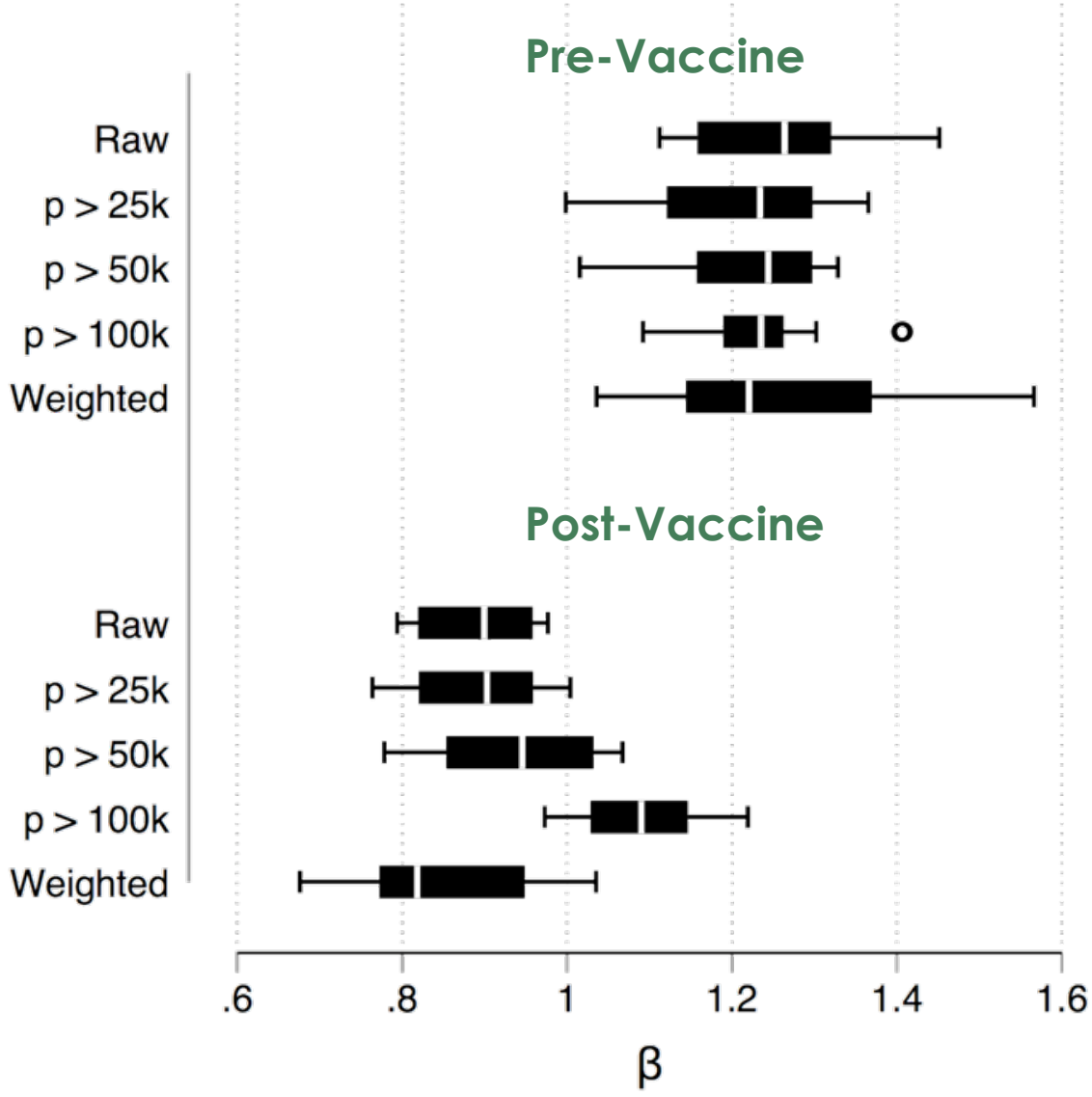

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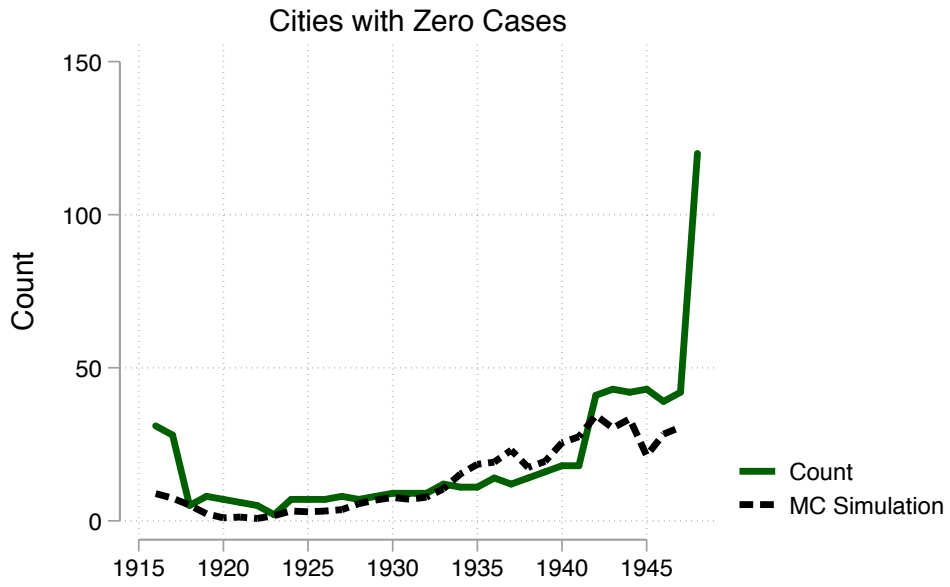
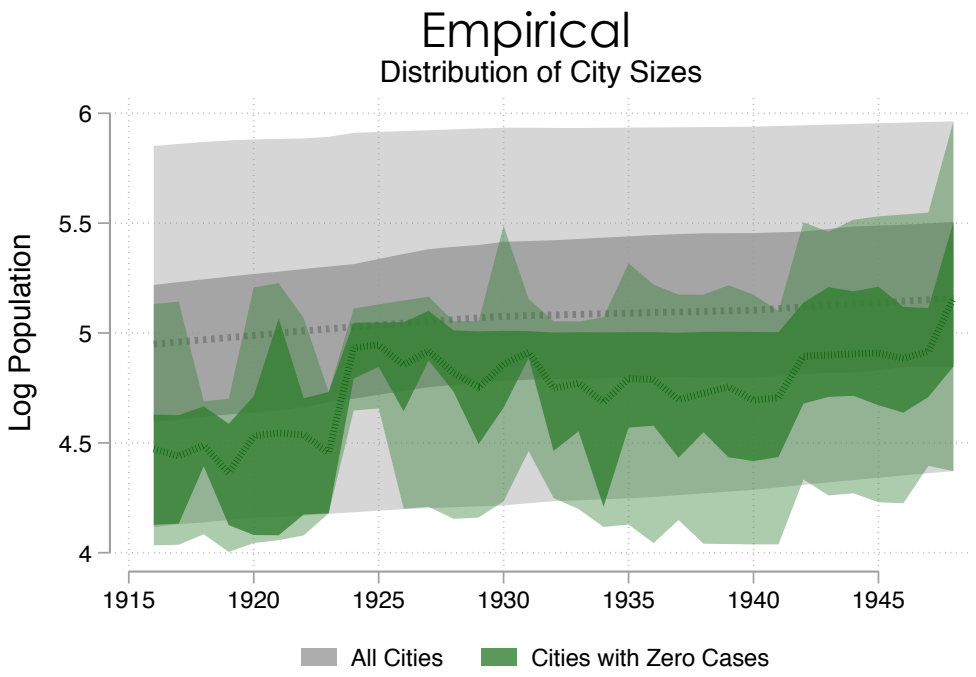
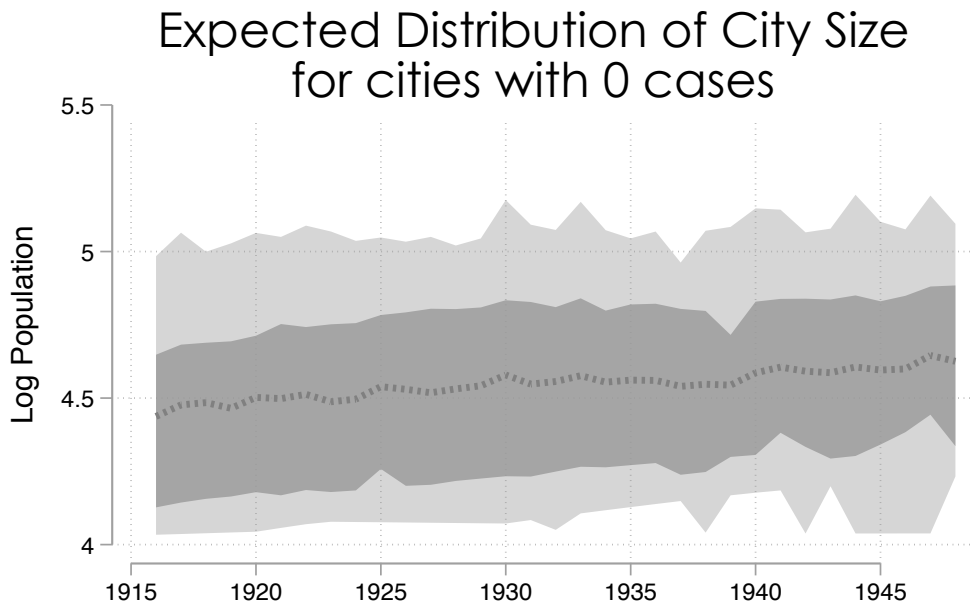
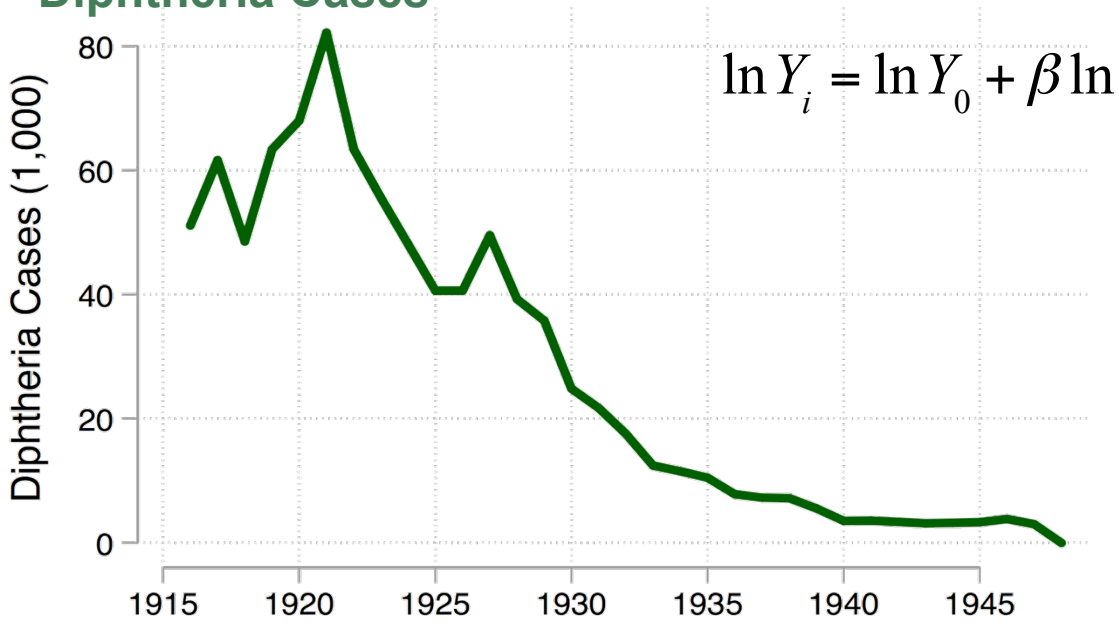
Some Cities Have Zero Cases





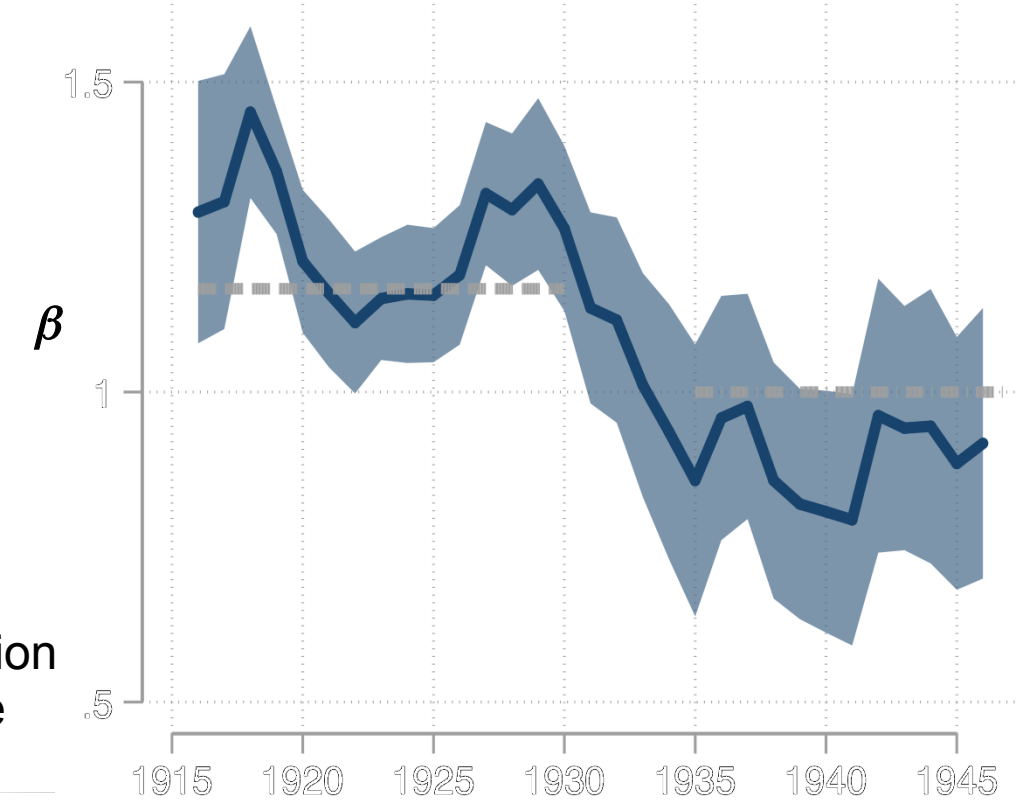


Diphtheria Cases

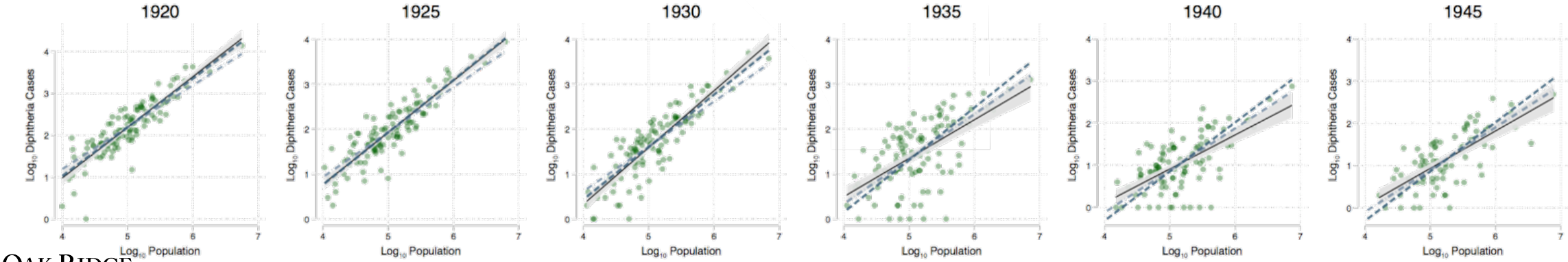


$$\ln Y_i = \ln Y_0 + \beta \ln N_i + \varepsilon_i$$

Annual & Independent β Estimates



The change in β shows that a fundamental change in transmission dynamics within and across urban environments occurred at the same time as an effective vaccine became widely used.



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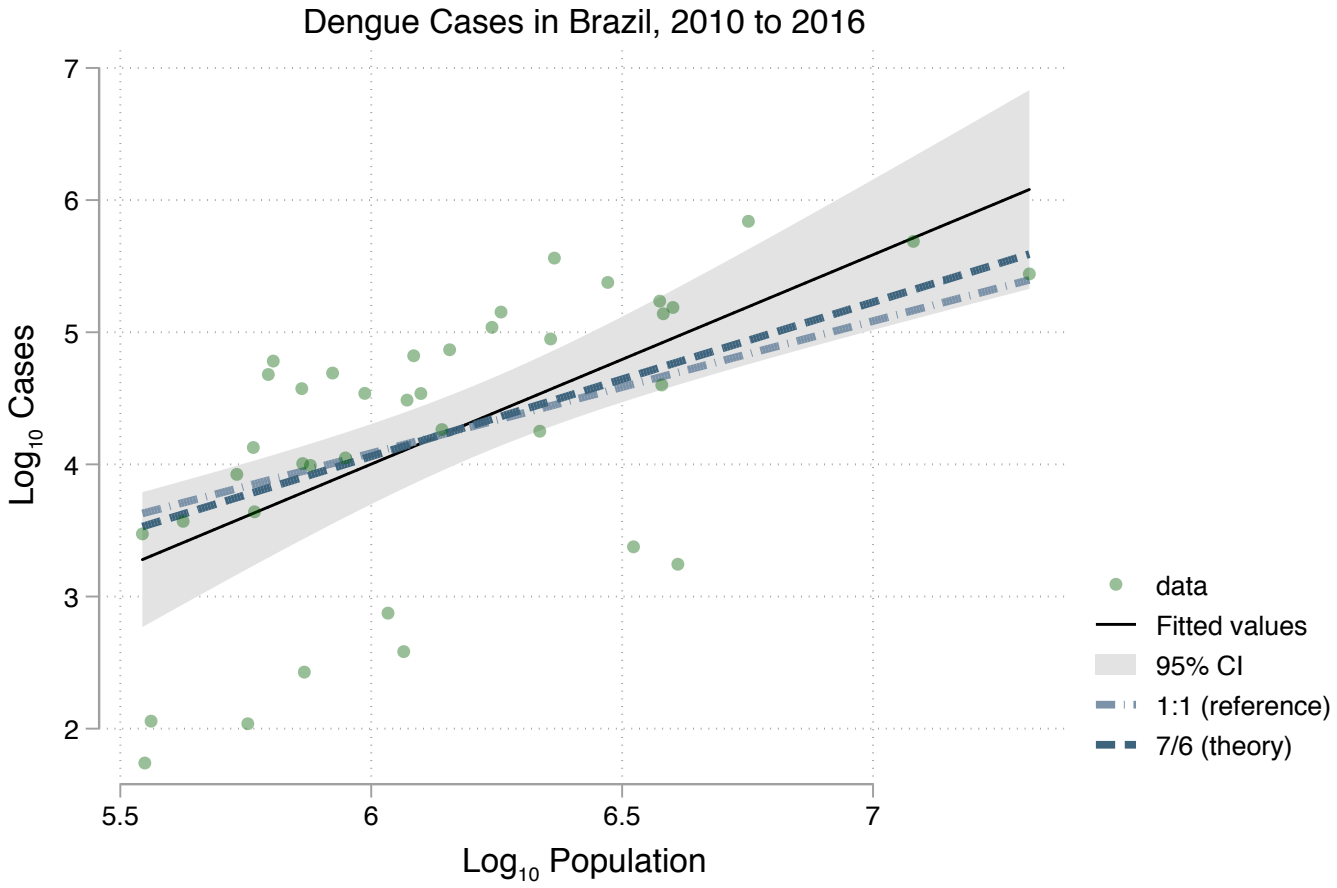
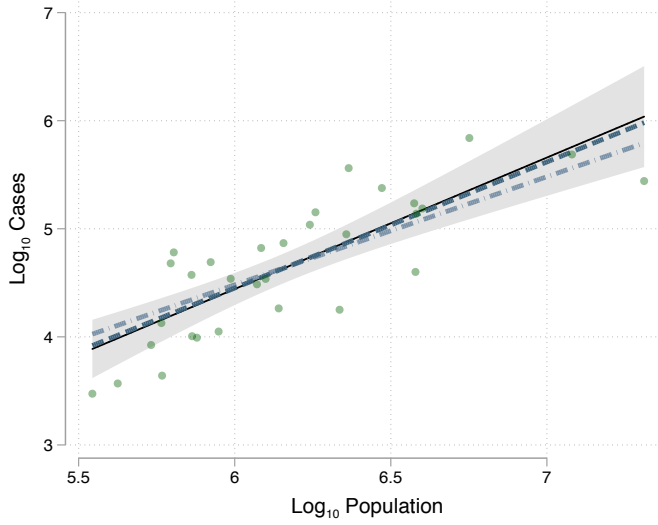
Zika, Dengue, and other Modern Infectious Diseases





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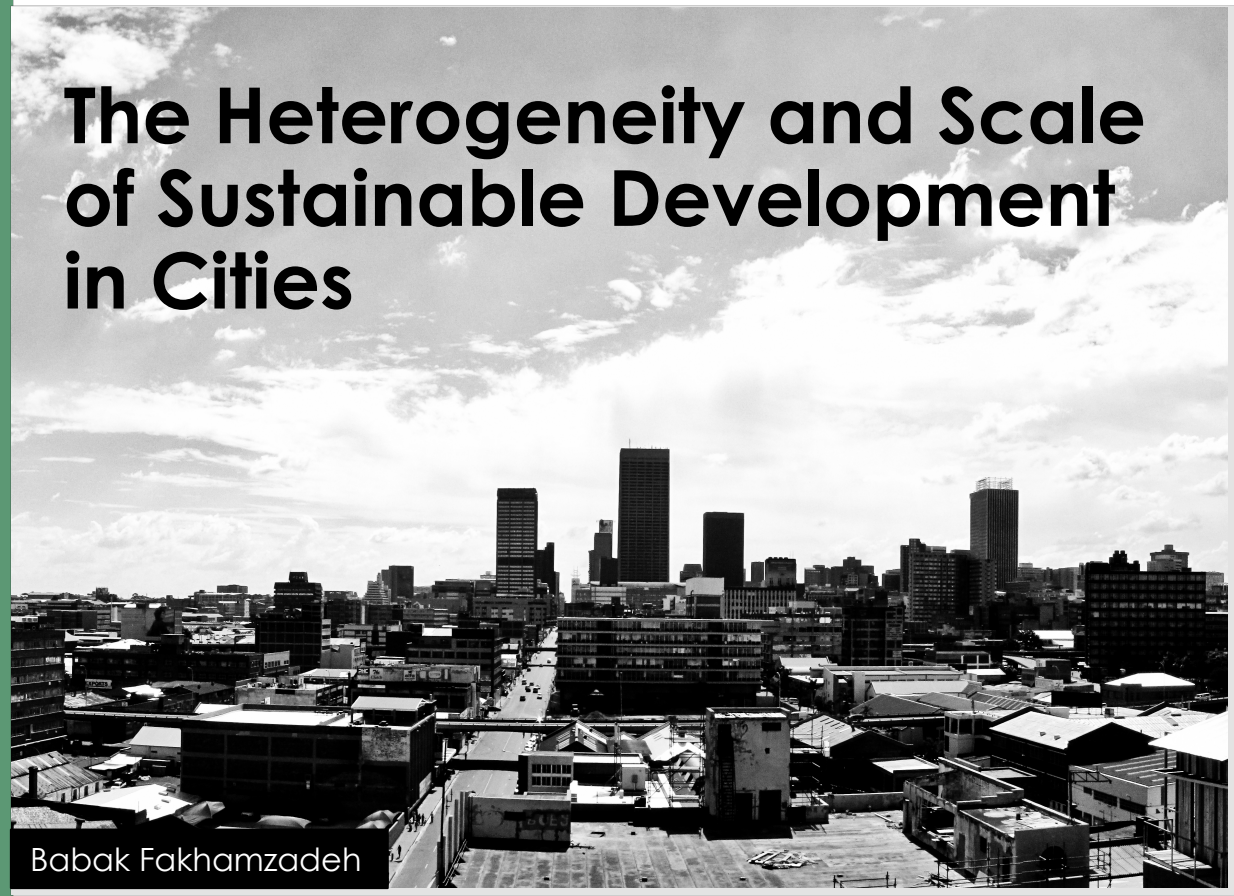
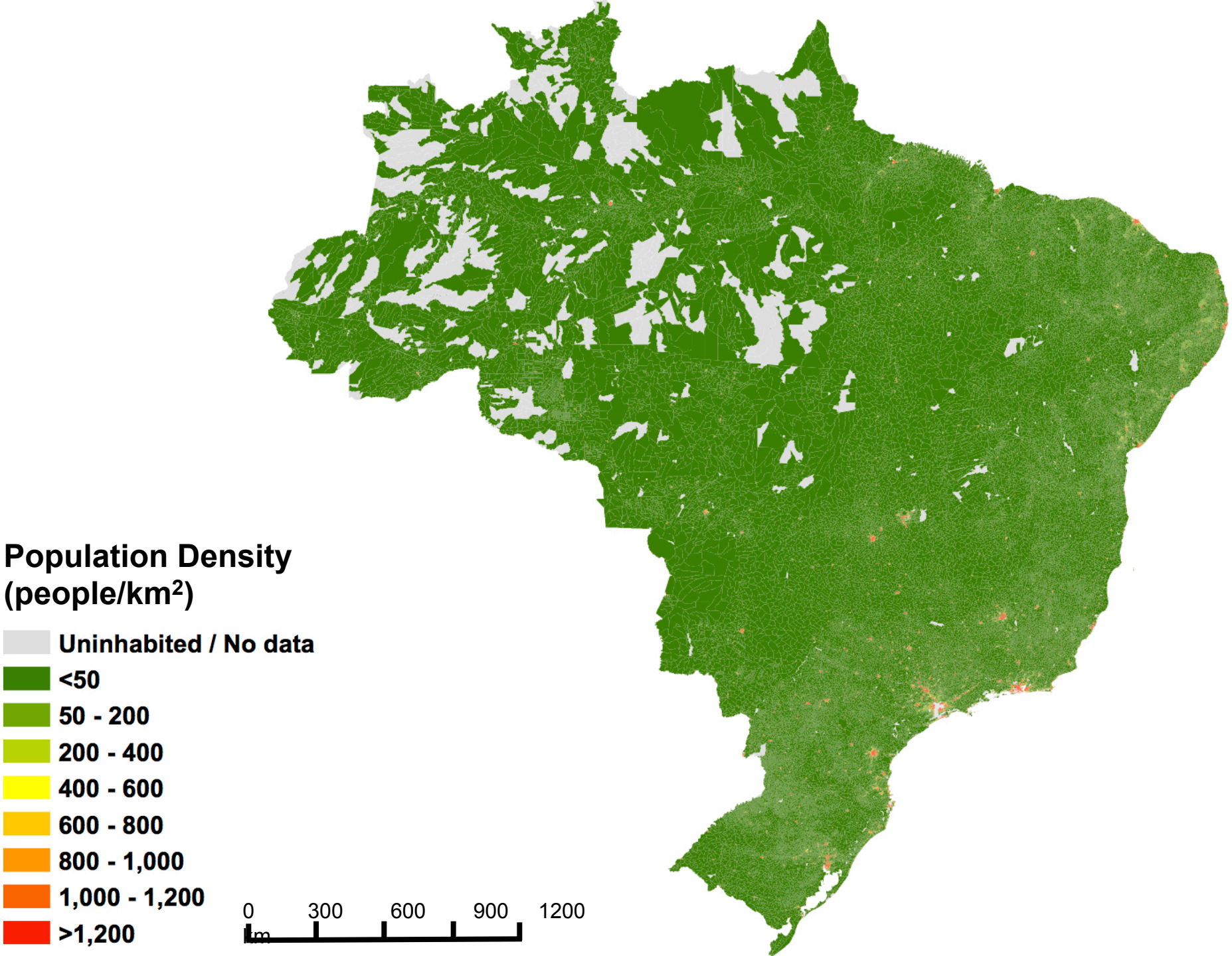


Brelsford, Lobo, Hand, Bettencourt *Proc. Natl. Acad. Sci.* (2017).



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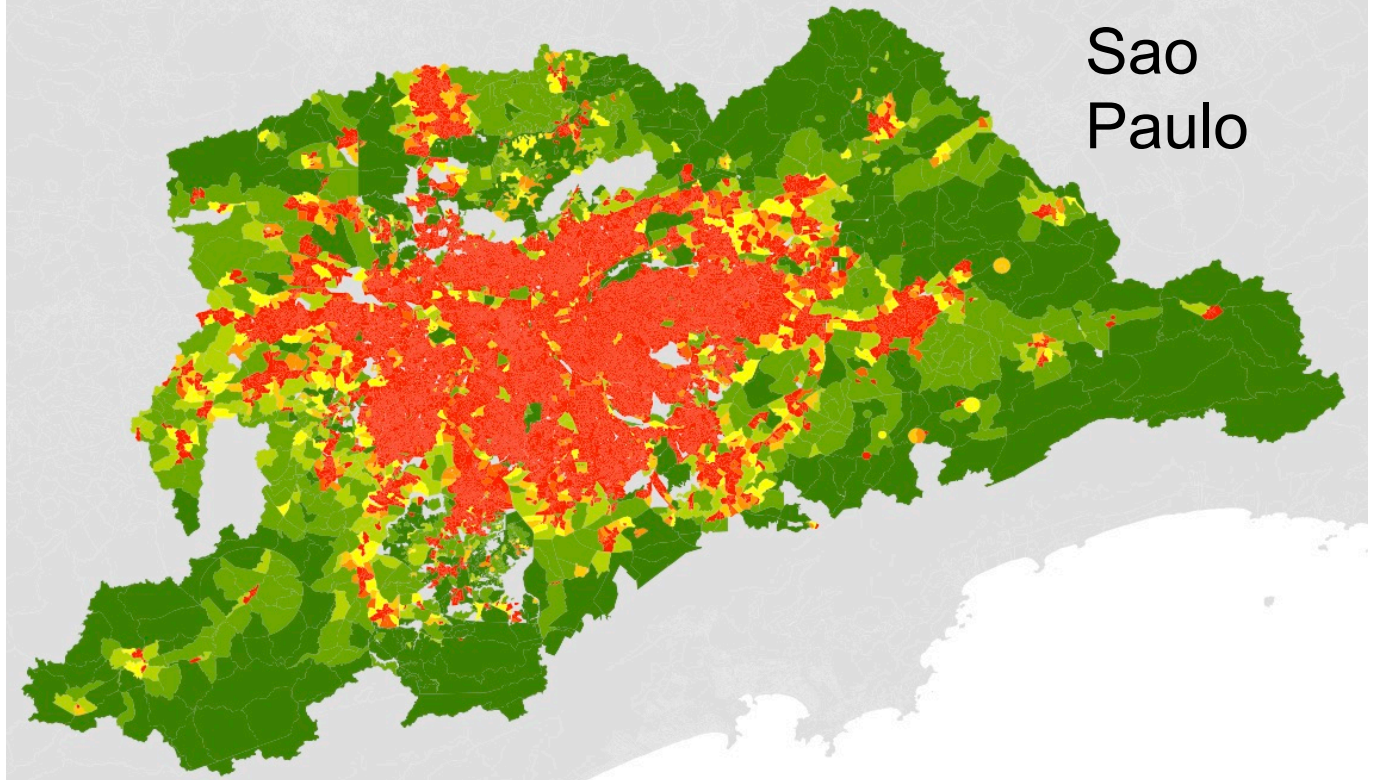
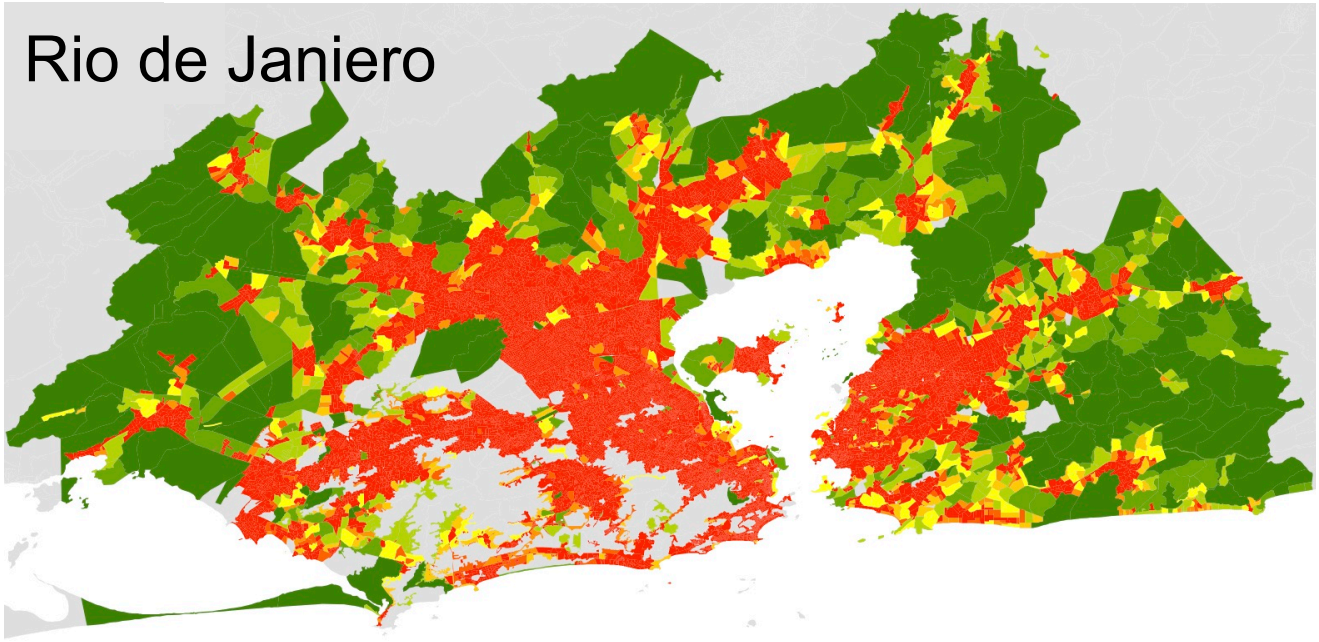
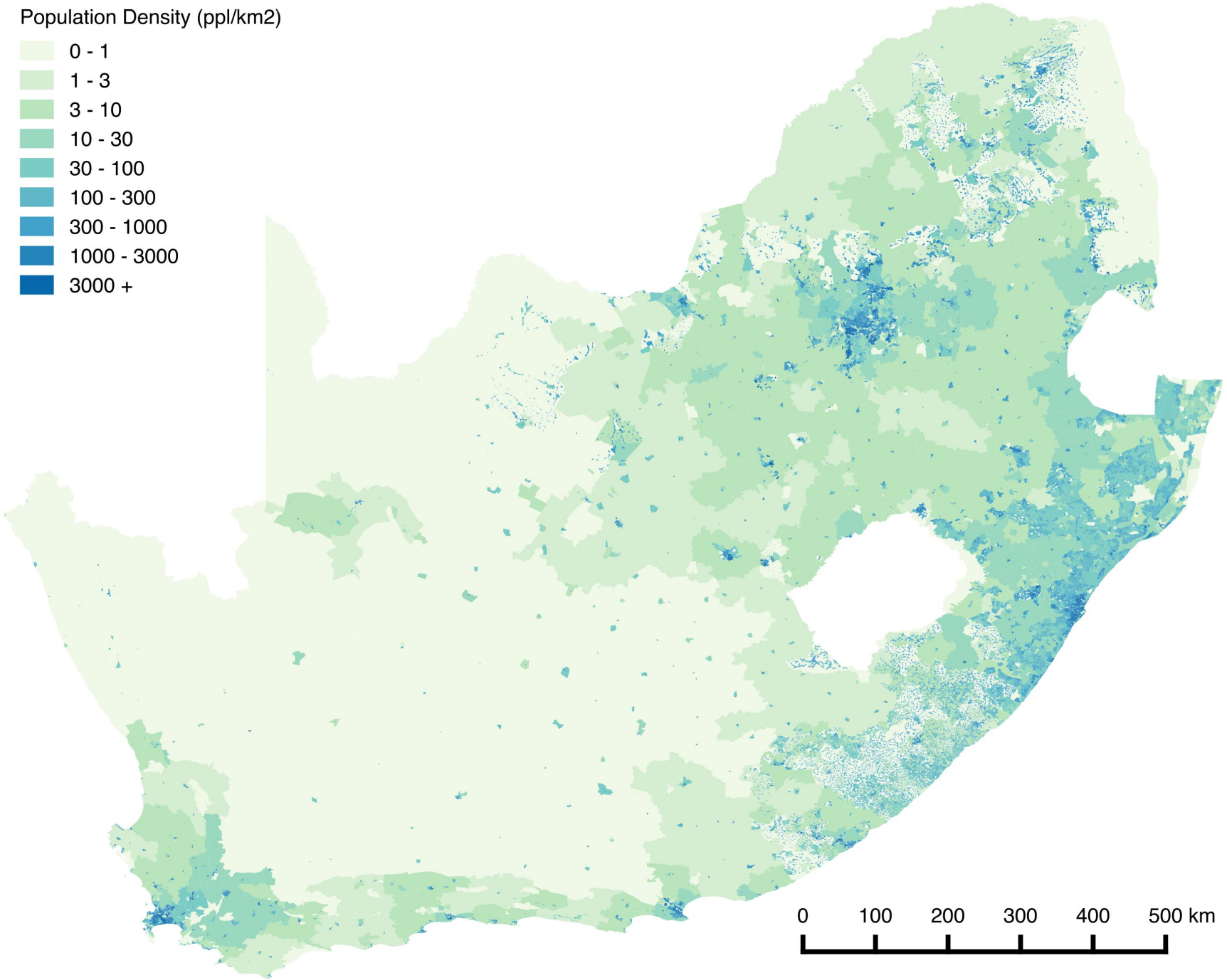
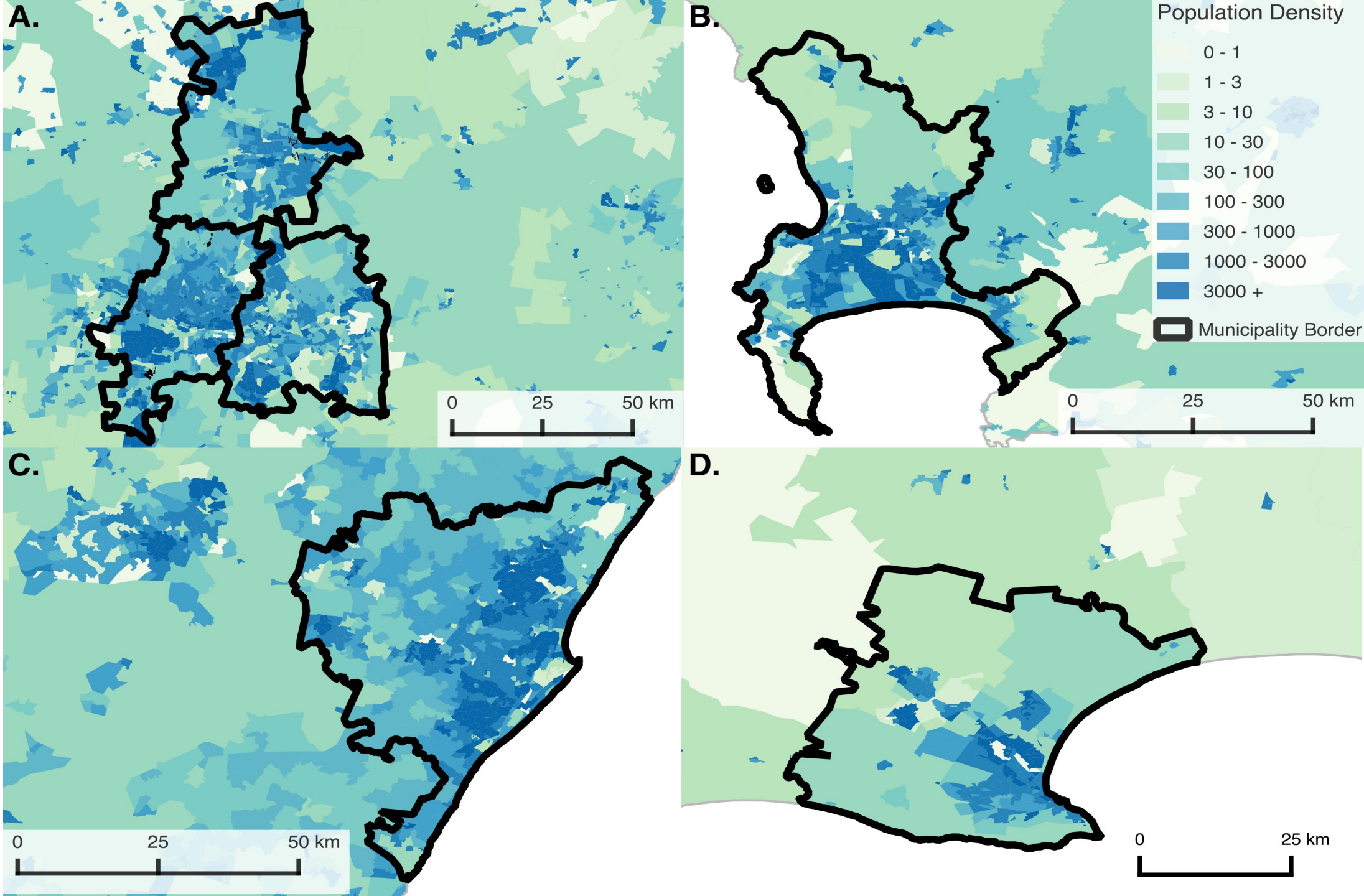


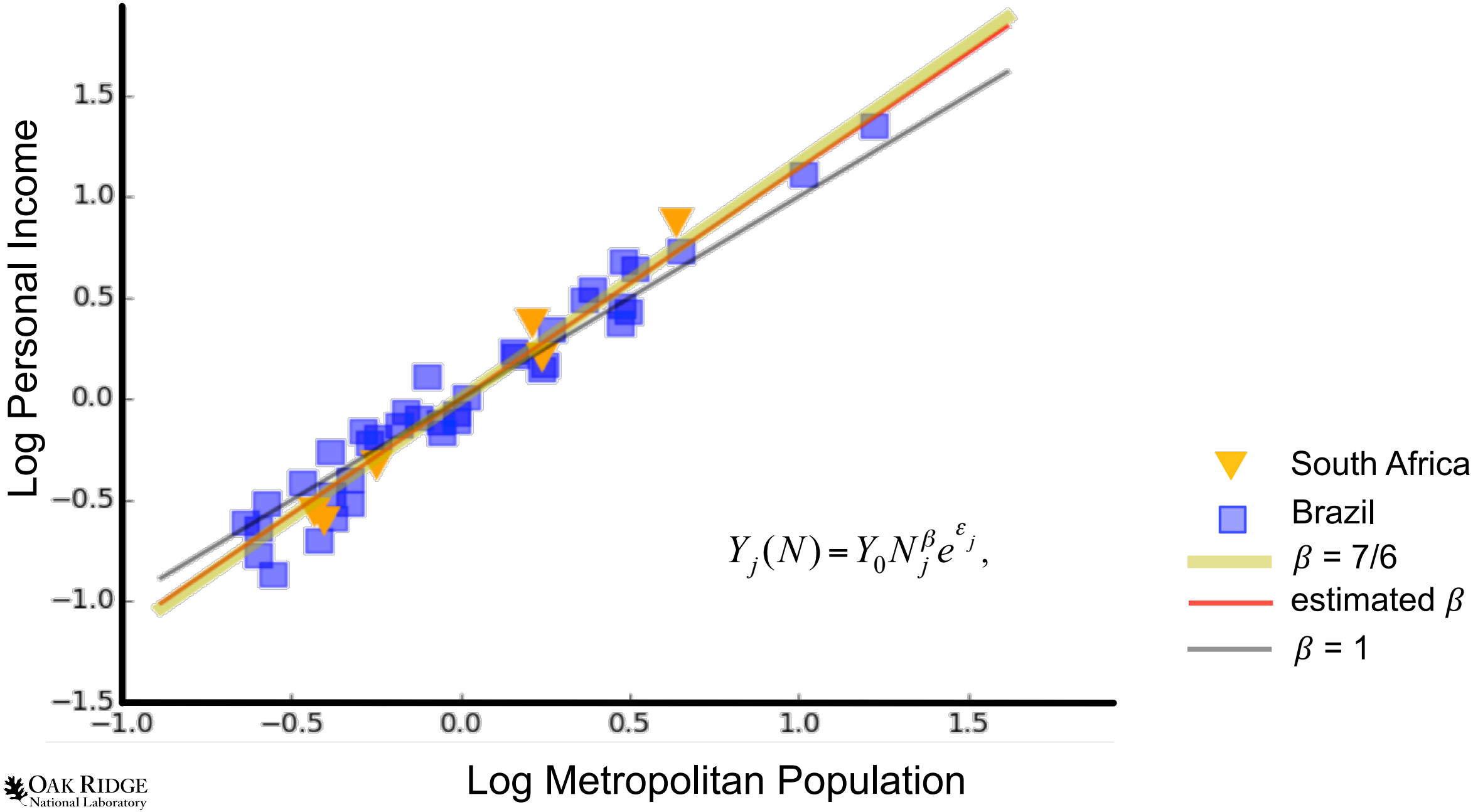
Population Density (people/km^2)

- Uninhabited / No data
- <50
- 50 - 200
- 200 - 400
- 400 - 600
- 600 - 800
- 800 - 1,000
- 1,000 - 1,200
- >1,200

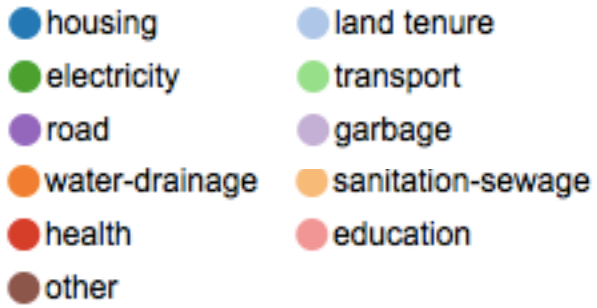


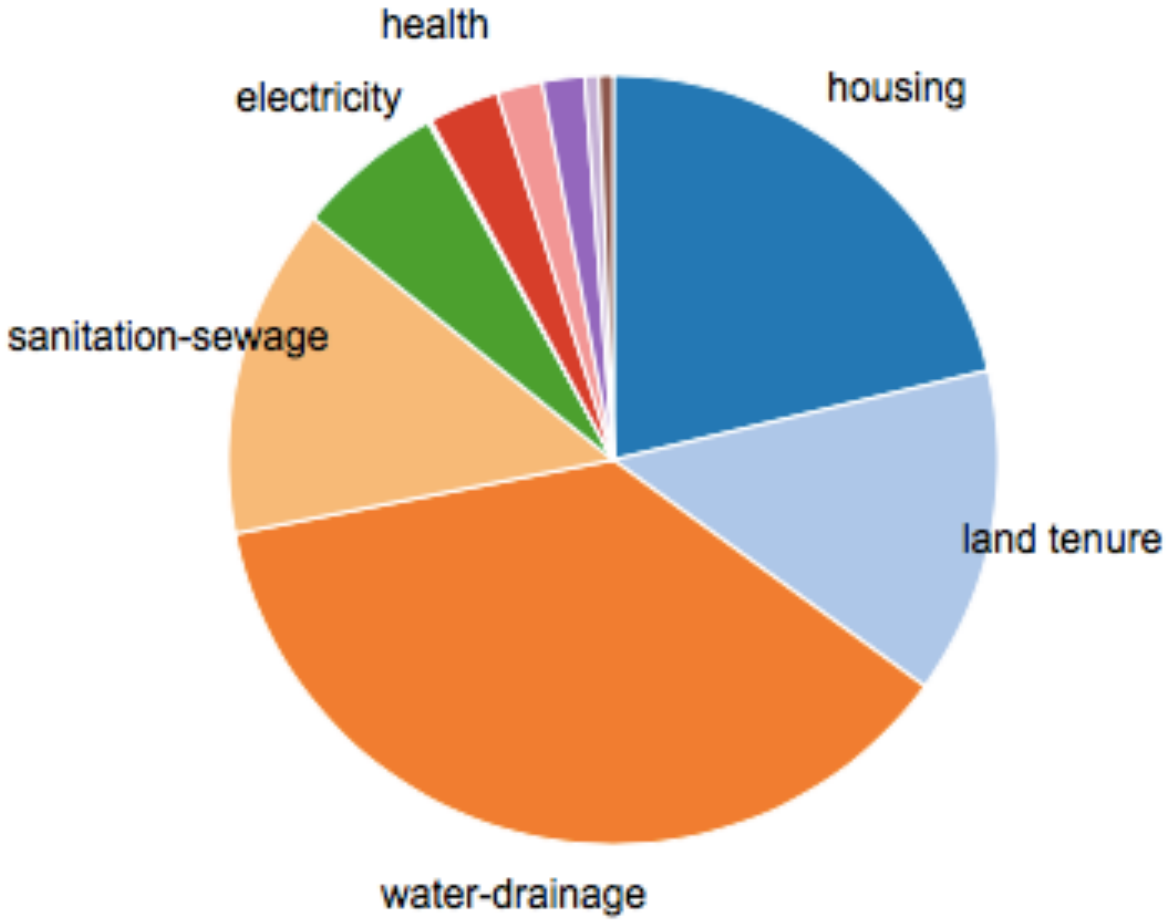

Population Density (ppl/km2)
0 - 1
1 - 3
3 - 10
10 - 30
30 - 100
100 - 300
300 - 1000
1000 - 3000
3000 +
0
100
200
300
400
500 km



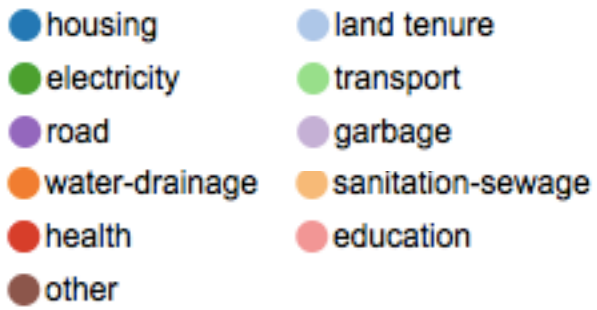

Log Personal Income
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Log Metropolitan Population
$Y_j(N) = Y_0 N_j^{\beta} e^{\varepsilon_j}$,
South Africa
Brazil
β = 7/6
estimated β
β = 1

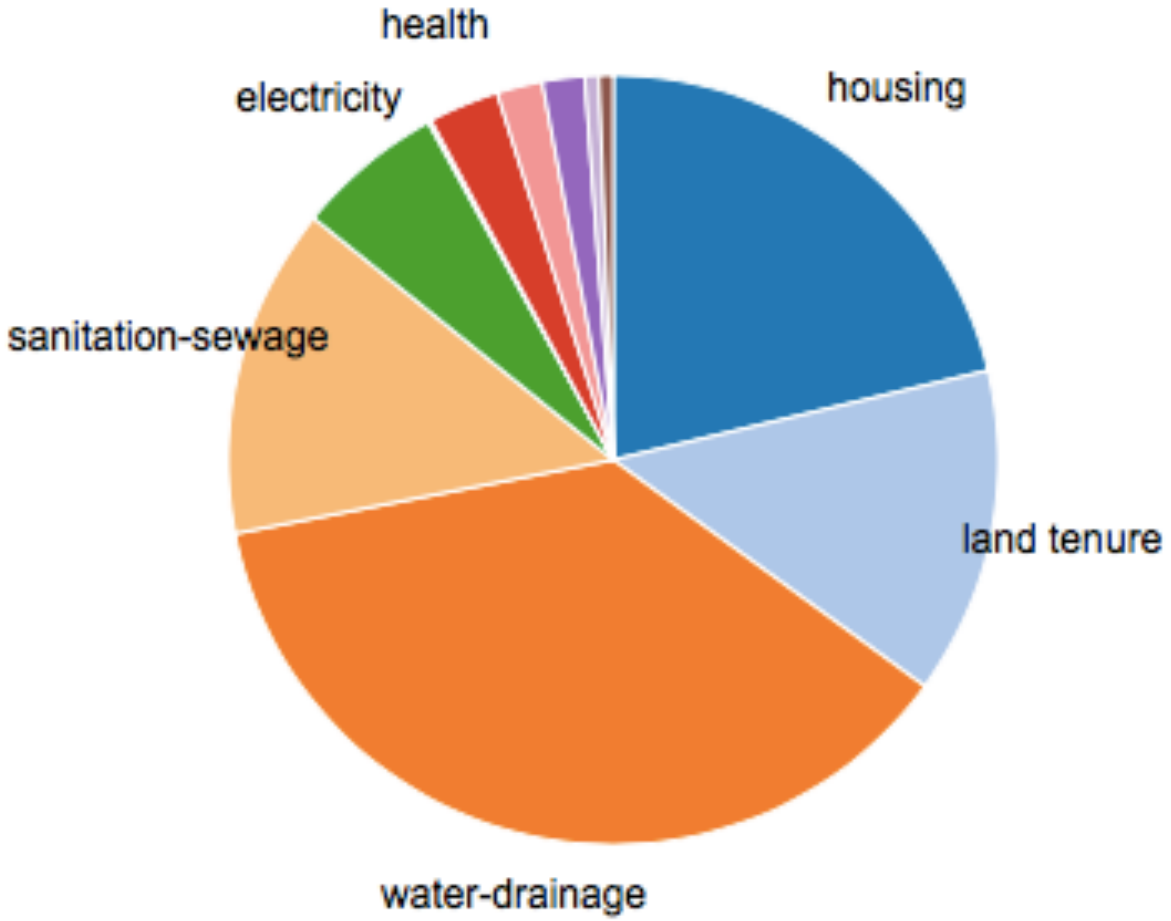
Self Identified Development Priorities



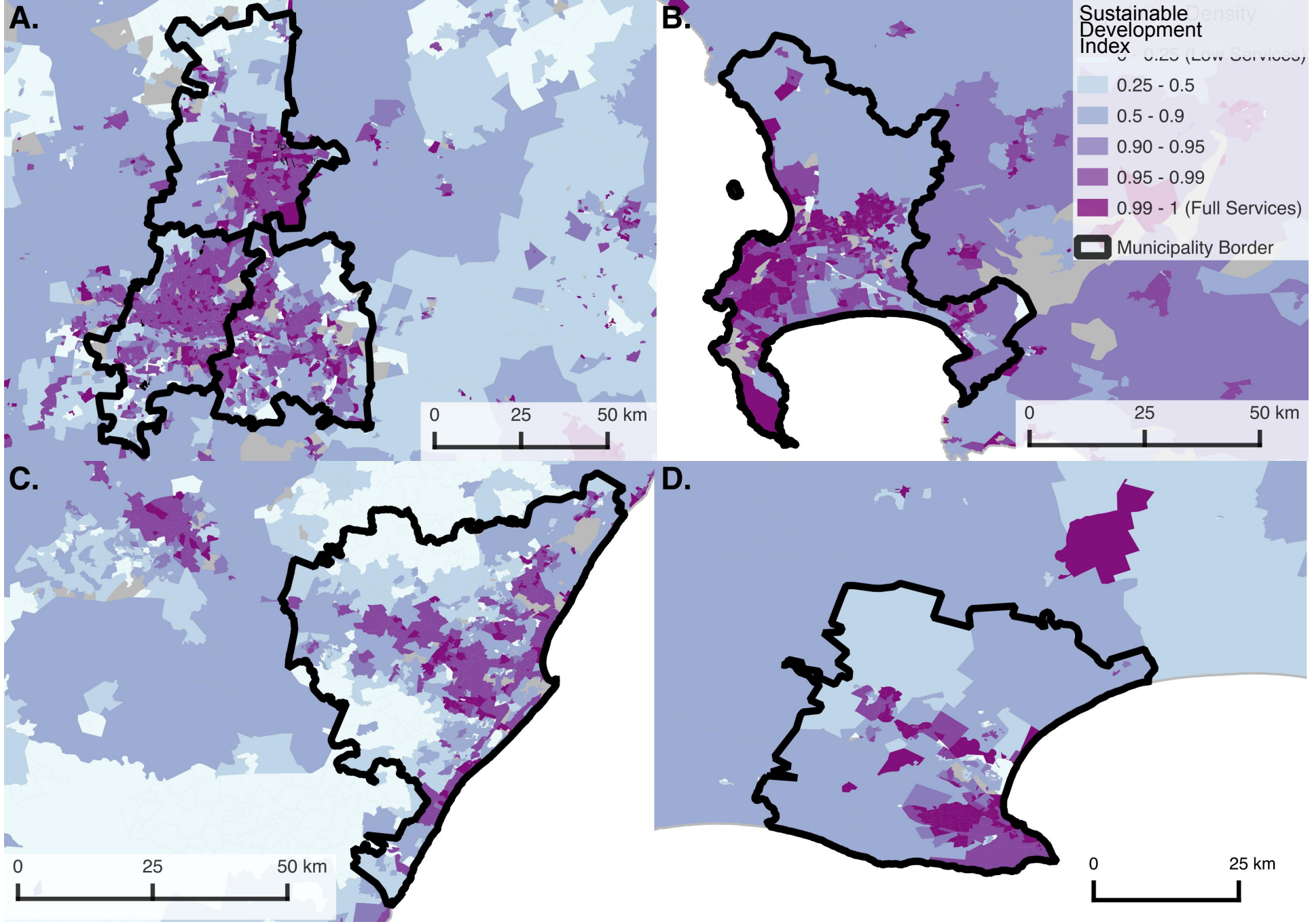


Self Identified Development Priorities





$$X\downarrow i = \sqrt{4}\&X\downarrow i\uparrow housing \times X\downarrow i\uparrow water \times X\downarrow i\uparrow sanitation \times X\downarrow i\uparrow electricity$$



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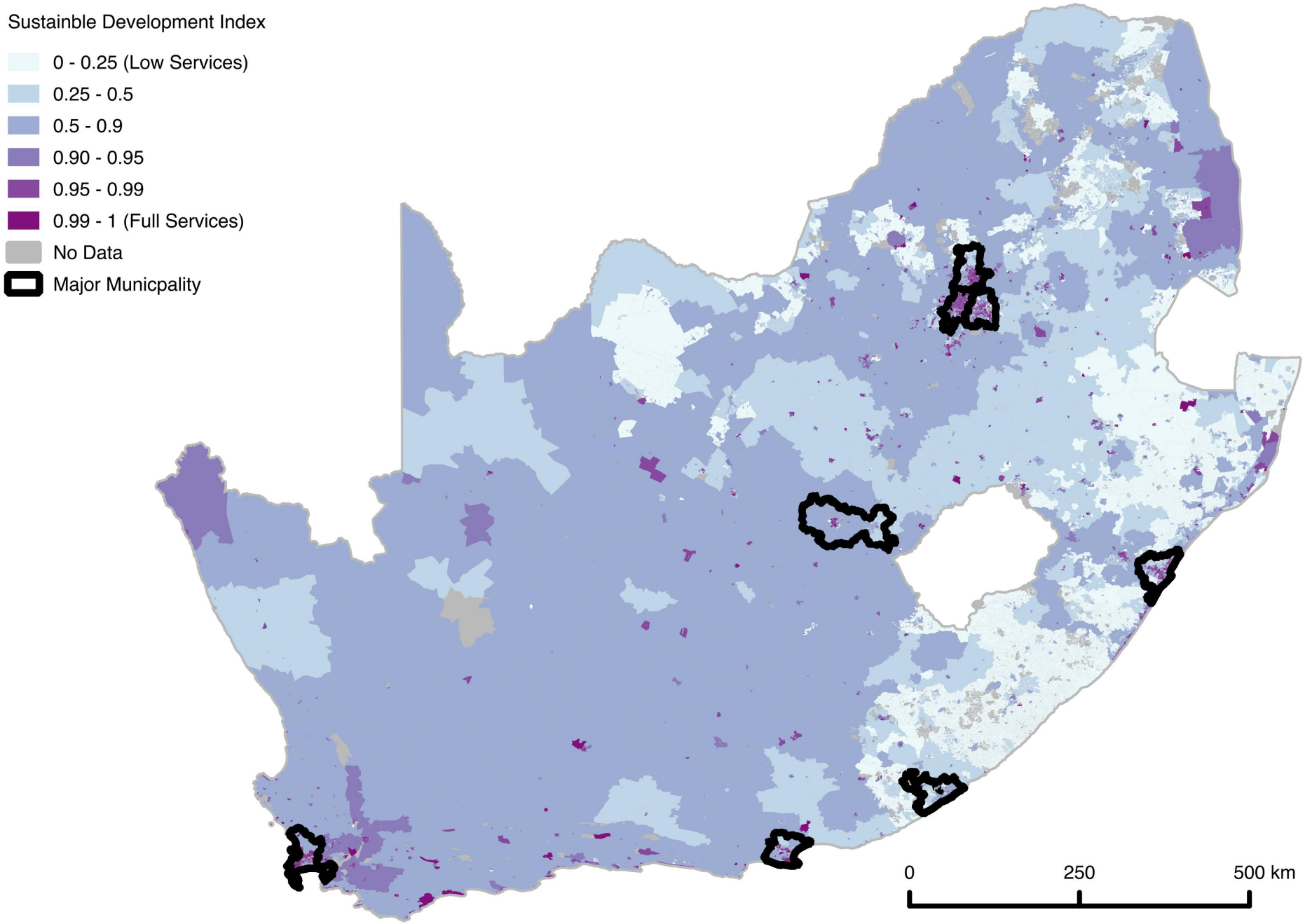
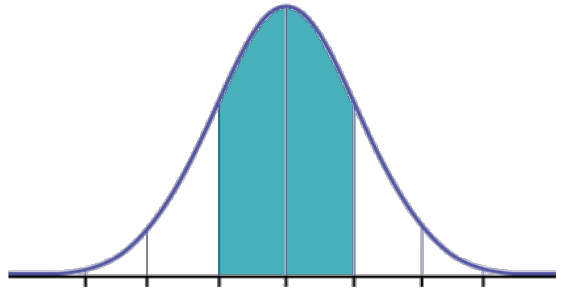

Sustainble Development Index
0 - 0.25 (Low Services)
0.25 - 0.5
0.5 - 0.9
0.90 - 0.95
0.95 - 0.99
0.99 - 1 (Full Services)
No Data
Major Municpality
0
250
500 km

Measures of Heterogeneity

- Standard deviation $\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}$



Measures of Heterogeneity

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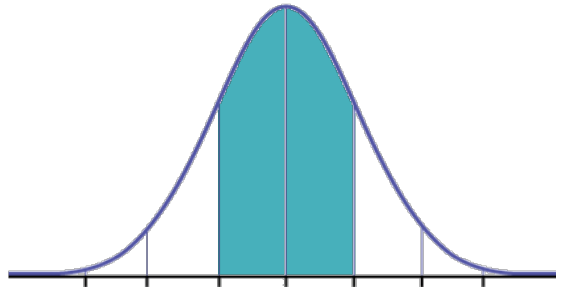
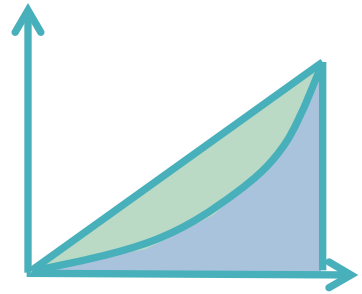


- Gini Coefficient $$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}|x_i - x_j|}{2n\sum_{i=1}^{n}x_i}$$



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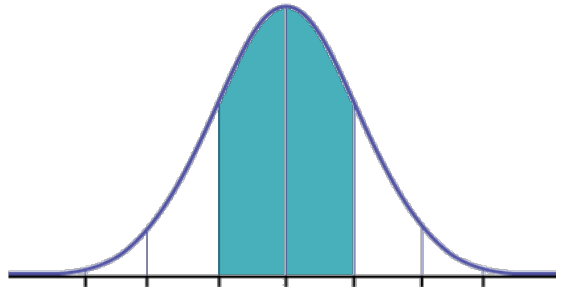

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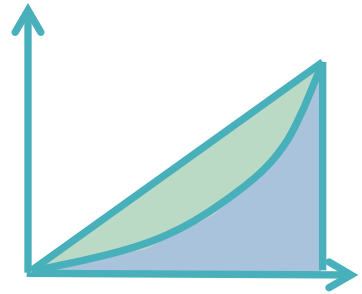
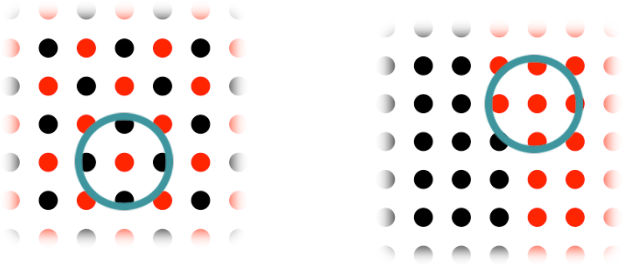
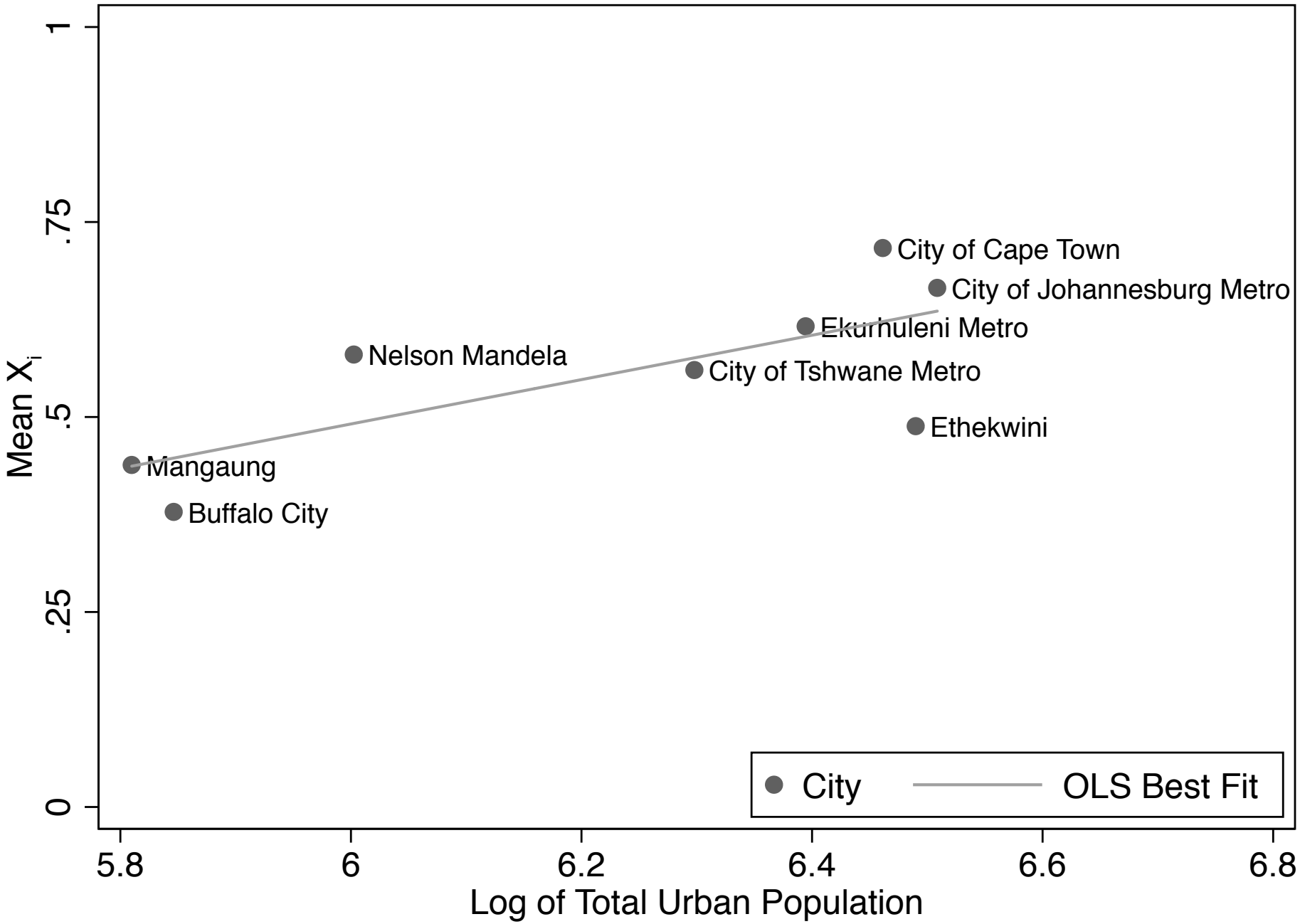
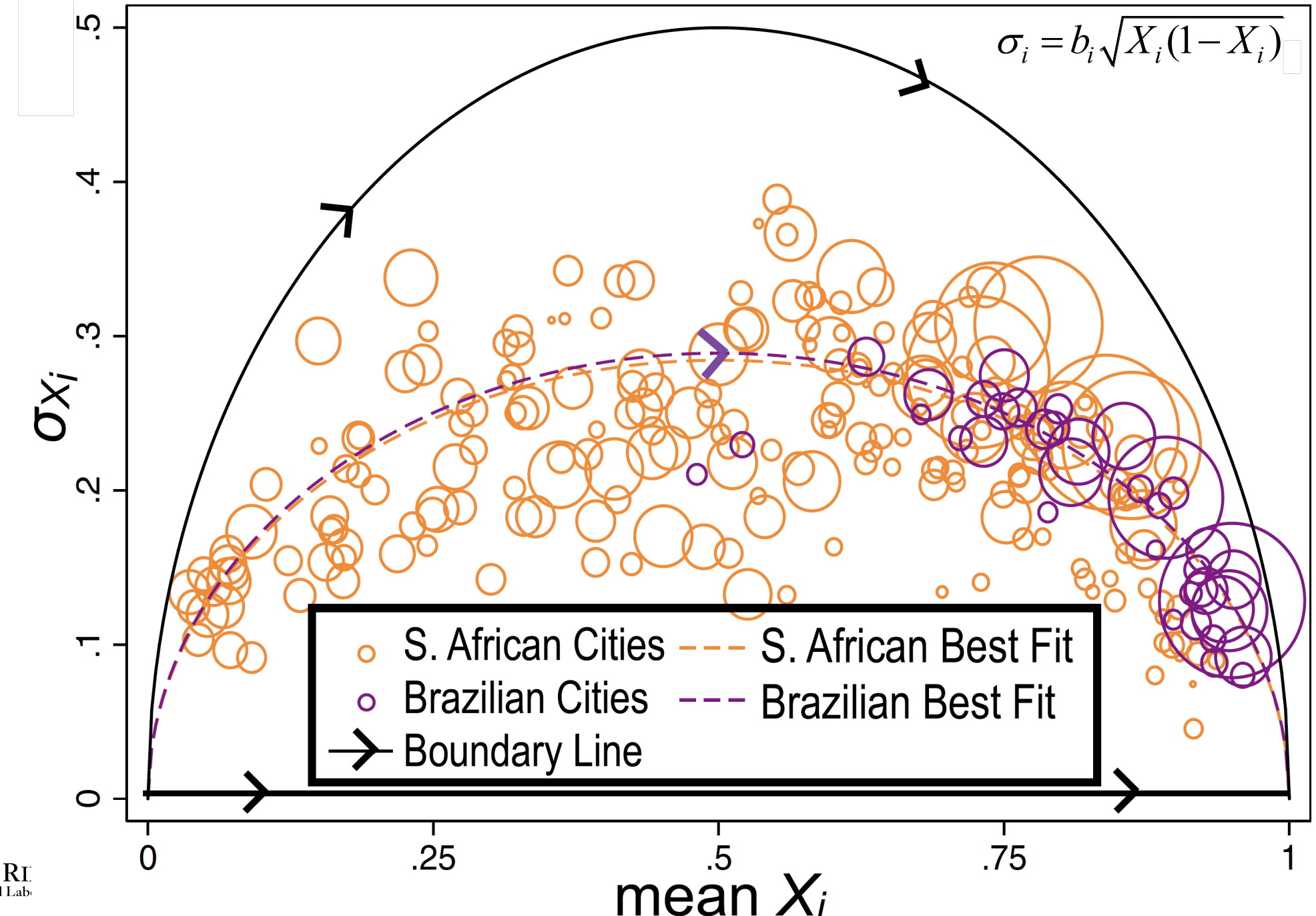


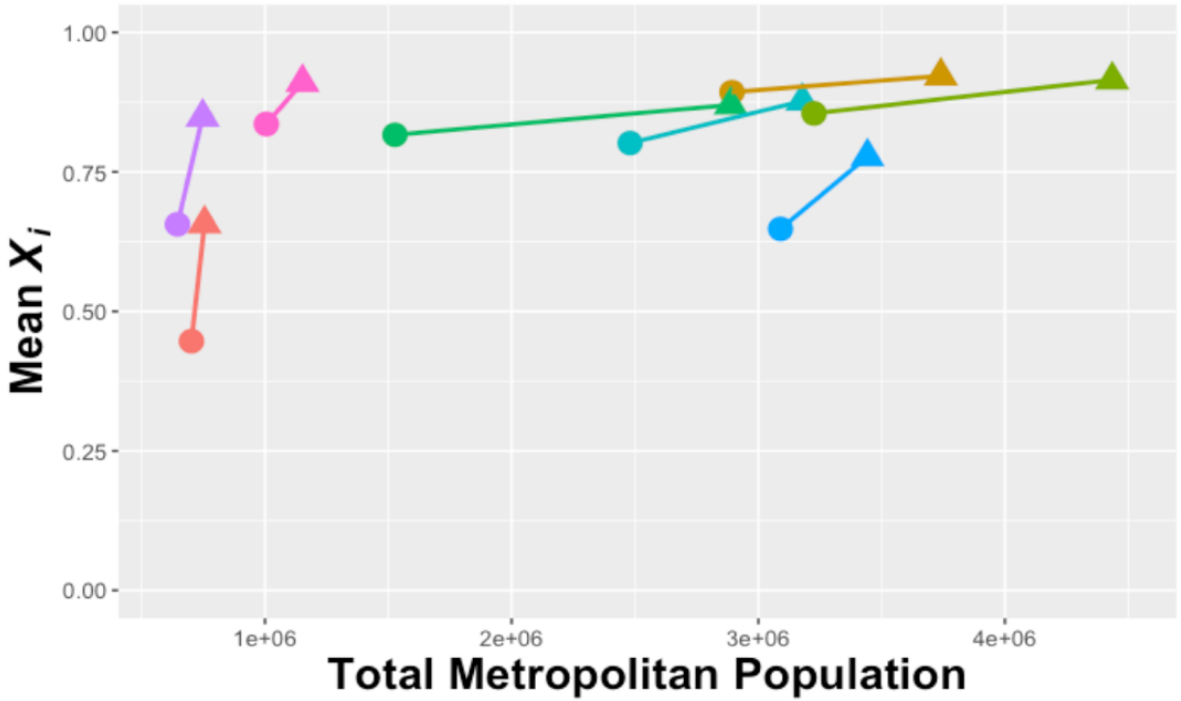
- Moran's I $I = \frac{N\sum_{i,j=1}^{N} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{W\sum_{i=1}^{N}(x_i - \bar{x})^2}$

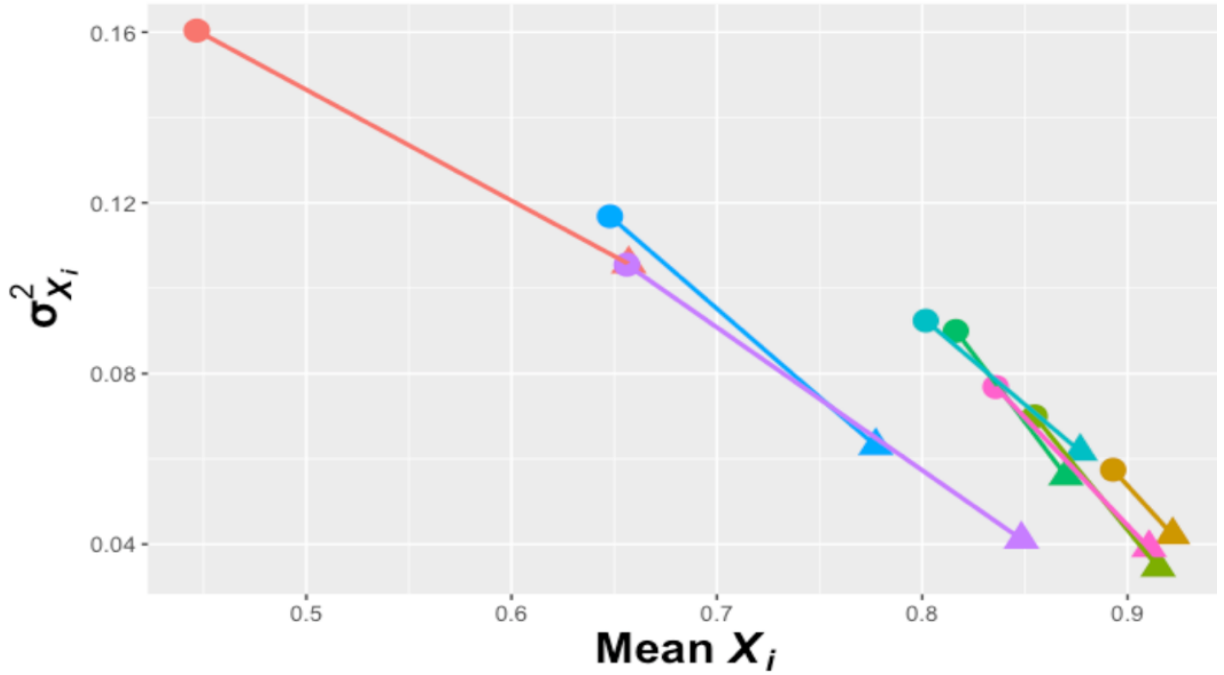



Mean X_i
0
.25
.5
.75
1
5.8
6
6.2
6.4
6.6
6.8
Log of Total Urban Population
City of Cape Town
City of Johannesburg Metro
Ekurhuleni Metro
Nelson Mandela
City of Tshwane Metro
Ethekwini
Mangaung
Buffalo City
City
OLS Best Fit

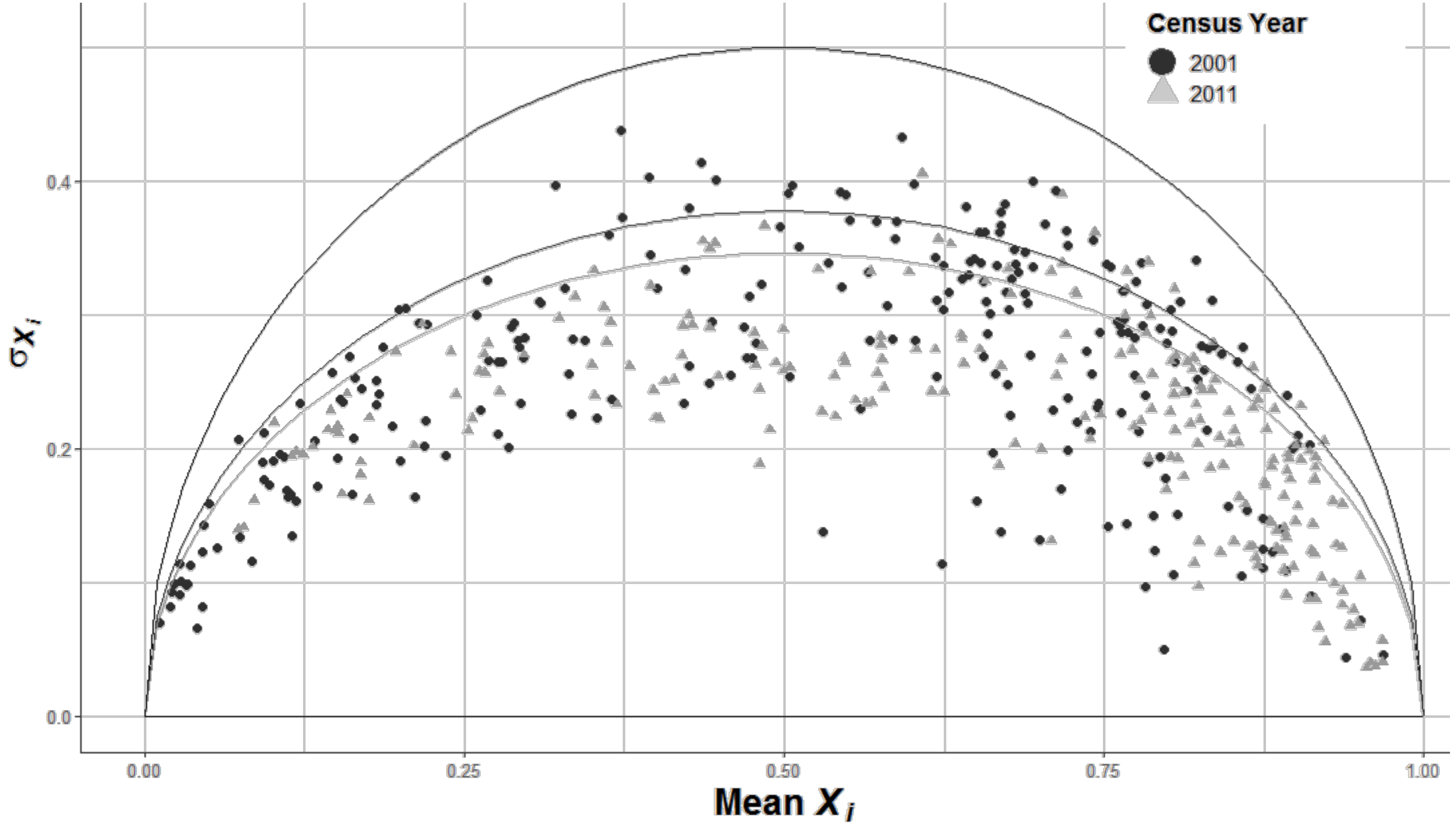

$\sigma_i = b_i\sqrt{X_i(1-X_i)}$
σX_i
0
.1
.2
.3
.4
.5
0
.25
.5
.75
1
mean X_i
S. African Cities
Brazilian Cities
Boundary Line
S. African Best Fit
Brazilian Best Fit

Temporal Changes in X_i





Mollie Gaines (ORNL summer student)



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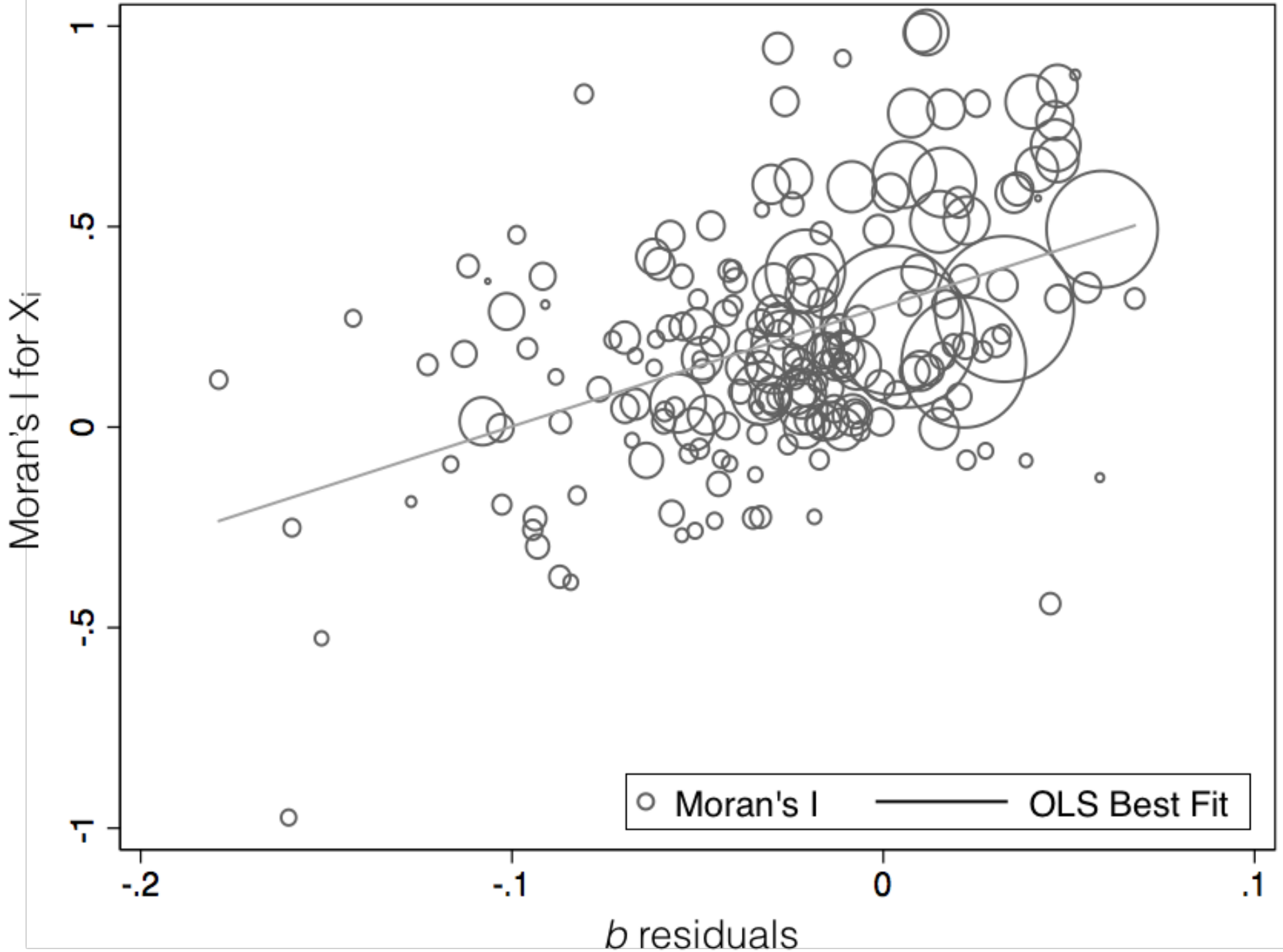


What makes a city?

What makes a neighborhood?

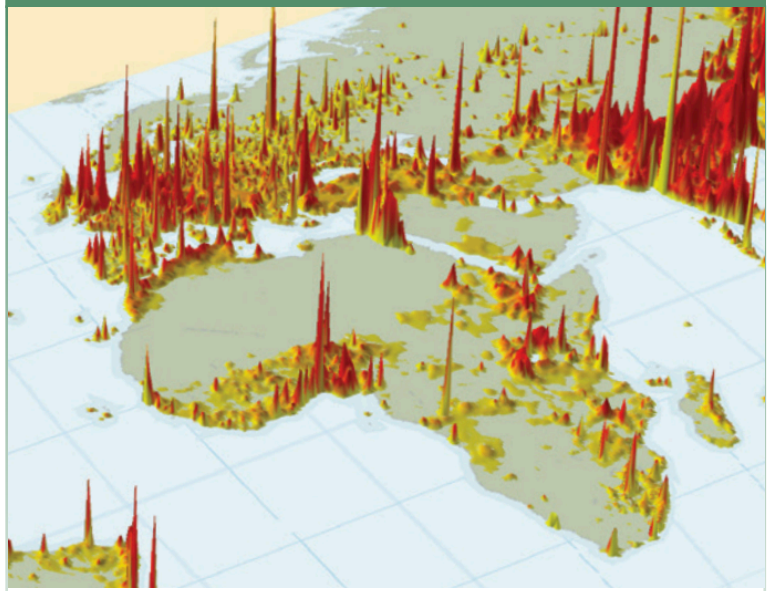
What about social ties that aren't geographically contiguous?

What makes a city?

USGS from LANDSAT images. (2014)
https://earthshots.usgs.gov/earthshots/node/4#ad-image-0-0

How much space does a city take up?

Population Density



Tim Gulden using ORNL Landscan Global Dataset. Published in Florida, *the Atlantic*. (2005)

Infrastructure

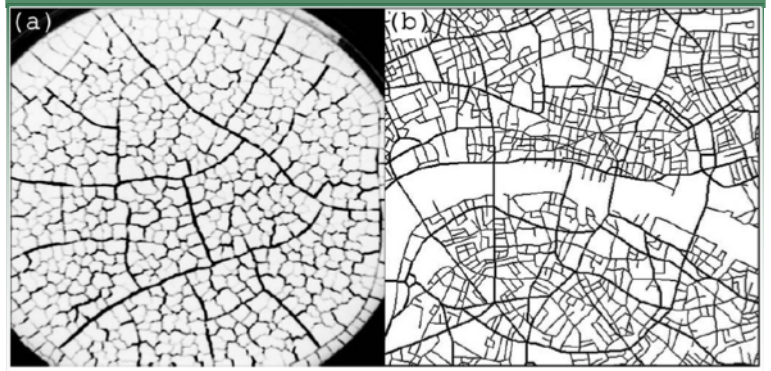
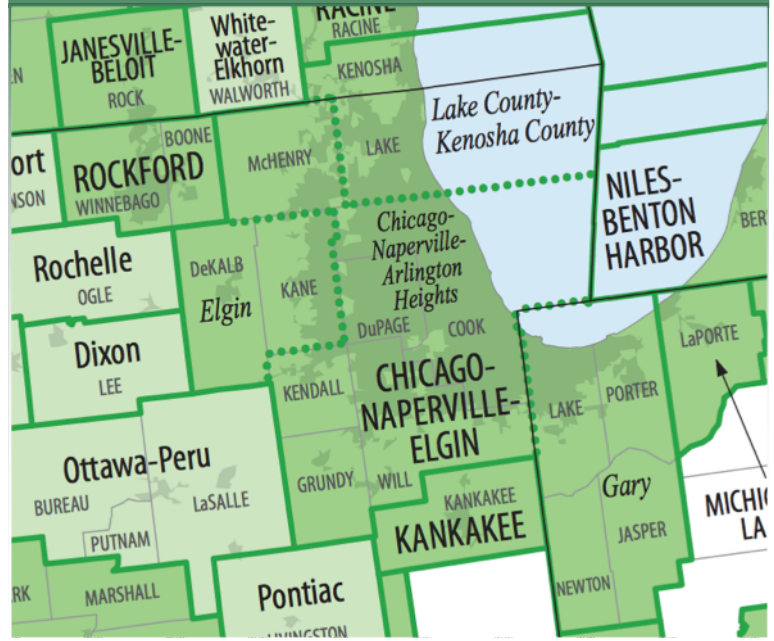


FIG. 1. (a) Crack pattern formation from drying a solution of corn starch and distilled water [6]. (b) Street network pattern for part of central London around the Thames, where the thick lines represent mayor roads.

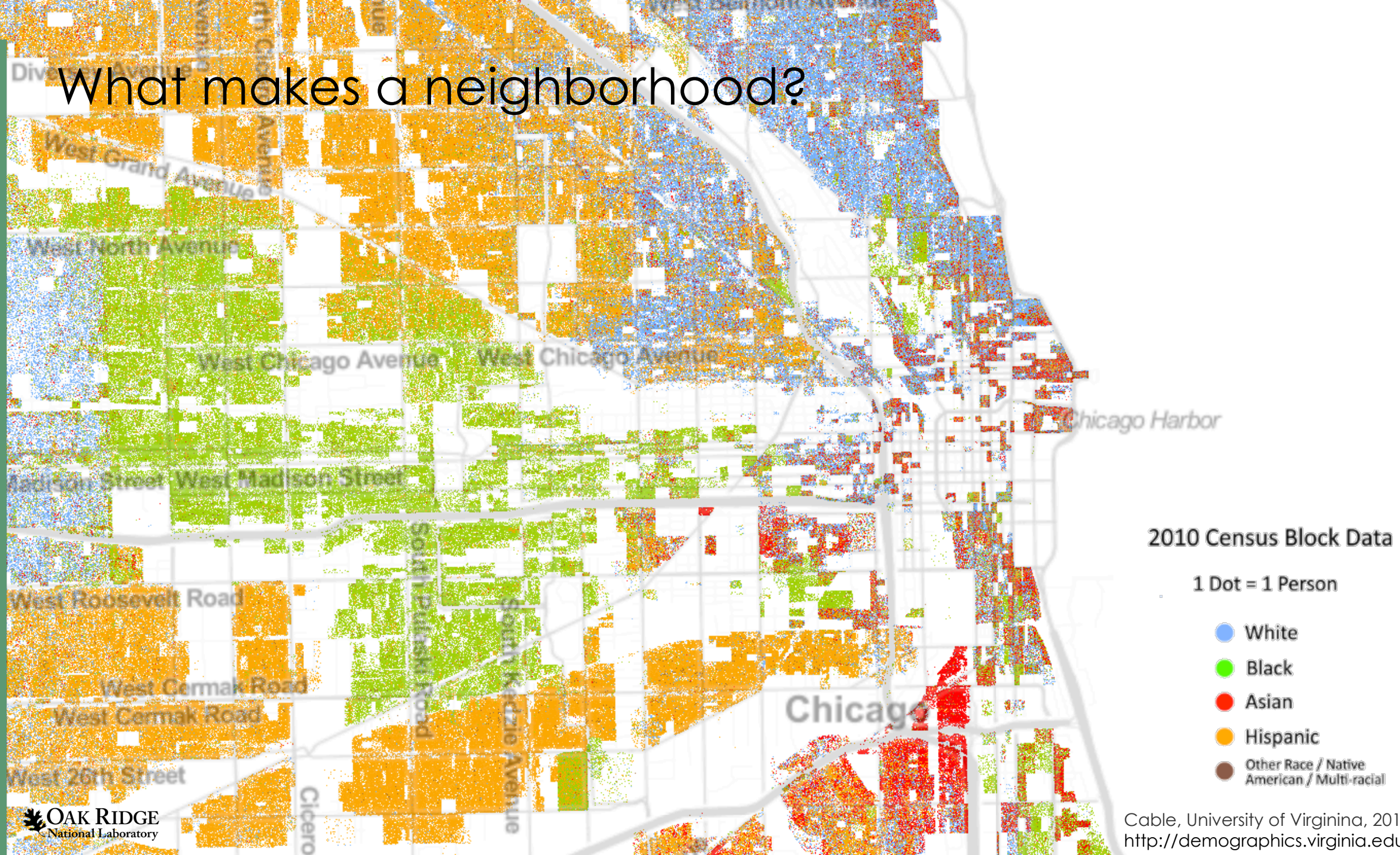
Mascussi, Stanilov and Batty. Phys Rev E. (2014)

Census Bureaus



Metropolitan and Micropolitan Statistical Areas (CBSAs) of the United States and Puerto Rico. US Census Bureau, (2017)

What makes a neighborhood?

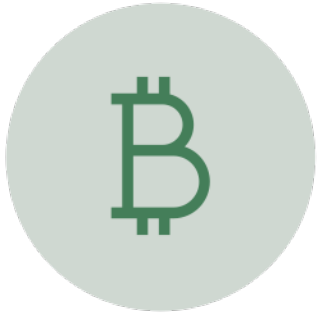


Cable, University of Virginina, 2019
http://demographics.virginia.edu/DotMap

Do distant social ties even matter?

CLIMATE

EL NIÑO



INFRASTRUCTURE:

BLACKOUTS

TRADE:

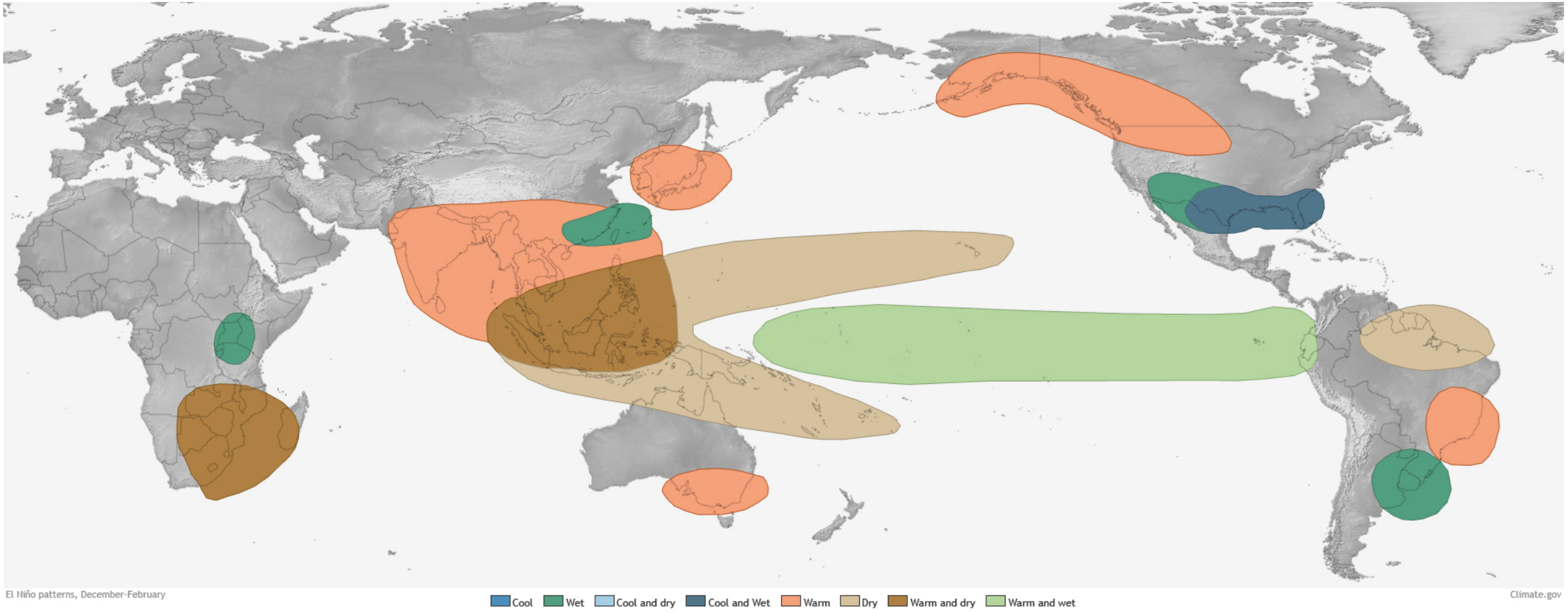
GLOBAL SHIPPING

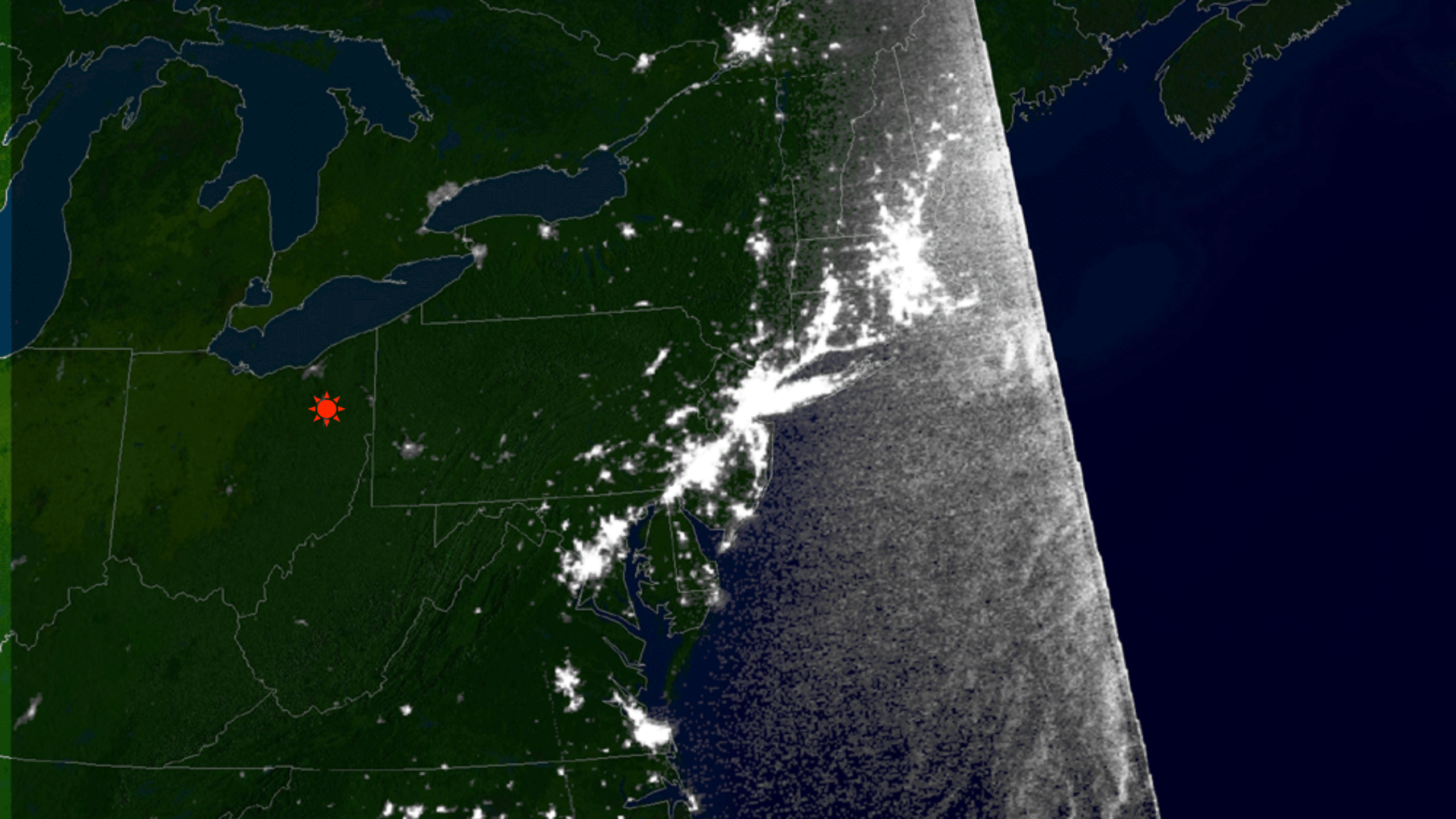
IDEAS

ARAB SPRING

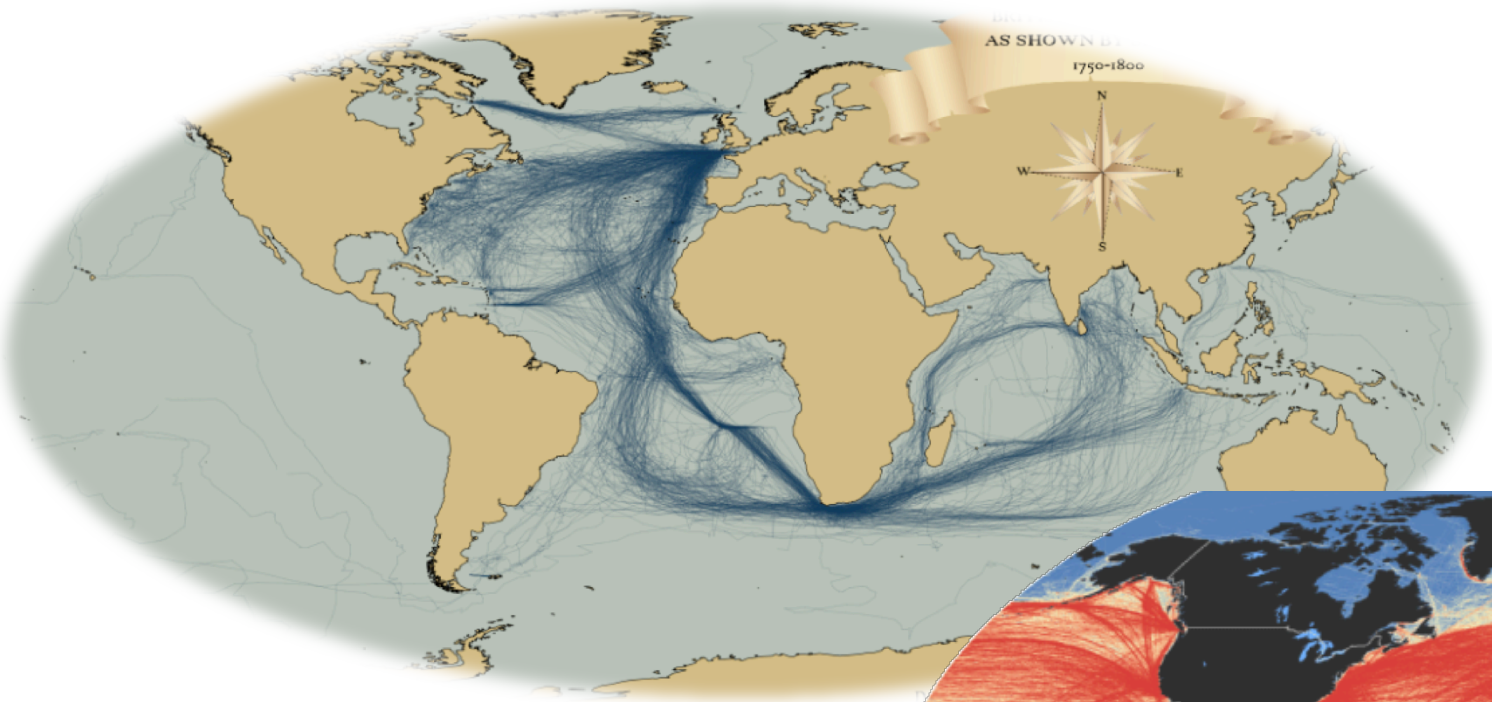
e.g. Moser & Hart (2015)

El Niño Southern Oscillation



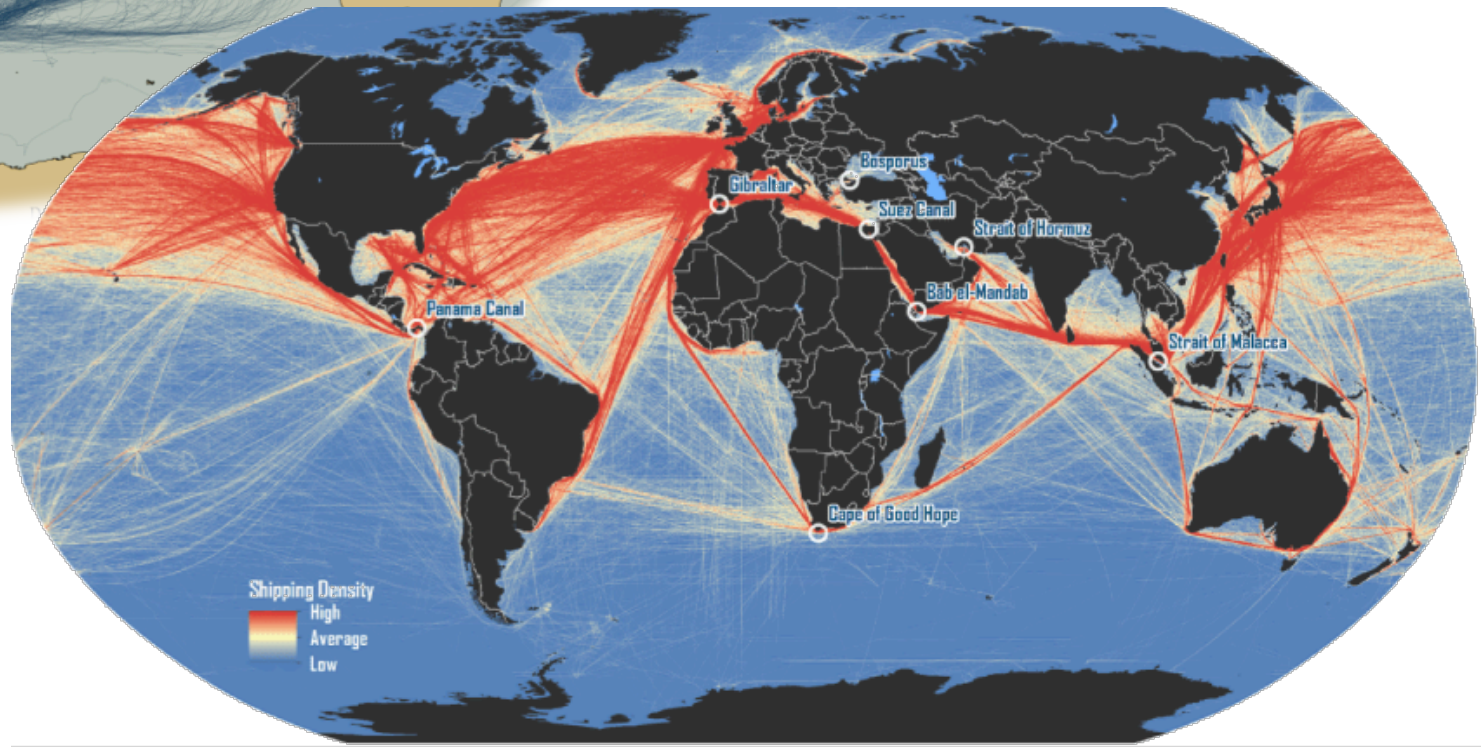


Do distant social ties even matter?



British Shipping Routes:
1750-1800

Contemporary Shipping Traffic



OAK RIDGE National Laboratory

Tunisia

December 18th, 2010
223 Deaths

OAK RIDGE National Laboratory

Algeria

December 28th, 2010
8 Deaths

OAK RIDGE National Laboratory


Lebanon
January 12th, 2011
0 Deaths
OAK RIDGE National Laboratory
Romania
Croatia
Serbia
Bulgaria
Black Sea
Georgia
Uzbekistan
Kyrgyz
Italy
Spain
Barcelona
Portugal
Naples
Albania
Istanbul
Azerbaijan
Turkmenistan
Tajikistan
Greece
Turkey
Mashhad
Tehran
Algiers
Cyprus
Afghanistan
Tunisia
Tripoli
Israel
Cairo
Kuwait
Morocco
Pakistan
Libya
Karachi
Western Sah
United Arab Emirates
Saudi Arabia
Jeddah
Mauritania
Mali
Niger
Chad
Khartoum
Eritrea
Arabian Sea
Mumbai
Senegal
Sudan
Guinea-Bissau
Guinea
Burkina Faso
Kano
Benin
Nigeria
Sierra Leone
Ivory Coast
Togo
Ethiopia
Liberia
Ghana
Lagos
Central African Republic
South Sudan
Somalia
Cameroon
Equatorial Guinea
Gabon
Republic of the Congo
Democratic Republic of
Uganda
Kenya
Rwanda
Nairobi


Jordan
January 14th, 2011
1 Death
OAK RIDGE National Laboratory
Romania
Croatia
Serbia
Bulgaria
Black Sea
Georgia
Uzbekistan
Kyrgyz
Italy
Spain
Barcelona
Portugal
Naples
Albania
Istanbul
Azerbaijan
Turkmenistan
Tajikistan
Greece
Turkey
Mashhad
Tehran
Algiers
Tunisia
Tripoli
Afghanistan
Morocco
Cairo
Kuwait
Pakistan
Libya
Egypt
Karachi
Western Sahara
Saudi Arabia
United Arab Emirates
Jeddah
Mumbai
Mauritania
Mali
Niger
Chad
Khartoum
Eritrea
Yemen
Arabian Sea
Senegal
Sudan
Guinea-Bissau
Guinea
Burkina Faso
Kano
Benin
Nigeria
Sierra Leone
Ivory Coast
Togo
Ethiopia
Liberia
Ghana
Lagos
Central African Republic
South Sudan
Somalia
Cameroon
Equatorial Guinea
Gabon
Republic of the Congo
Democratic Republic of the Congo
Uganda
Kenya
Rwanda
Nairobi
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18

Mauritania, Sudan, Oman

January 17th, 2011
6 Deaths

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OAK RIDGE National Laboratory

Yemen

January 18th, 2011
1,800 Deaths (ongoing)


Saudi Arabia
January 21st, 2011
6 Deaths
Arabian Sea
Black Sea
Romania
Croatia
Serbia
Bulgaria
Italy
Spain
Portugal
Barcelona
Naples
Albania
Istanbul
Greece
Turkey
Georgia
Azerbaijan
Uzbekistan
Kyrgyz
Turkmenistan
Tajikistan
Mashhad
Tehran
Afghanistan
Pakistan
Algiers
Tunisia
Tripoli
Cyprus
Israel
Cairo
Kuwait
Morocco
Libya
Egypt
Saudi Arabia
United Arab Emirates
Jeddah
Karachi
Mumbai
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
Khartoum
Eritrea
Senegal
Guinea-Bissau
Guinea
Sierra Leone
Liberia
Ivory Coast
Ghana
Burkina Faso
Kano
Benin
Togo
Nigeria
Lagos
Cameroon
Central African Republic
South Sudan
Ethiopia
Somalia
Kenya
Uganda
Rwanda
Nairobi
Democratic Republic of the Congo
Republic of the Congo
Gabon
Equatorial Guinea
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OAK RIDGE National Laboratory


Egypt
January 25th, 2011
846 Deaths
OAK RIDGE National Laboratory
Romania
Croatia
Serbia
Bulgaria
Black Sea
Georgia
Uzbekistan
Kyrgyz
Italy
Spain
Barcelona
Portugal
Naples
Albania
Istanbul
Azerbaijan
Turkmenistan
Tajikistan
Greece
Turkey
Mashhad
Tehran
Algiers
Cyprus
Afghanistan
Tunisia
Tripoli
Israel
Cairo
Kuwait
Pakistan
Karachi
Libya
United Arab Emirates
Western Sah
Jeddah
Mauritania
Mali
Niger
Chad
Khartoum
Eritrea
Arabian Sea
Senegal
Sudan
Guinea-Bissau
Guinea
Burkina Faso
Kano
Benin
Nigeria
Sierra Leone
Ivory Coast
Togo
Ghana
Liberia
Lagos
Ethiopia
South Sudan
Central African Republic
Somalia
Cameroon
Equatorial Guinea
Gabon
Republic of the Congo
Democratic Republic of
Uganda
Kenya
Rwanda
Nairobi
Mumbai
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Djibouti

January 28th, 2011
2 Deaths

OAK RIDGE National Laboratory

Morocco

January 30th, 2011
0 Deaths

OAK RIDGE National Laboratory

Iraq

February 10th, 2011
29 Deaths

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Bahrain, Iran
February 14th, 2011
61 Deaths
OAK RIDGE National Laboratory
Romania
Croatia
Serbia
Bulgaria
Black Sea
Georgia
Uzbekistan
Kyrgyz
Italy
Spain
Barcelona
Naples
Albania
Istanbul
Azerbaijan
Portugal
Greece
Turkey
Turkmenistan
Tajikistan
Mashhad
Tehran
Algiers
Cyprus
Afghanistan
Tunisia
Tripoli
Israel
Cairo
Kuwait
Pakistan
Libya
Karachi
United Arab Emirates
Jeddah
Saudi Arabia
Western Sahara
Mauritania
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Guinea
Burkina Faso
Kano
Benin
Nigeria
Sierra Leone
Ivory Coast
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Liberia
Lagos
Ethiopia
South Sudan
Central African Republic
Somalia
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Equatorial Guinea
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Republic of the Congo
Democratic Republic of the Congo
Uganda
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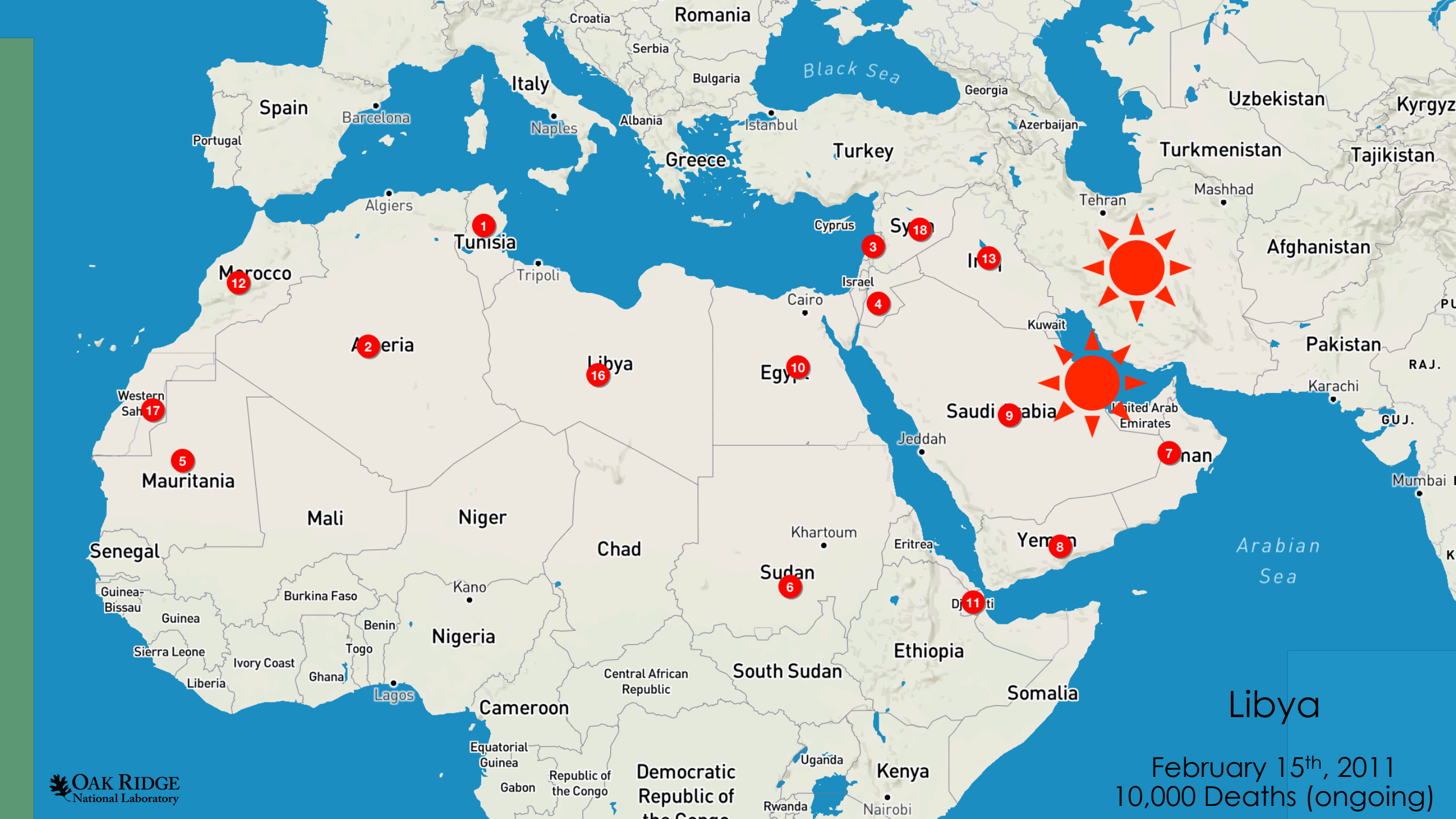

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Western Sahara

February 20th, 2011
1 Death

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Syria

March 15th, 2011
40,000 Deaths (ongoing)

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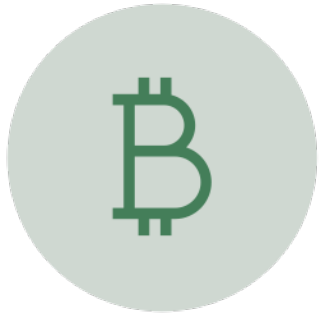
Teleconnections have an effect on the world.

CLIMATE:

EL NIÑO



INFRASTRUCTURE:

BLACKOUTS

TRADE:

GREAT DEPRESSION

IDEAS

ARAB SPRING

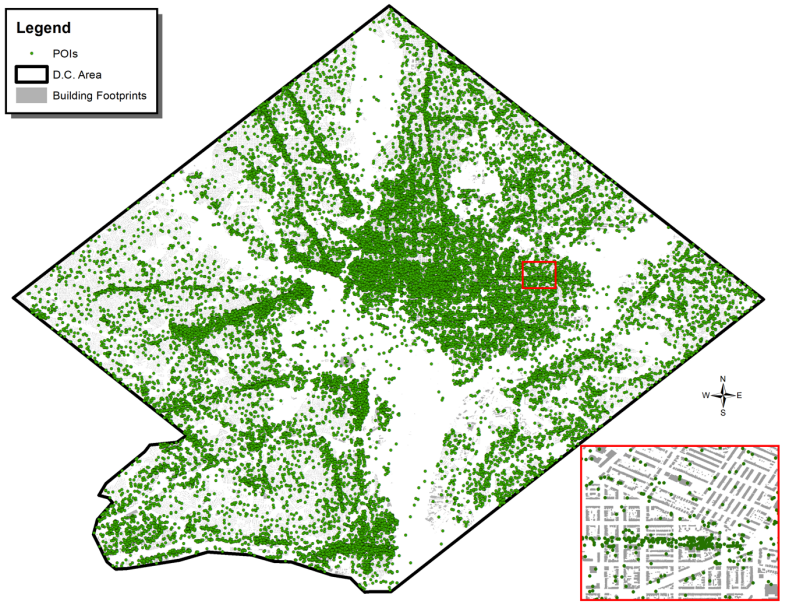
How can we measure them?

e.g. Moser & Hart (2015)

Geo-located tweets give a measure of spatially embedded social structure.

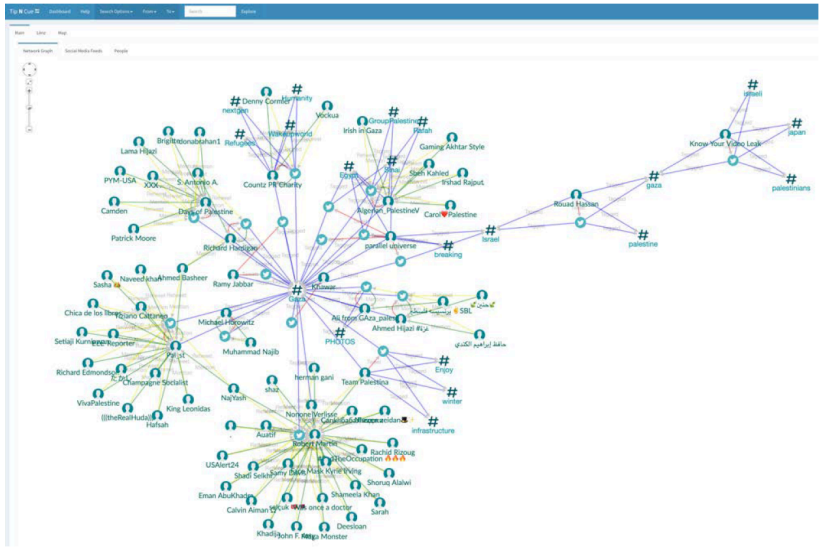
Thakur, Bhaduri, Piburn, Sims, Stewart, Urban.
ACM SIGSPATIAL Proceedings (2015)
http://arxiv.org/abs/1507.05245

Points of Interest



Sparks, Palumbo, in prep. 2019

Tweets



Thakur 2019

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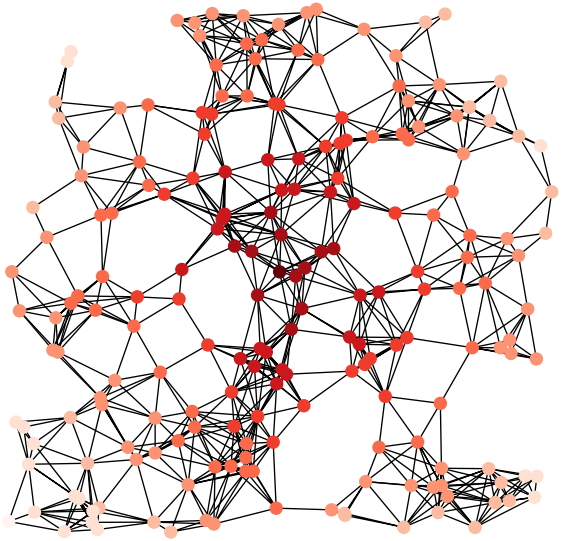
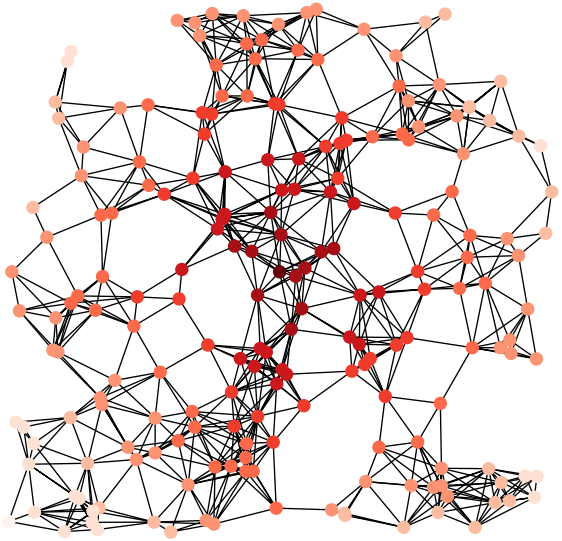
Methods

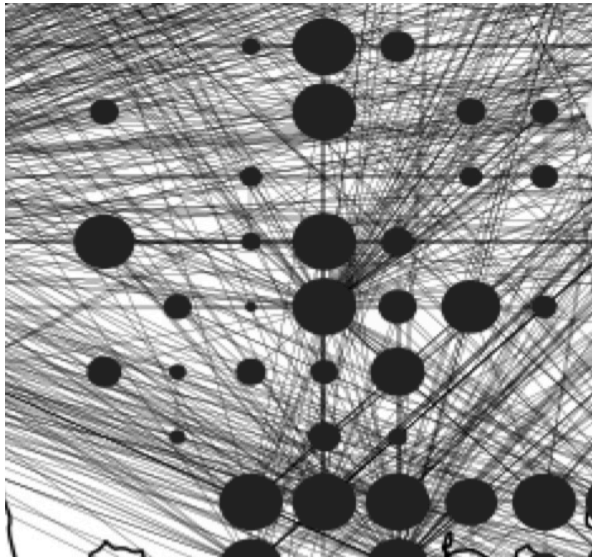
- An aspatial network of direct twitter mentions is created



Methods

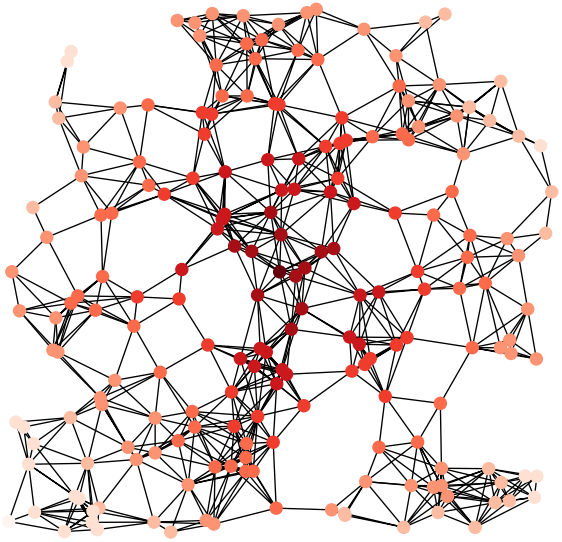
- An aspatial network of direct twitter mentions is created
- Those tweets are aggregated into grid cells

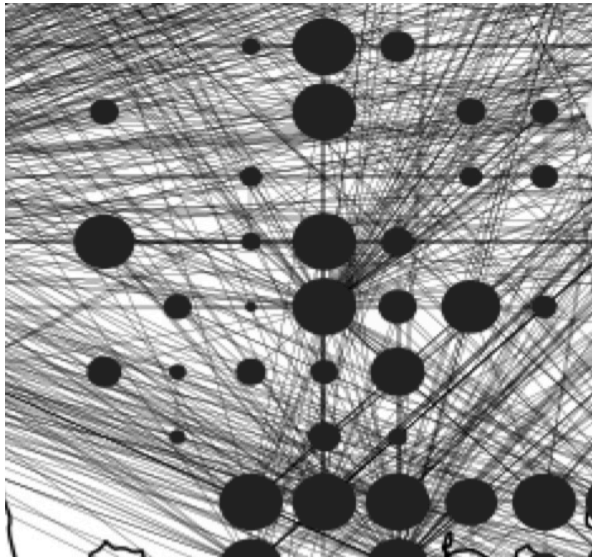


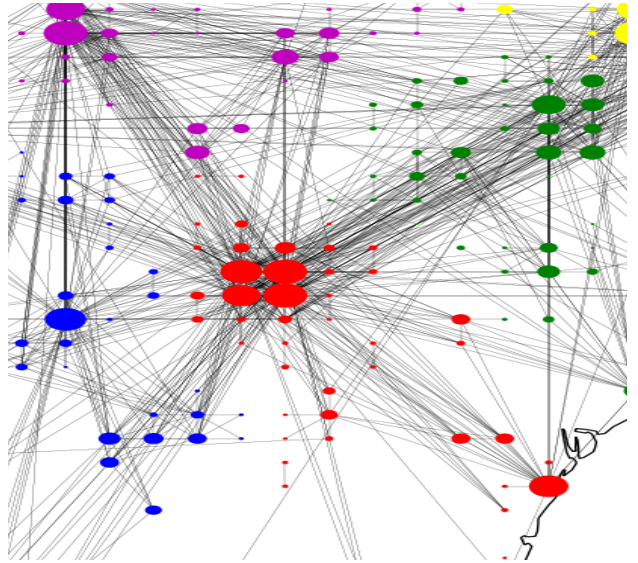


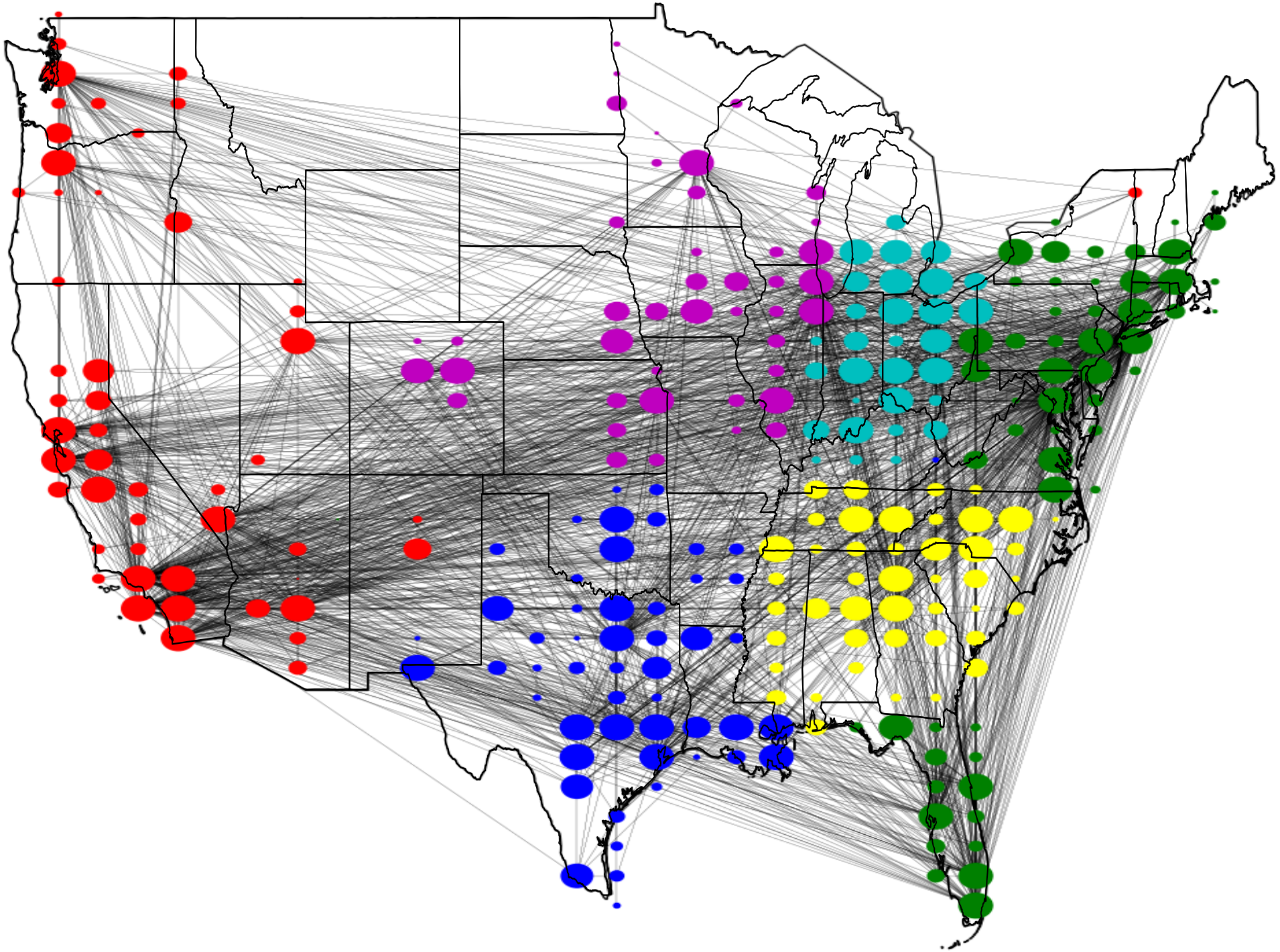
Methods

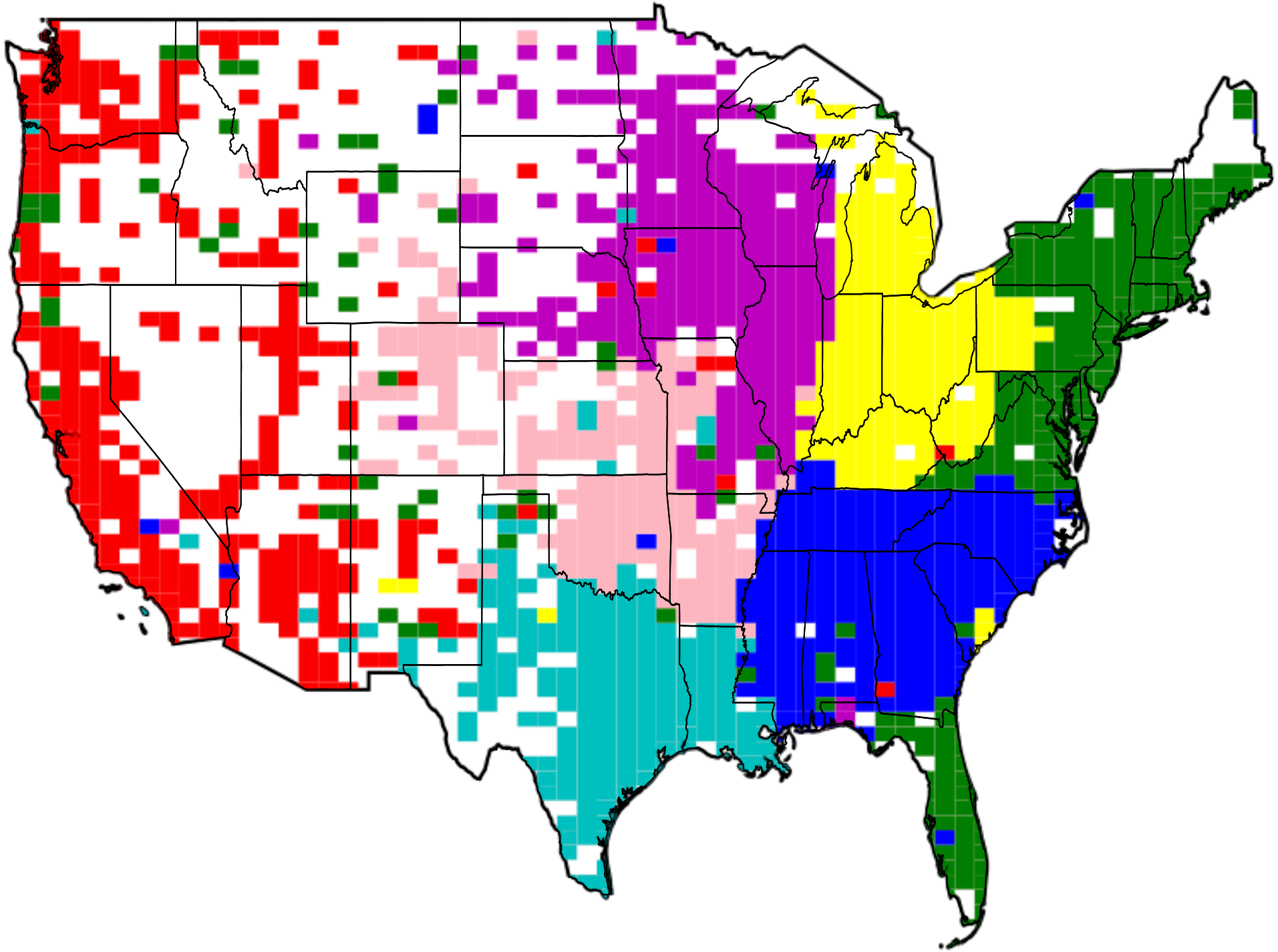
- An aspatial network of direct twitter mentions is created
- Those tweets are aggregated into grid cells
- Clusters within the aggregate network are identified.

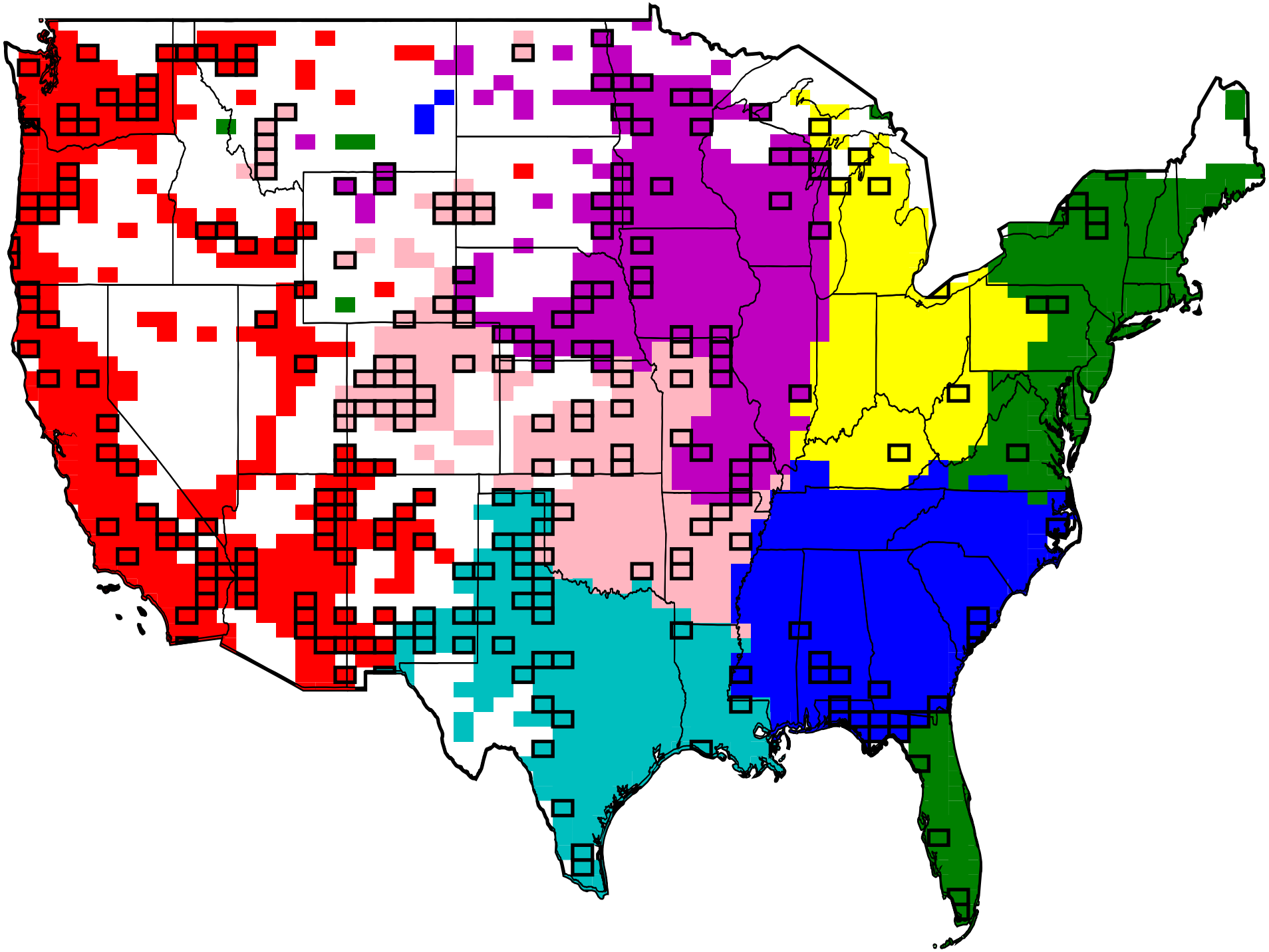




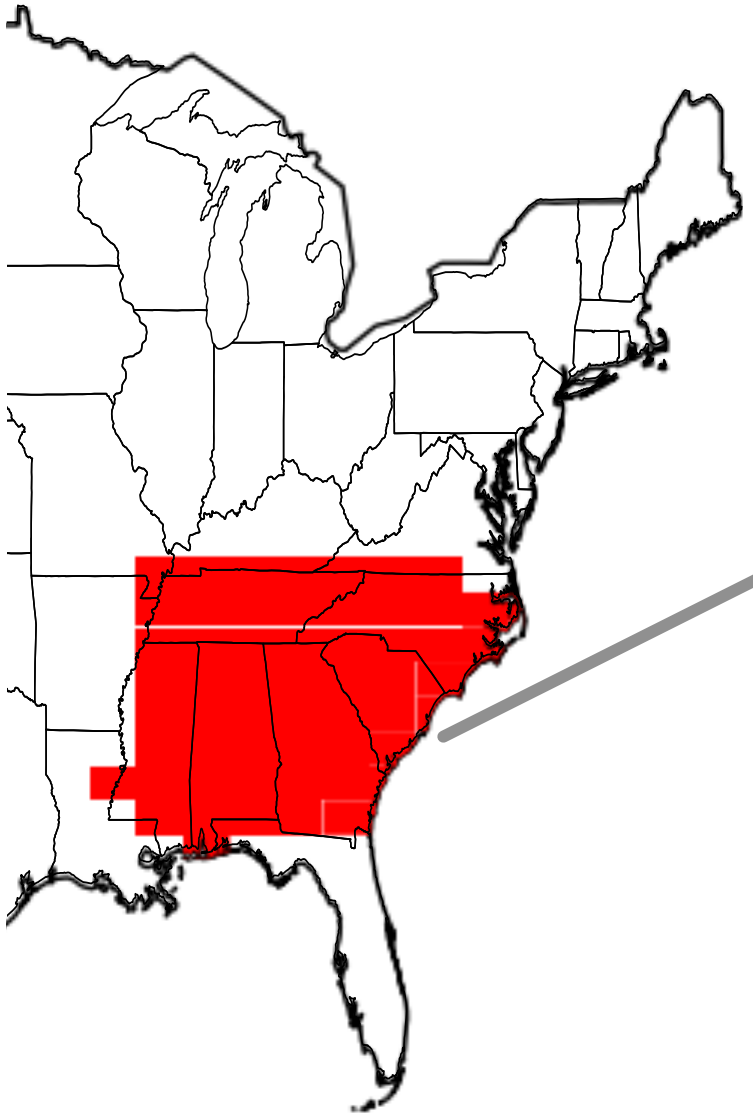


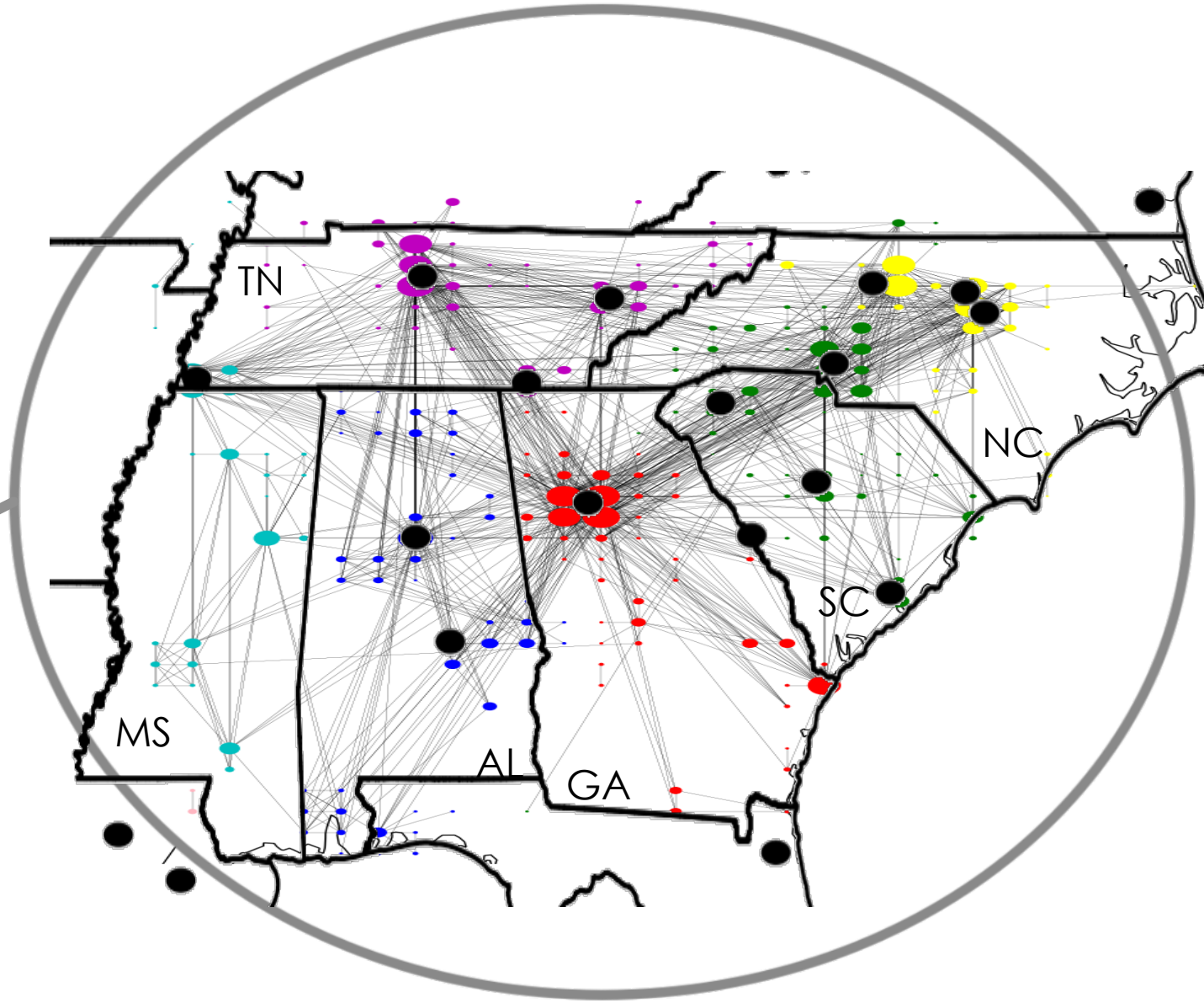






Southern States




TN
NC
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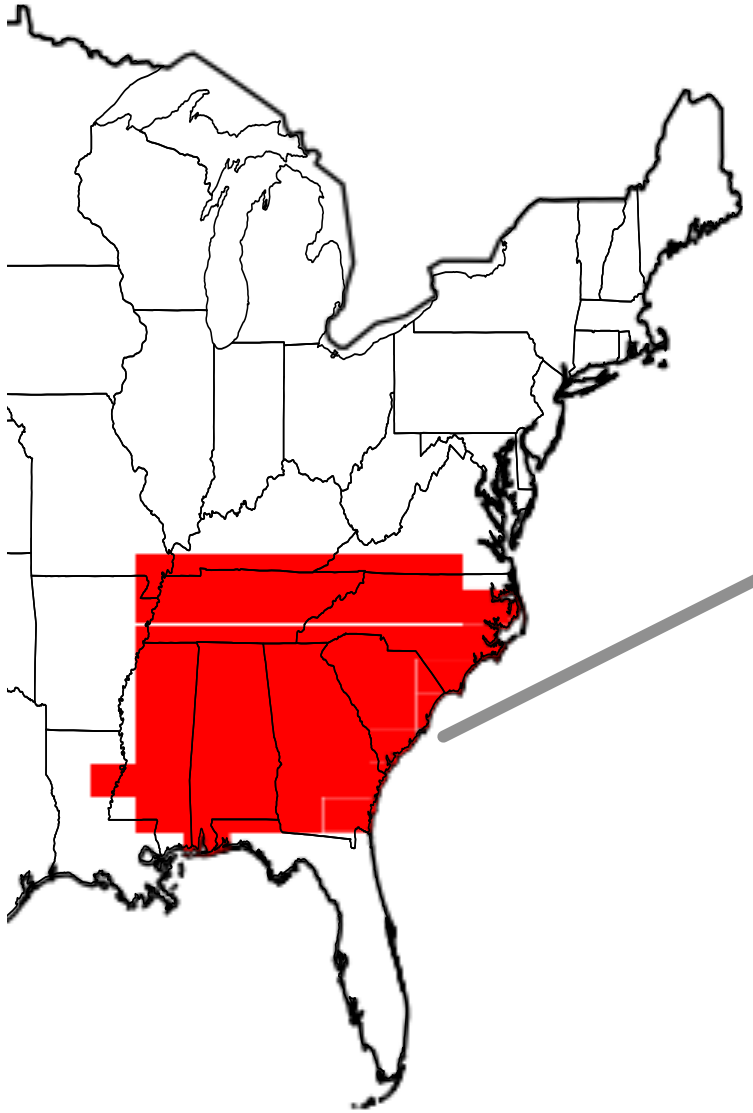

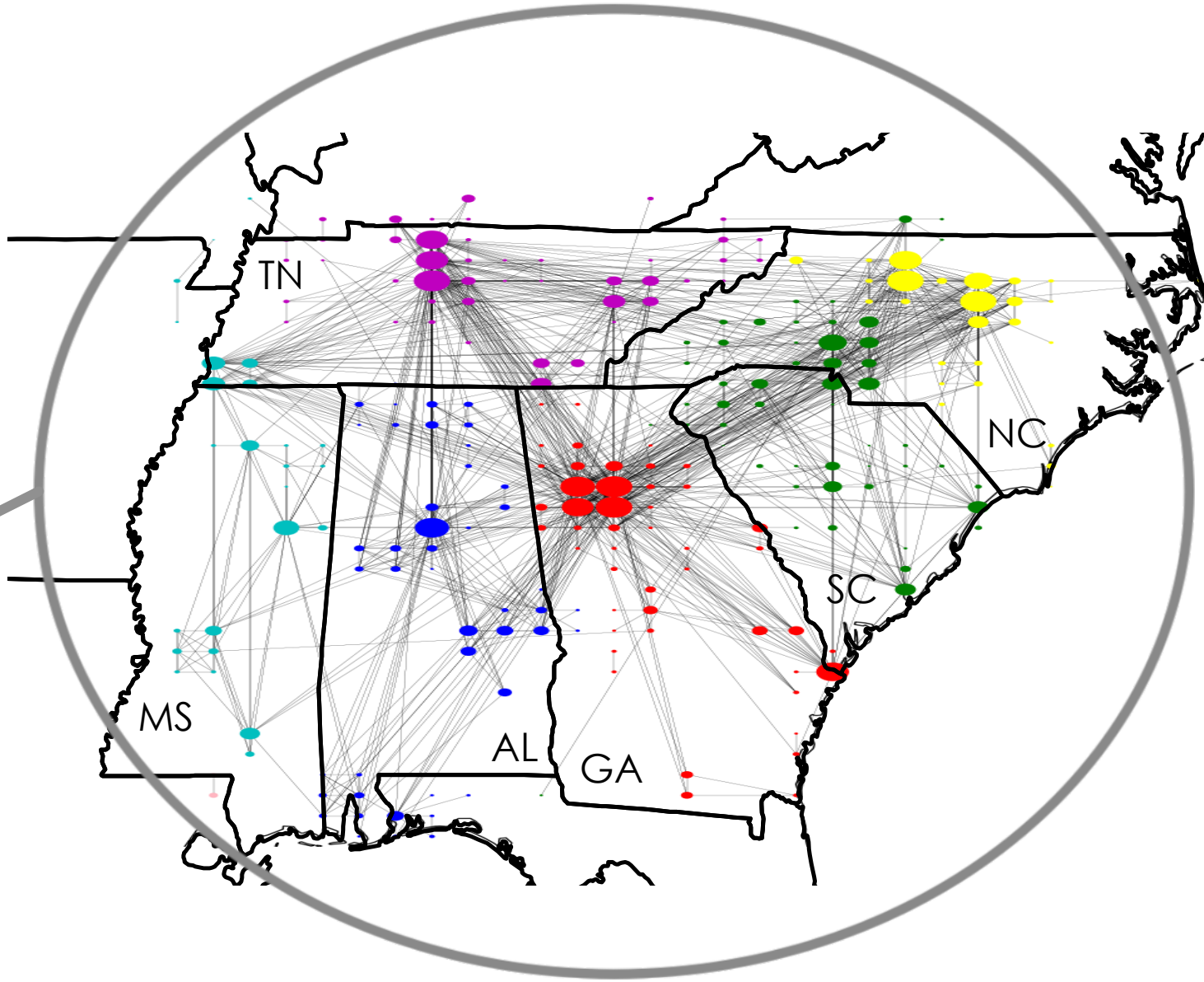
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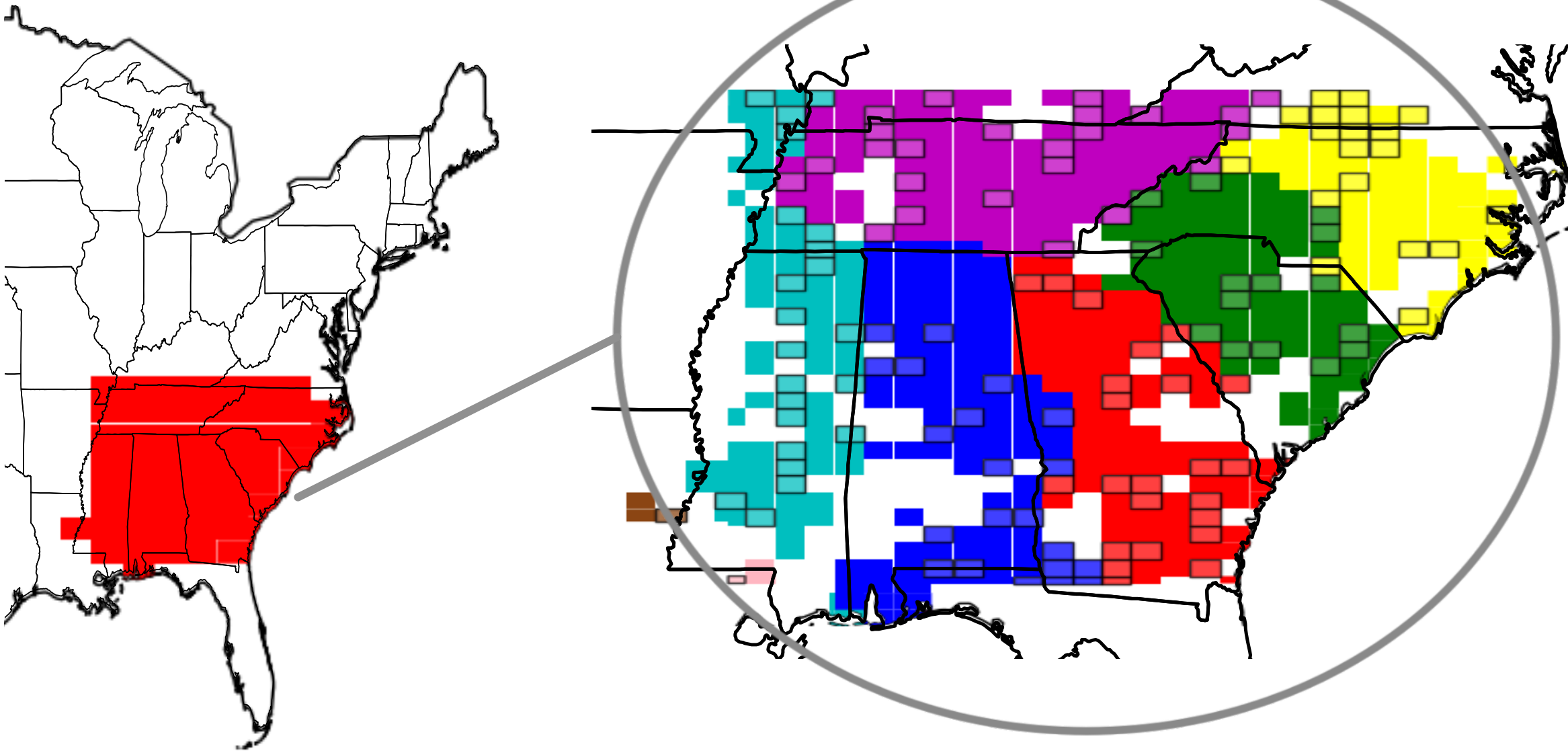
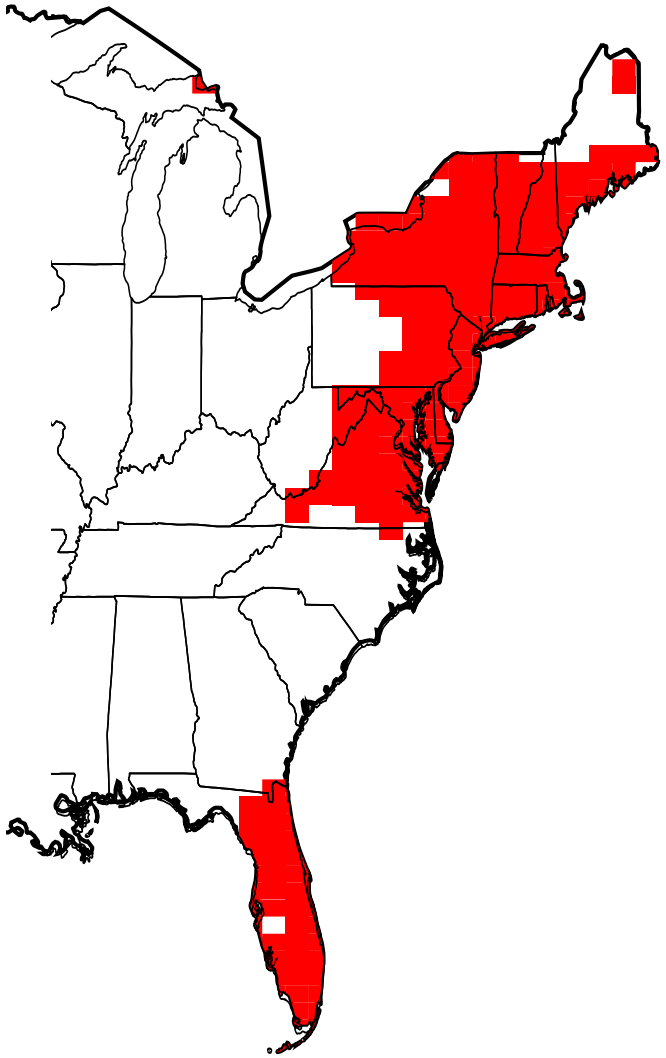
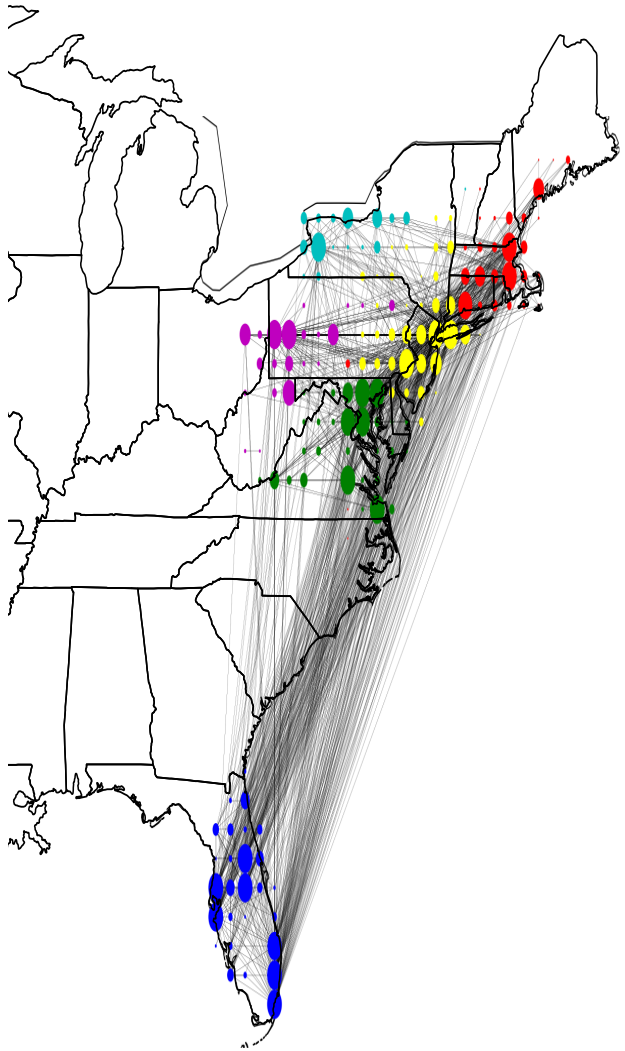
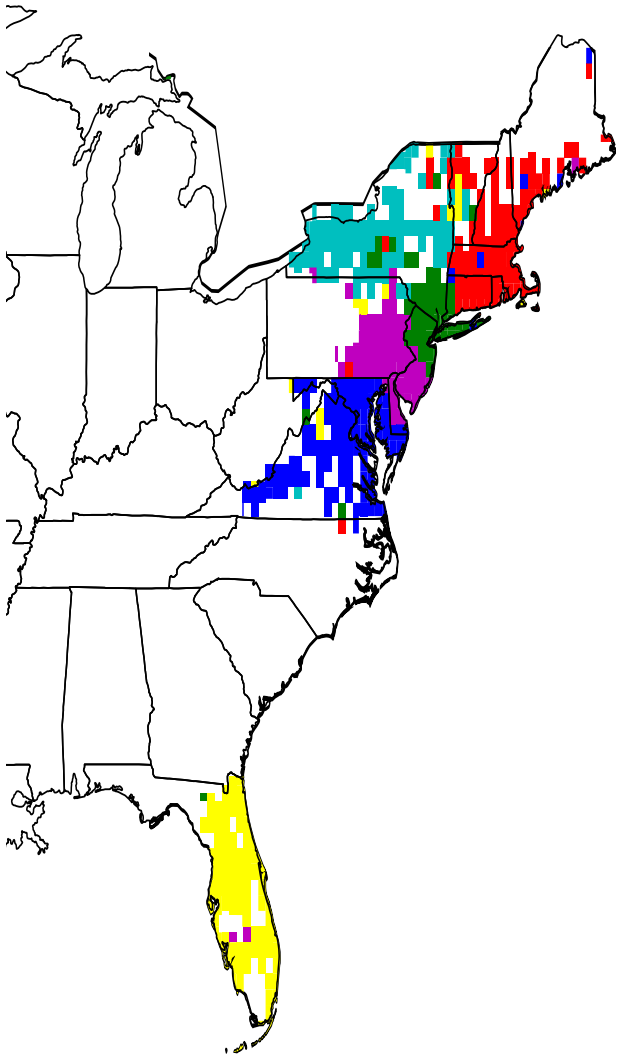
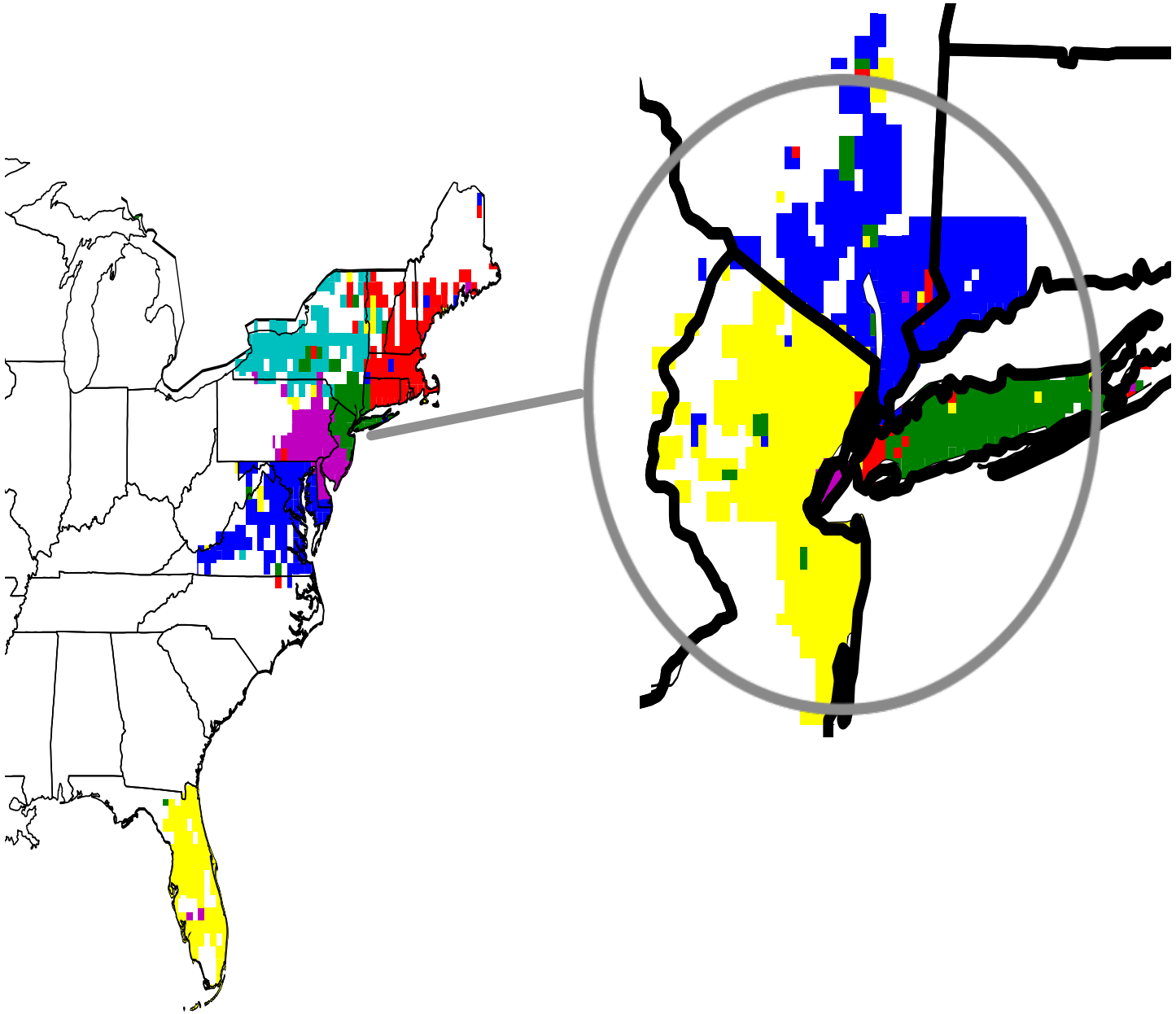


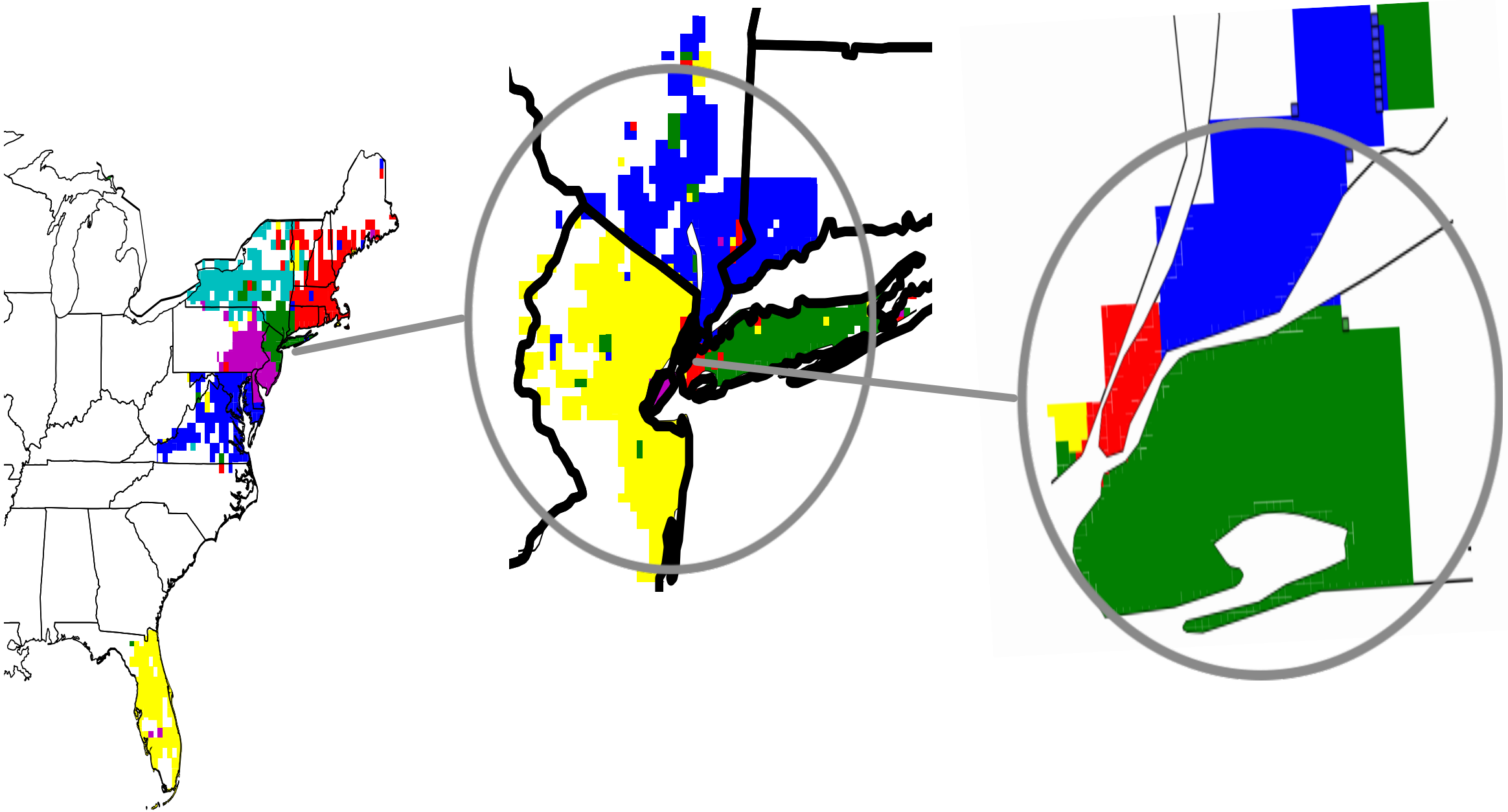
Urban NorthEast



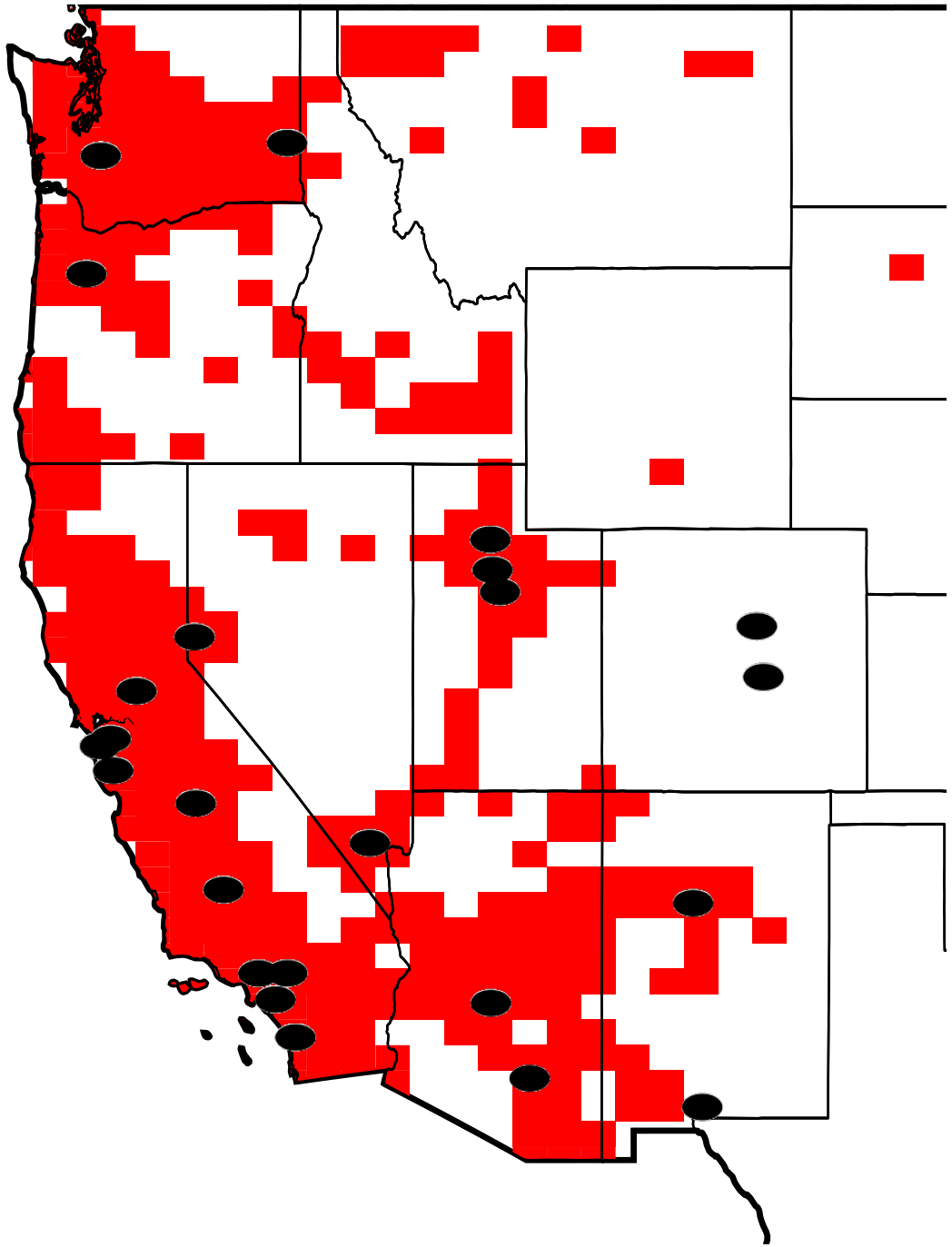


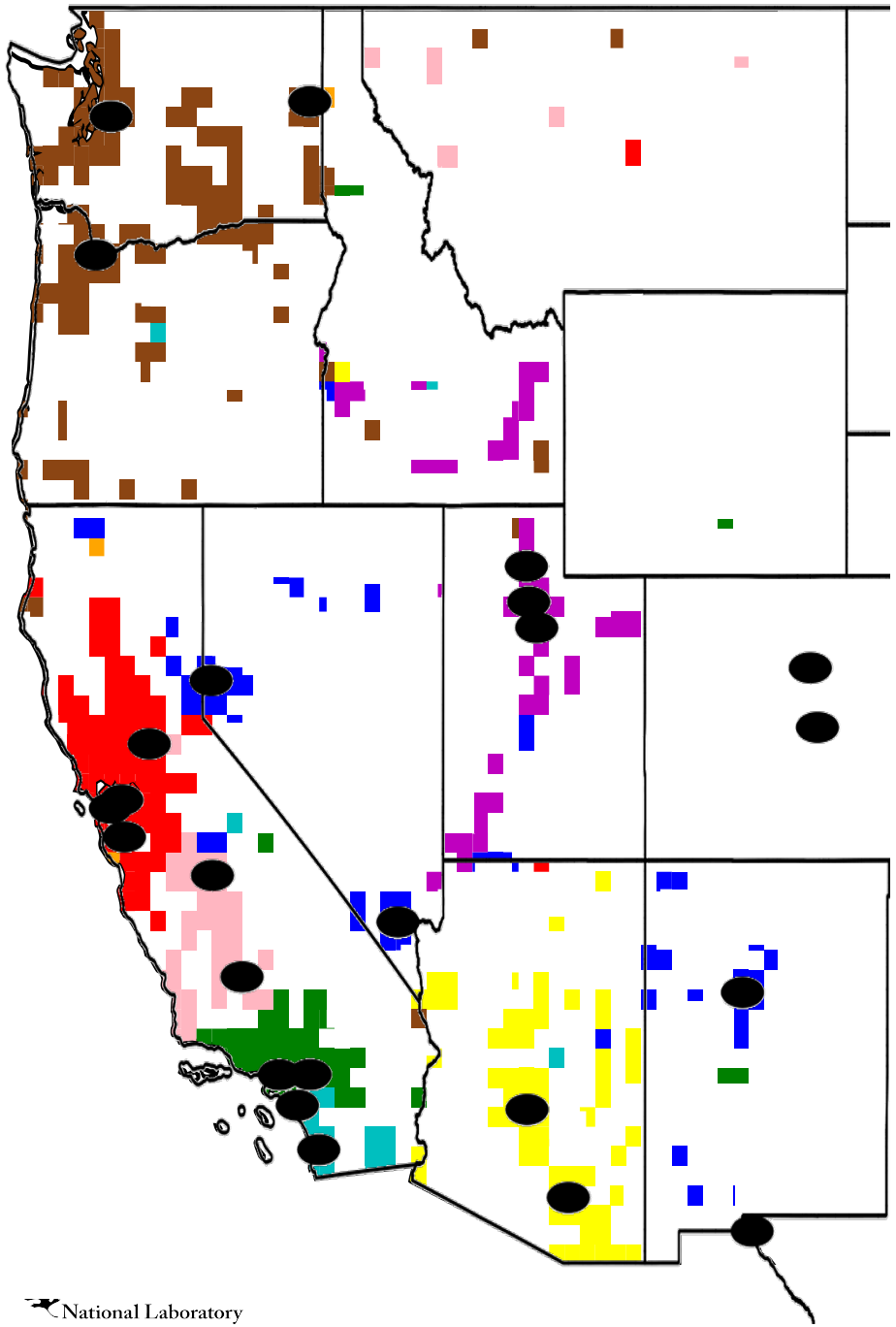


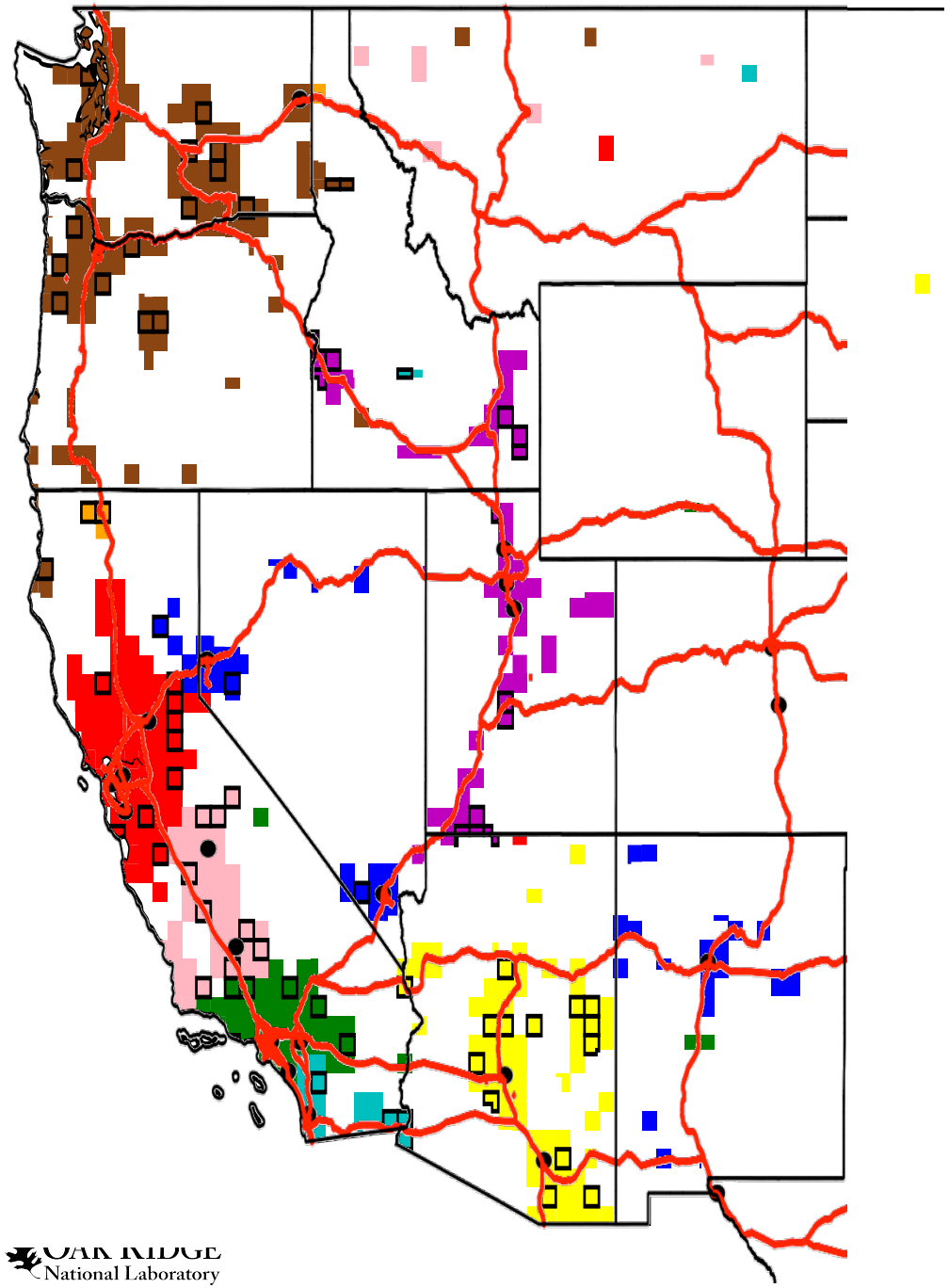


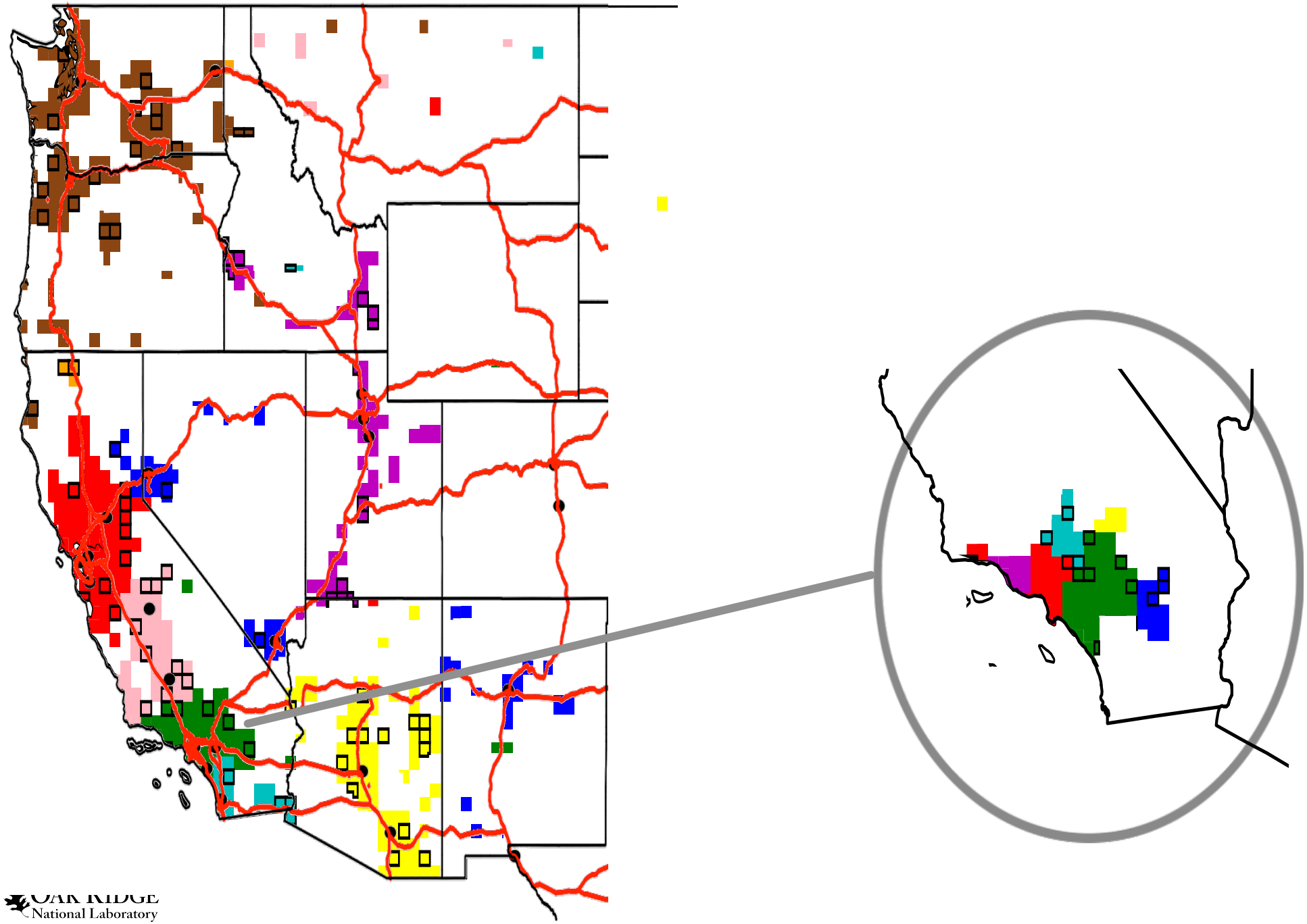


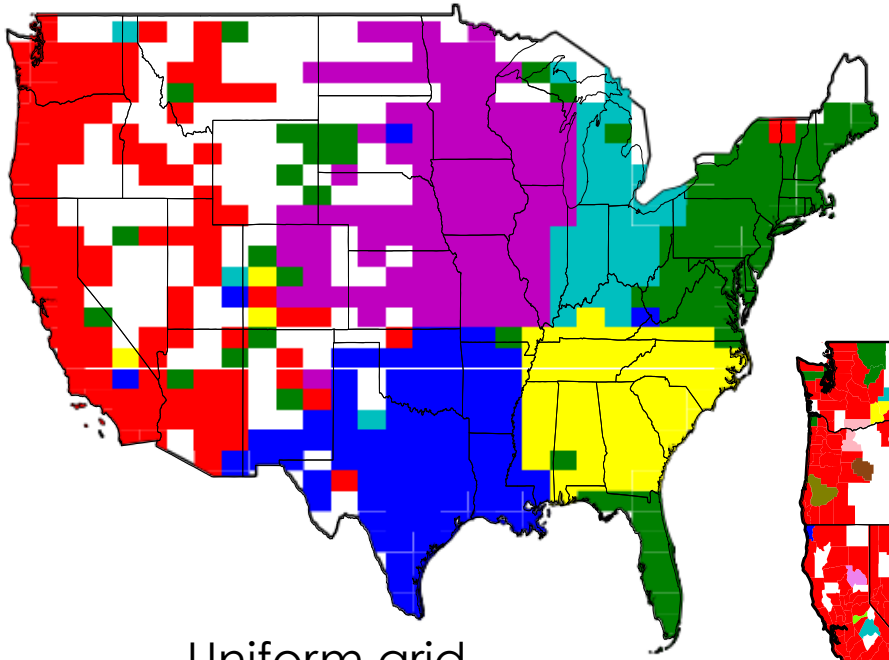
WESTERN STATES



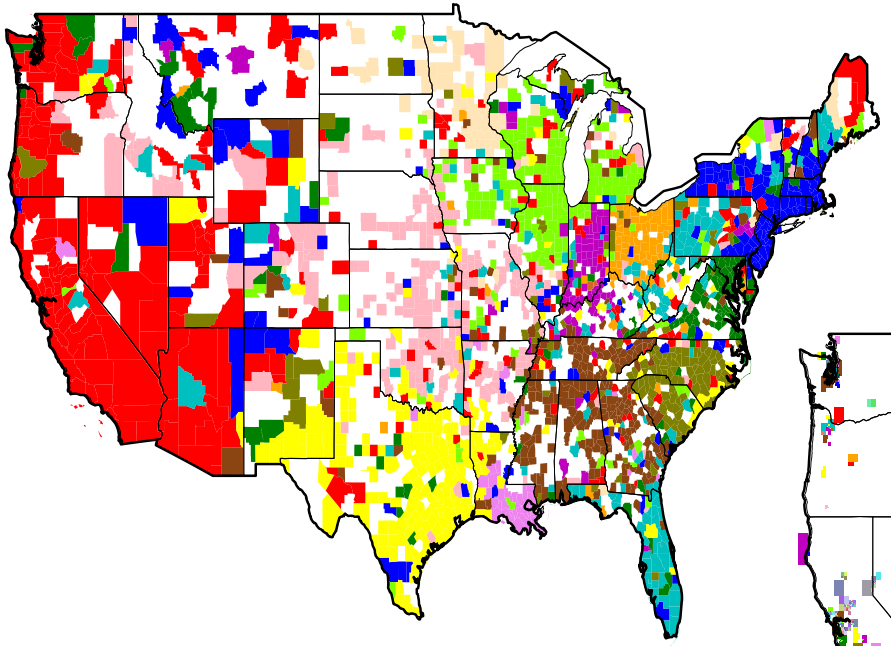




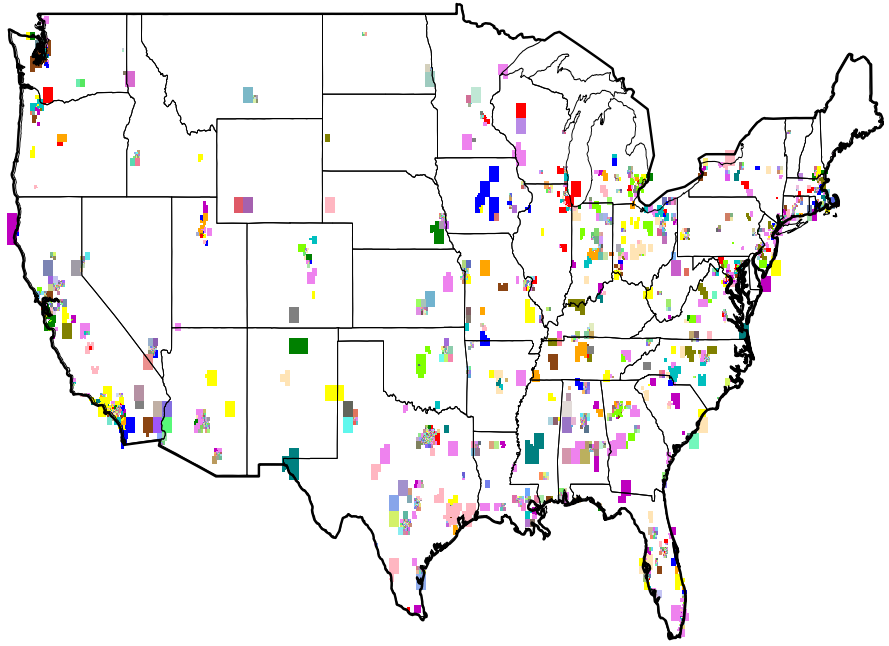




Uniform grid



US counties



Population dependent grid size

How does this dataset inform our understanding of societal teleconnections?

Results & Conclusions

- This is a globally scalable method that can be applied to any relational geographic dataset.
- Internationally consistent.
- Regional clusters from twitter in the United States broadly concur with typical descriptions of regions.
- Level 1 hierarchical clusters begin to identify major urban areas, and level 2 clusters identify sub-city regions that are consistent with known socio-political regions.

Challenge Questions

- How can we use multi-scalar research to better understand urban processes? Which processes should be studied at which scales?
- What theoretical and empirical tools are useful for thinking about how processes at different scales interact with each other and co-evolve?

Thank You!

brelsfordcm@ornl.gov

www.christabrelsford.com

co-authors & collaborators : Luís Bettencourt,, Mollie Gaines, José Lobo, Gautam Thakur, Rudy Arthur, Hywel Williams.