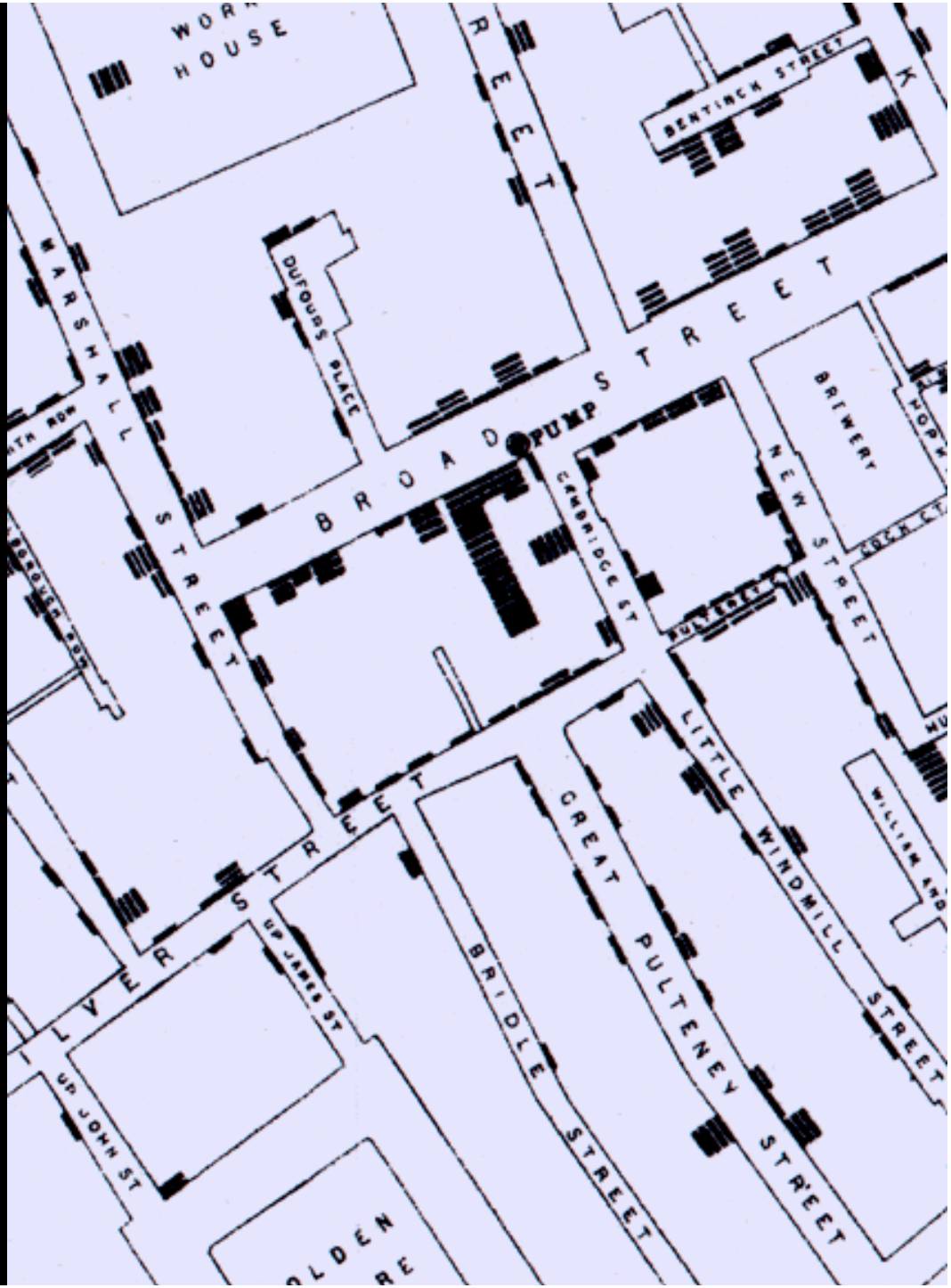
Spatial ecology of disease



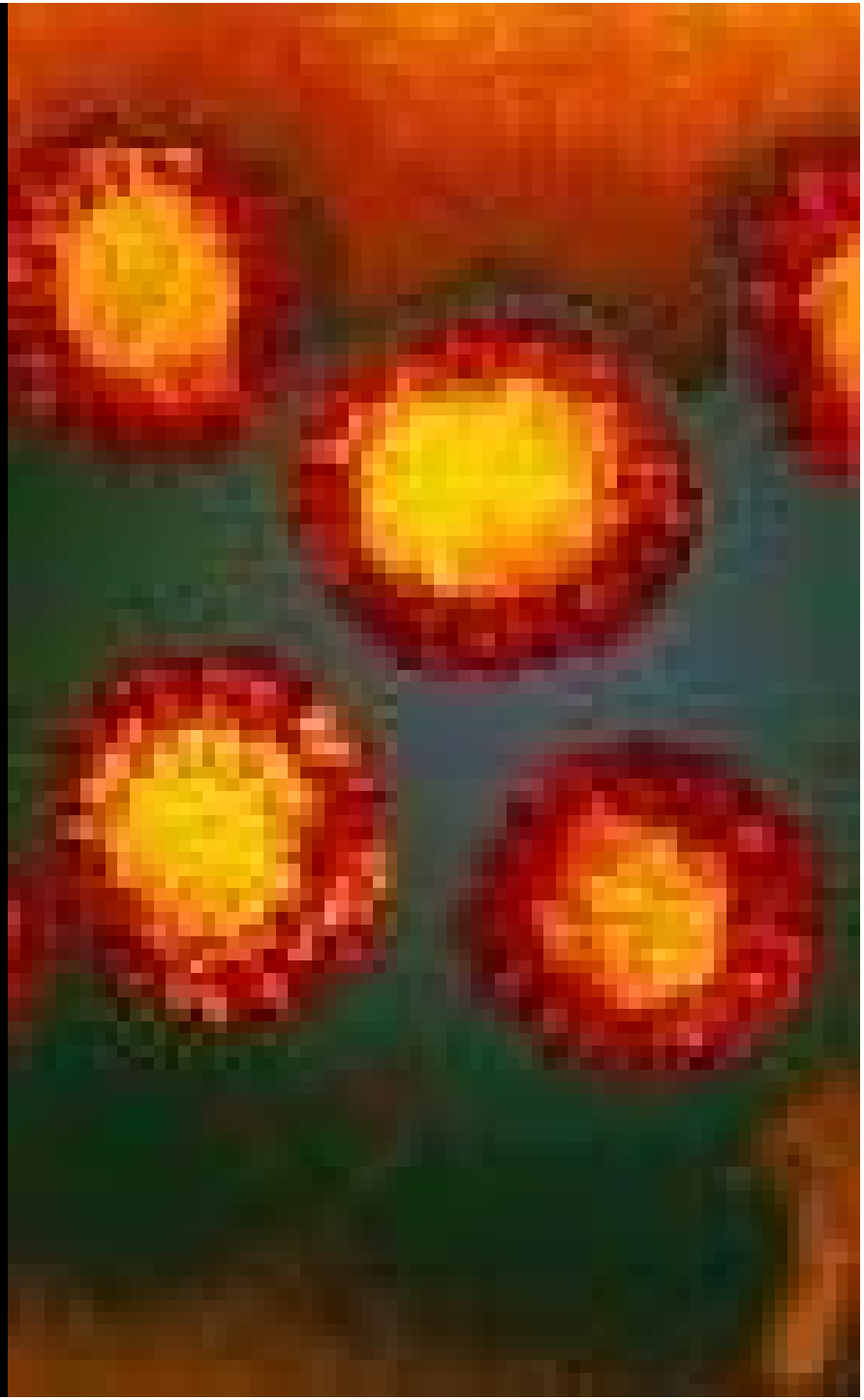
What is a disease outbreak?

Cluster – observation of above-normal number of cases

Outbreak – sudden increase in disease cases

Epidemic – outbreak on large scale

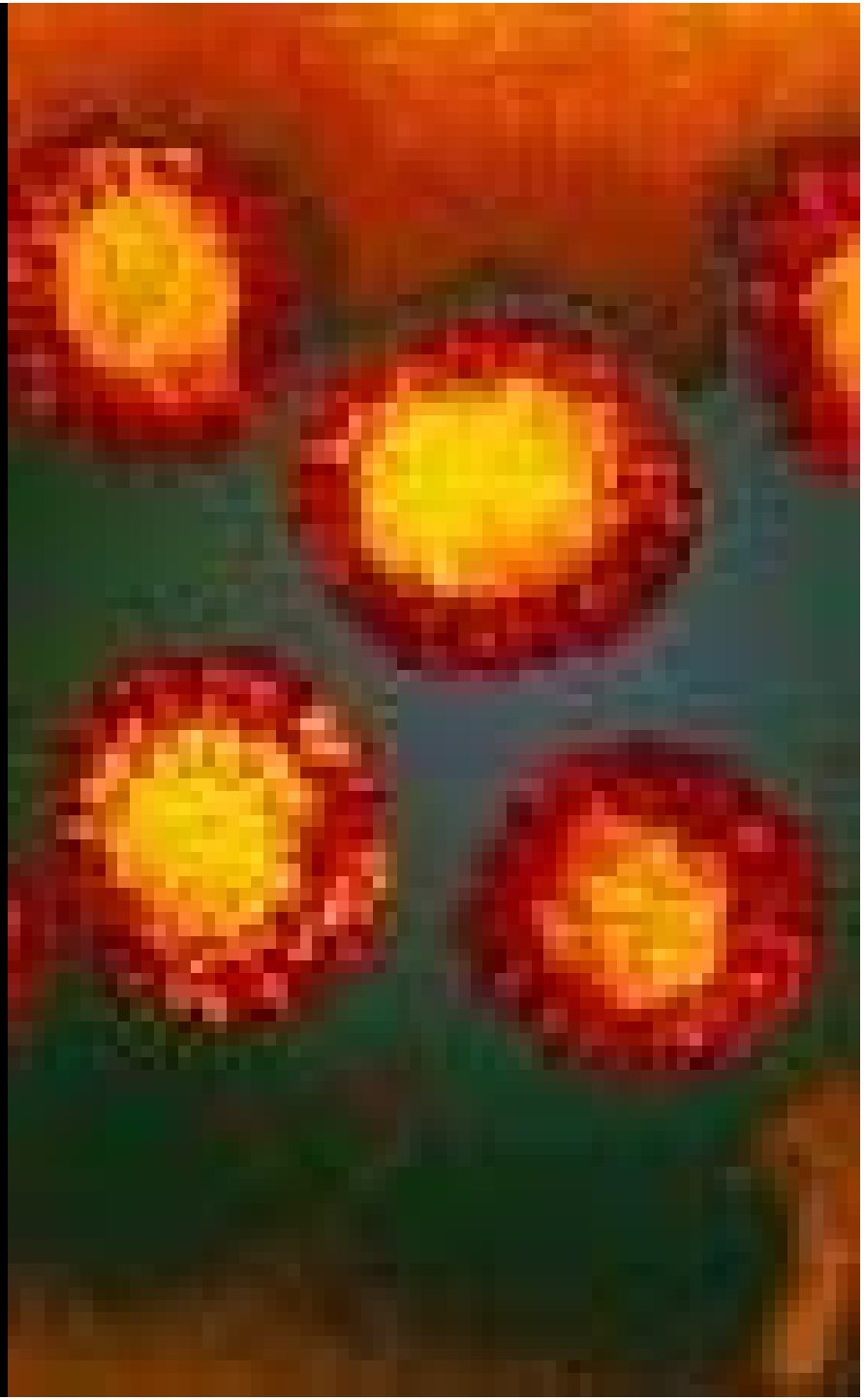
Pandemic – outbreak at international/global scale

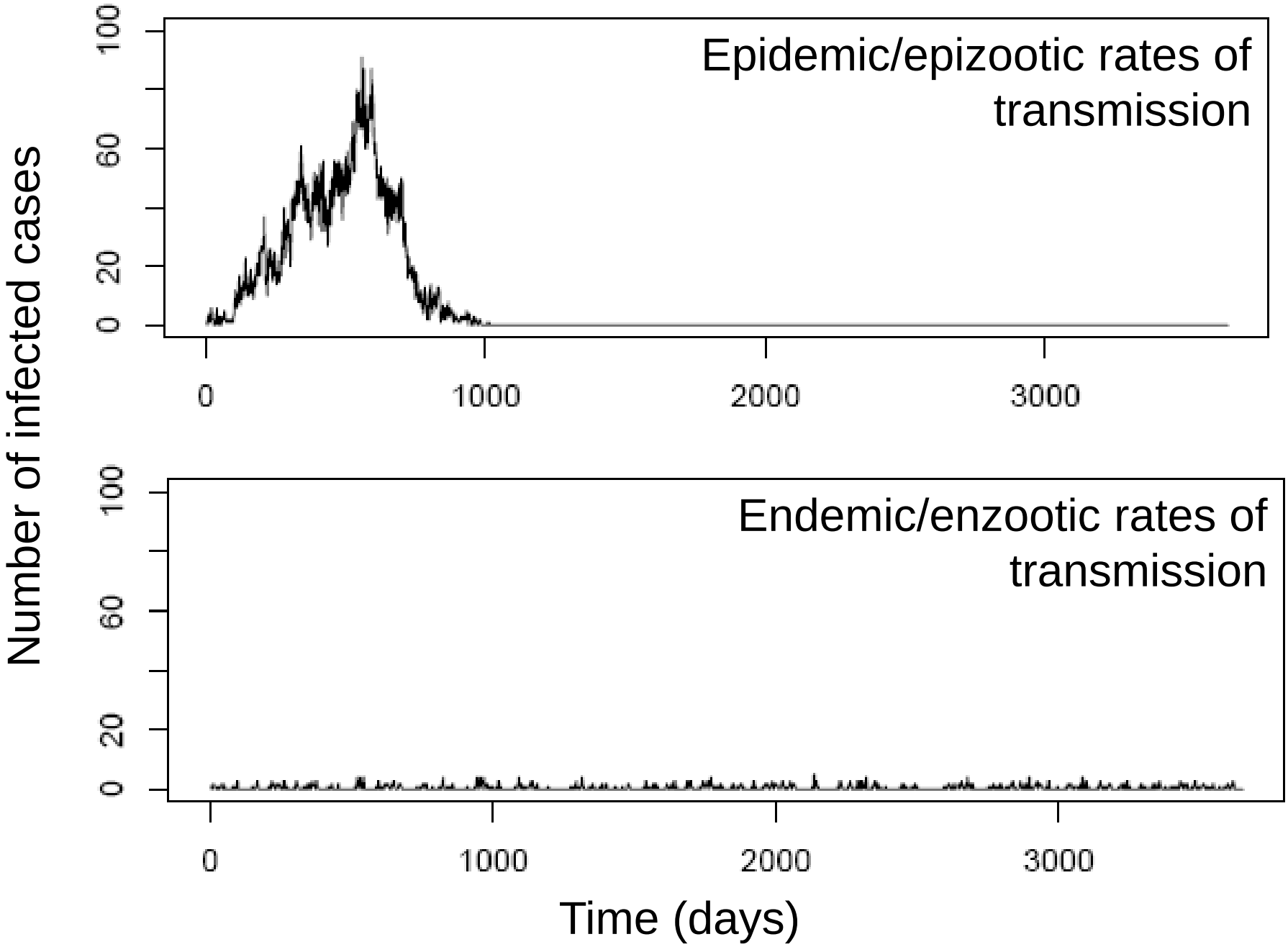


Endemic – normal, baseline, natural distribution/rates of disease

Epizootic – epidemic for wildlife

Enzootic – endemic for wildlife



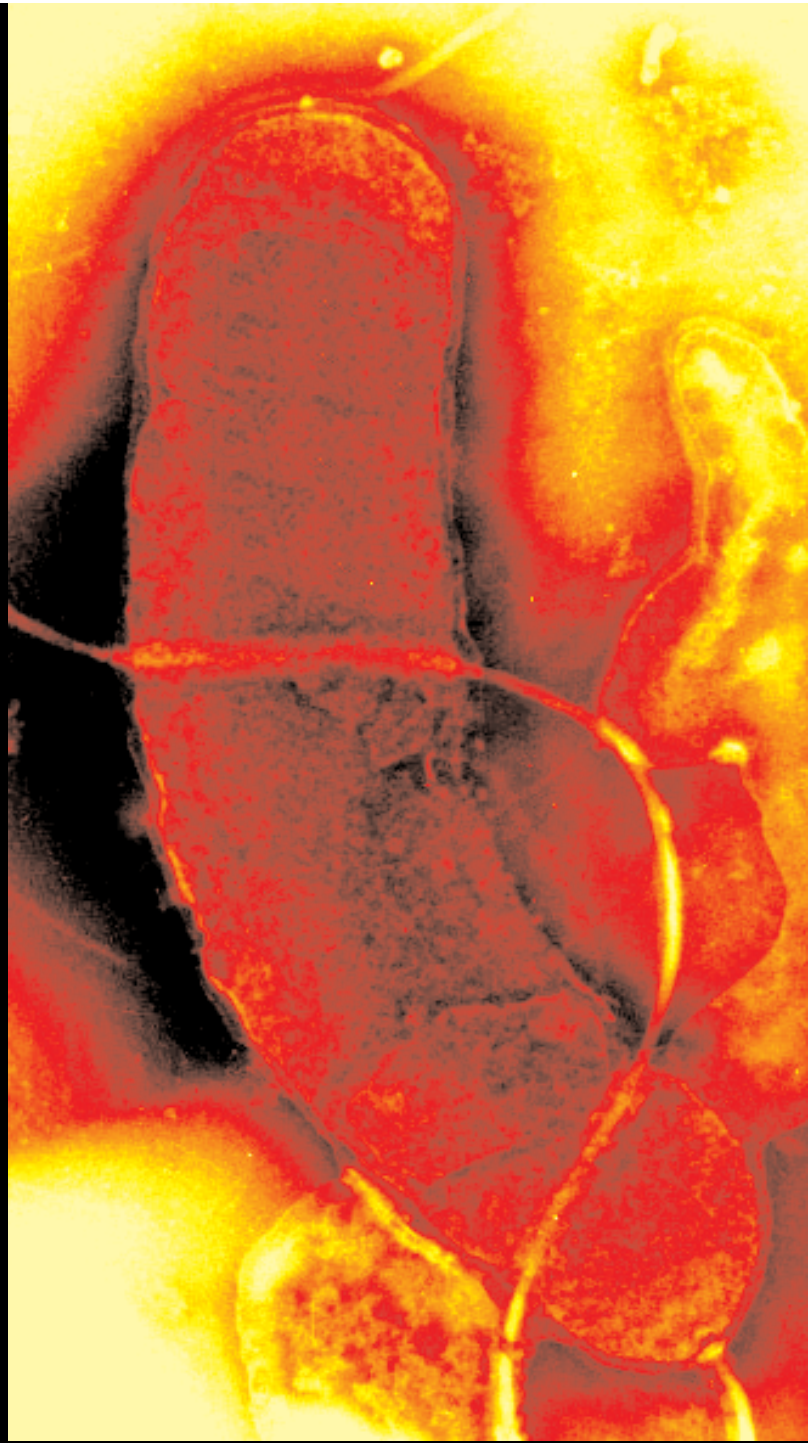

Epidemic/epizootic rates of transmission
Endemic/enzootic rates of transmission
Number of infected cases
Time (days)
0
20
60
100
0
1000
2000
3000

Cholera outbreaks – London, 1800s

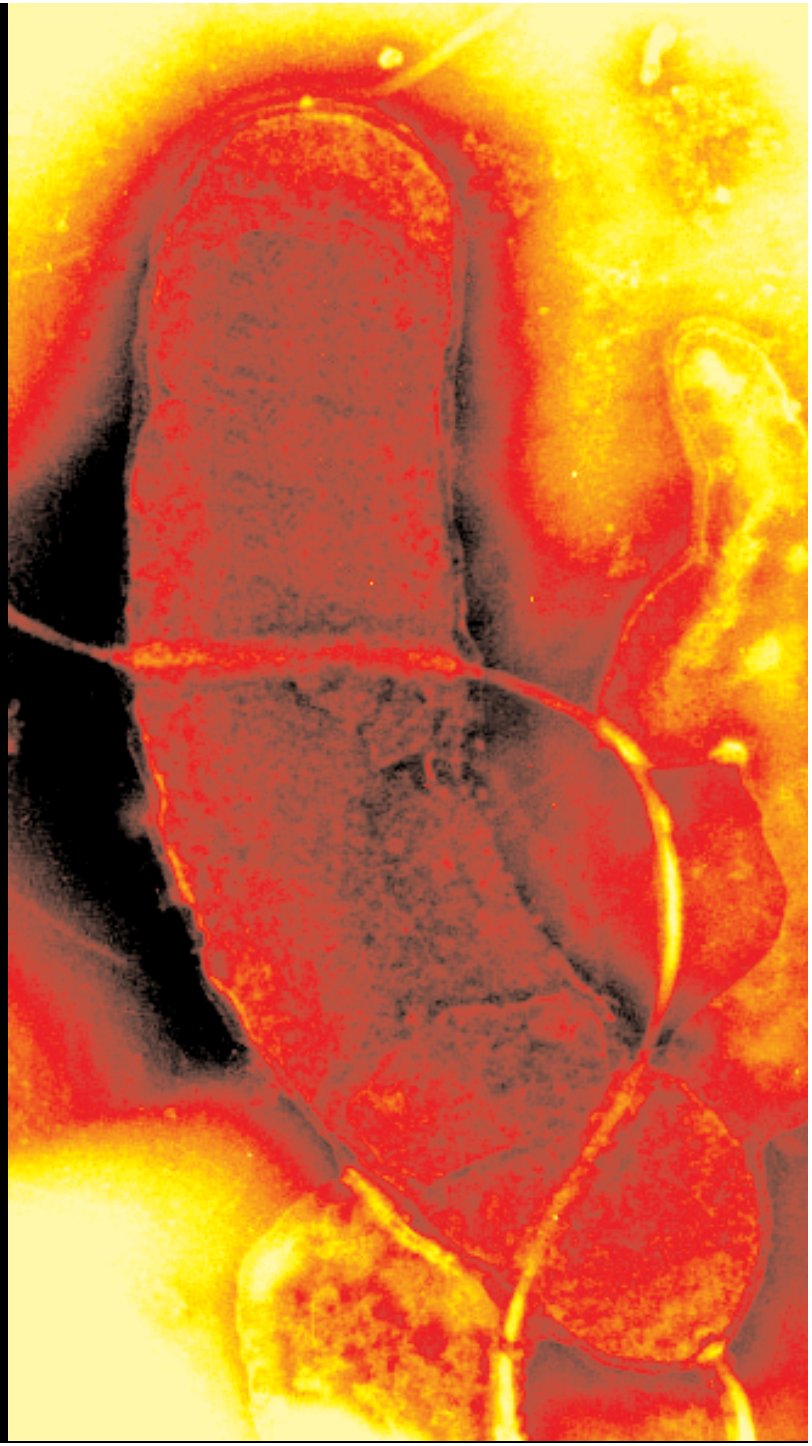
Disease symptoms: acute intestinal infection – queasiness, stomach-ache, vomiting, diarrhoea, death by severe dehydration

Pattern: sudden outbreaks with subsequent spread

Agent:
miasma – bad air



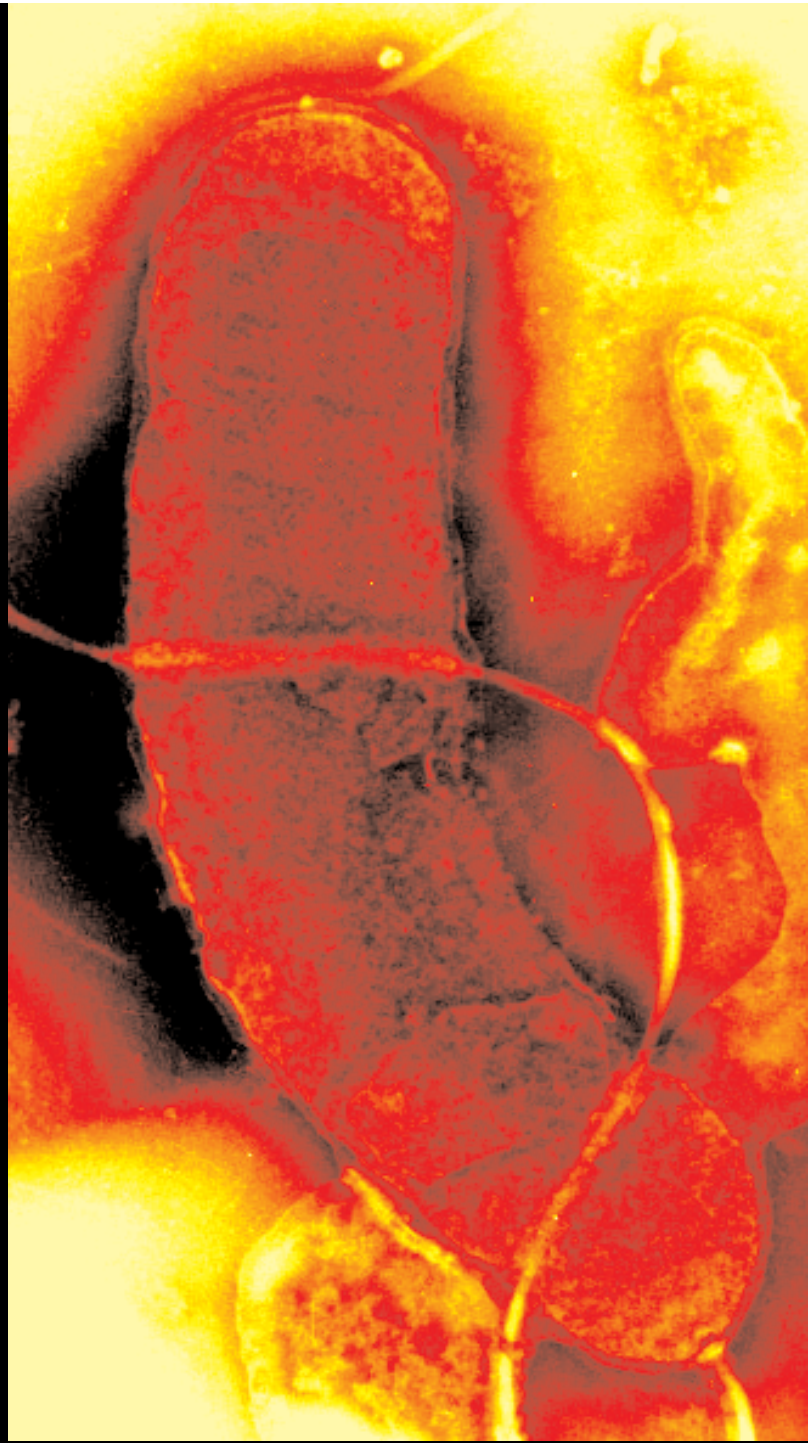
Index case:
the initial patient in the population sample of an epidemiological investigation (also: *primary case* or *patient zero*)



Cholera – London, 1800s

Index case:
22nd September 1848

Transmission: second case died of cholera 8 days later.

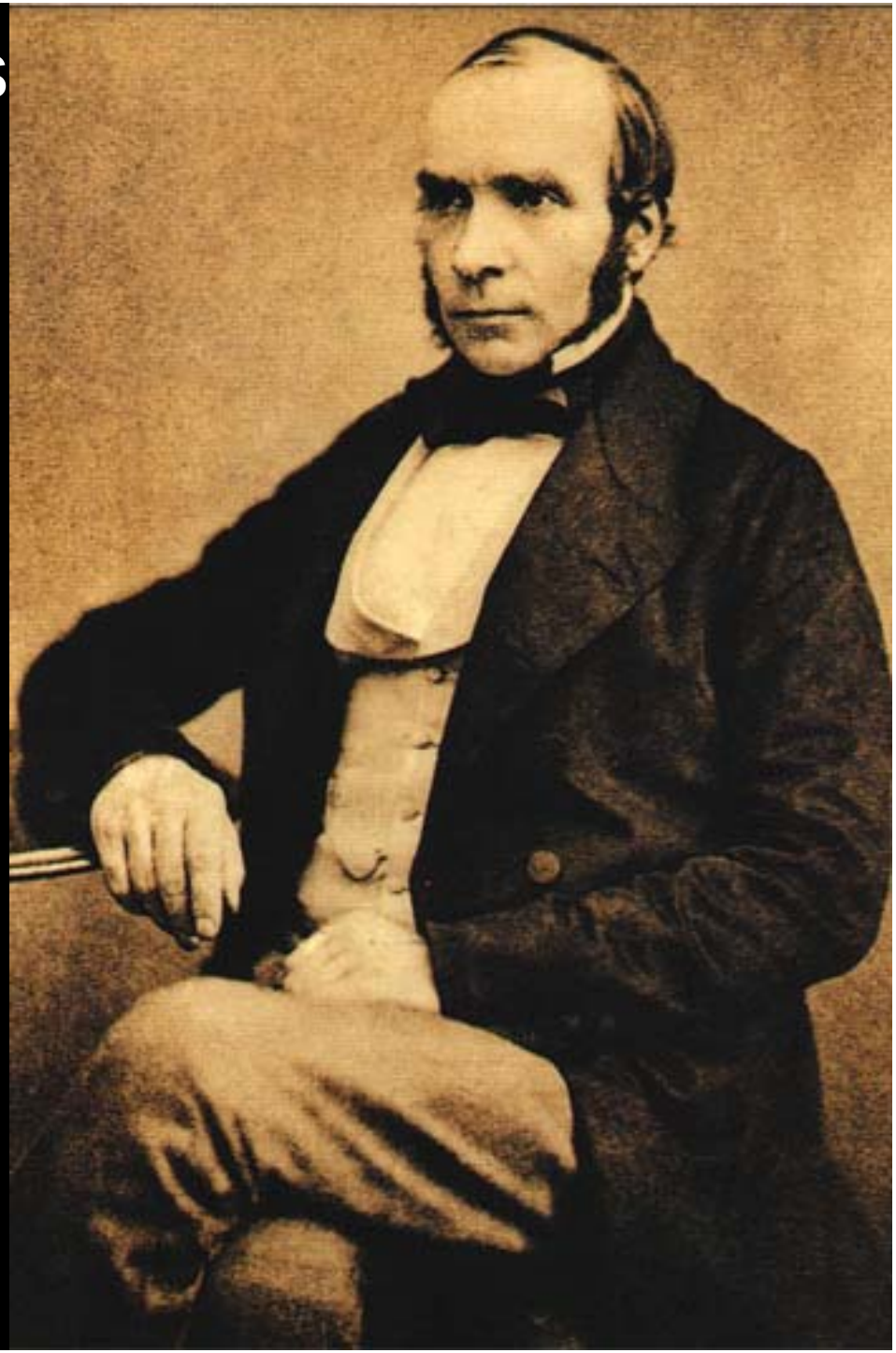


‘Father of Epidemiology:’
John Snow

Cholera – London, 1800s

‘Father of Epidemiology:’
John Snow, M.D.
(1813–1858)

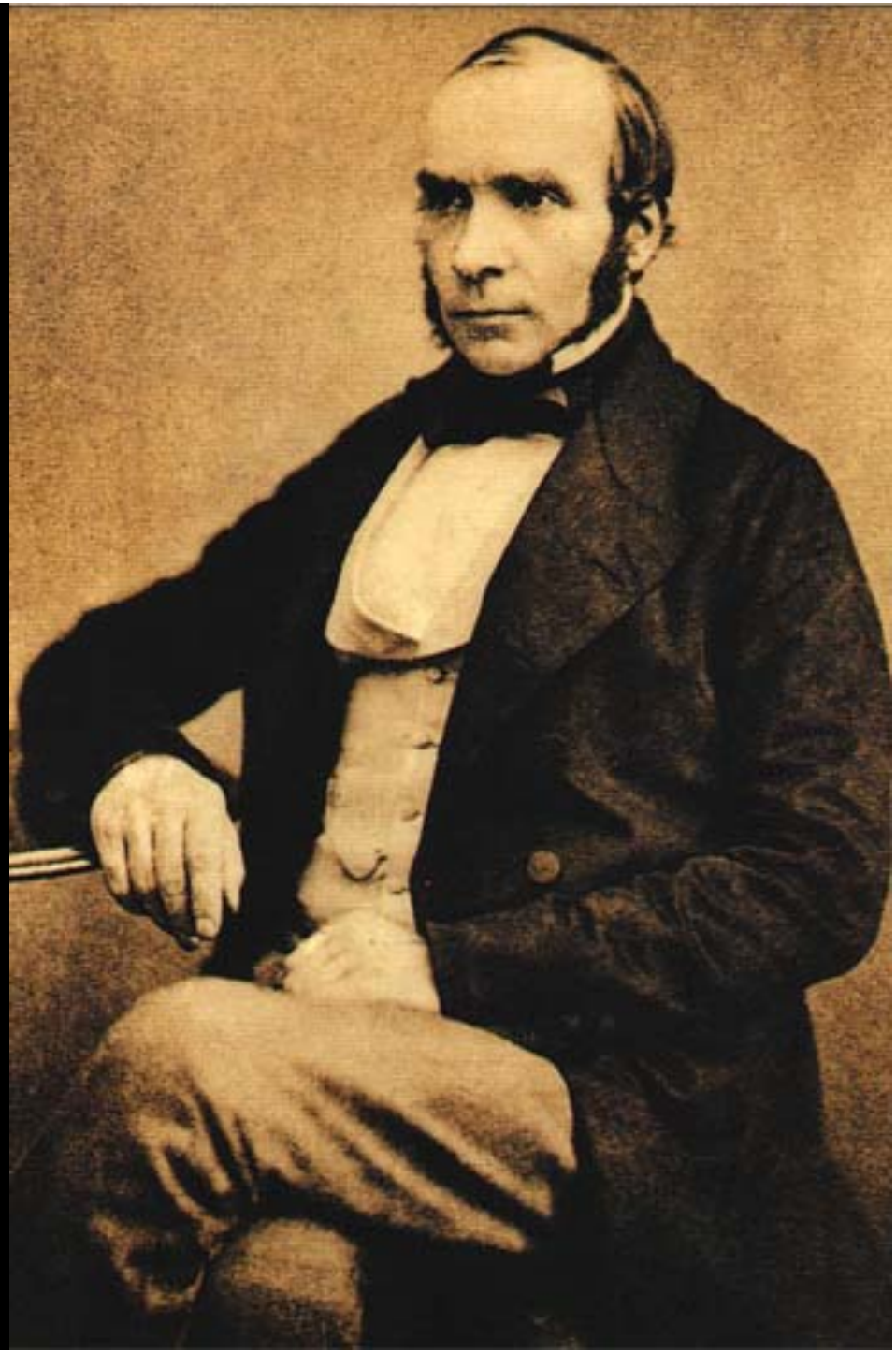
Developing hypotheses:
miasma?
Contagious disease
(germ theory)?



The ‘Grand Experiment’ of 1854:

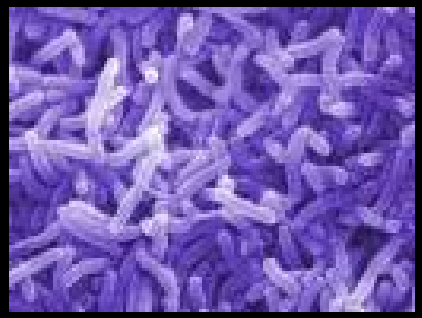
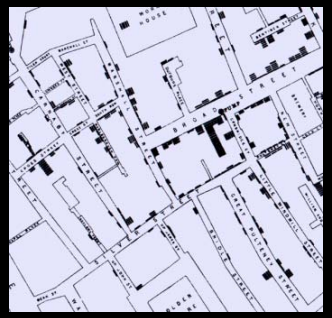
Compare cholera deaths in residents supplied by two different water companies:

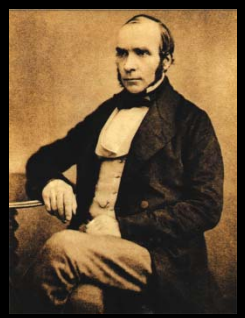
1. Southwark & Vauxhall Water Company – polluted by sewage
2. Lambeth Water Company – intake facilities above the sewage outlets



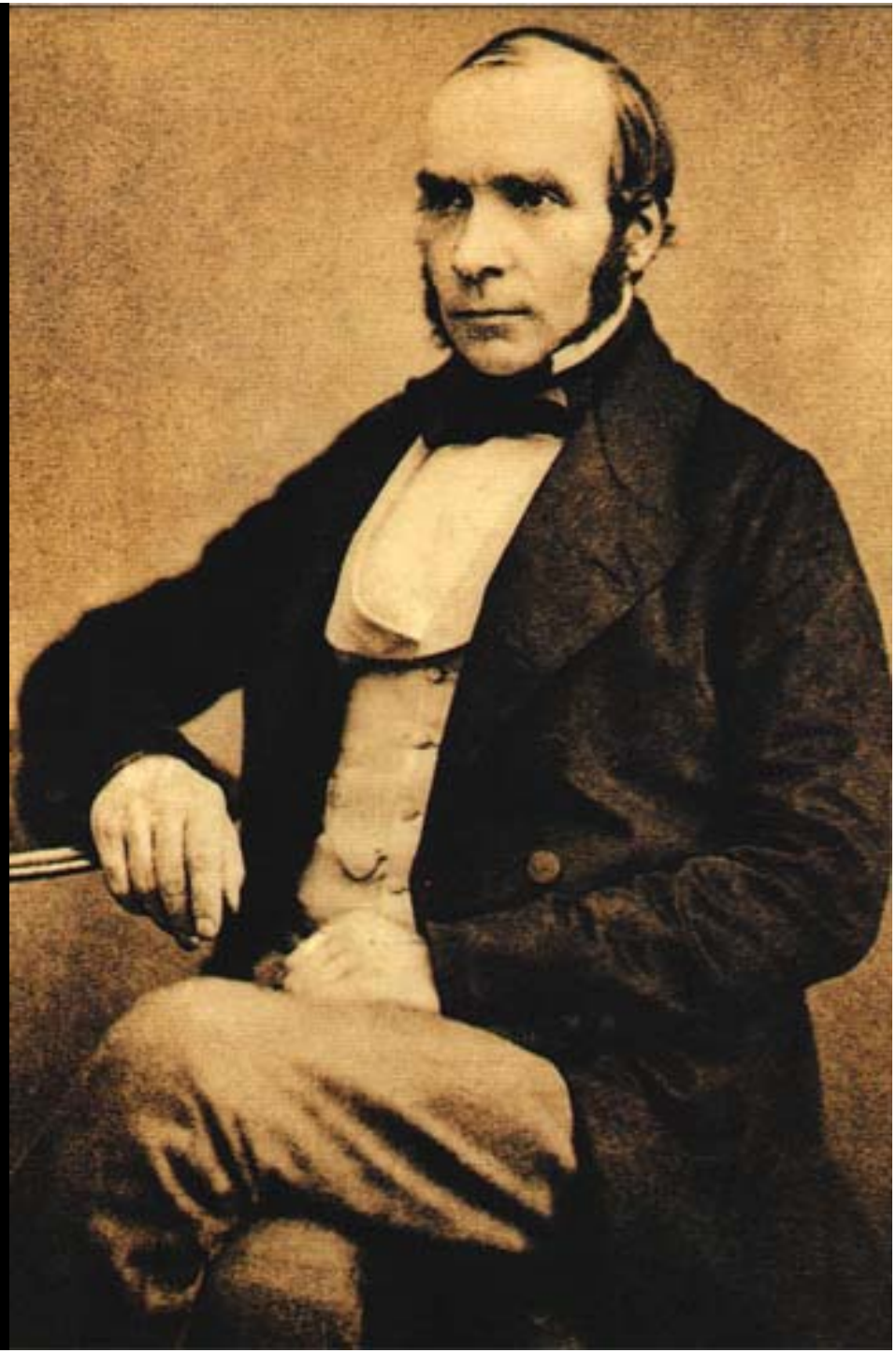
The experiment, too, was on the grandest scale. No fewer than three hundred thousand people of both sexes, of every age and occupation, and of every rank and station, from gentlefolks down to the very poor, were divided into two groups without their choice, and, in most cases, without their knowledge; one group being supplied with water containing the sewage of London, and, amongst it, whatever might have come from the cholera patients, the other group having water quite free from such impurity.

- John Snow




Epidemiologic investigation:
38/44 cholera deaths occurred in houses supplied by Southwark & Vauxhall WC (polluted water).



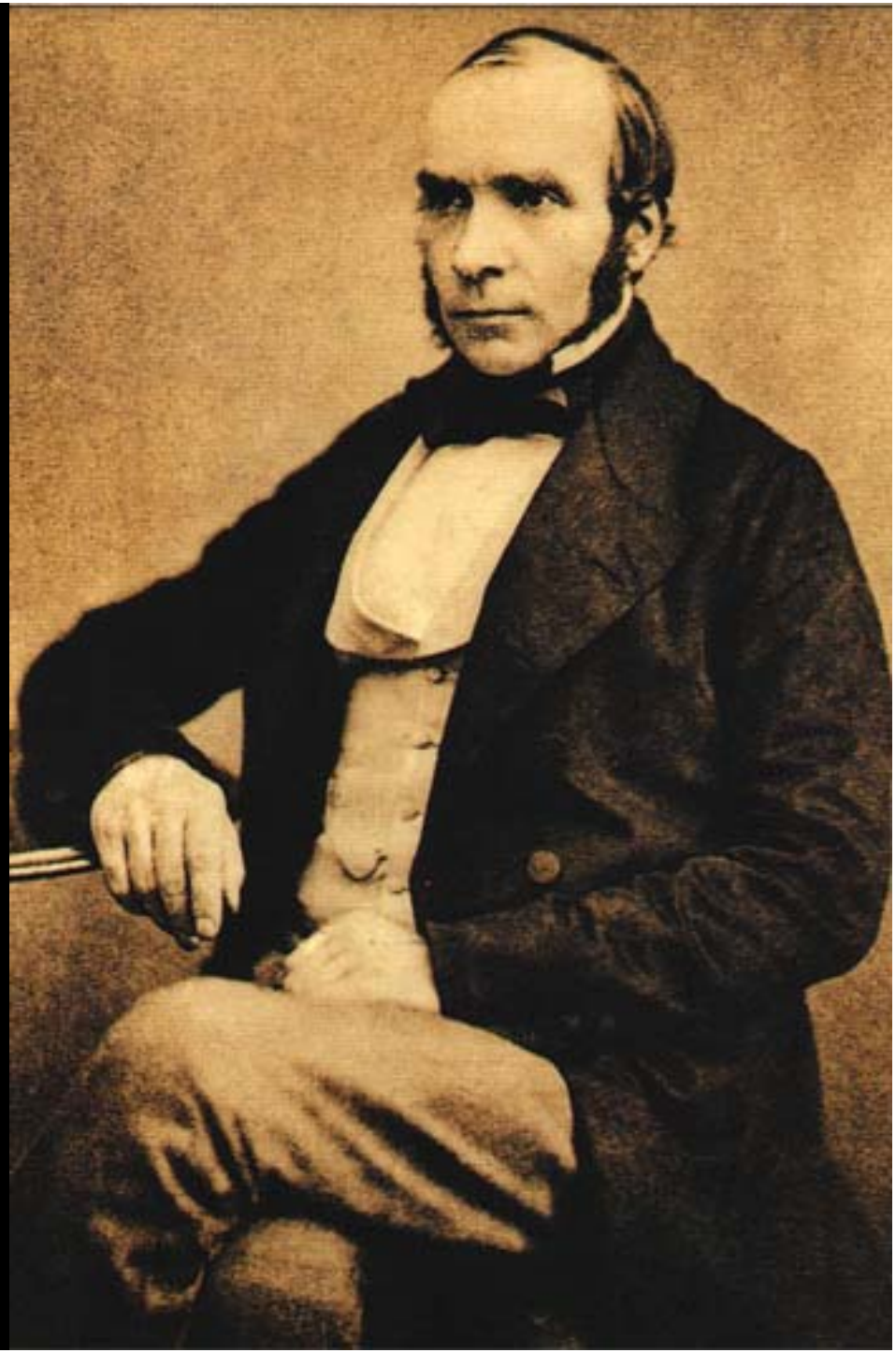
Epidemiologic investigation:

Increased scope to 4-week period (July 8th to August 5th):

286/334 victims used Southwark & Vauxhall WC (polluted)

14 victims used Lambeth water (not polluted)

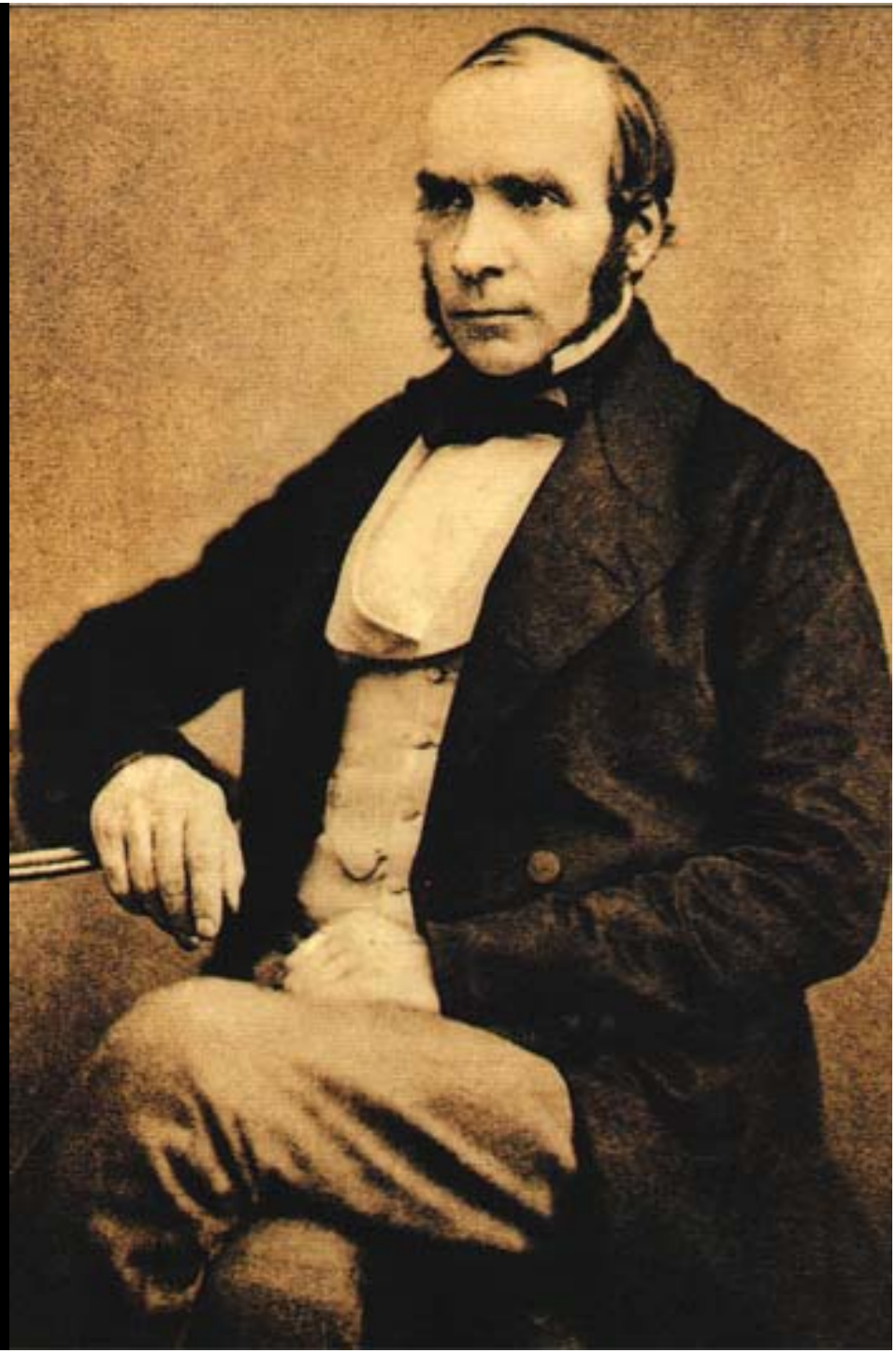
Ratio = 71:5



Result:

cholera due to contaminated and contagious water

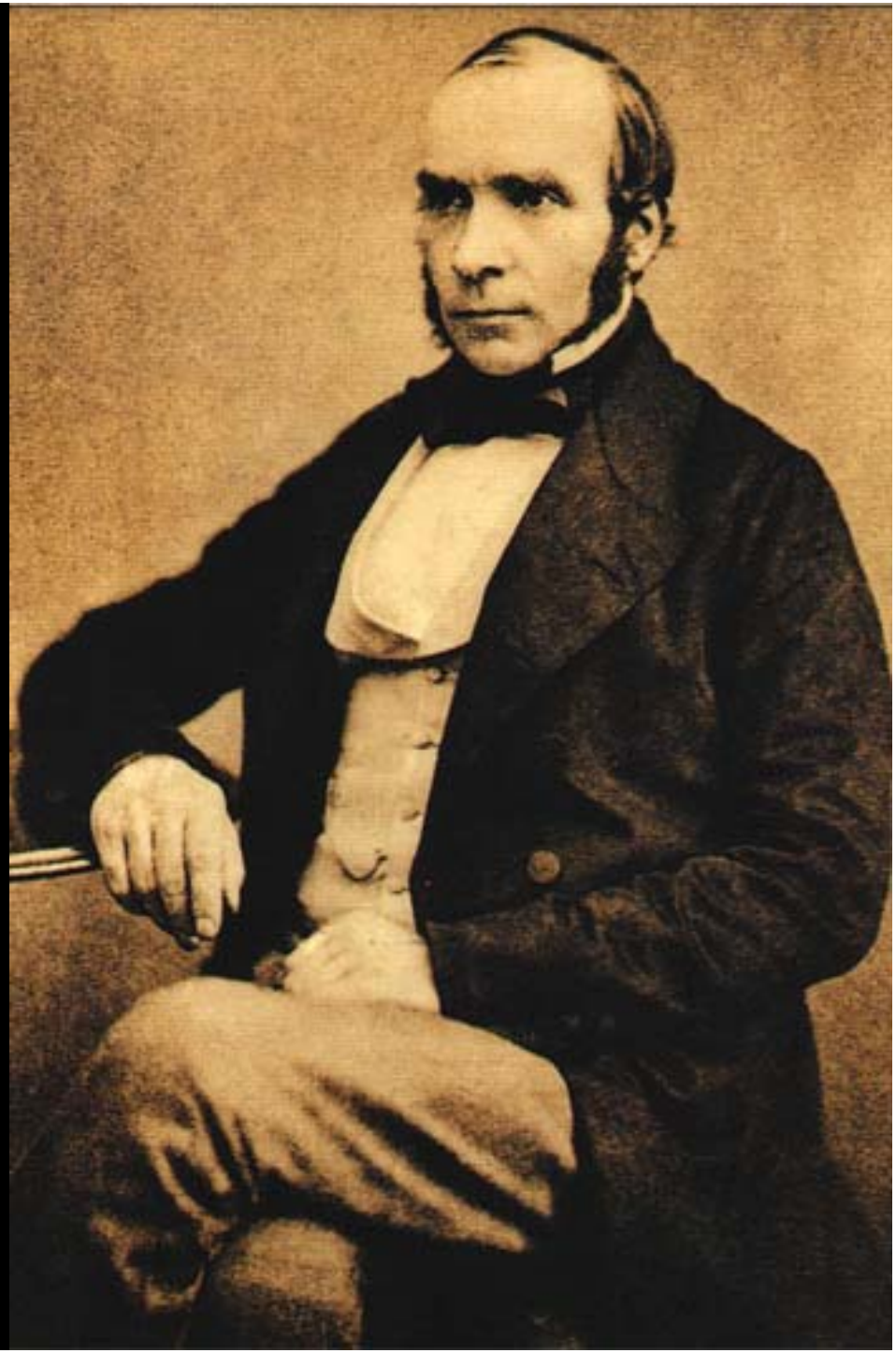
Snow rejected miasma hypothesis



Soho cholera outbreak #2
(31st August 1854)

83 deaths in week, ending September 2nd.

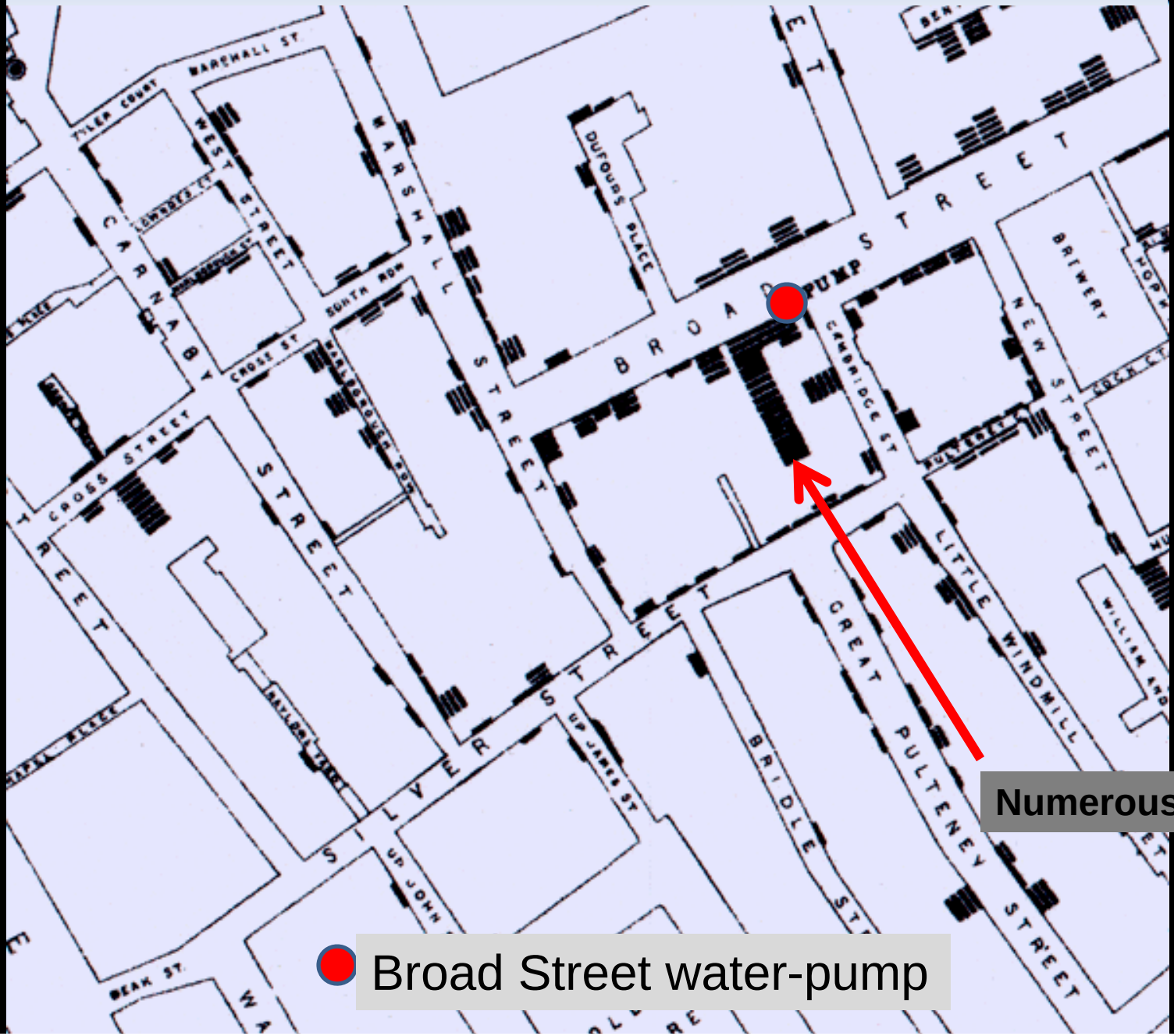
> 500 deaths in 10 days



Broad Street, circa 1850, showing the pump in front of #40

Closest water-source for 73 deaths was **Broad Street water pump**

Epidemiology & mapping

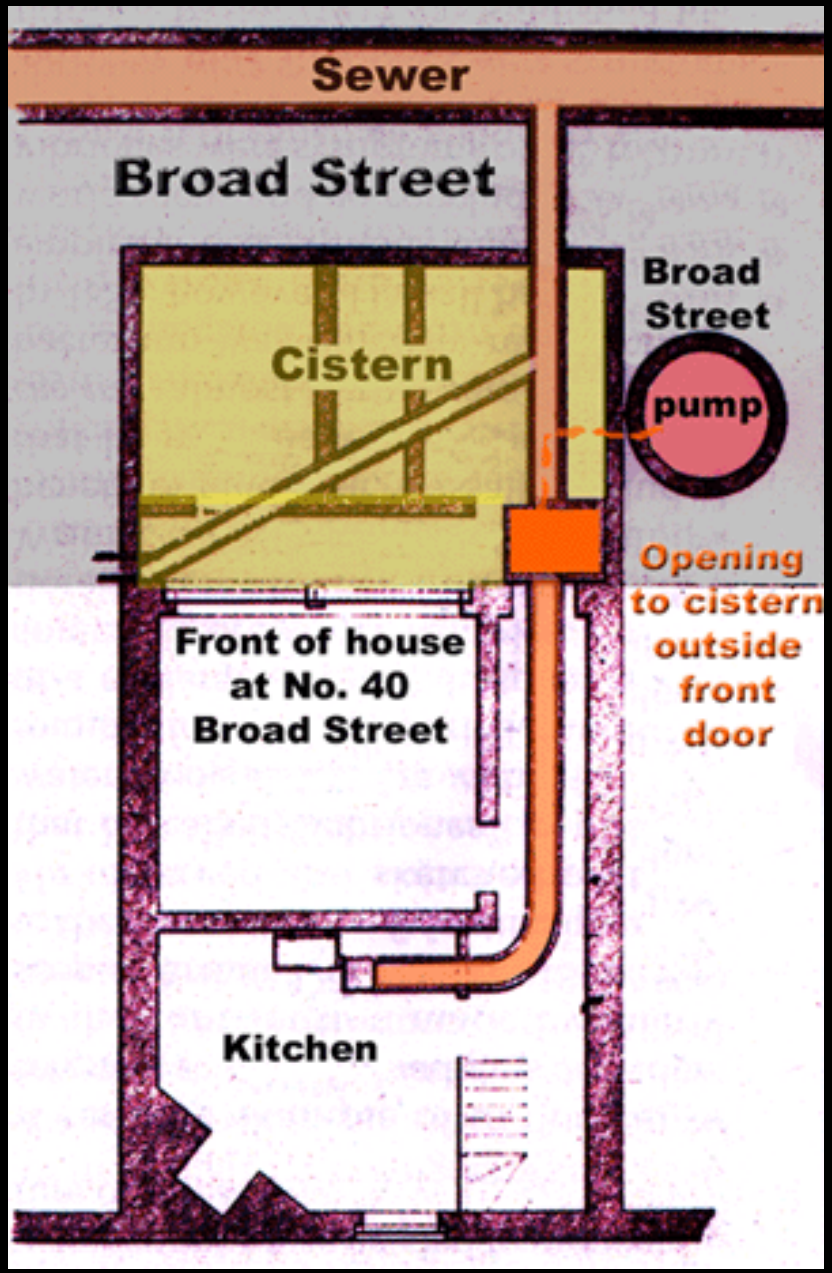


Broad Street, circa 1850, showing the pump in front of #40

Thursday 6th – Snow recommended removal of Broad Street pump handle

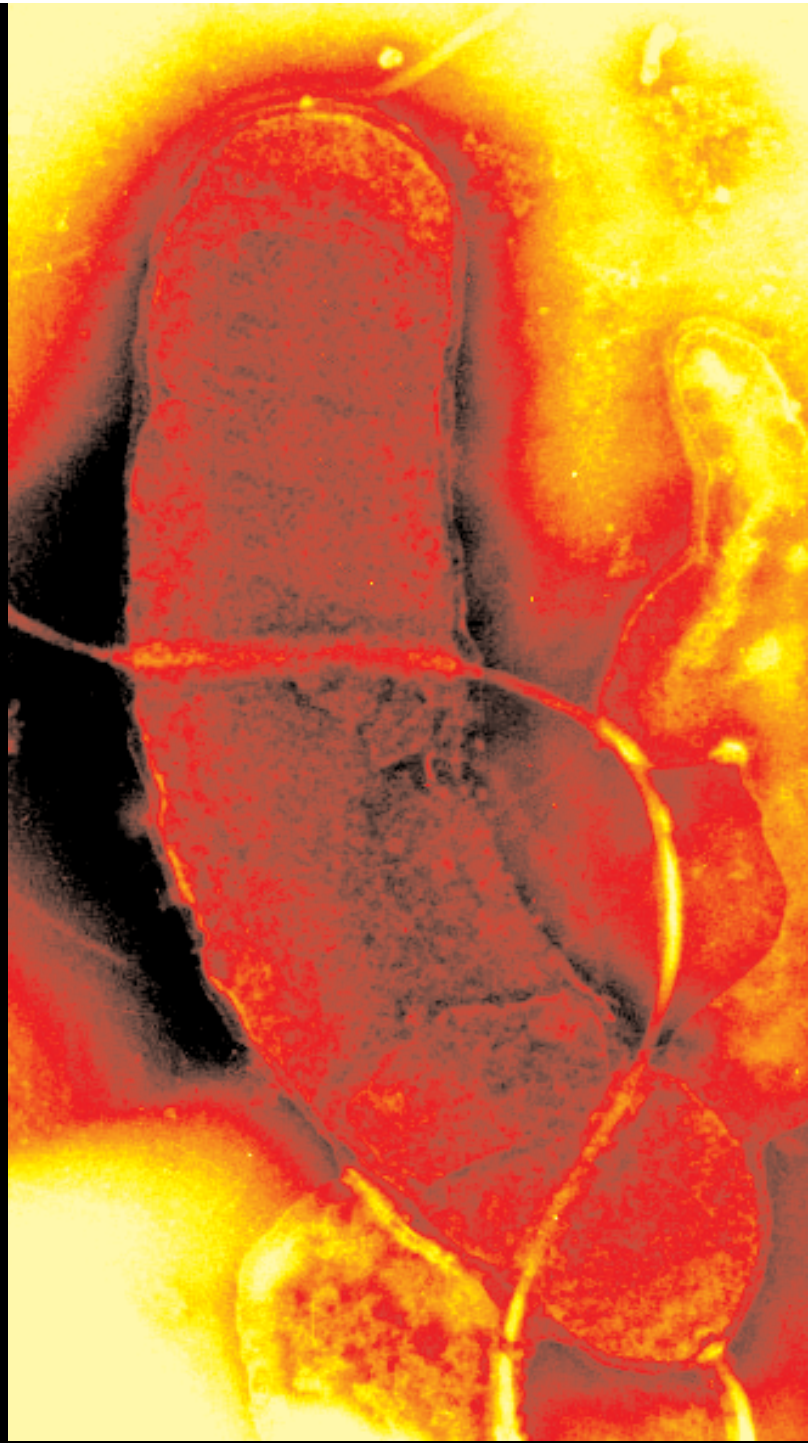
Outbreak ended

Broad Street, circa 1850, showing the pump in front of #40



Epidemiologic process:

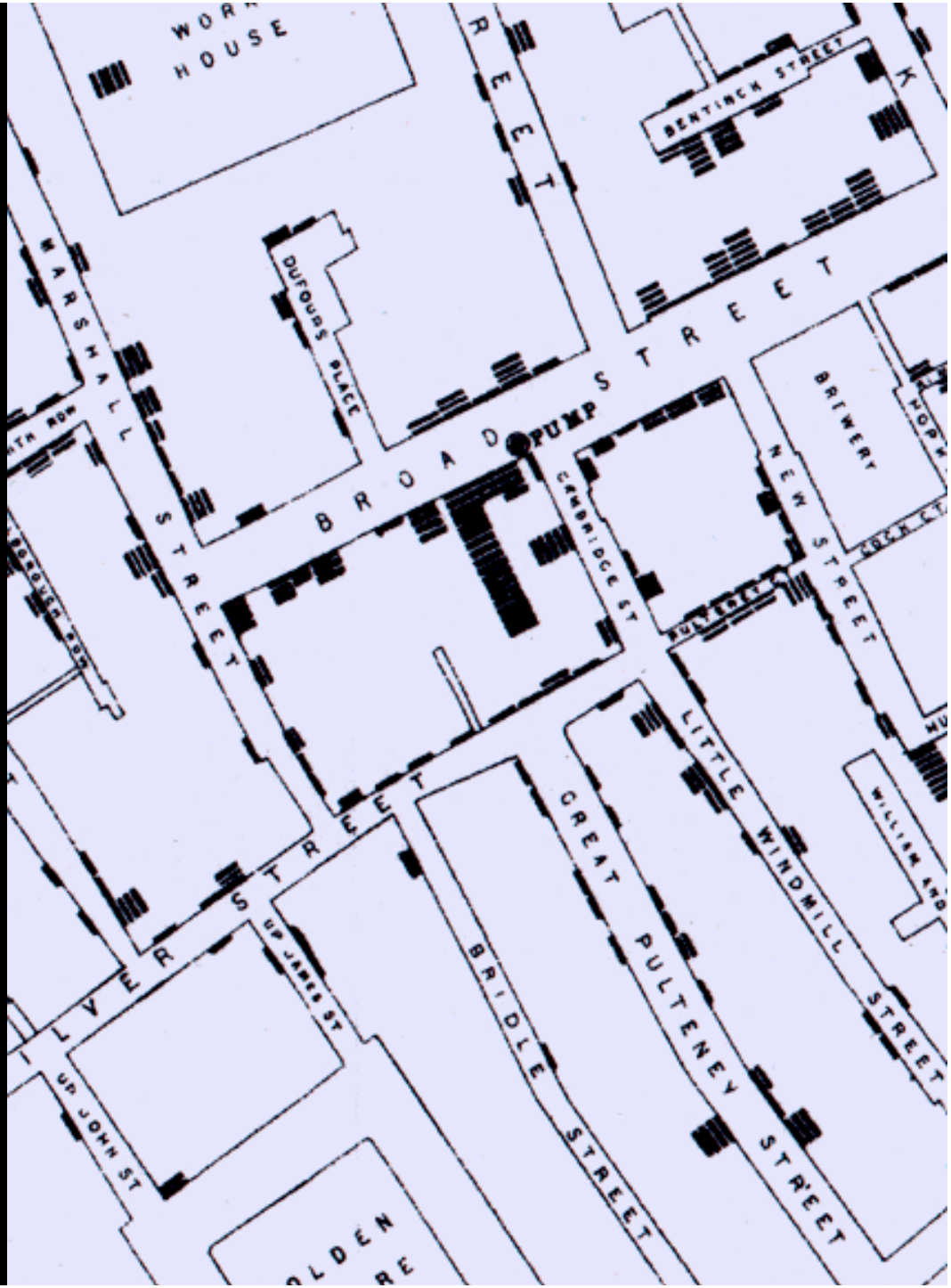
1. Describe disease risks and trends
2. Explain the factors responsible
3. Make predictions (health policy & planning)
4. Instigate control and prevention initiatives
5. Evaluate control/prevention
6. Advocate and educate



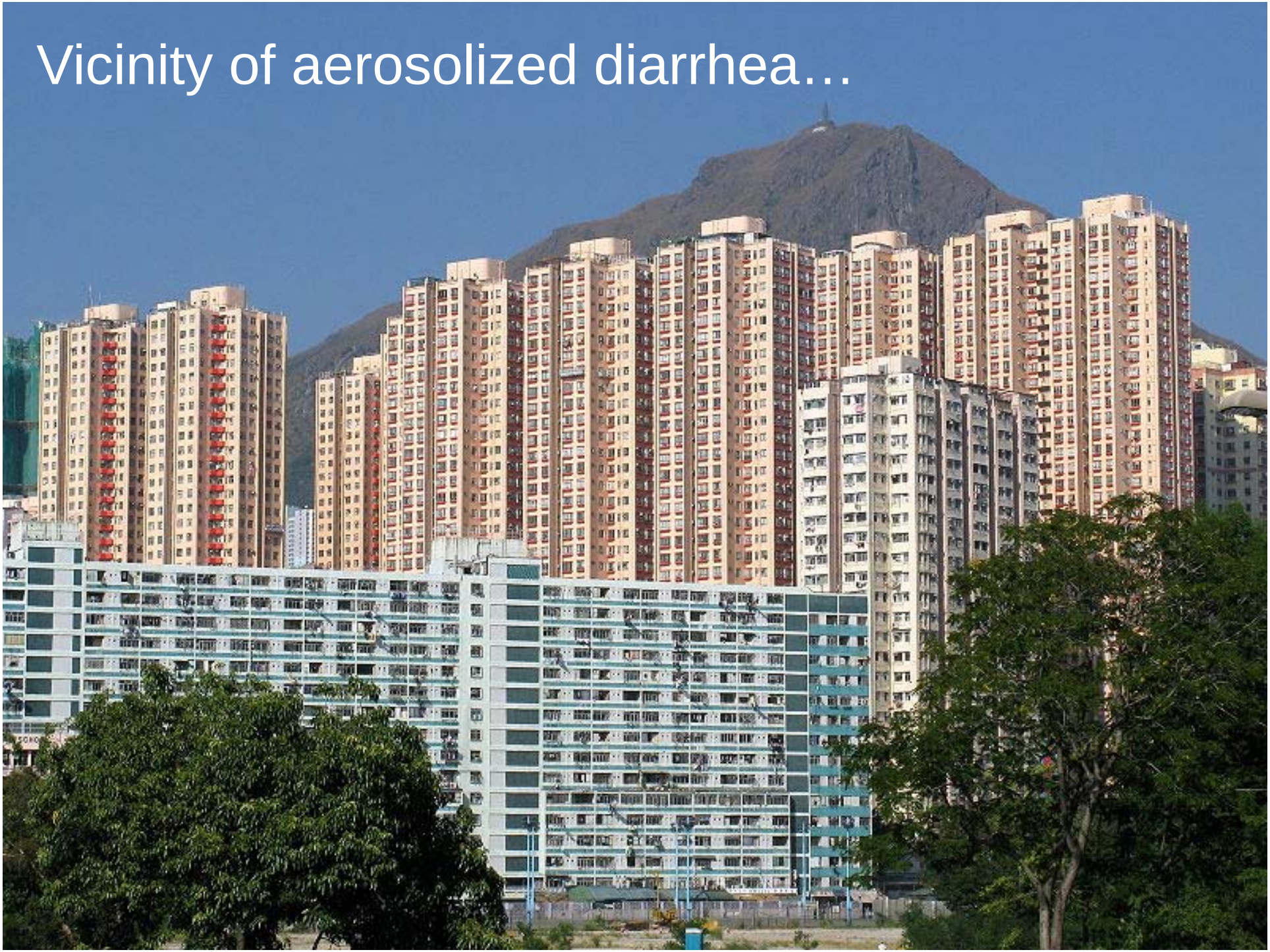
Where?

Geographical influence on likelihood of being exposed to cholera, London, 1850s

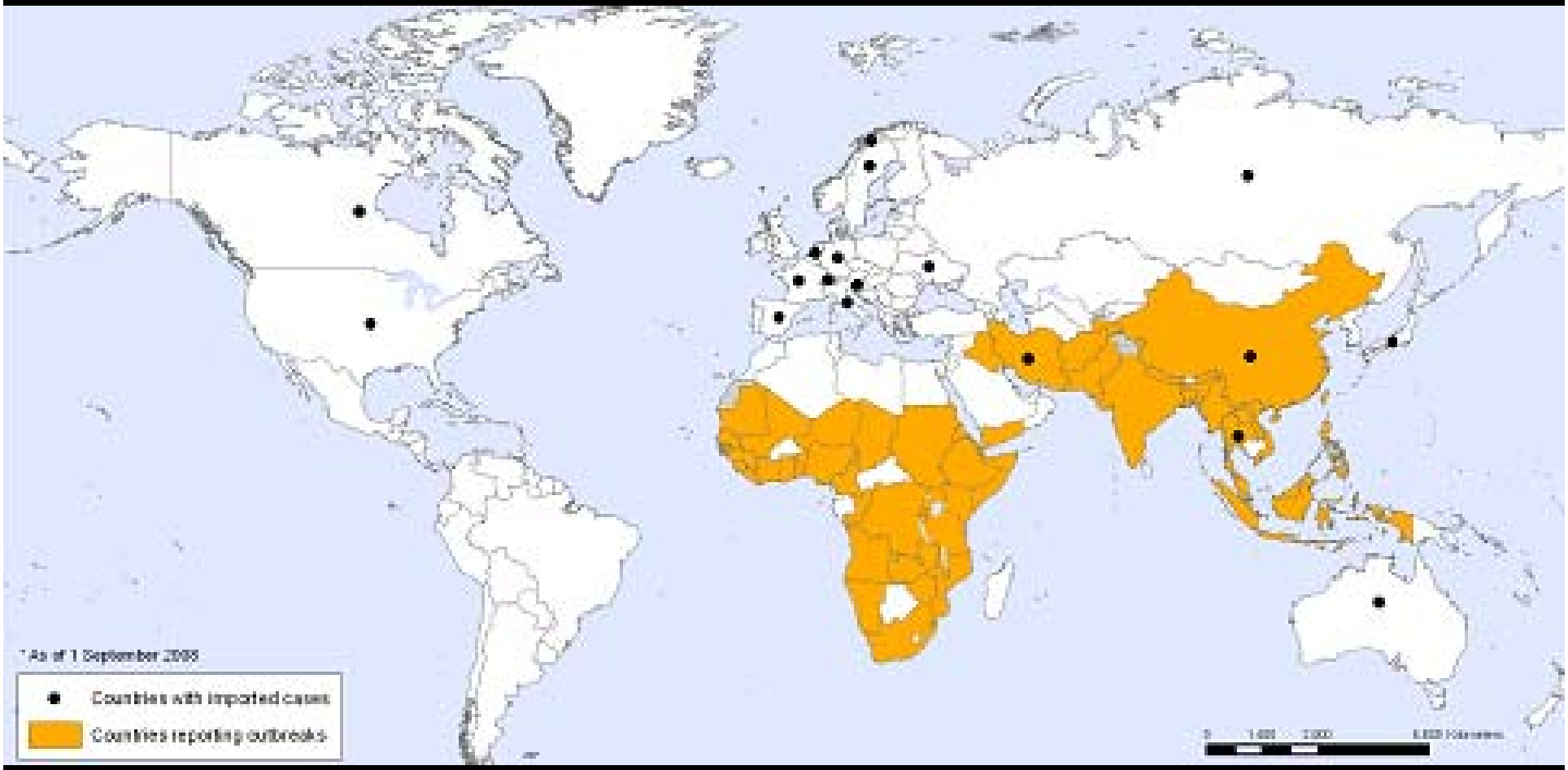
- vicinity of contaminated water-pump



Vicinity of aerosolized diarrhea…



Distribution of cholera (2006-2008)

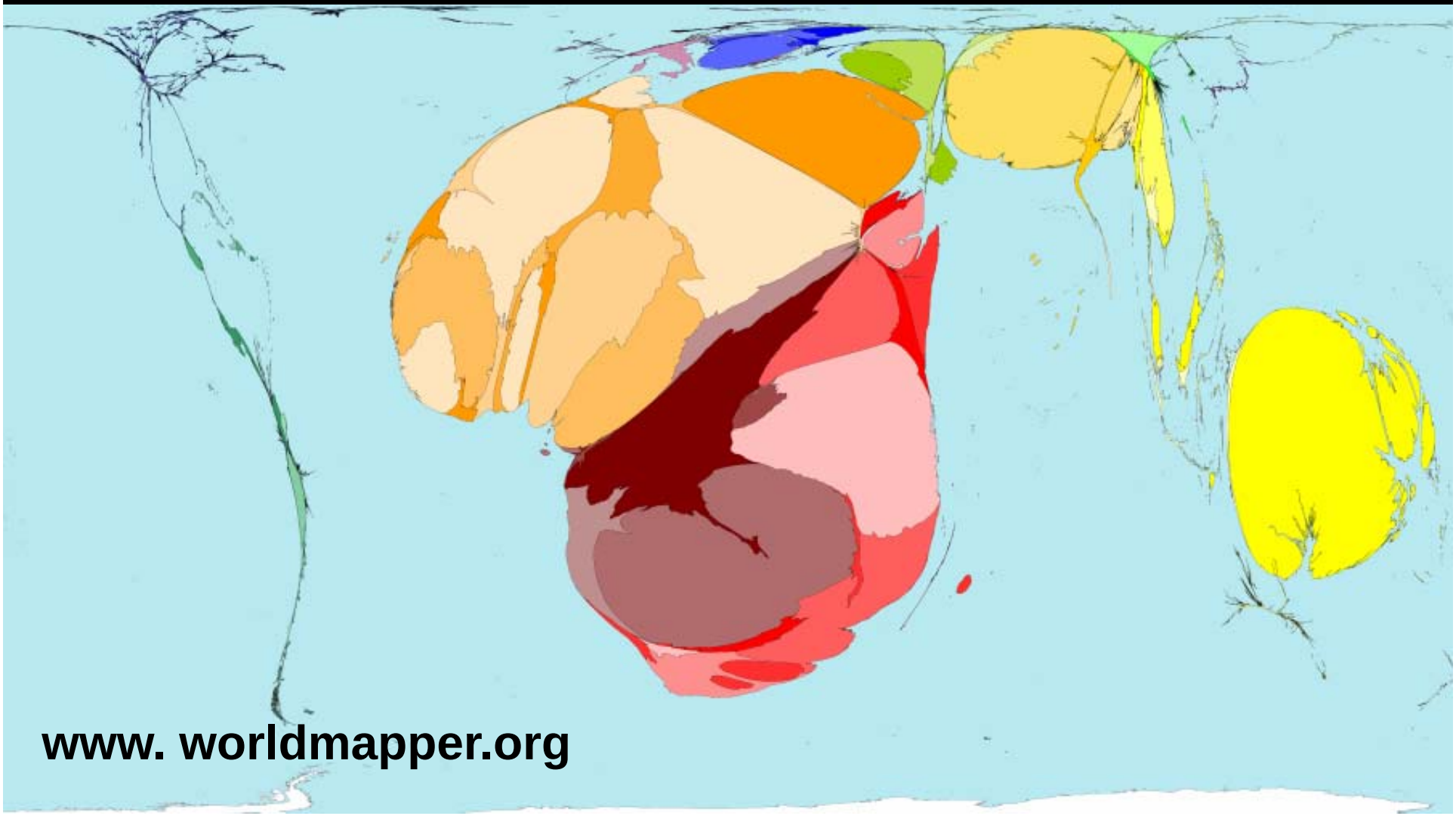


1998: 293,113 cases; 10,586 deaths
2001: 184,311 cases, 2,728 deaths

Worldwide cholera deaths

(severe dehydration, treatable)

Case fatality rate: 2.5% (context dependent)



www. worldmapper.org

Sadr City, Baghdad, Iraq
September 13th, 2008

Cholera epidemics in Iraq (September 2007: 4696 cases; 24 deaths)

October 2008: 40% of Iraq's population had no access to clean water (Red Cross).

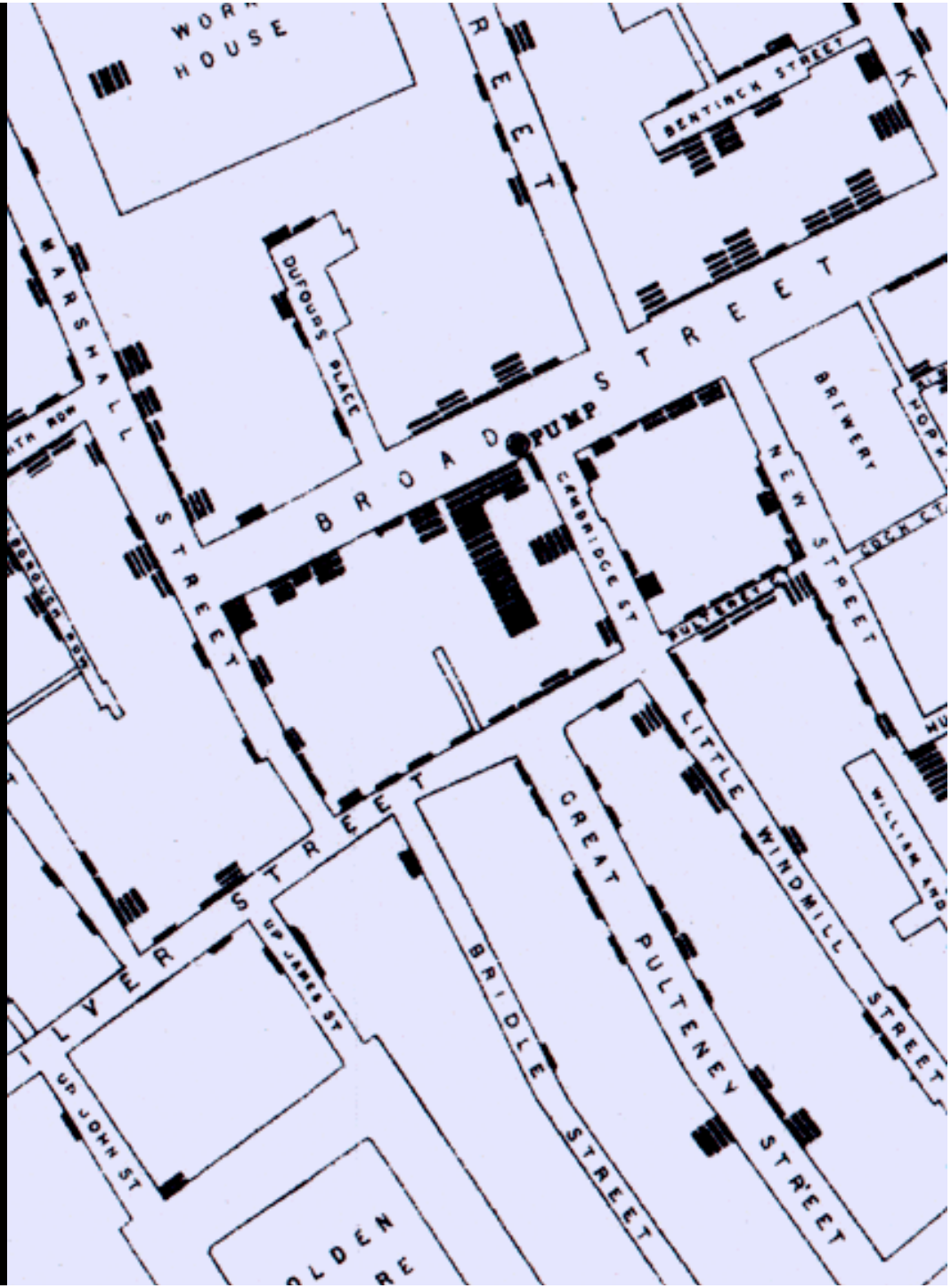
Sadr City, Baghdad, Iraq
September 13th, 2008

July 2009: Zimbabwe cholera outbreak, 9 months, killed > 4,000 people

2010: Nigeria cholera outbreak, killed > 350 people

Mapping disease

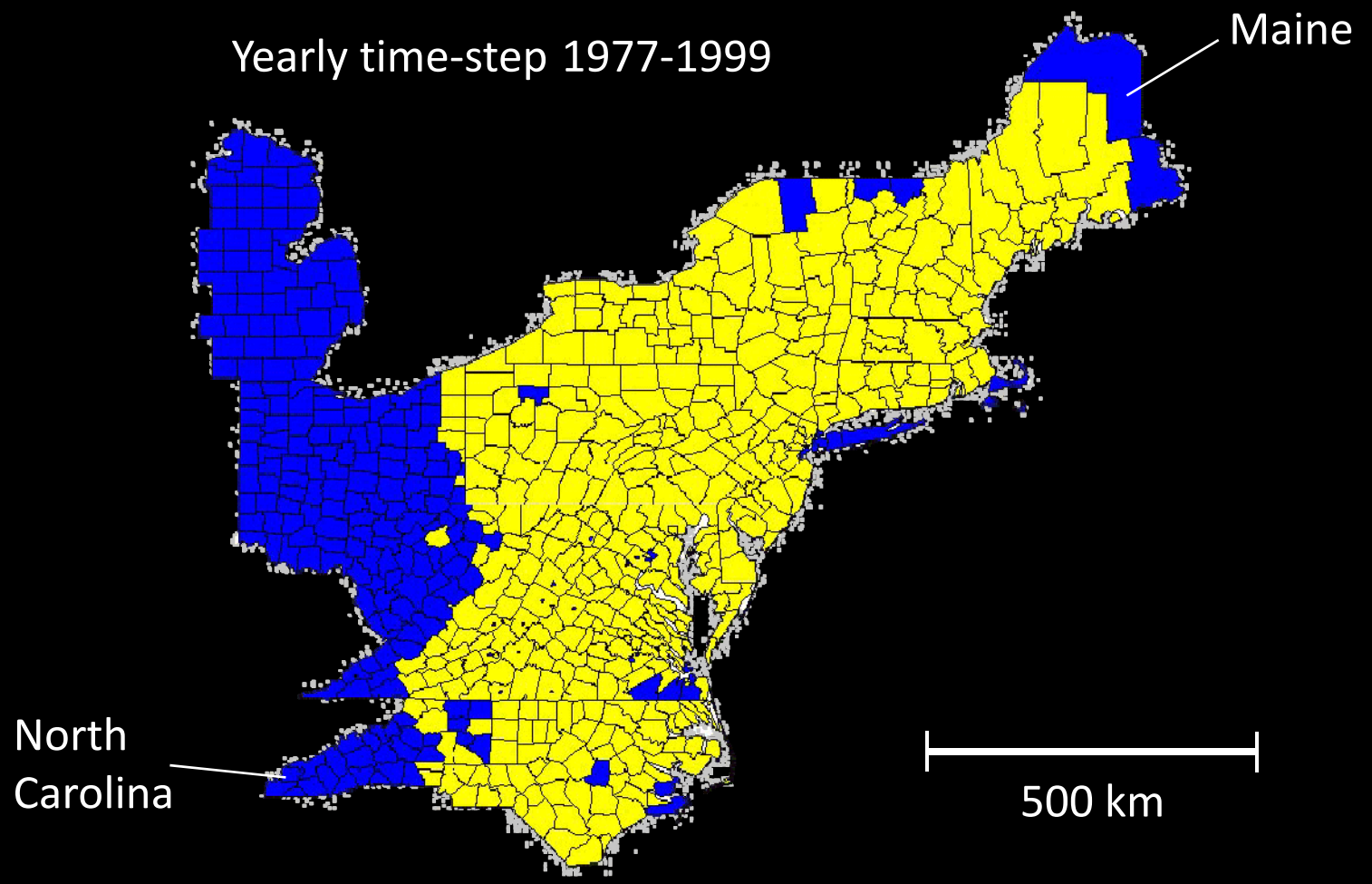
Predict disease spread



Infectious disease highly influenced by spatial dynamics

e.g. raccoon (*Procyon lotor*) rabies

Raccoon rabies in eastern North America



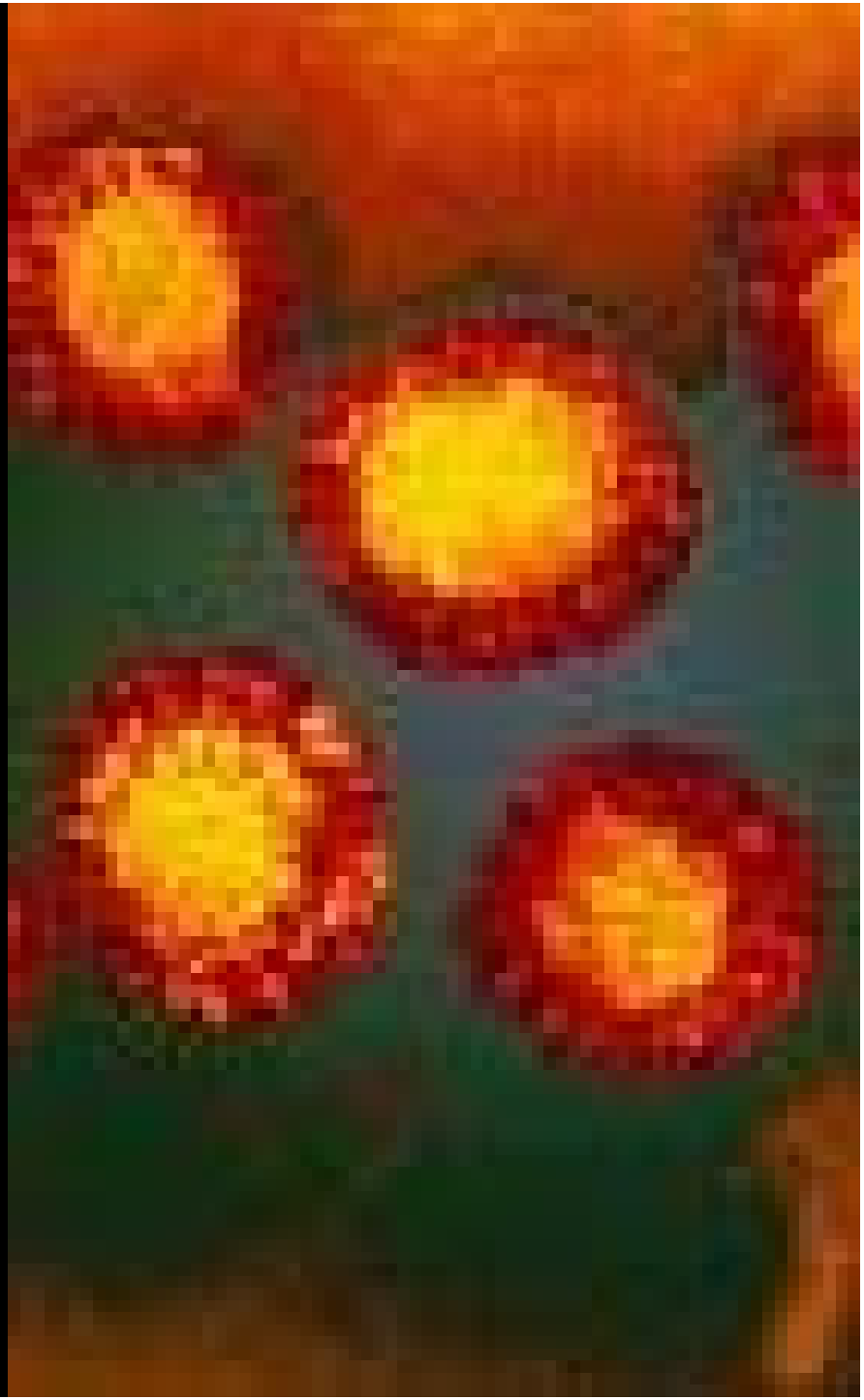
Thanks to Roman Biek

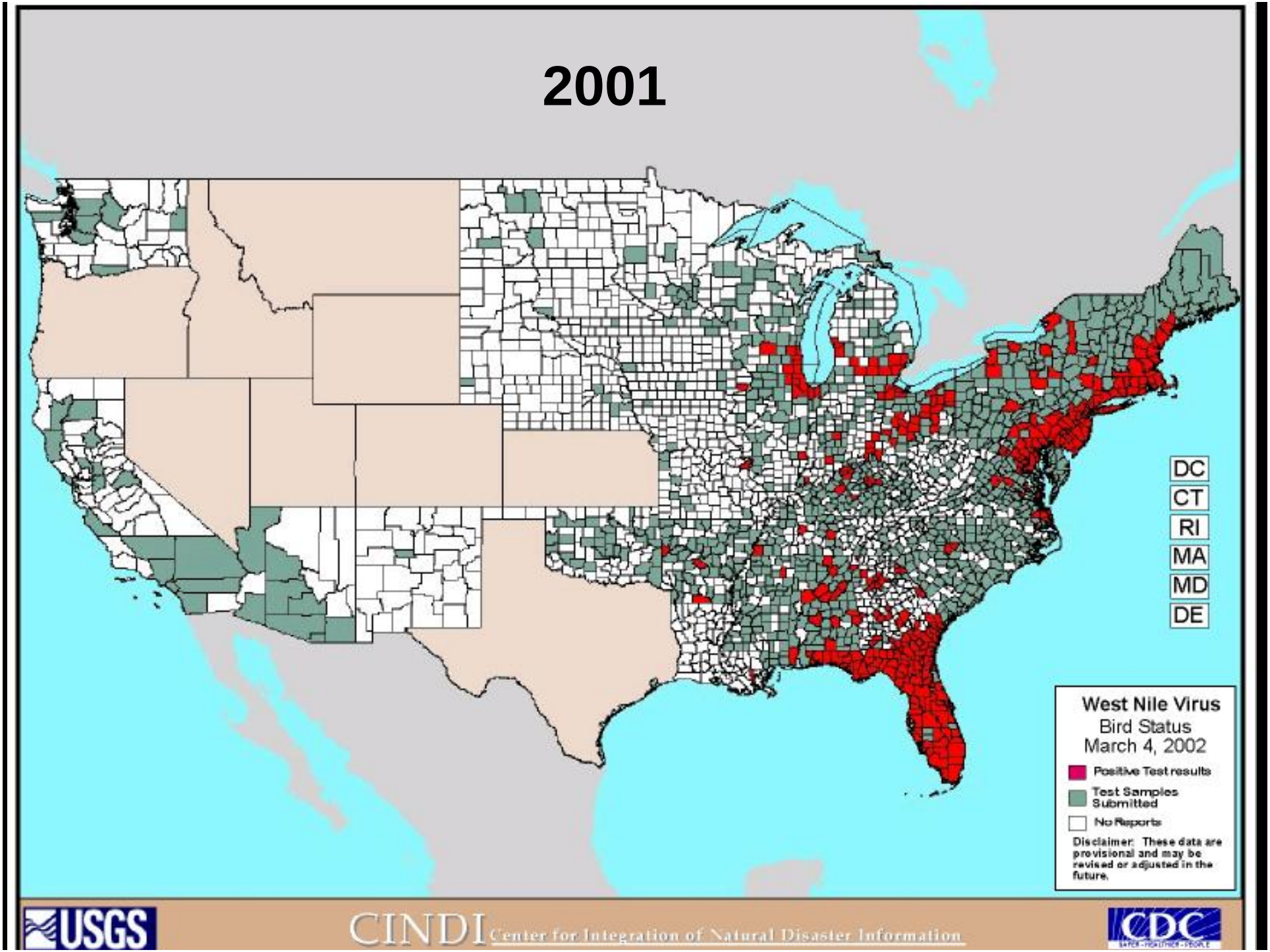
West Nile virus

Emerged in New York, 1999

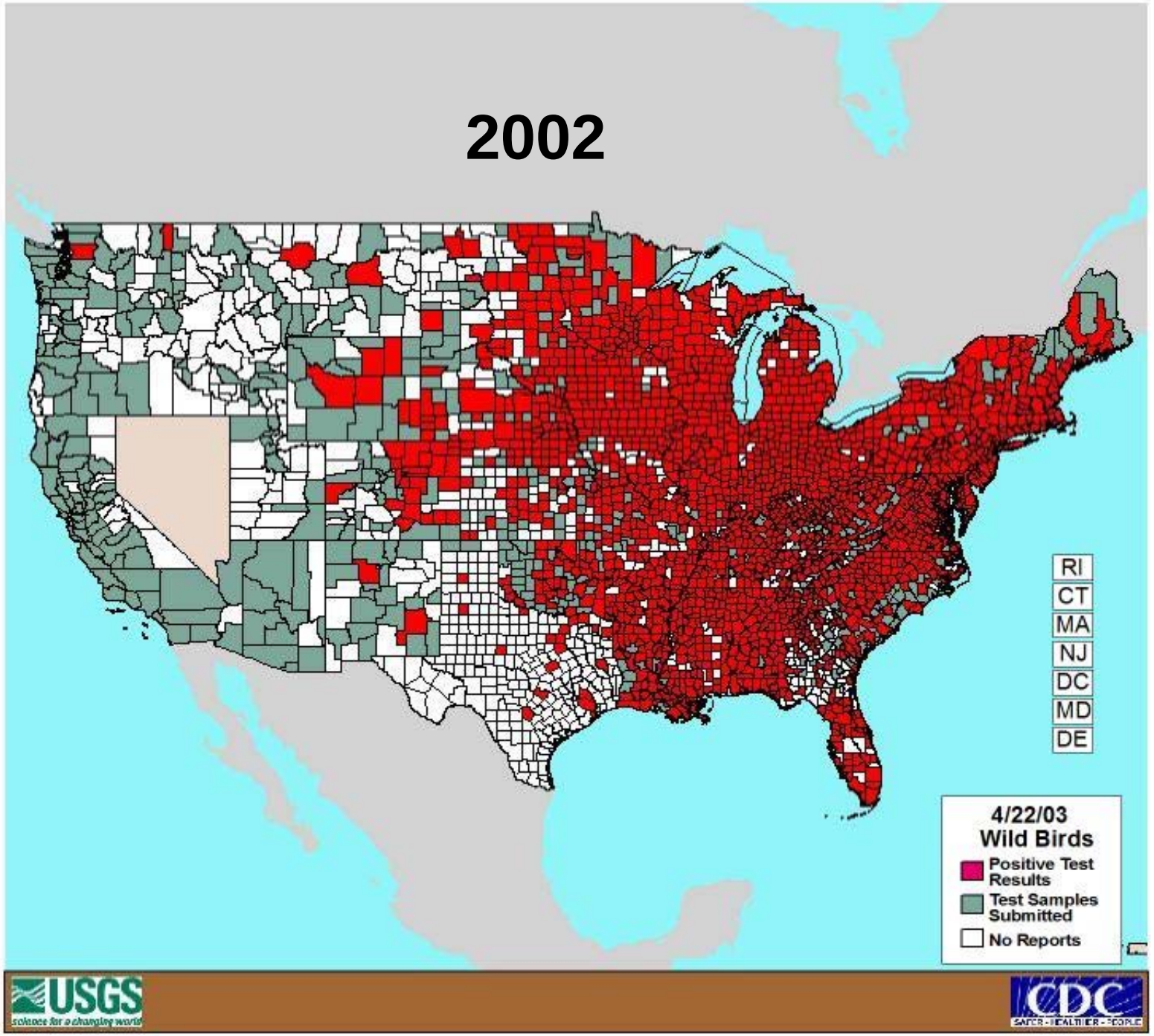
Mode of transmission?

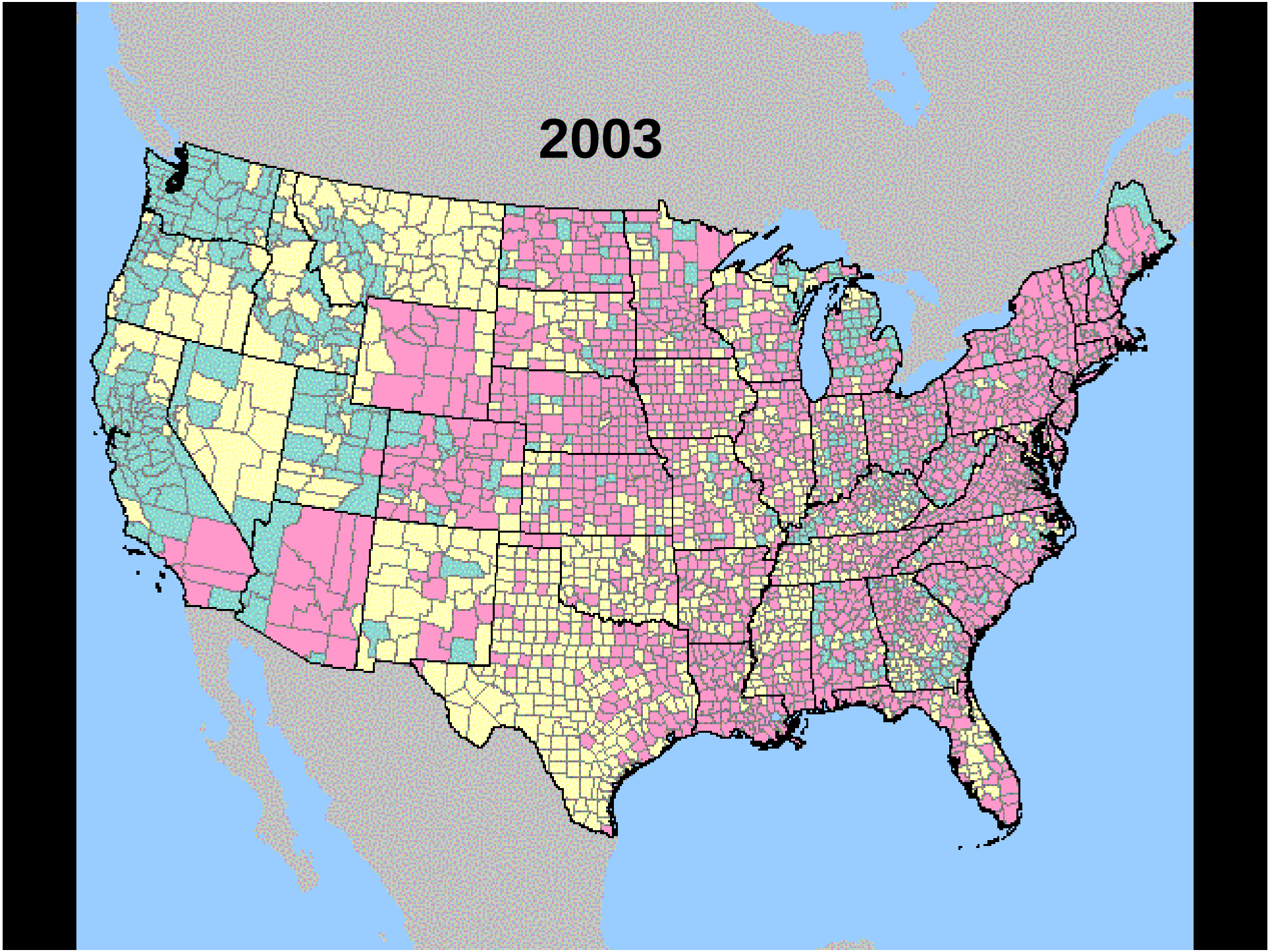
Reservoir?

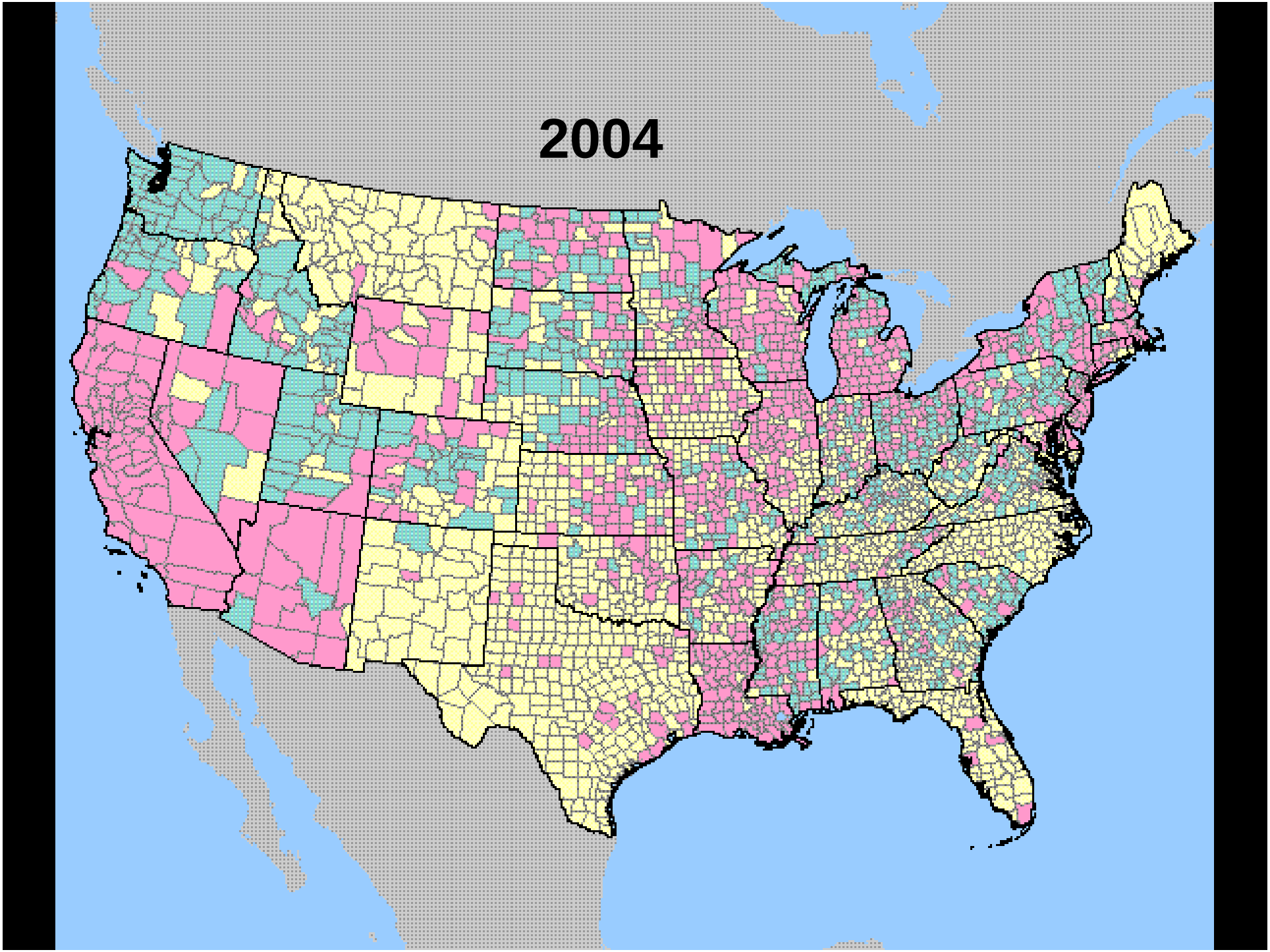


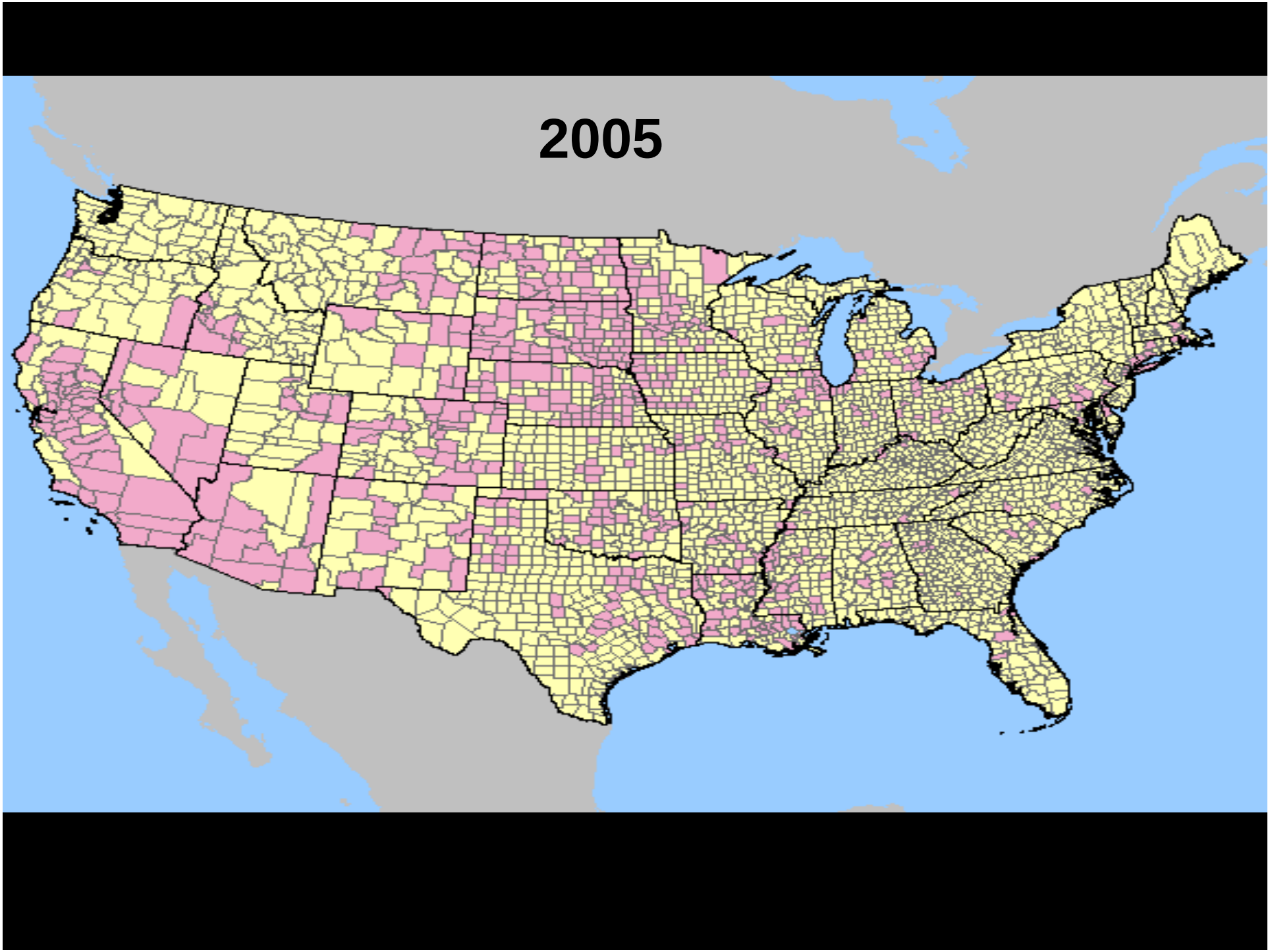

2001
DC
CT
RI
MA
MD
DE
West Nile Virus
Bird Status
March 4, 2002
Positive Test results
Test Samples Submitted
No Reports
Disclaimer: These data are provisional and may be revised or adjusted in the future.
USGS
CINDI Center for Integration of Natural Disaster Information
CDC

2002

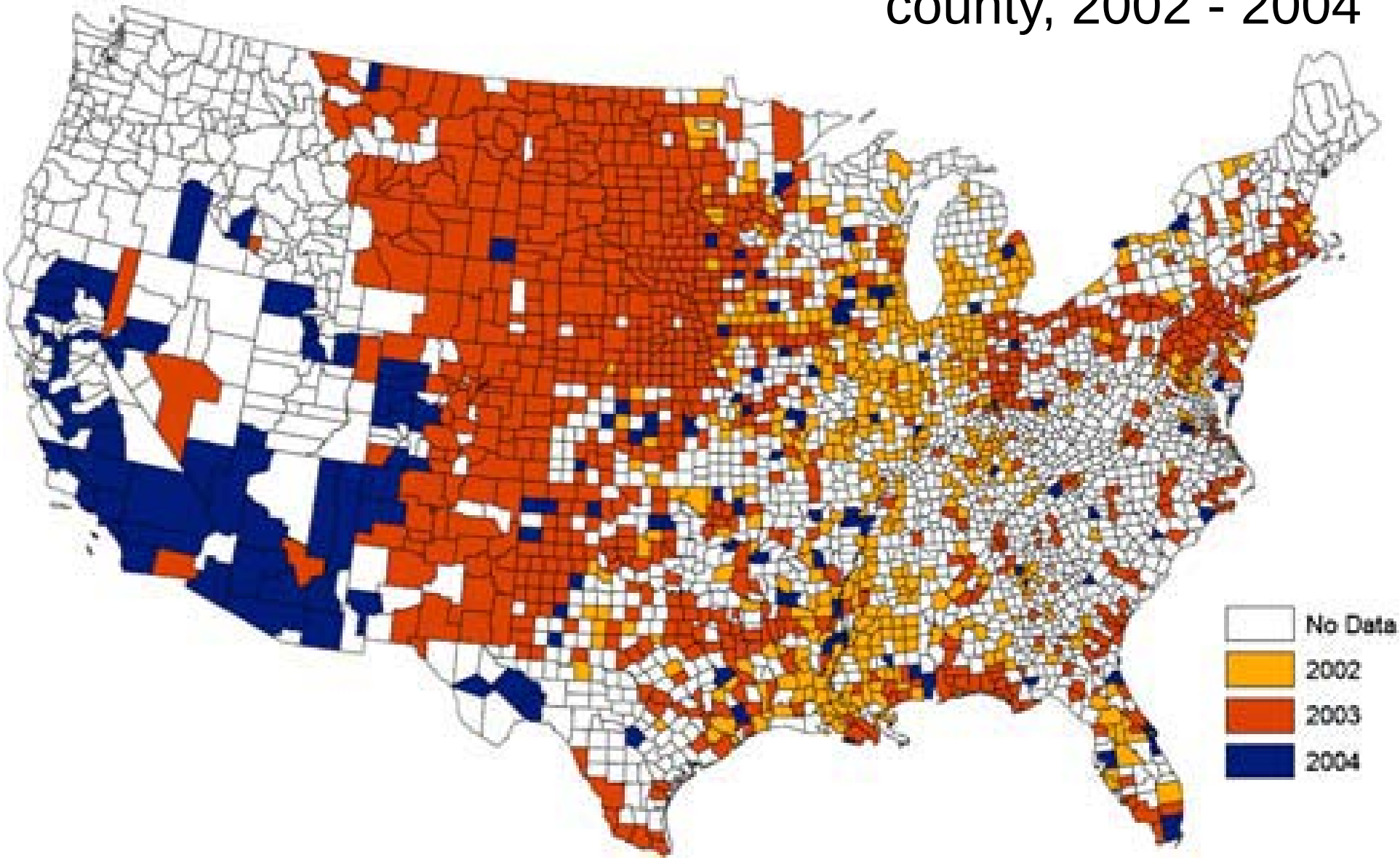

RI
CT
MA
NJ
DC
MD
DE
4/22/03
Wild Birds
Positive Test Results
Test Samples Submitted
No Reports
USGS
science for a changing world
CDC


2003

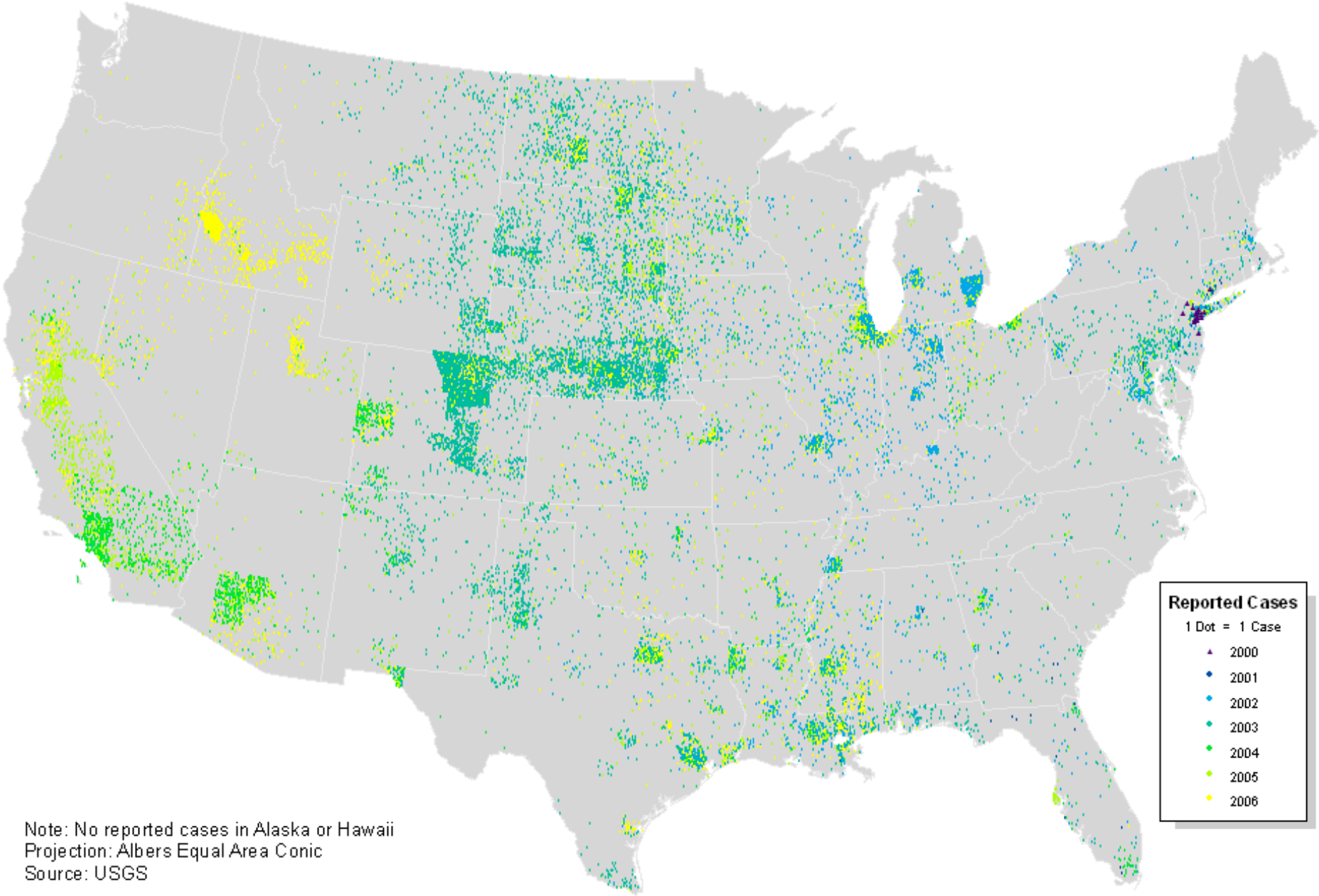

2004


2005

Spread of West Nile virus (WNV) across the US depicted by peak year of human incidence by county, 2002 - 2004

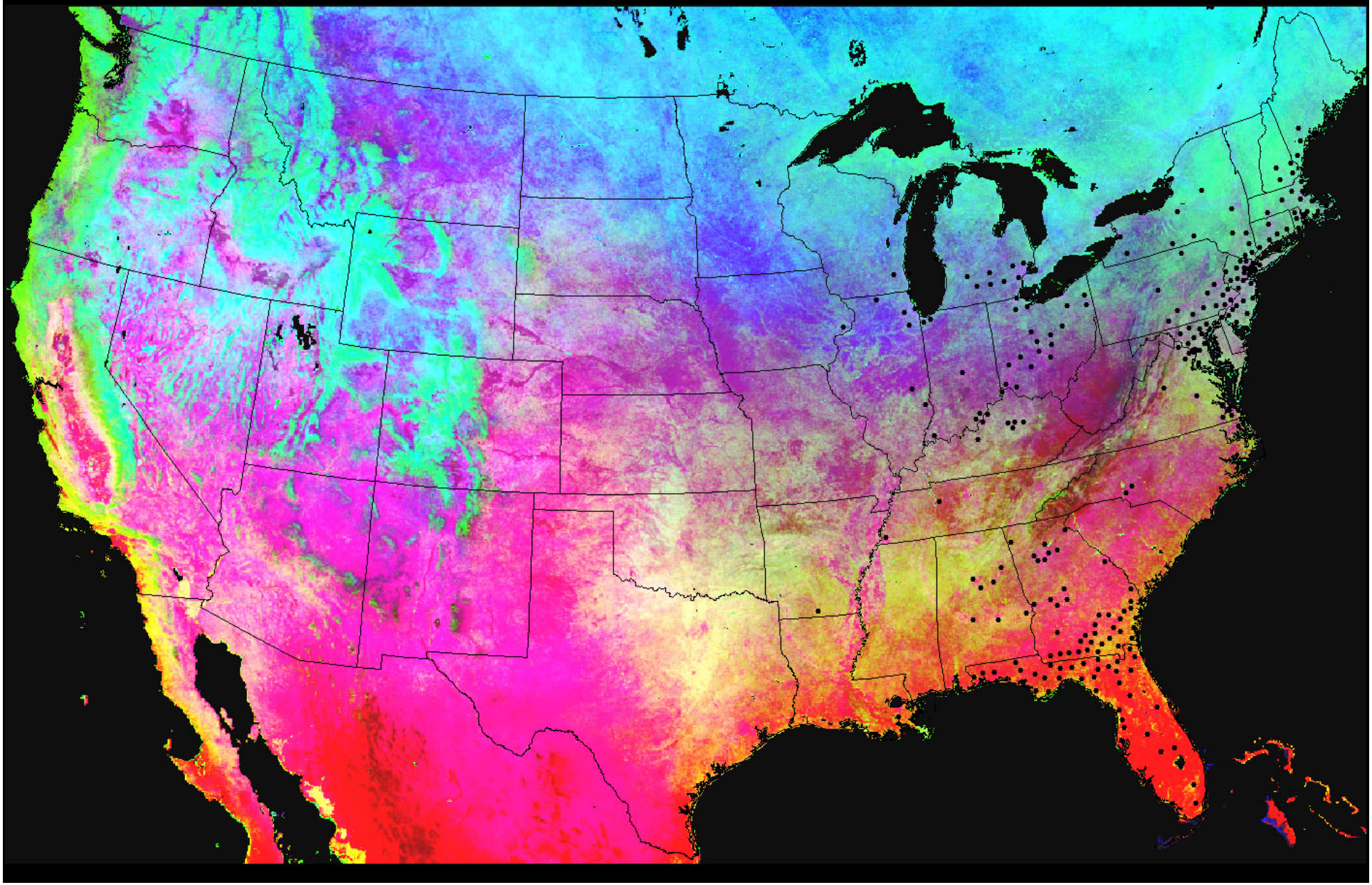


West Nile Virus in Humans 2000-2006



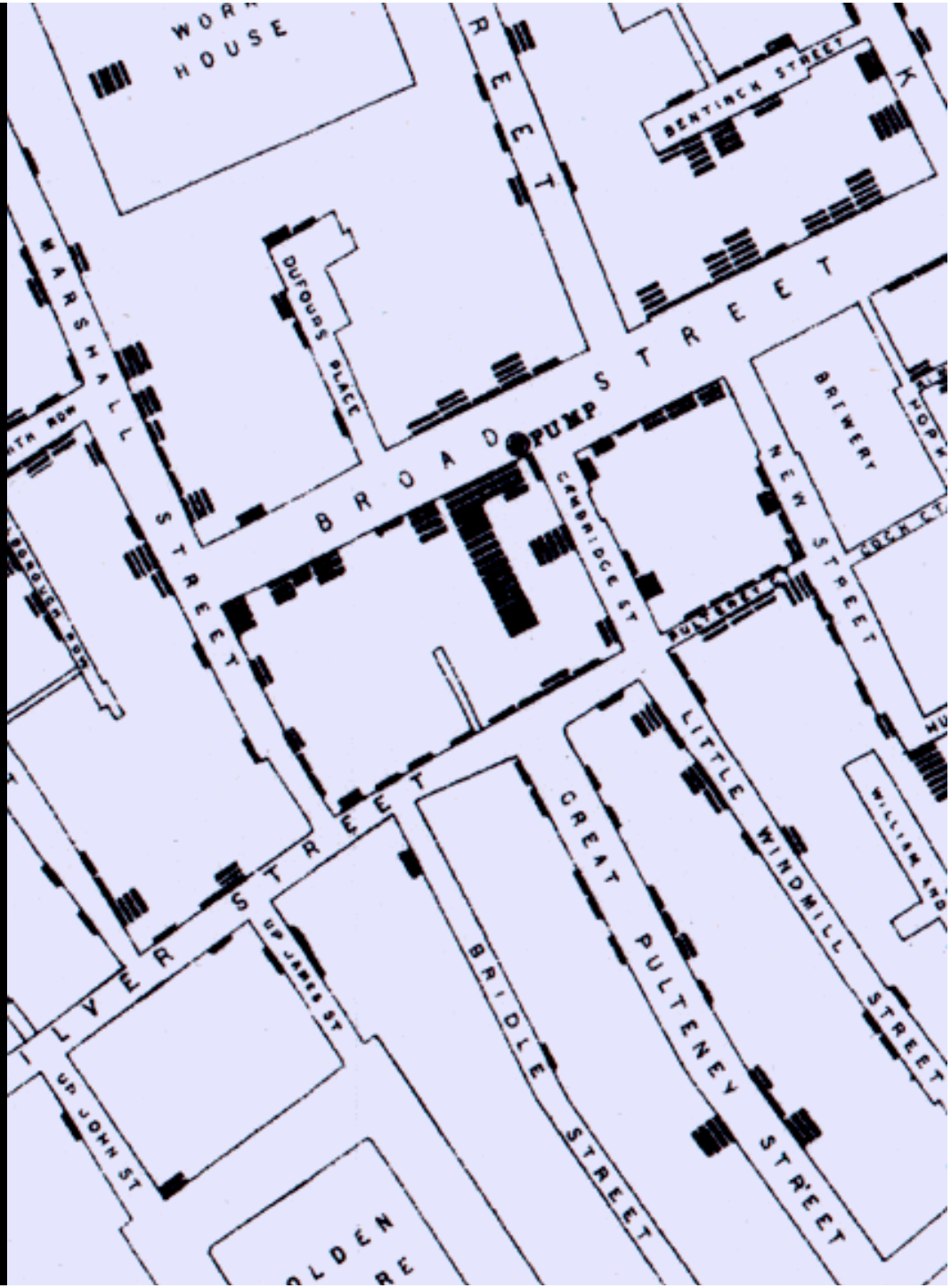
Note: No reported cases in Alaska or Hawaii
Projection: Albers Equal Area Conic
Source: USGS

http://diseasemaps.usgs.gov/wnv_us_veterinary.html

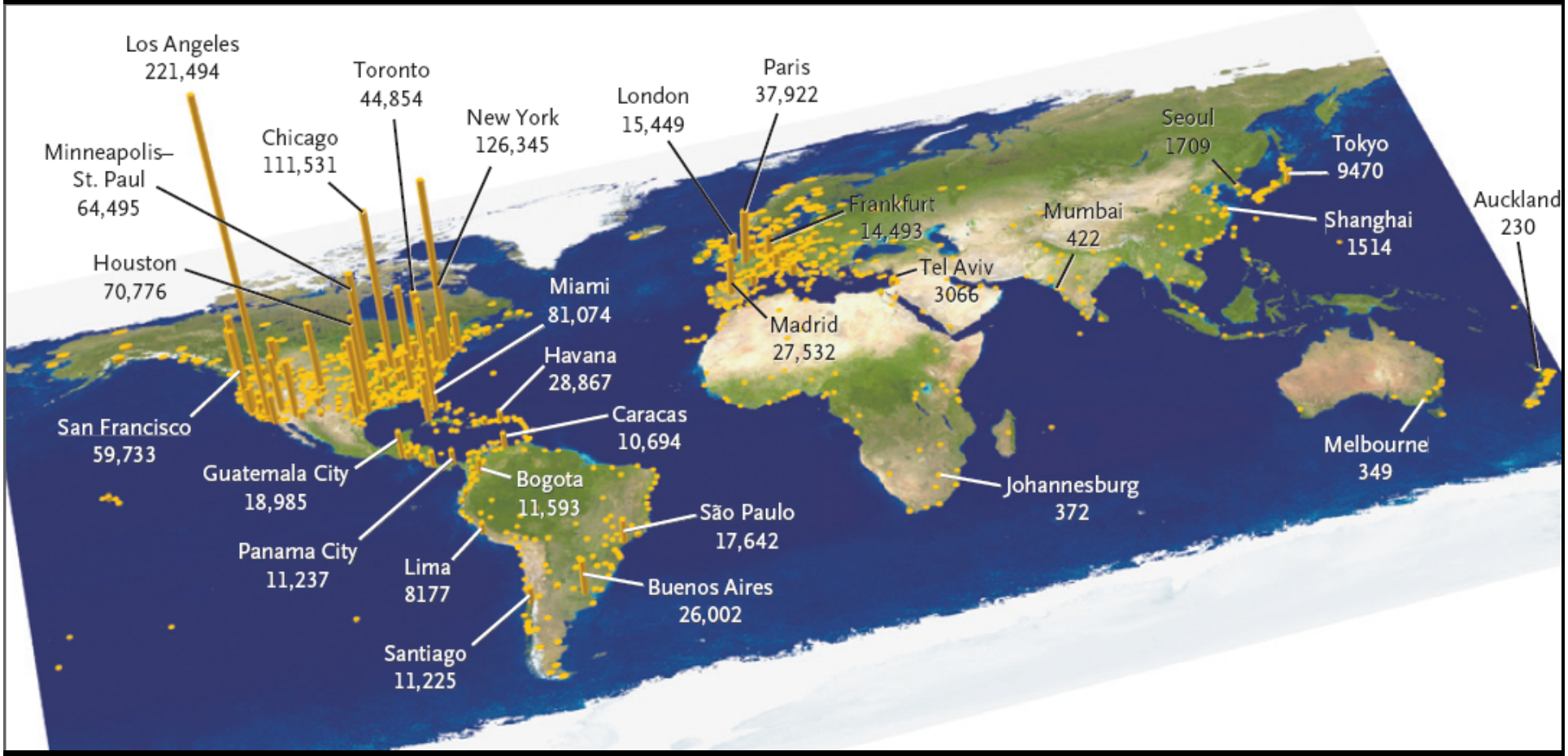


What do maps tell us?

Predict spread and allow instigation of control/preparations

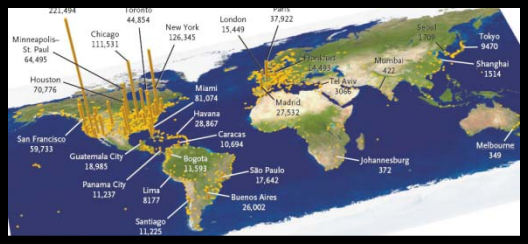


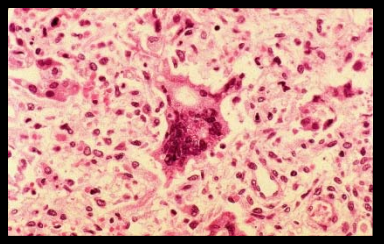
Destination cities and corresponding volumes of international passengers arriving from Mexico between March 1 and April 30, 2008.

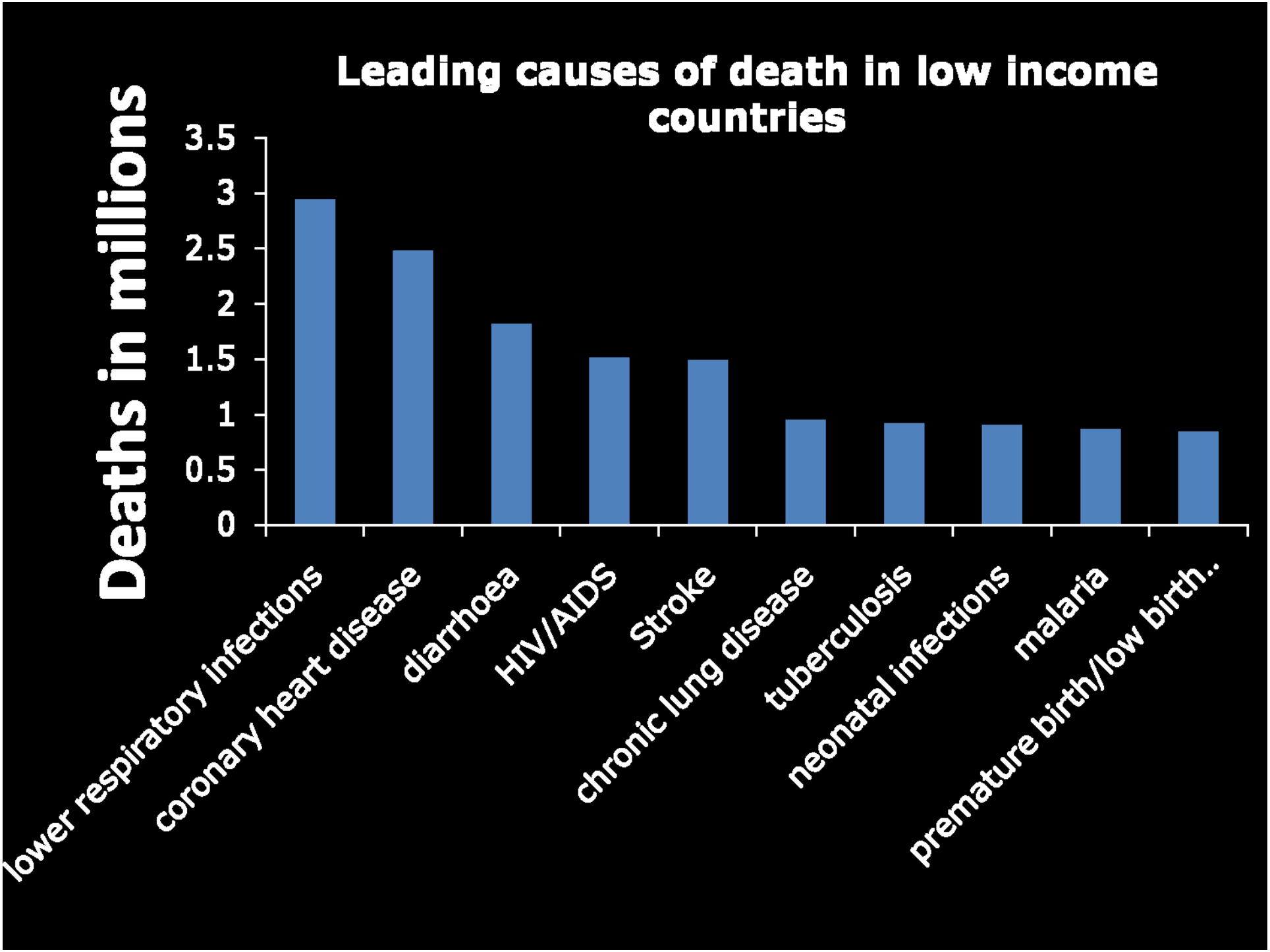


Khan et al. 2008 NEJM

How many people suffer from a disease?






Leading causes of death in low income countries
Deaths in millions
3.5
3
2.5
2
1.5
1
0.5
0
lower respiratory infections
coronary heart disease
diarrhoea
HIV/AIDS
Stroke
chronic lung disease
tuberculosis
neonatal infections
malaria
premature birth/low birth..

How many people suffer from a disease?

> 55,000 people die of rabies every year

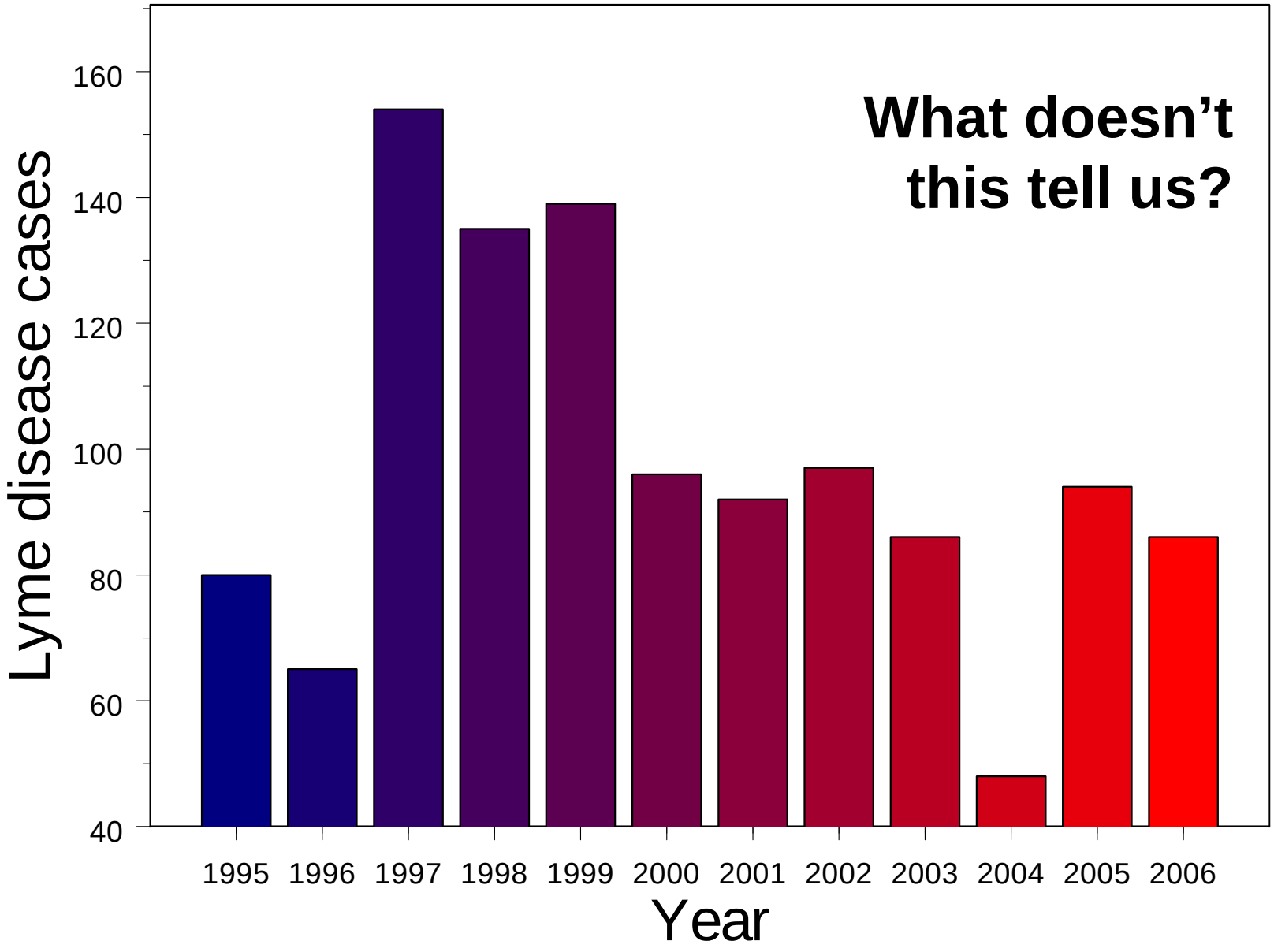
Plain numbers:

Present scale of problem

Meaningful for advocacy

Logistically informative

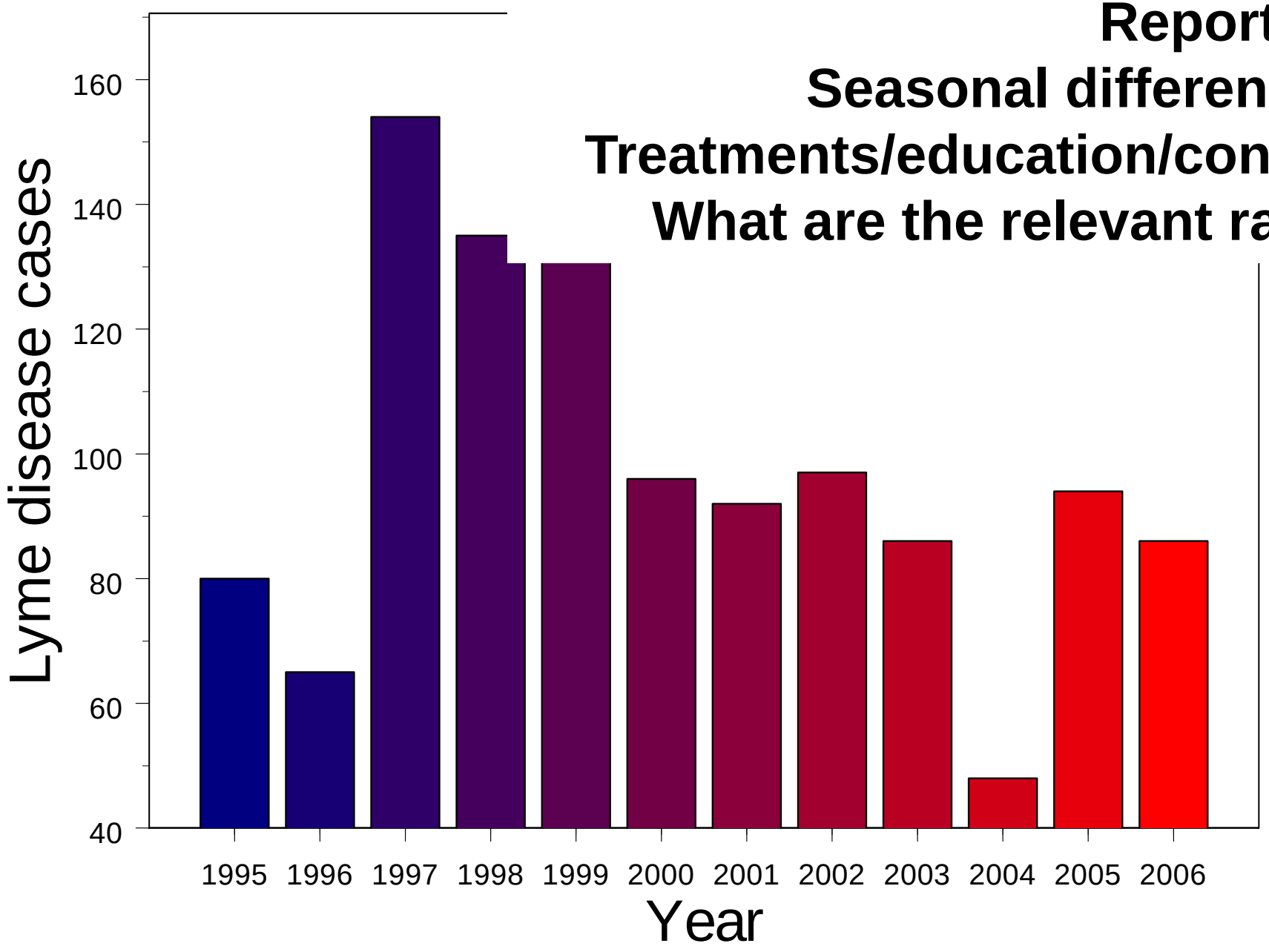
Californian cases of Lyme disease



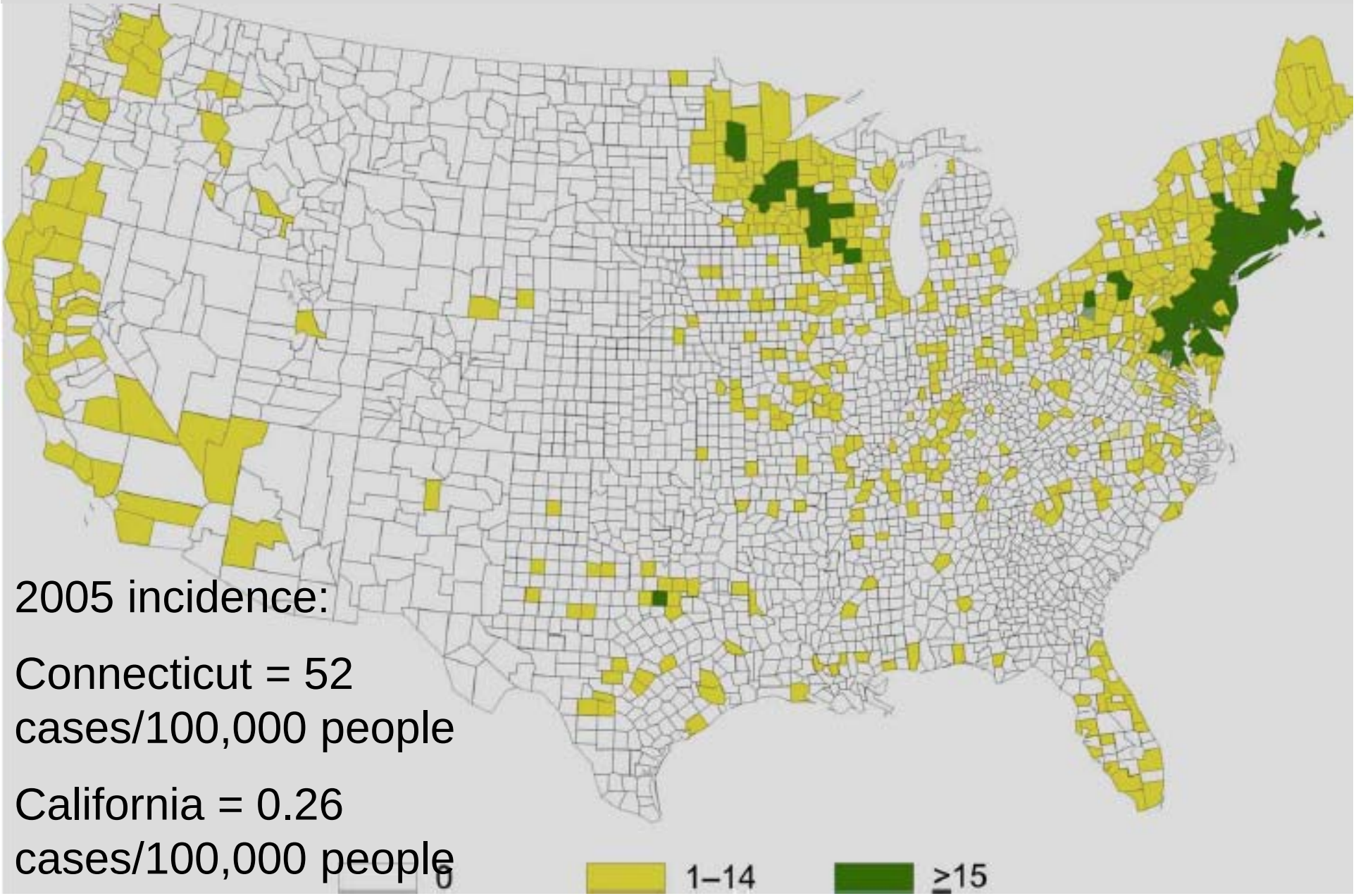
What is the denominator?
What is the size of the population at risk?

What is the context?
Compared to what?

Changes in exposed population?
Reporting?
Seasonal differences?
Treatments/education/control?
What are the relevant rates?



Geographical variation in incidence of Lyme disease



2005 incidence:

Connecticut = 52 cases/100,000 people

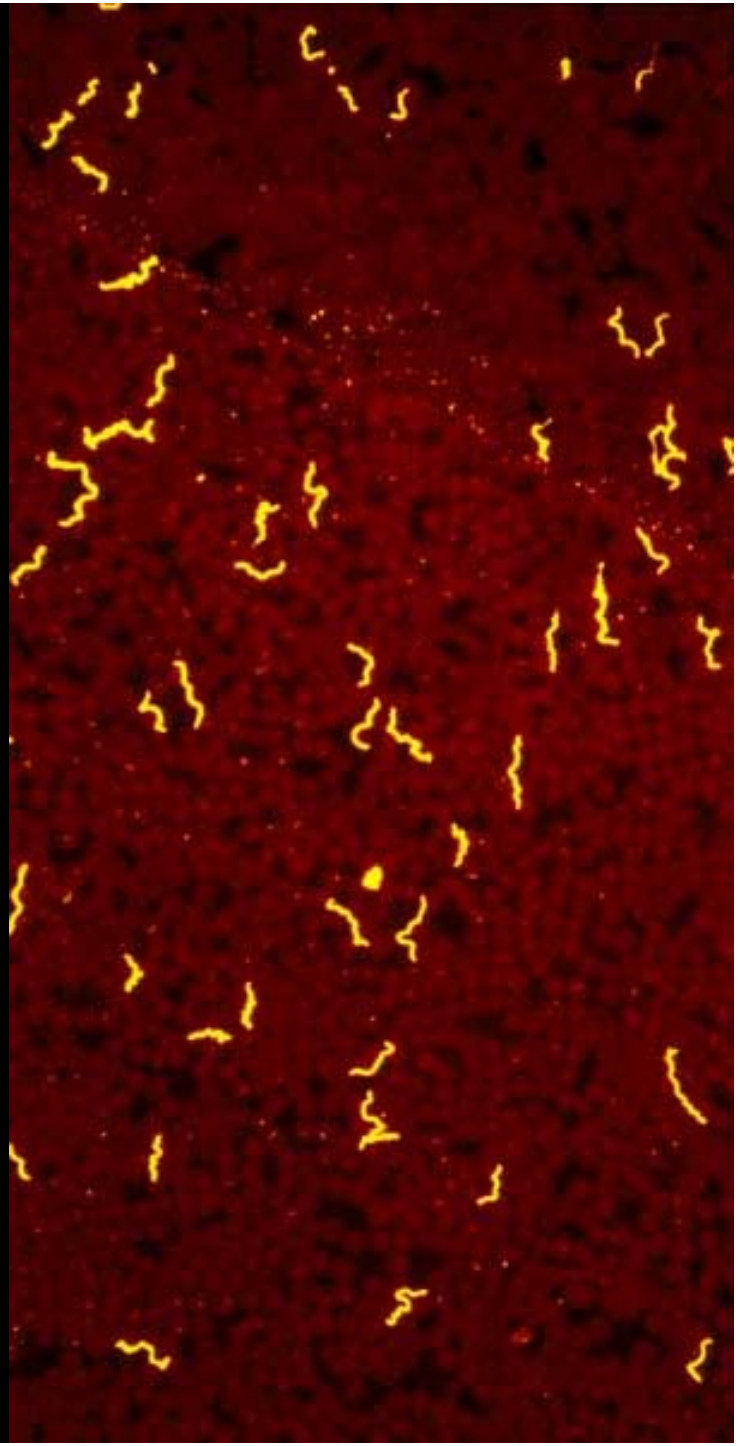
California = 0.26 cases/100,000 people

Anatomy of Lyme disease?

Agent: bacterium *Borrelia burgdorferi*

Transmission: vector-borne, *Ixodes* ticks

Reservoir/source: small mammals

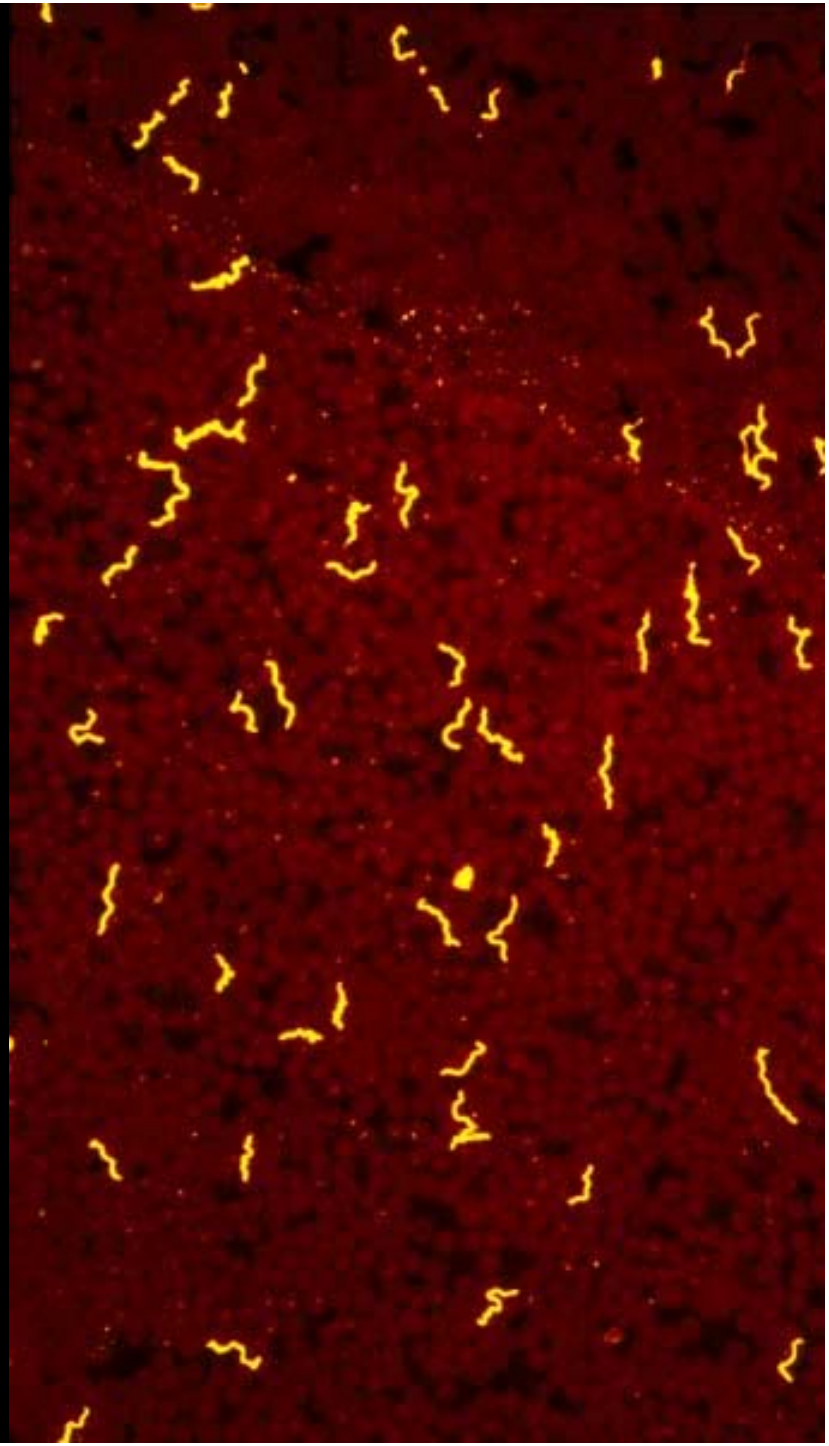


Incidence = number of new cases that occur during a specified period of time, in a population at risk for developing the disease

NB: ‘new cases’

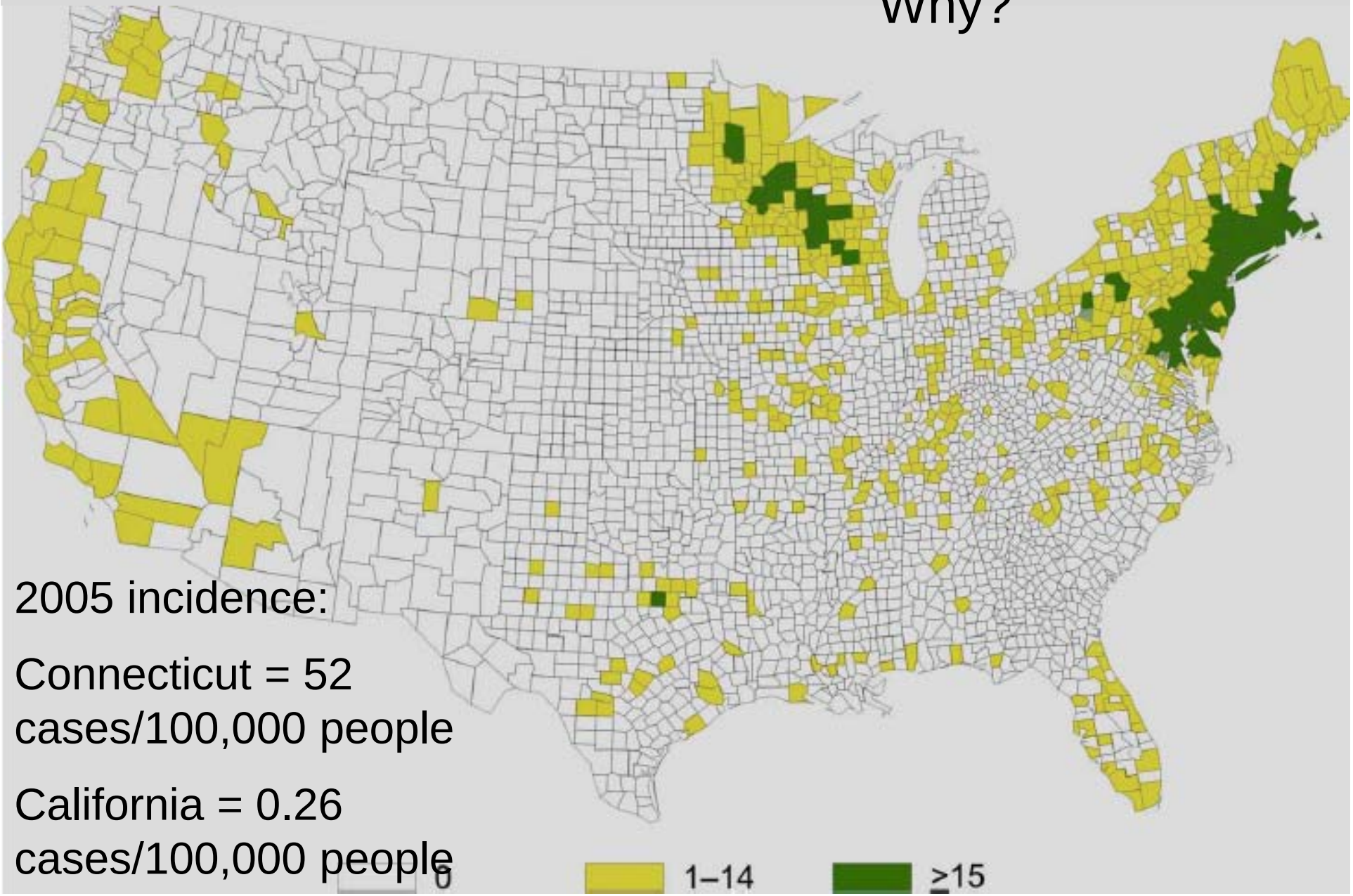
‘population at risk’

‘specified period of time’



Geographical variation in incidence of Lyme disease

Why?

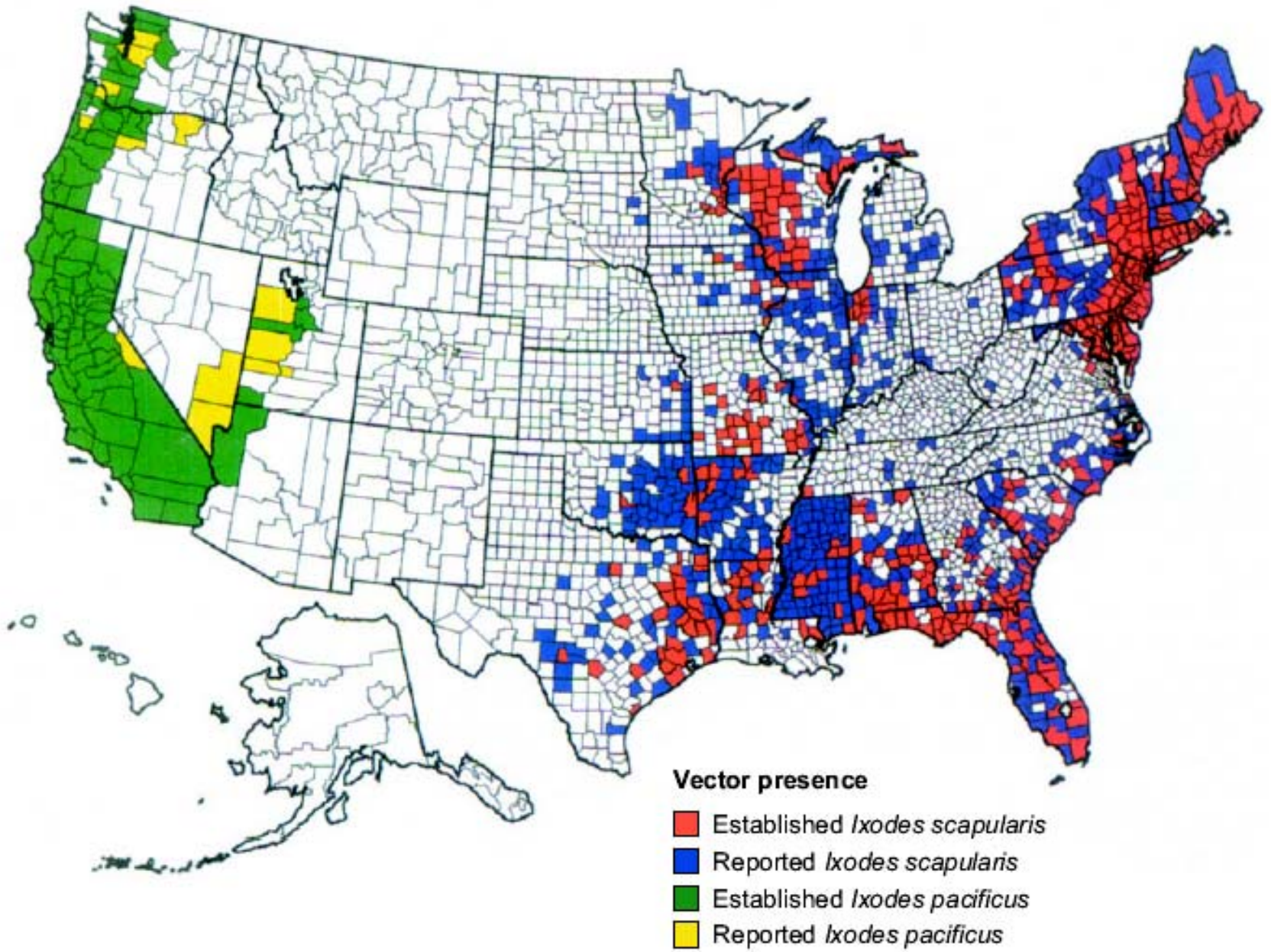


2005 incidence:

Connecticut = 52 cases/100,000 people

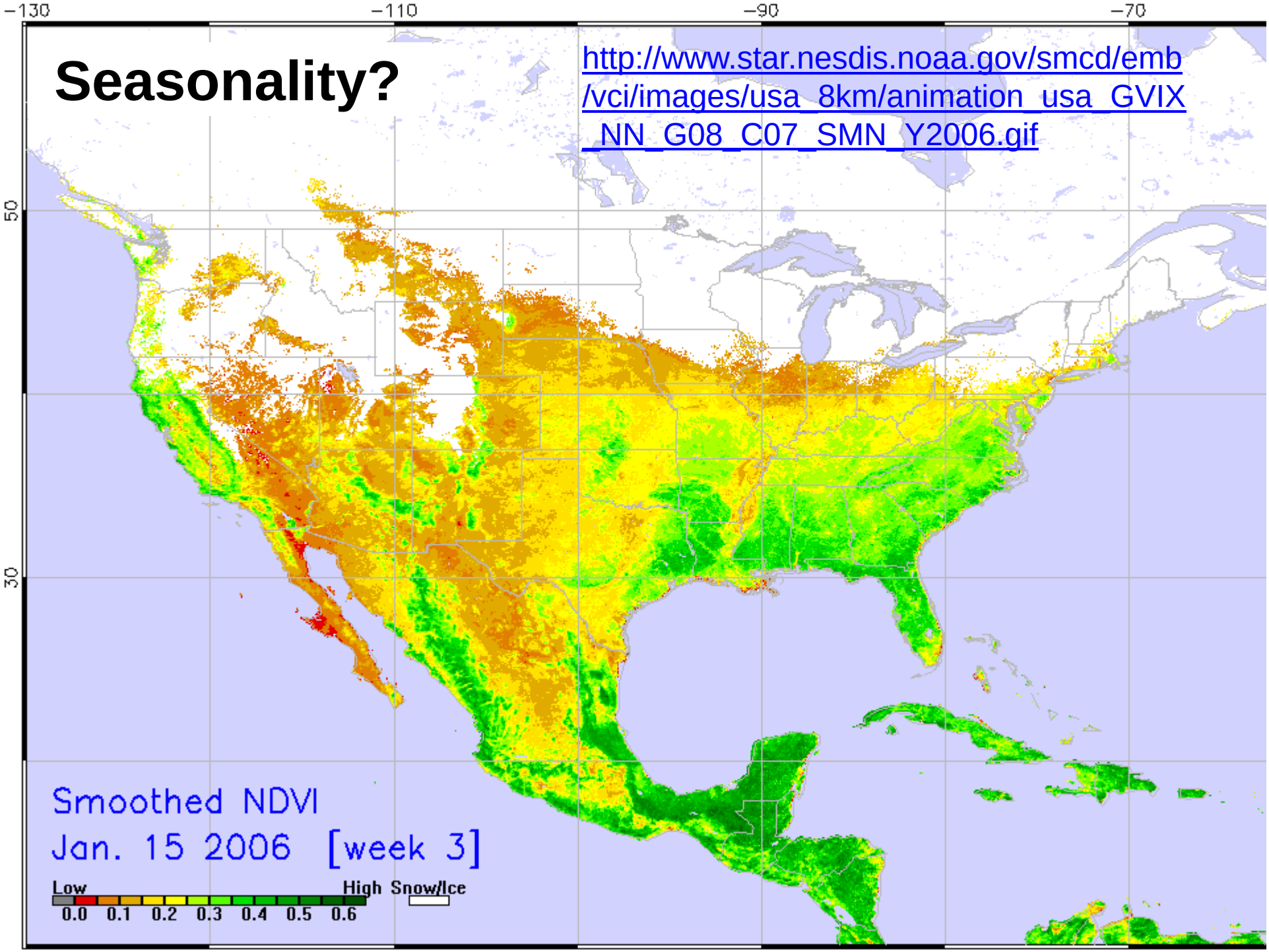
California = 0.26 cases/100,000 people

USA distribution of *Ixodes* ticks



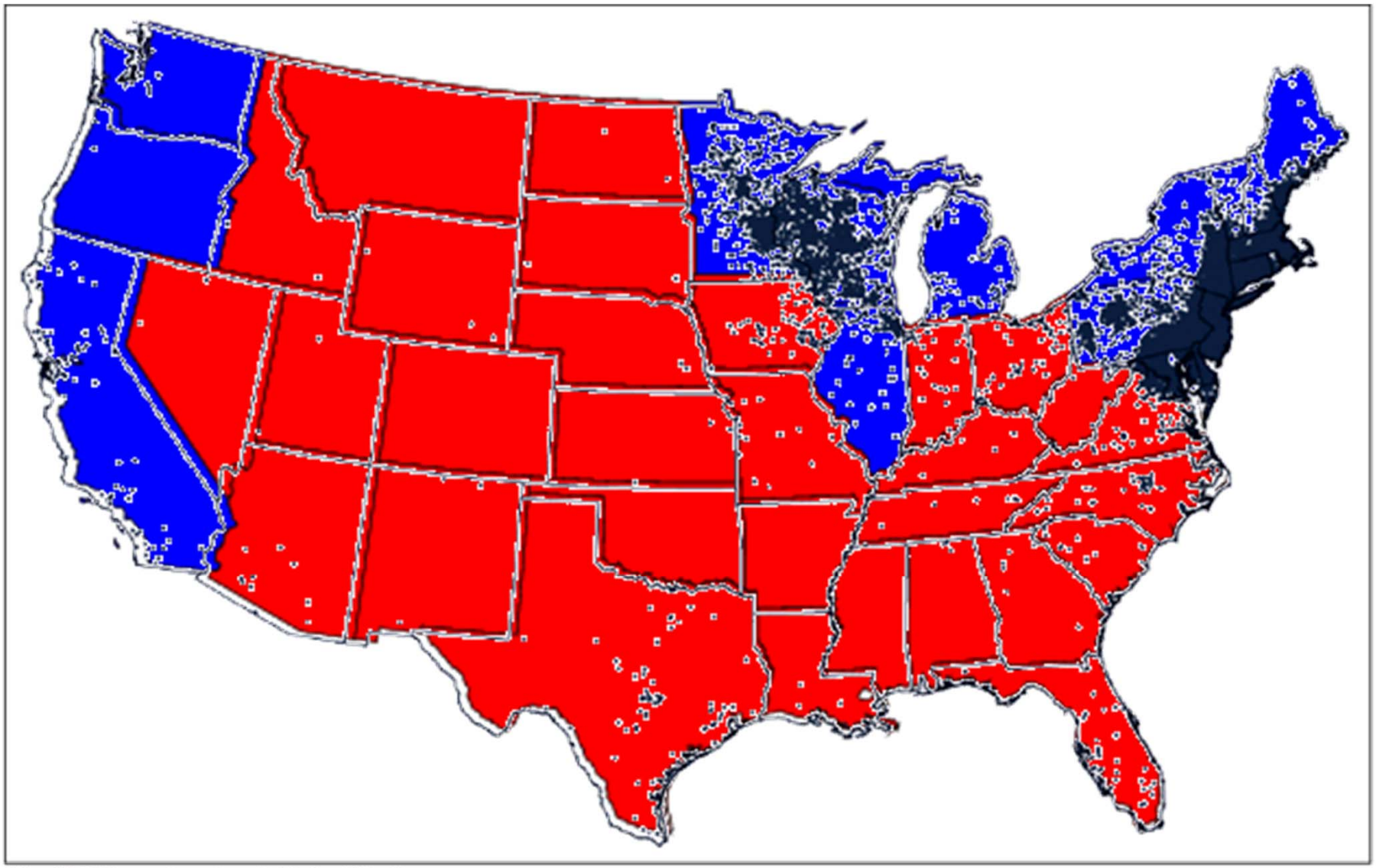
Seasonality?

http://www.star.nesdis.noaa.gov/smcd/emb/vci/images/usa_8km/animation_usa_GVIX_NN_G08_C07_SMN_Y2006.gif



SES -

Lyme disease cases, by county, USA 2005

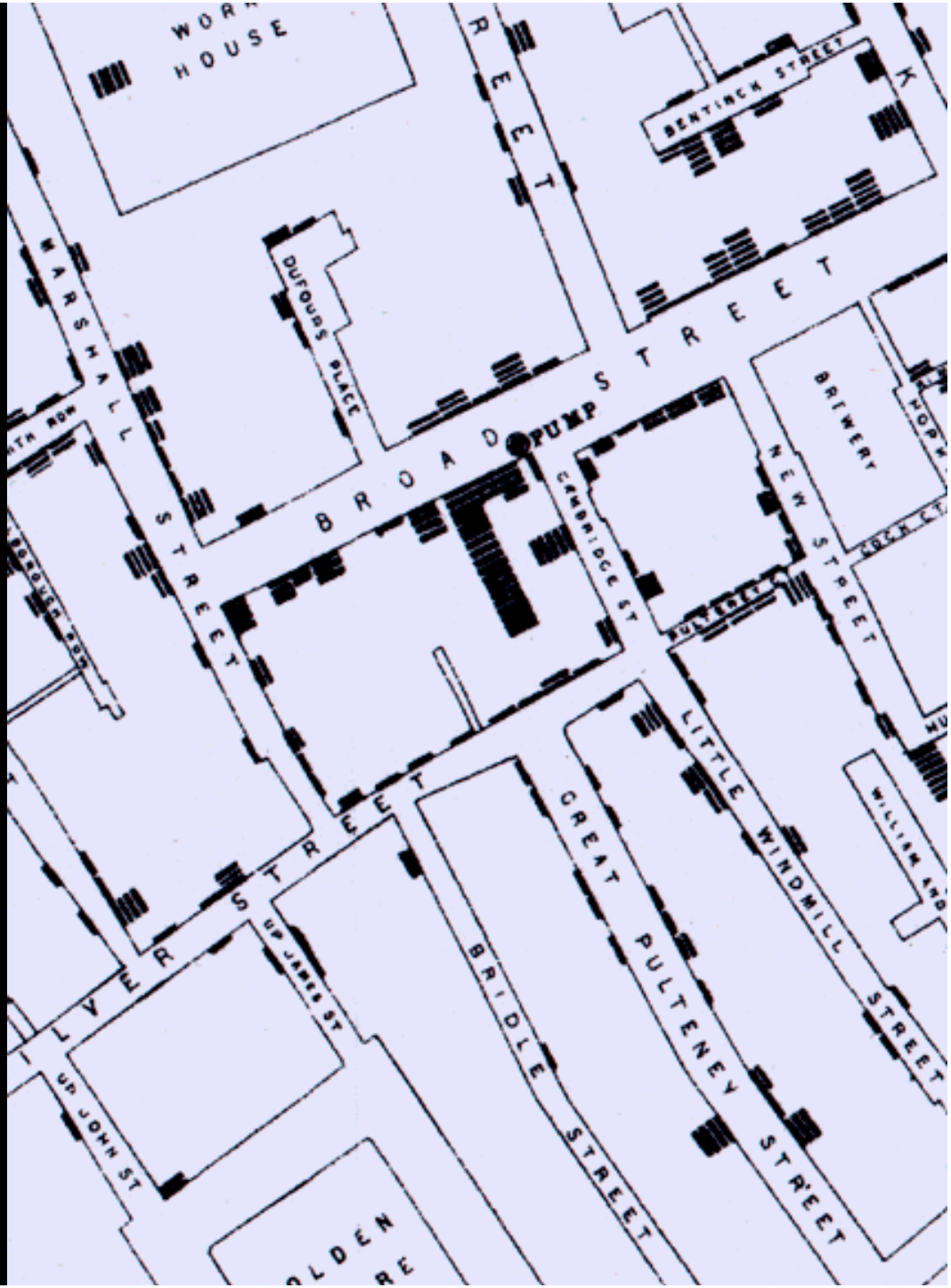


* N = 23,174; county not available for 131 other cases.

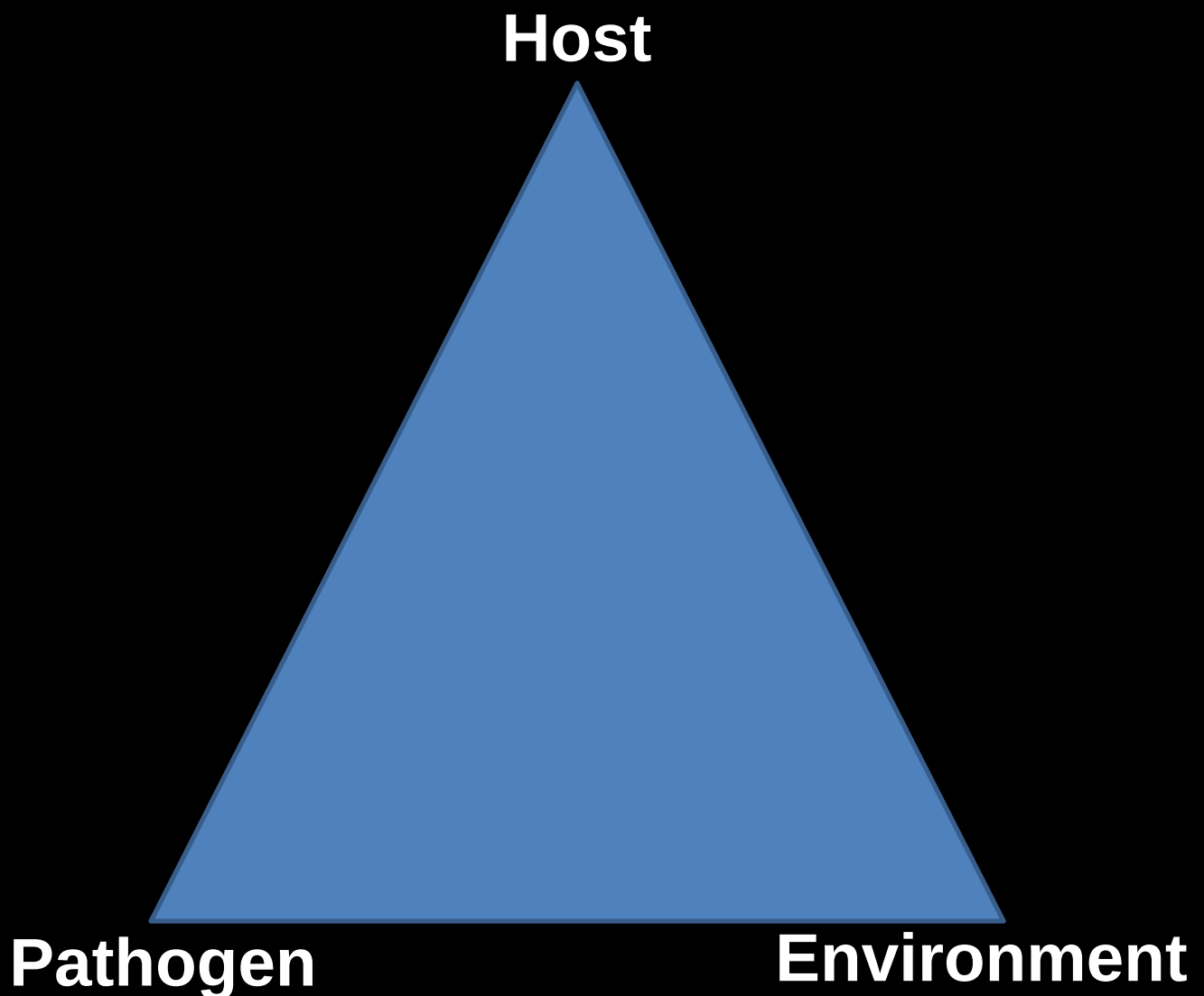
What do maps tell us?

Insight into disease ecology and disease risk.

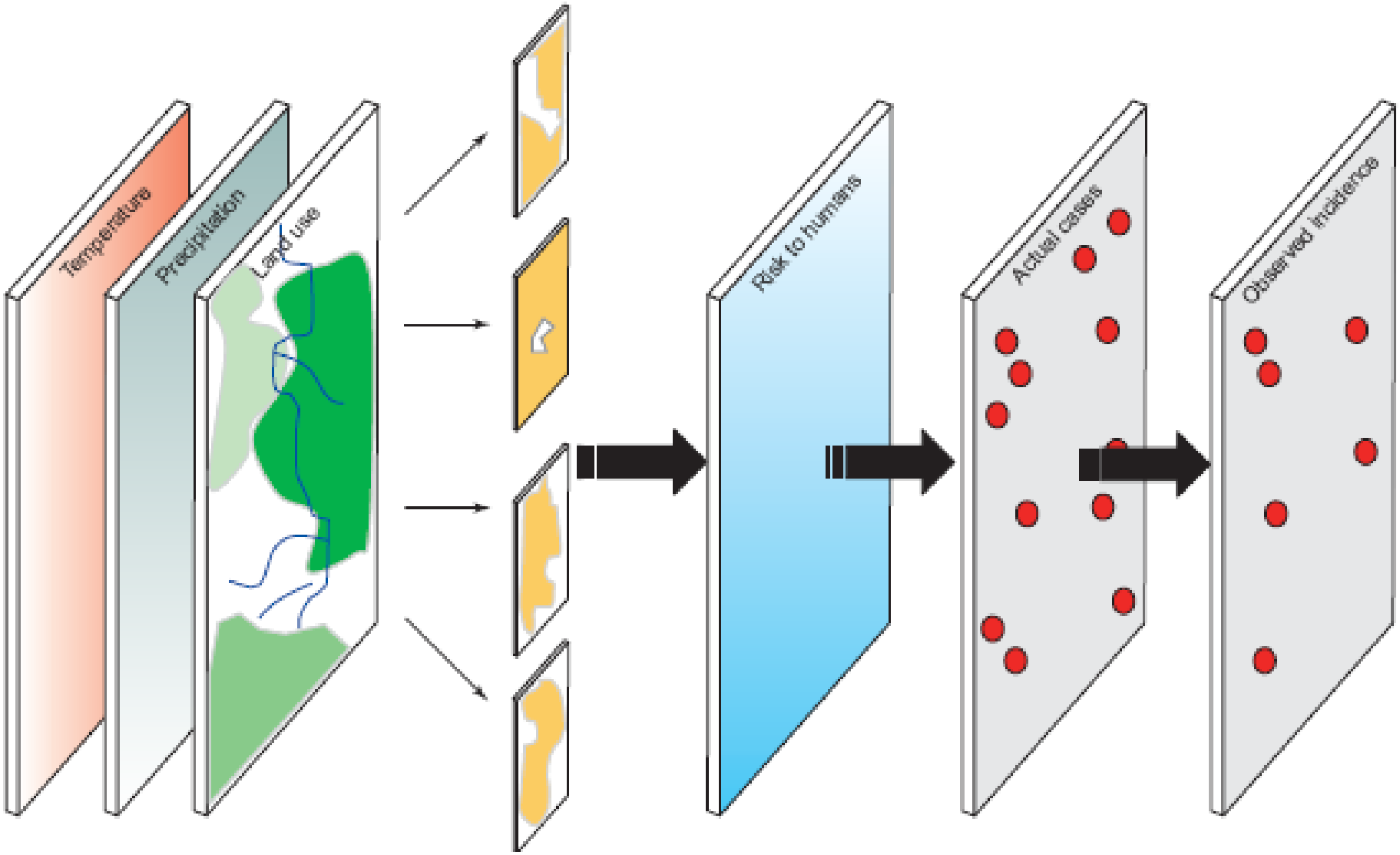
e.g. cholera due to contaminated water/vehicle-borne



The epidemiologic triangle



Spatial epidemiology

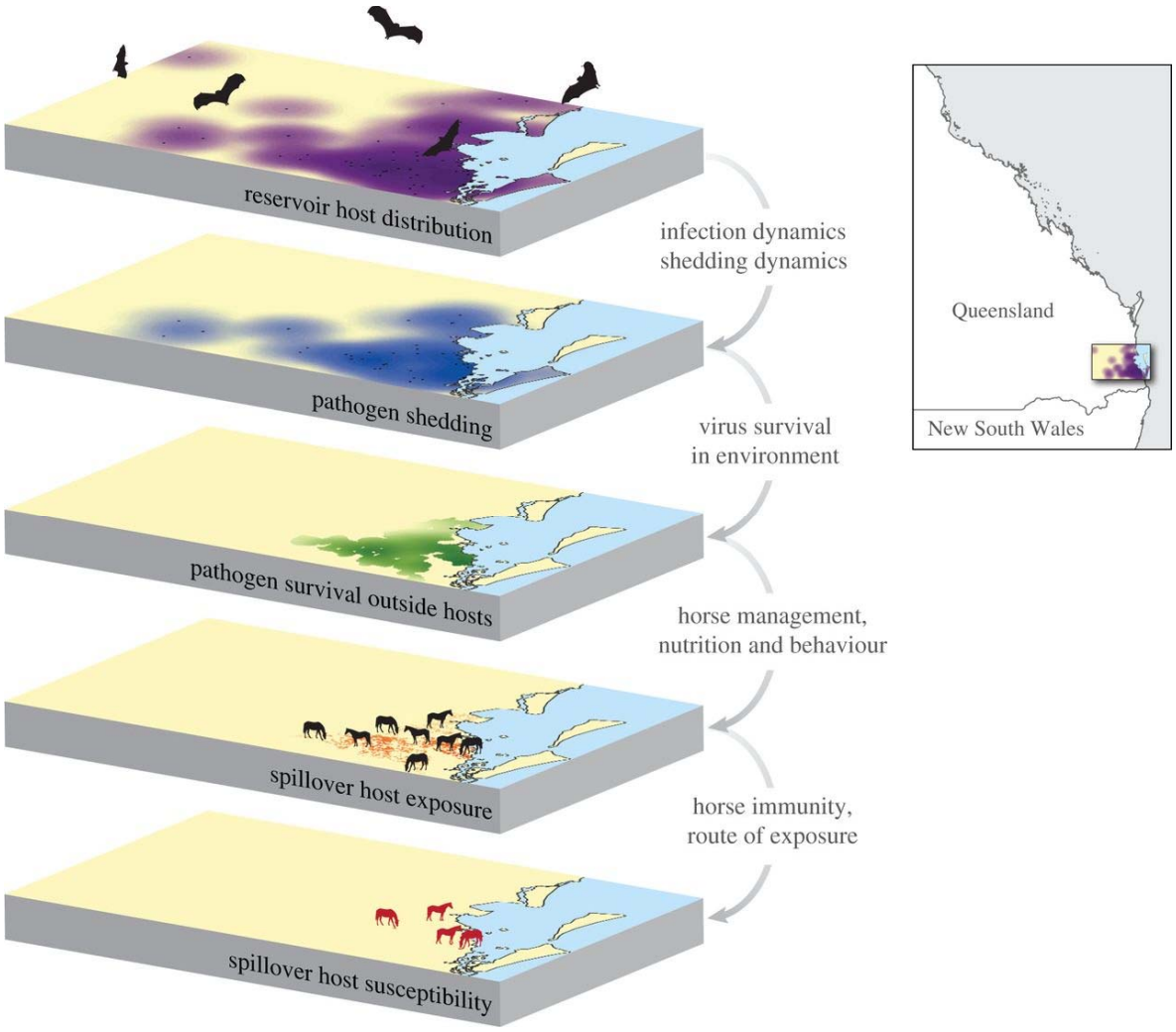


Environmental factors

Vector & host distributions

Human risk & cases

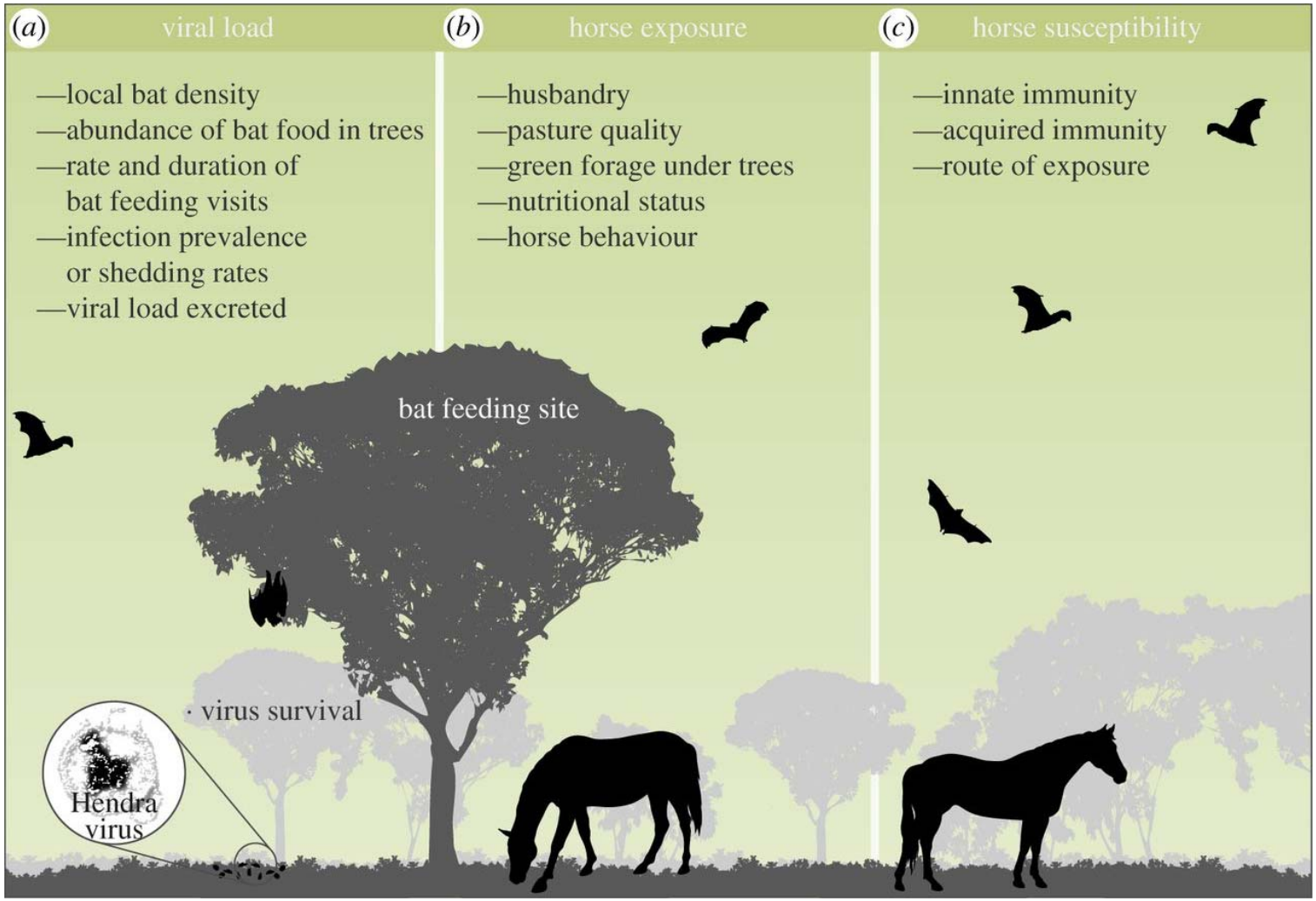
Enabling conditions for Hendra virus spillover.



Plowright R K et al. Proc. R. Soc. B 2015;282:20142124

PROCEEDINGS OF THE ROYAL SOCIETY B

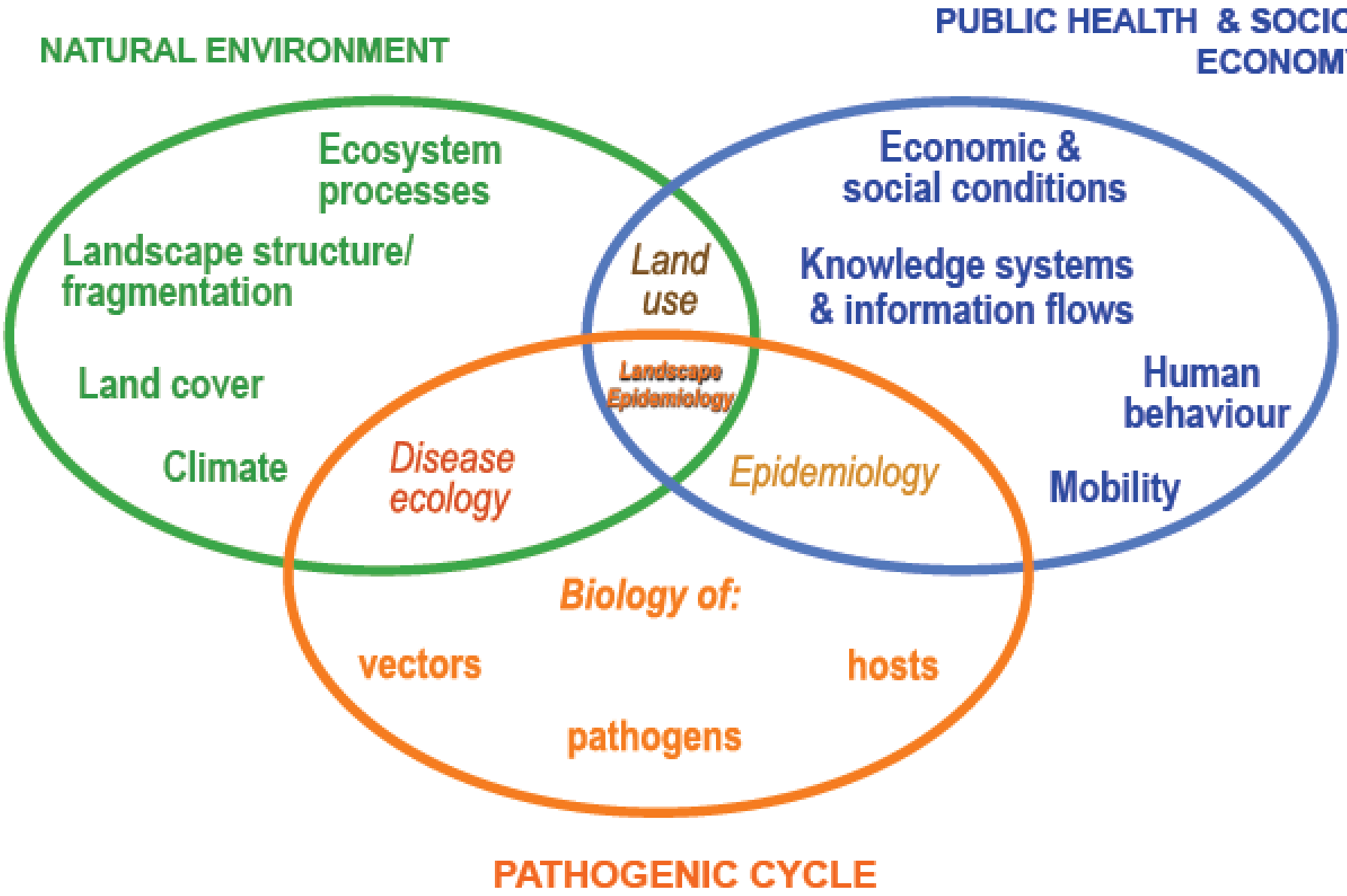
Risk factors for development of Hendra virus by horses.



Plowright R K et al. Proc. R. Soc. B 2015;282:20142124

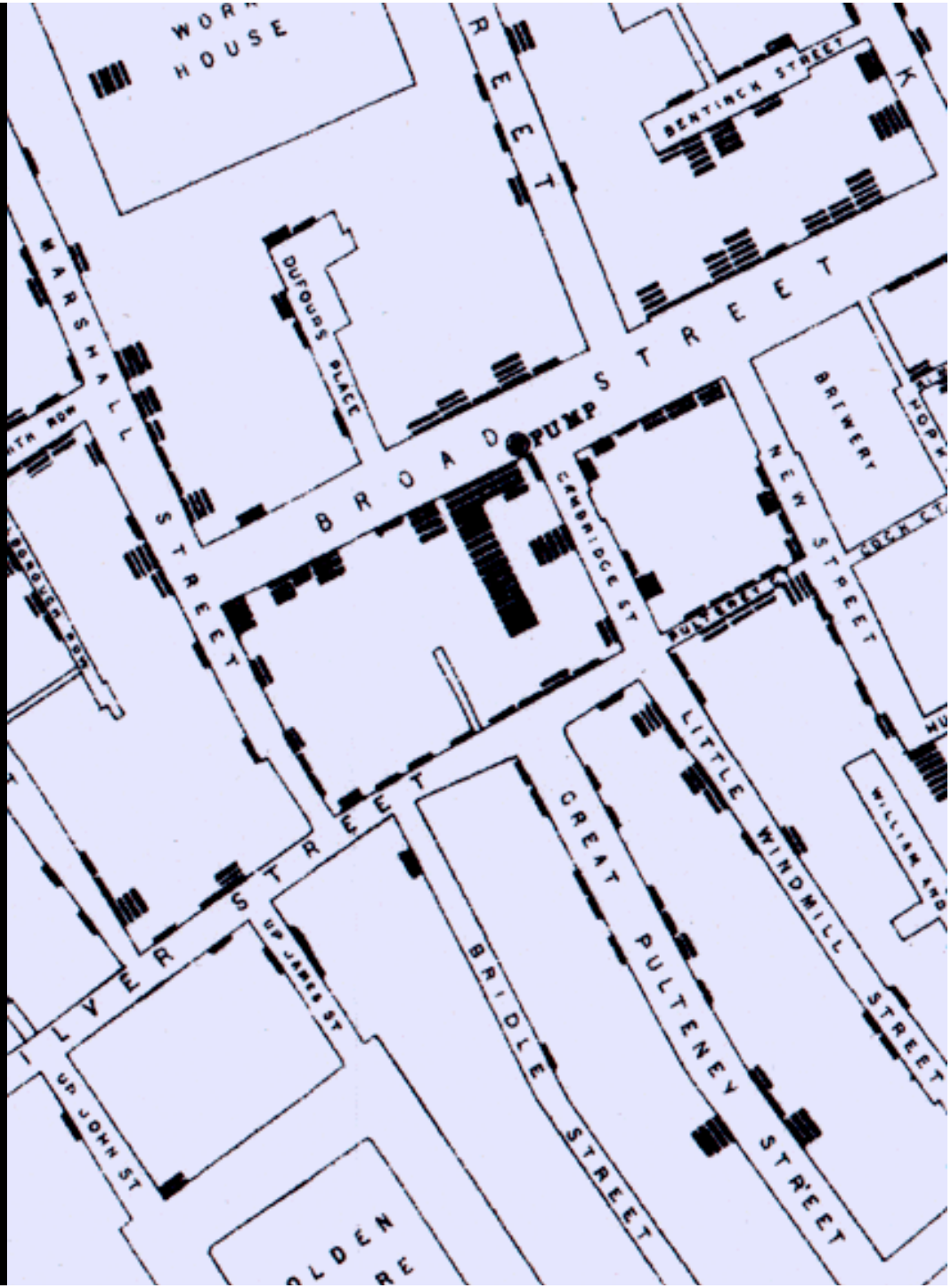
PROCEEDINGS OF THE ROYAL SOCIETY B

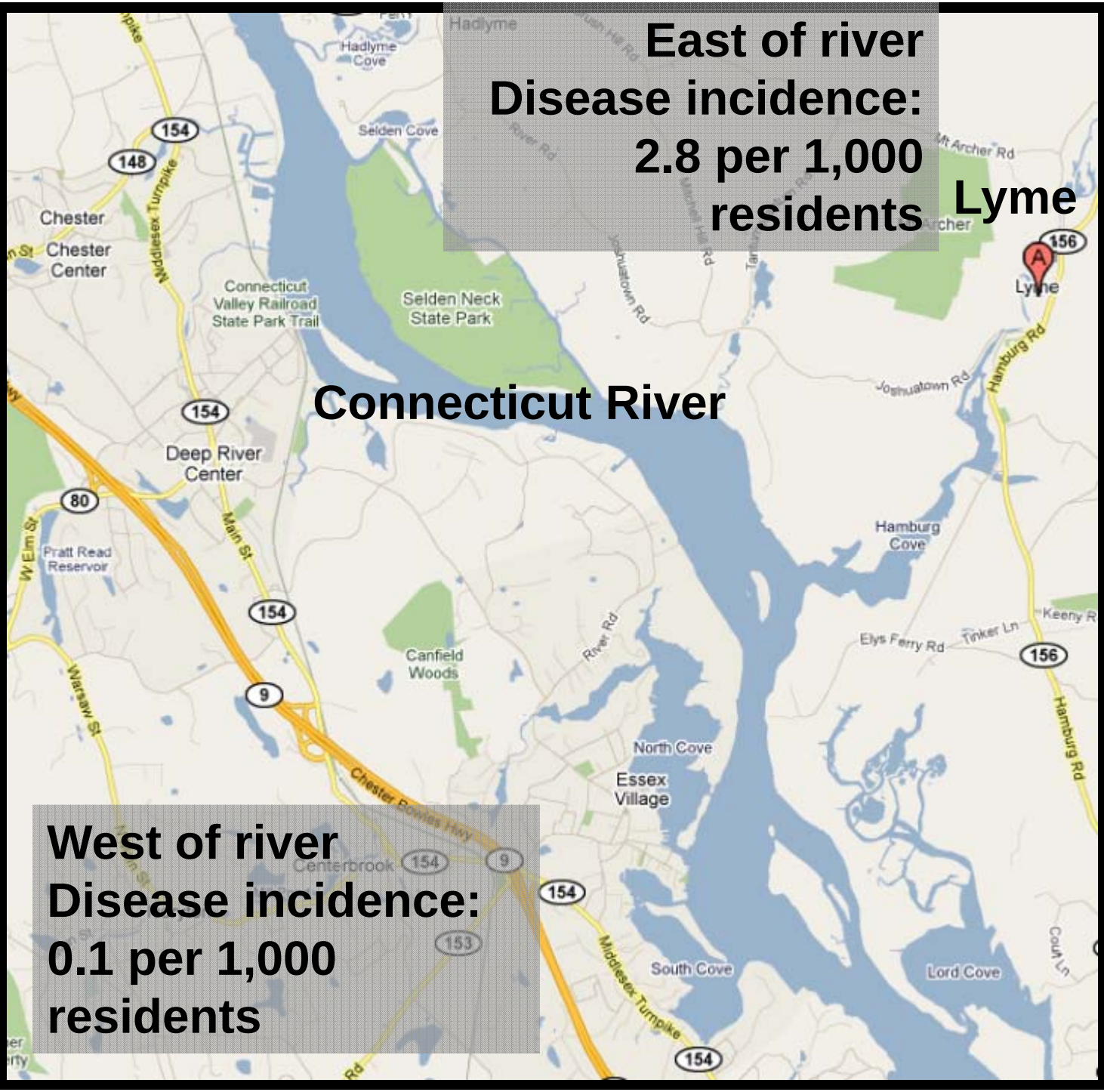
Spatial epidemiology

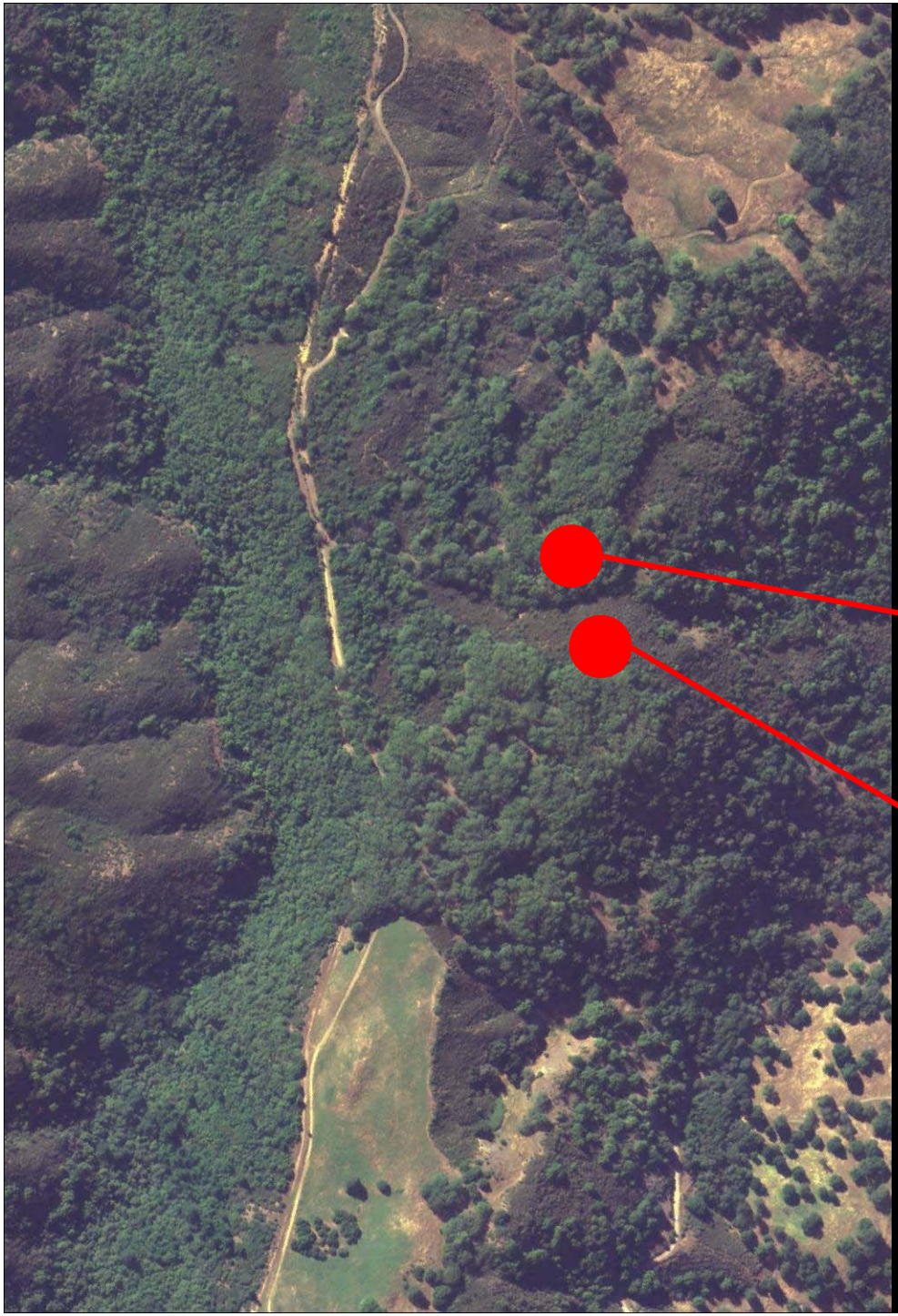


What do maps tell us?

The importance of local context & scale




East of river
Disease incidence:
2.8 per 1,000
residents
Lyme
Connecticut River
West of river
Disease incidence:
0.1 per 1,000
residents
Hadlyme
Hadlyme Cove
Selden Cove
Chester
Chester Center
Connecticut Valley Railroad State Park Trail
Selden Neck State Park
Deep River Center
Pratt Read Reservoir
Canfield Woods
Hamburg Cove
North Cove
Essex Village
Centerbrook
South Cove
Lord Cove
Middlesex Turnpike
Hamburg Rd
Joshuatown Rd
Mt Archer Rd
River Rd
Main St
W Elm St
Warsaw St
Chester Bowles Hwy
Ely's Ferry Rd
Tinker Ln
Keeny R
Coun Ln
148
154
80
9
153
156



Influence of habitat type on disease risk

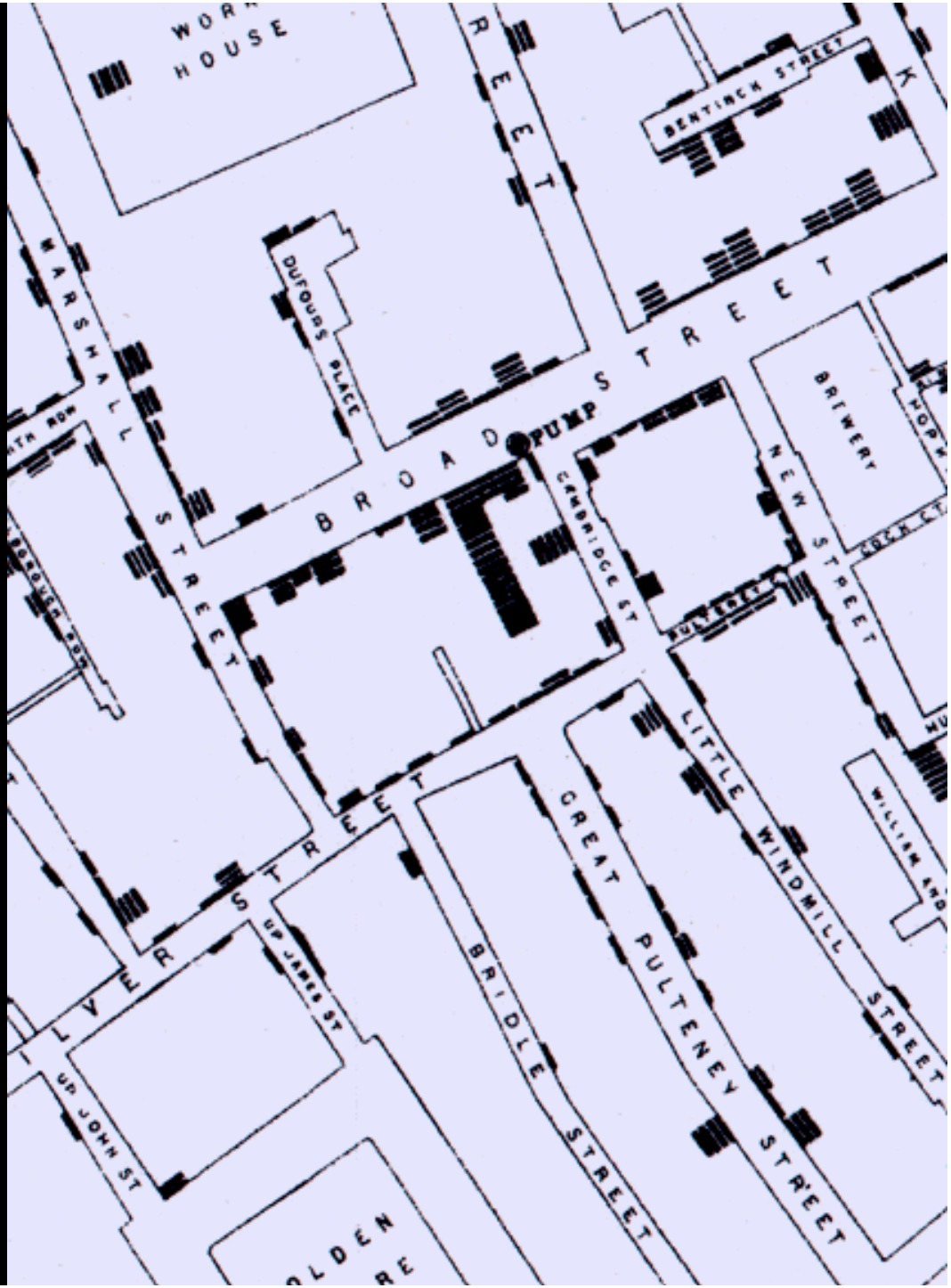
Geographic variation in disease dynamics

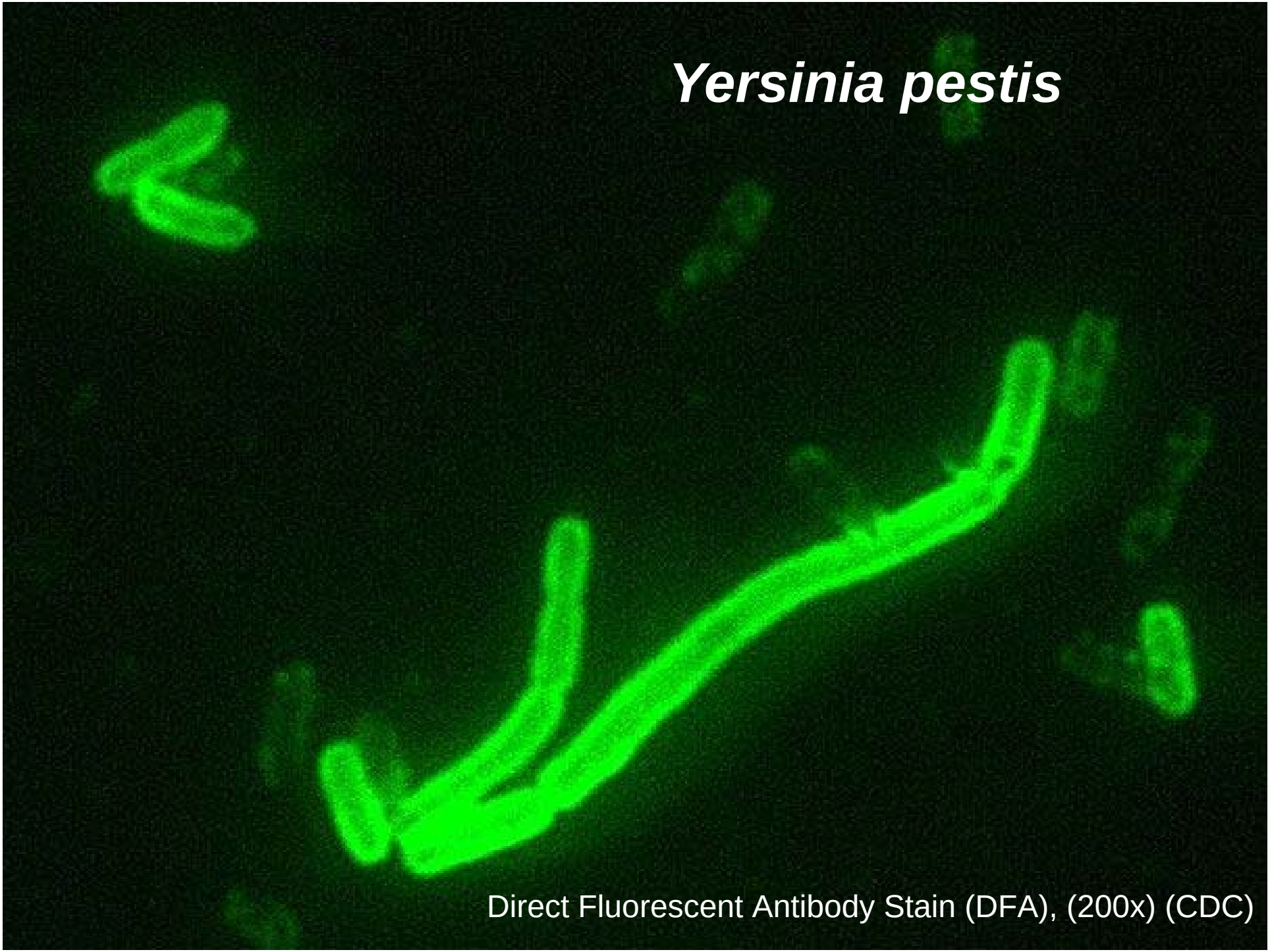
B. burgdorferi s.s. - black oak woodland

B. bissettii – chaparral

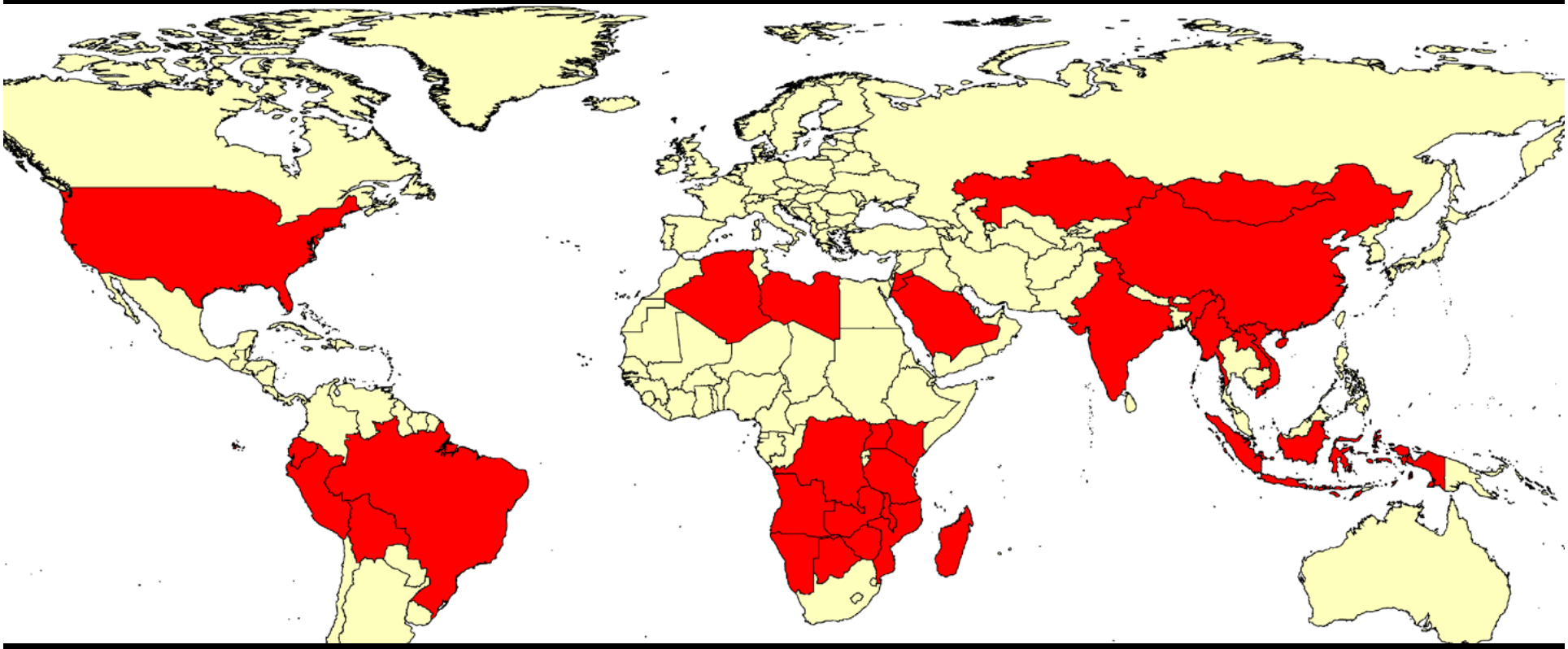
So what is the appropriate scale?

Depends on the question…

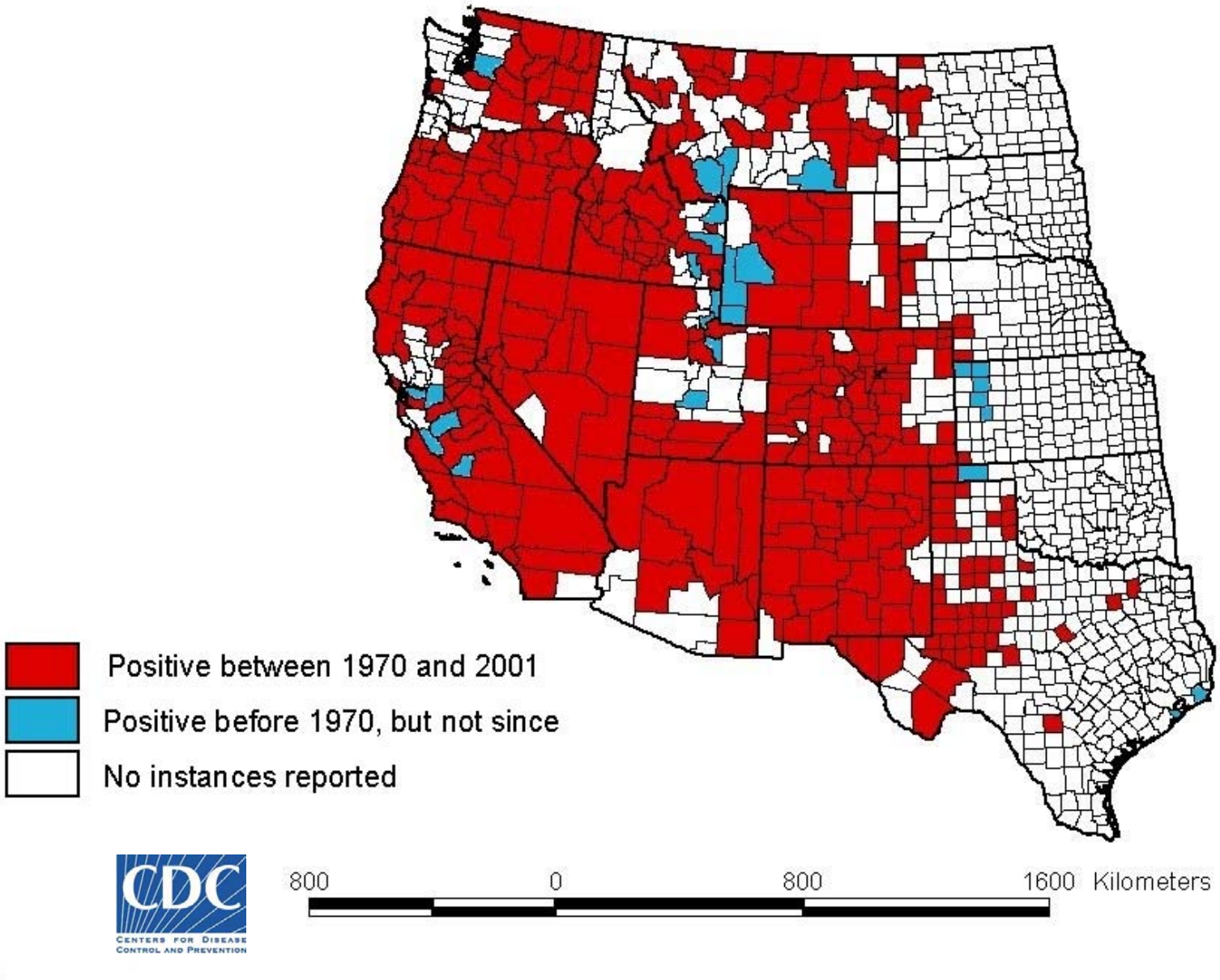


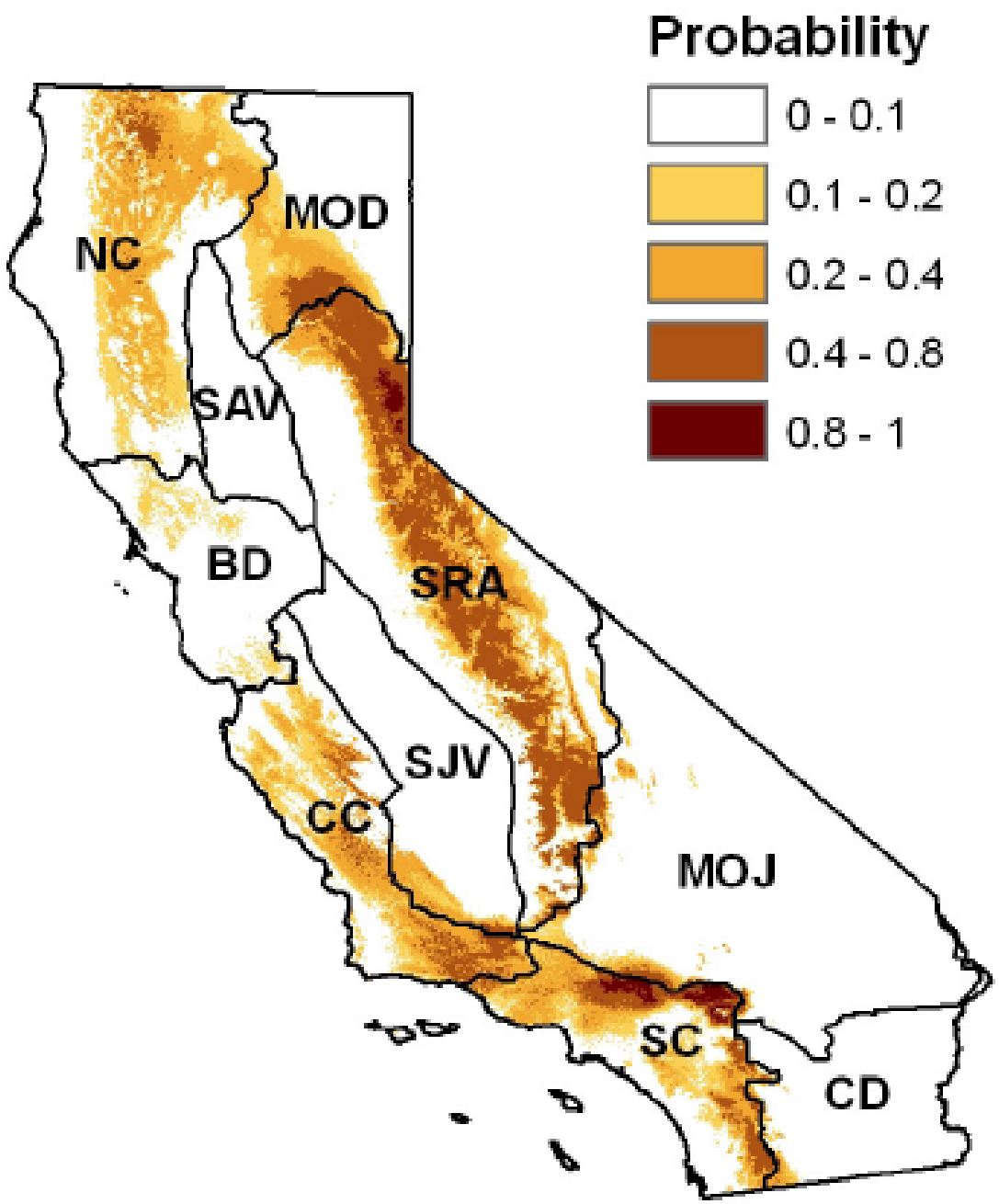

Yersinia pestis
Direct Fluorescent Antibody Stain (DFA), (200x) (CDC)

Global distribution of plague (*Yersinia pestis*) by country



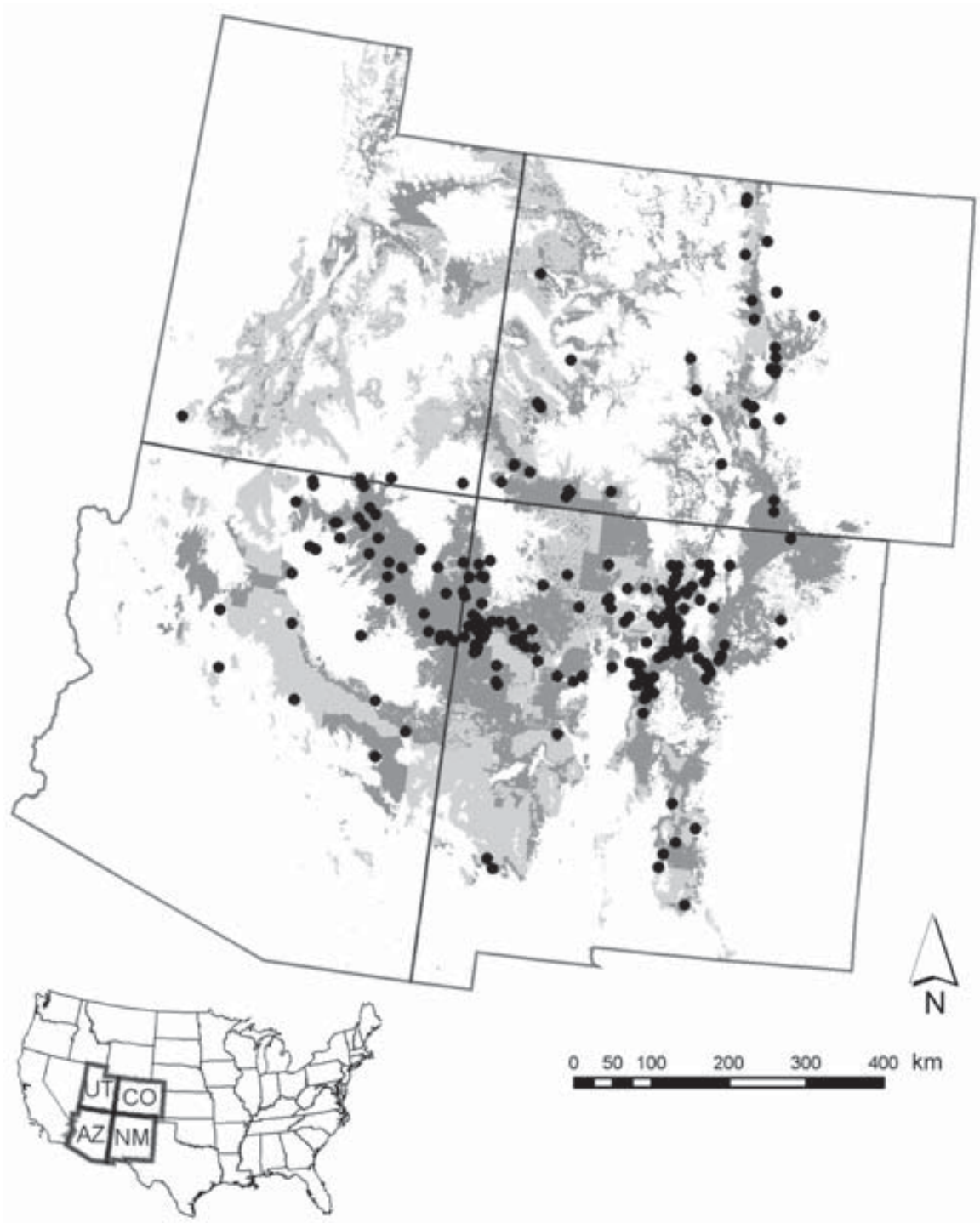
Western US Counties With Plague Positive Data





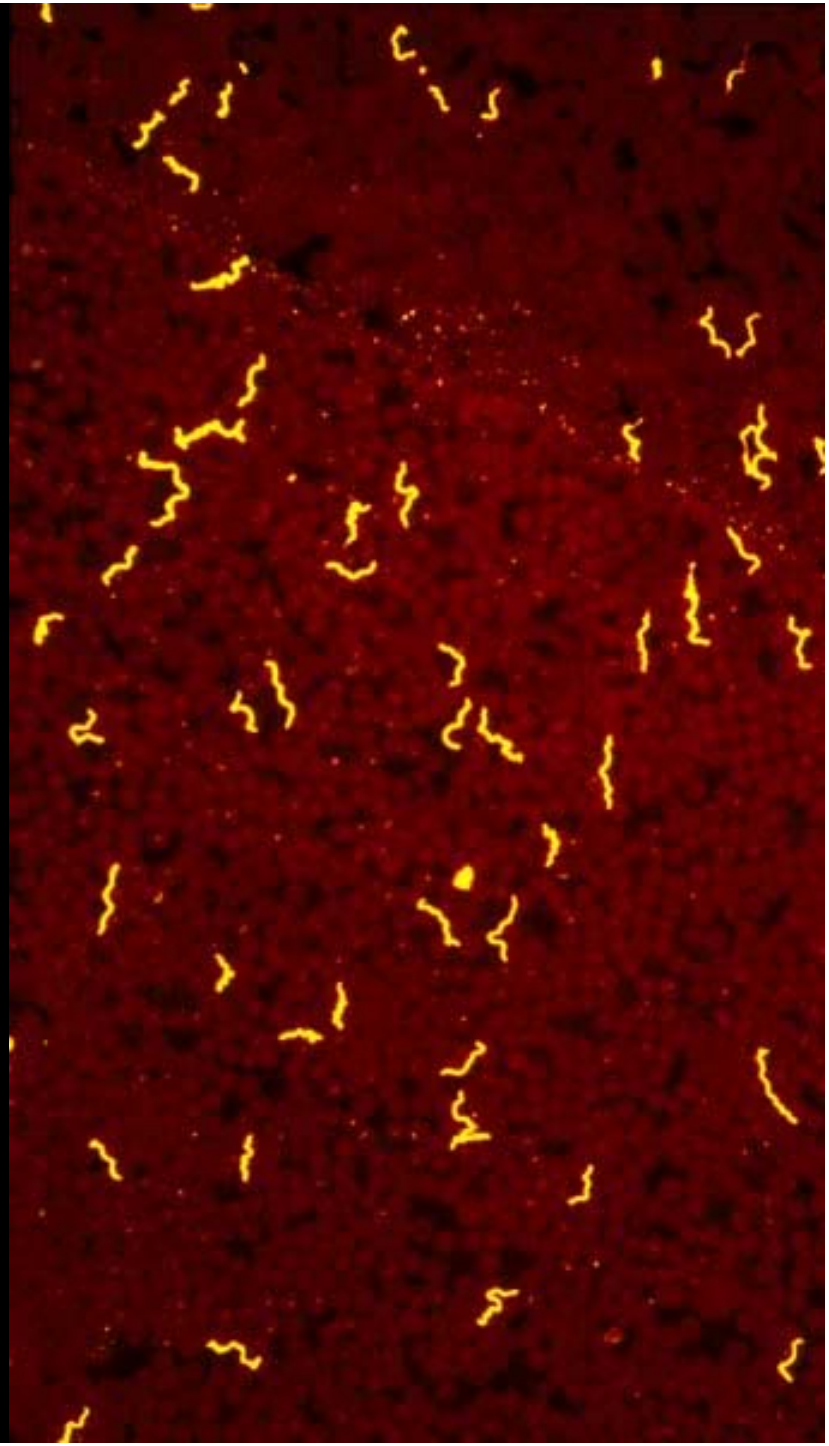
Plague risk map for CA

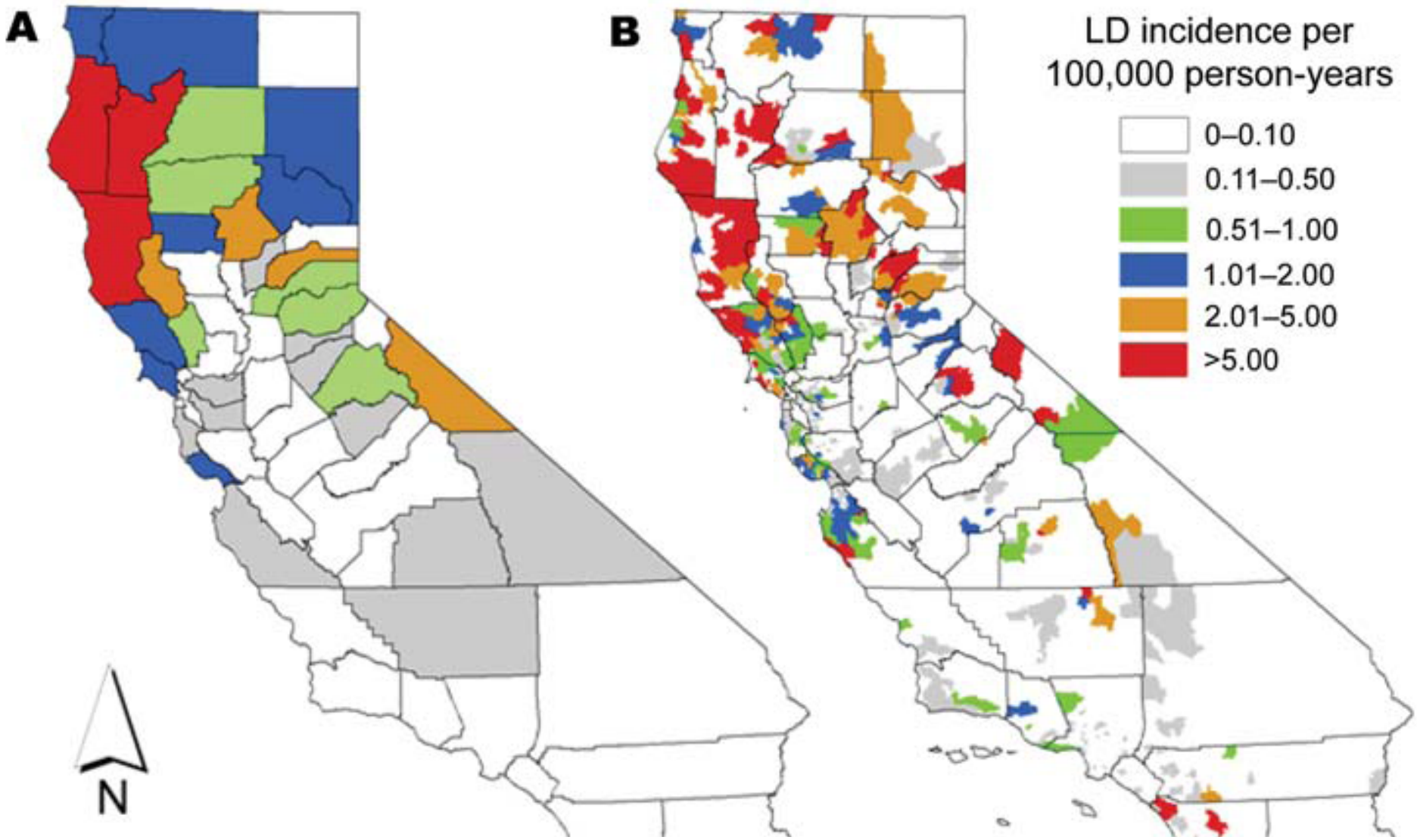
Model using environmental data and plague results in rodents and carnivores



Risk model based on peridomestically acquired human plague cases (1957–2004) in the Four Corners Region, USA

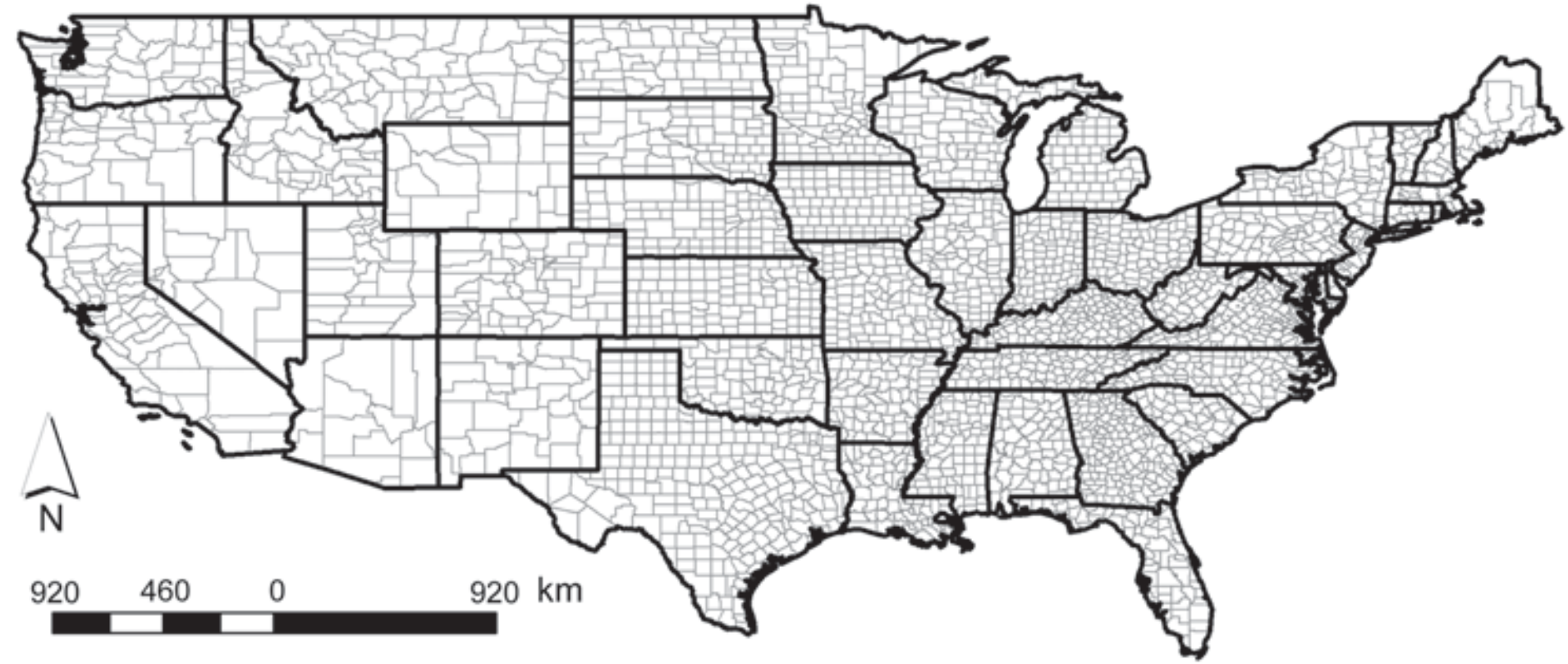
Borrelia burgdorferi



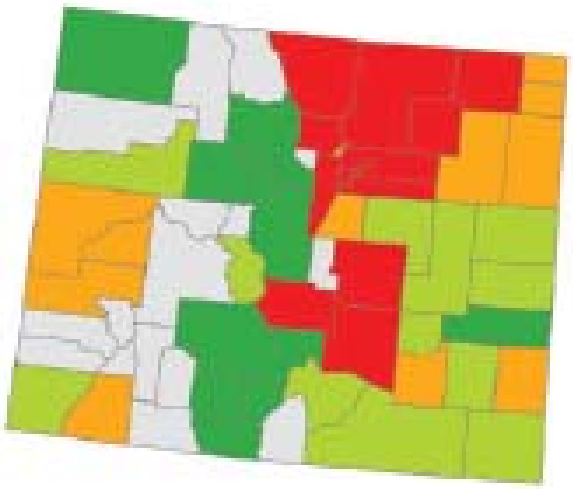


Different methods of illustrating Lyme disease epidemiology:
A = county level, B = 5-digit ZIP spatial unit

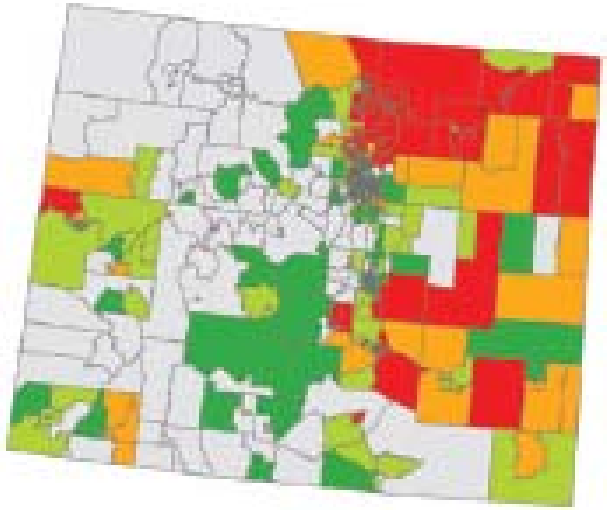
State and county boundaries within the contiguous United States.



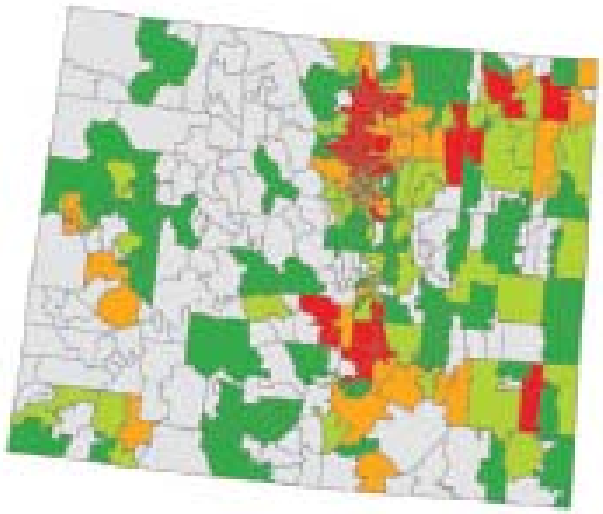
West Nile virus disease case counts (2003 & 2007 combined) in Colorado



county



census tract

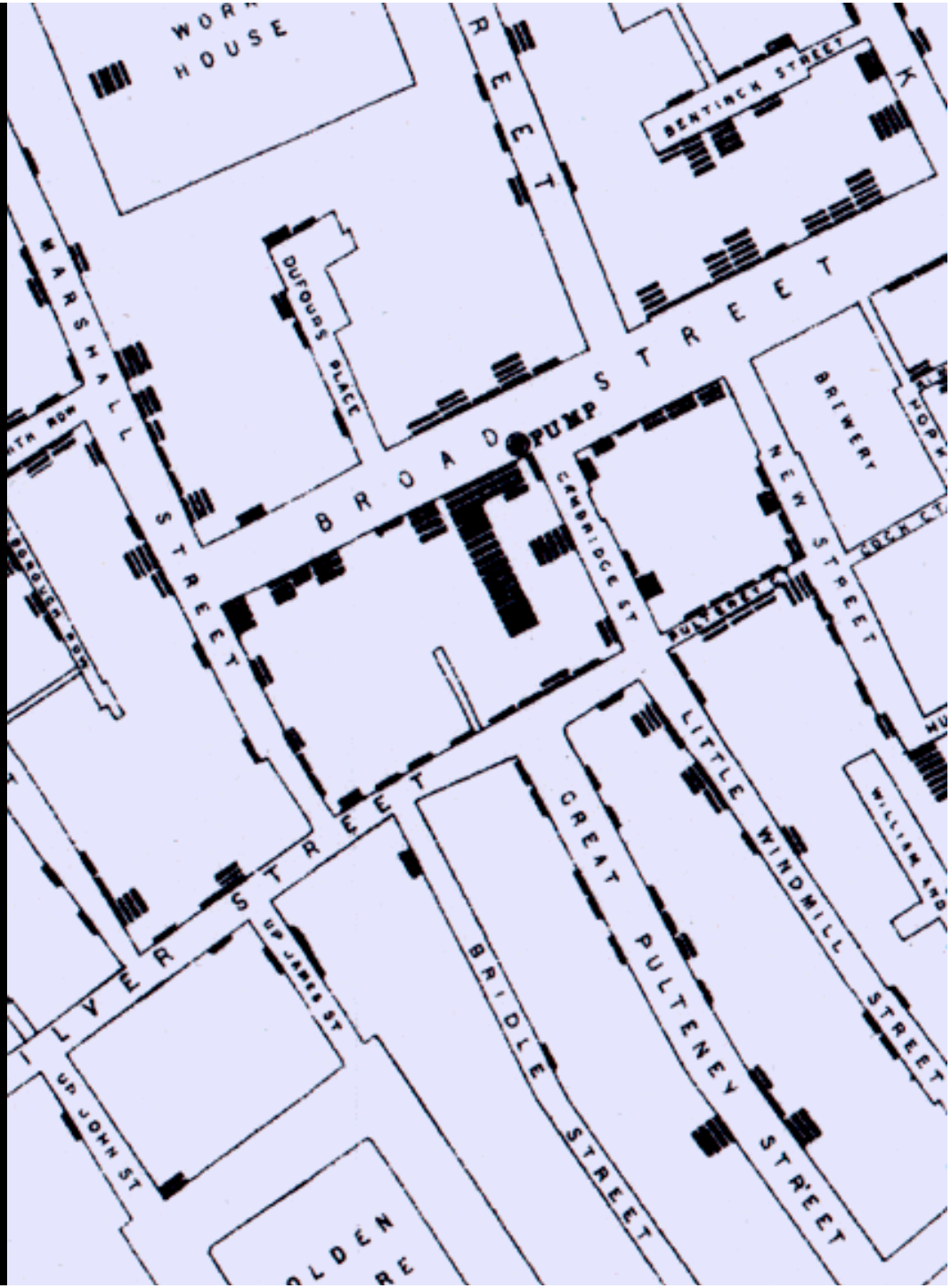


zip code

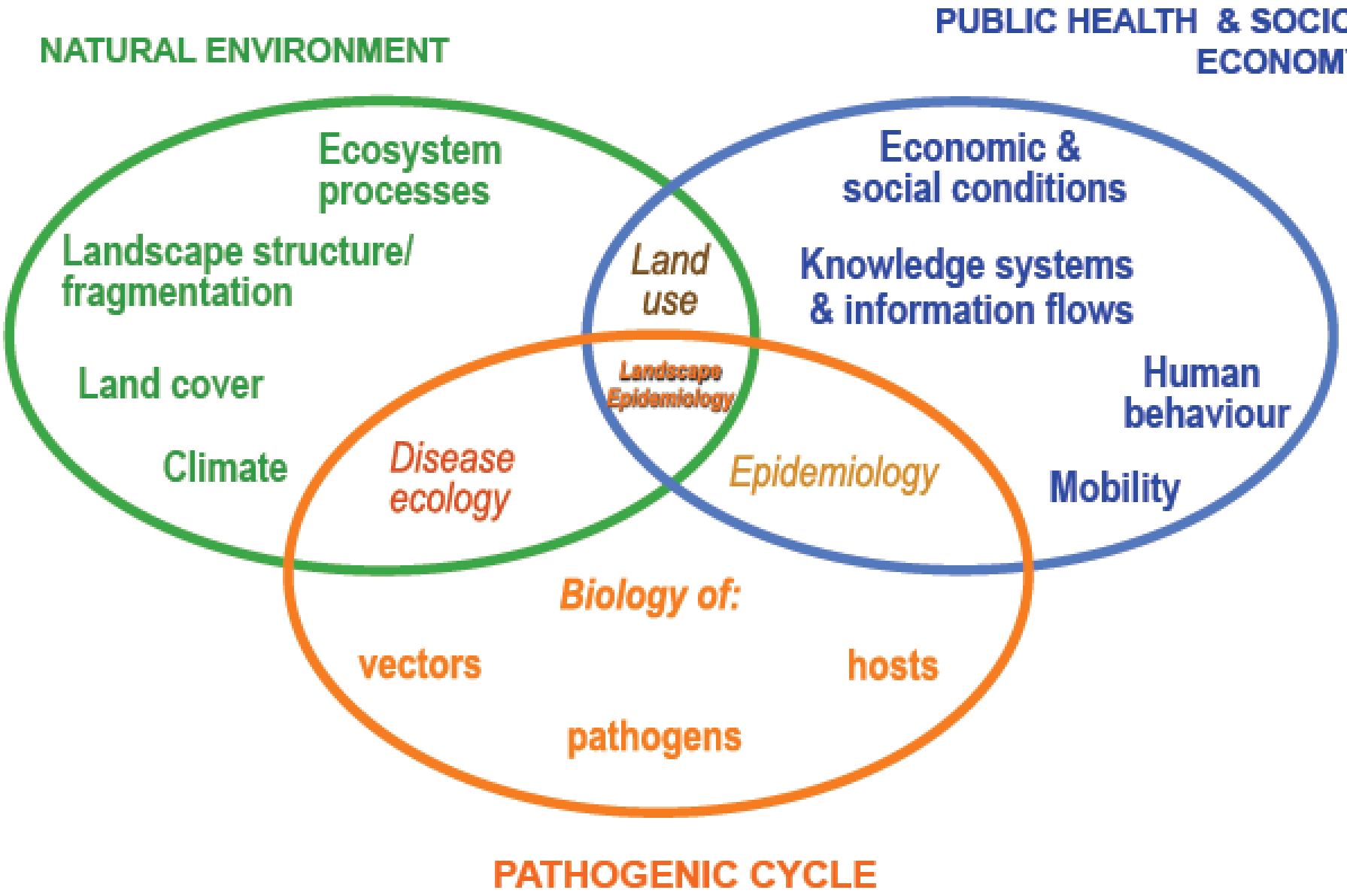
Quartile:
(Range of cases for county, census tract, and zip code)

- 1st [(1–3), (1), (1–2)]
- 2nd [(4–11), (2–3), (3–6)]
- 3rd [(12–67), (4–7), (7–15)]
- 4th [(>67), (>7), (>15)]
- No cases reported

Why should geography have an impact?



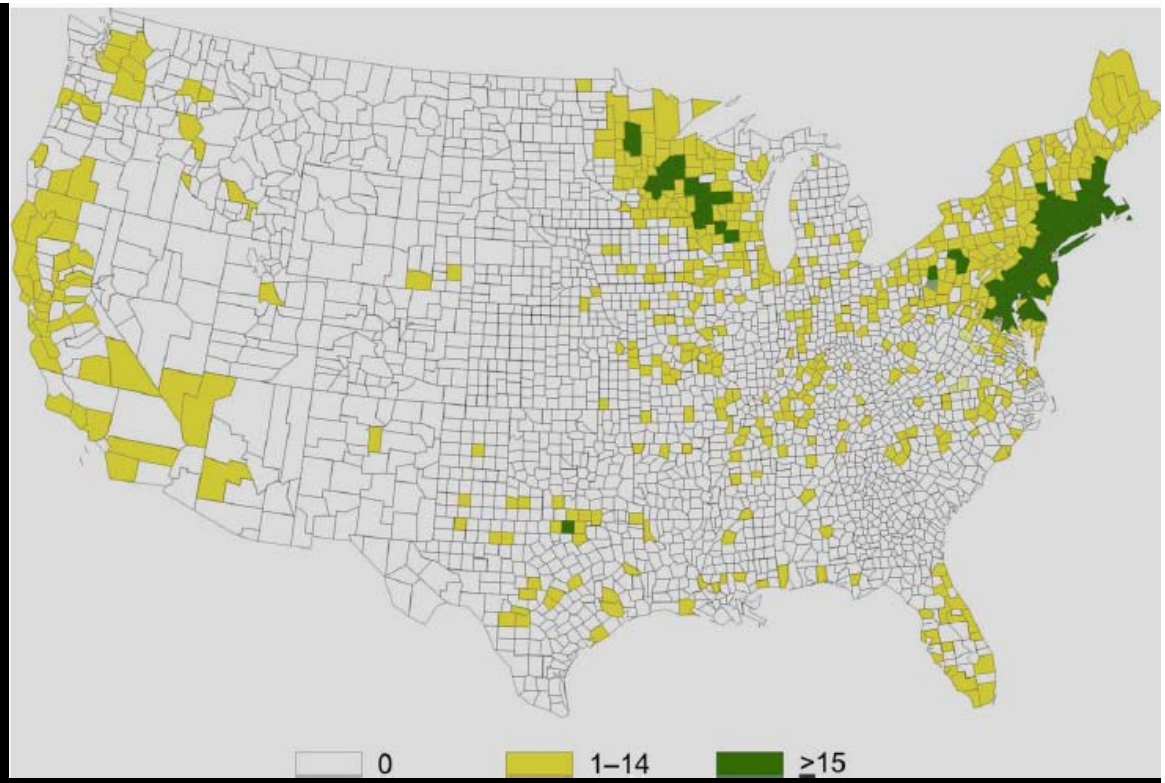
Spatial epidemiology

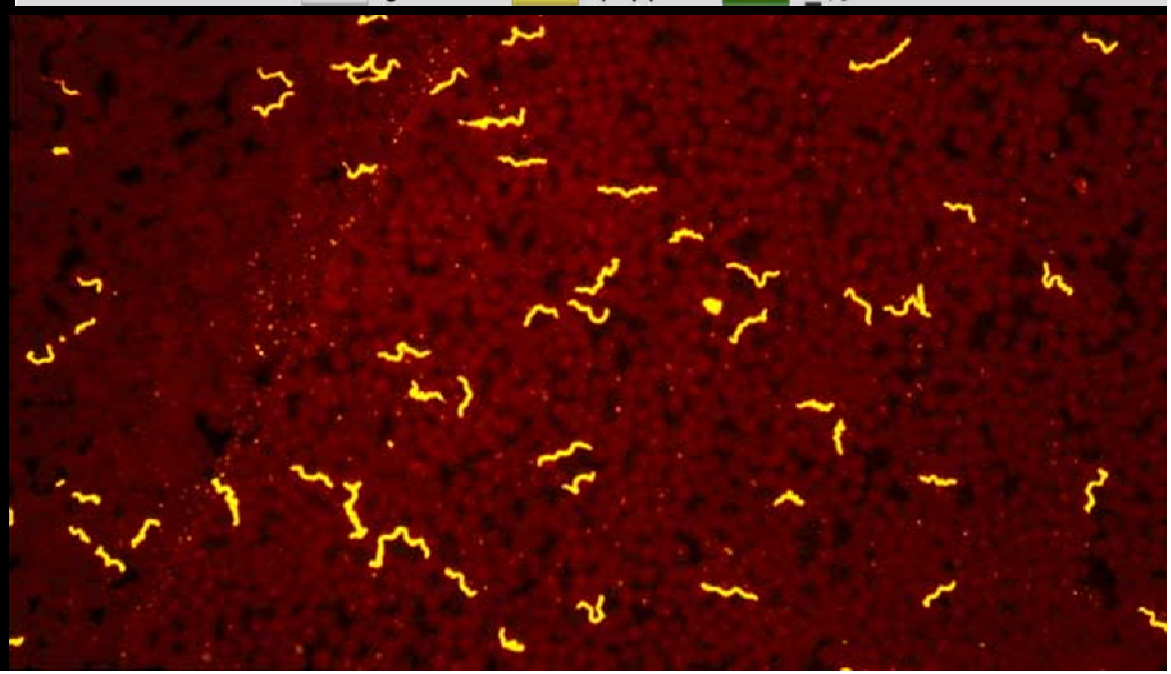


Appropriate scale of epidemiology?

How do different regions differ in disease dynamics?

Why does geography have an impact?





Impacts of seasonality on disease dynamics?

- Vector biology
- Animal biology
- Human behavior
- Implications for global climate change…