Spatial analysis for vector-borne diseases

1. Spatial aspects in surveillance and research
2. Tools for spatial analysis
3. Spatial statistics
4. Landscape ecology
5. Scale and resolution
6. Risk maps
7. Opportunities and limitations

Research questions

- Spatial determinants of transmission and risk
- Spatial associations of risk factors with disease and interaction with temporal processes
- Origins of diseases and hazards
Surveillance and control questions

- Spatial and temporal distribution of disease and risk factors
- Planning of surveillance program and presentation of surveillance findings and control activities
- Focusing of control efforts – improved allocation of limited resources

Sources & existing tools for spatial data

- GPS
  - Field data
- GIS
  - Surveillance data
  - Field data
  - Environmental data
- Remote sensing
- Spatial statistics, time series, dynamic models
  - Data analysis
- Approaches:
  - Landscape ecology & epidemiology, metapopulation biology ecological risk assessment

Temporal and spatial scale and resolution

- Geographic - ranging from the village/town to the continental level
- Temporal - ranging from the duration of an outbreak, through the seasonal to multi-year models
- Multiple scales can be considered simultaneously or in succession, but with caution
Global Positioning System (GPS)

- A system that allows for calculation of position with a high degree of accuracy
- Based on a ground receiver and a system of 32 satellites orbiting earth
- Triangulation to determine the location of an object with a 5-10 m accuracy (or less)

What is remote sensing?

Is the collection of information about an object without being in direct physical contact with the object

Most often through satellites

Sensors on satellites vary with regard to spatial, spectral, and temporal resolution
Environmental parameters

<table>
<thead>
<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>Rainfall</td>
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<td>Temperature</td>
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<td>Soil type</td>
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<td>Elevation/topography</td>
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<td>Human activities</td>
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<td>Water bodies</td>
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<td>Vegetation</td>
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All parameters can be sensed remotely and modeled spatially.

Geographic Information Systems (GIS)

- A system to capture, manage, manipulate, analyze, model, display spatially referenced data for research, management, and planning purposes.

- Human cases
- Human settlements
- Water bodies
- Soil type
- Vegetation data
- Adult mosquitoes

Spatial statistics

First law of geography
(Tobler 1979)

Everything is related to everything else, but near things are more related than distant things.
Calculation of spatial statistics

- Based on giving weight to the distances between items of interest:
  - No. of malaria cases in village or groups of houses
  - No. of mosquito larvae in aquatic habitats
  - Water conductivity or pH
  - Amount of rainfall in a given location

Spatial scale & resolution

- Ranges from local to global
- Determines appropriate digitized data bases
- Satellite images range from Ikonos (<5m) to AVHRR (1 km)
- Determines appropriate spatial statistics
- Multiple scales can be considered simultaneously or in succession

Prerequisites for an active zoonotic VBD focus

- Vector survival
- Presence of reservoir hosts
- Pathogen transmission
- Opportunities for human/animal exposure
Examples

- Human vector-borne diseases: Malaria, *Dengue*
- Mosquito borne Zoonoses – *West Nile virus*
  and other Arboviruses
- Other vector-borne zoonoses – African trypanosomiasis,
  *Chagas disease*, Leishmaniases, Lyme disease

1. West Nile virus: eco-epidemiology of disease emergence in urban areas*

- Develop a spatial model and risk maps based on:
  - Demographic and environmental risk factors for WNV and SLE in birds, mosquitoes and humans
  - Reservoir capacity and differential effects of WNV on various bird species
  - Anthropogenic features of the urban environment that support *Culex* mosquito production, mosquito-bird transmission and virus amplification
  - Dynamics of viral transmission over space and time using molecular evolutionary and phylogeographic techniques

* Funded by NSF/NIH ecology of infectious disease program

Research team

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- Linn Haramis

Illinois State Water Survey
- Kenneth Kunkel

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West Nile Virus in Illinois

- 2001 - 123 positive bird specimens, 0 human cases
- 2002 - 884 human cases, 66 deaths, more than any other state that year (U.S. - 4,156/284)
  Over 680 cases occurred in Chicago and surroundings
- 2003 - 54 human cases, 1 death (U.S. - 9,862/264)
- 2004 - 60 human cases, 4 deaths (U.S. - 2,539/100)
- 2005 - 252 human cases, 12 deaths (U.S. - 3000/119)
- 2006 - 210 human cases, 9 deaths (U.S. - 4180/149)

WNV cases in Illinois 2002-2006

West Nile Virus Biweekly Progression

Cases Through Aug 30, 2002
Cases of West Nile Virus
- Mosquito pools
- Birds
- At least one human case
- At least one equine case
- Positive mosquito
- Human case

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Locations of human WNV cases in 2002 with land cover

Human WNV case rate per 10,000 people

Human cases tend to be outside of the more densely populated urban core

3 areas with most cases (circled on map):
- In the south, near Oak Lawn
- In north, around Skokie
- Southwest of Skokie

WNV human cases with housing density
Dominant patterns in the Chicago urban landscape

• Each different colored area represents a place with a common set of factors related to housing, vegetation, socio-economics, and land use.

Ruiz et al., Int’l J Health Geog 2005

Urban type 5, dominated by 40s, 50s, and 60s housing;
Mostly white, moderate vegetation and moderate population density
• 435 cases (64%) were in this group, 2.27 cases per 10,000 people (RR>3.5); (all other types <0.65 cases per 10,000)

Area characterized by many undocumented storm drains
• In hot dry years standing water with organic matter provide habitat for Culex mosquito larvae

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Important processes behind the cluster patterns

- Ecological
  - Mosquito and bird habitat suitability
  - Housing, landscape and catch basins
- Socioeconomic
  - Lifestyle
  - Race, income
  - Access to healthcare, biased reporting
- Mosquito abatement districts
  - Control methods
  - Geographic location

2. Eco-epidemiology of Chagas disease in northwest Argentina

- Univ. of Buenos Aires, Argentina
- National Vector Control Program, Argentina
- Instituto Fatala Chabén, Argentina
- CNRS-IRD, France
- Rockefeller University, NY, USA
- CDC, USA
- Univ. of Illinois

Supported by NIH/NSF EID Program through FIC

Eco-Epidemiology of Chagas disease In Northwest Argentina – study area

Argentina
Santiago del Estero Province
Amama
Typical compound with home and multiple peridomestic structures

Peridomestic structures – refuge for bugs and sources for reinfection

Mapping and geostatistical tools

Sketch maps made in the field during 1993-2002

Joining of attribute data to GIS file

Clusters of high infestation and potential sources of community reinfection

Spatial statistics
Georeferencing - relating infestation data to locations

Reinfestation by *T. infestans* (5 years post-spraying)

**$G_i(d)$ local spatial statistic**

We used $G_i(d)$ to detect local and focal clustering of infestations (number of bugs per structure)

$$G_i(d) = \frac{\sum W_{ij}(d) \chi_j}{\bar{\chi}_i}$$

- Specific location of potential for infestation sources
- $W_{ij}(d)$ is a spatial weights matrix with values of one for all links within distance $d$ of a given $i$
- Concern about multiple comparisons (need to adjust significant z value)
Focal analysis of reinfestation in Amamá

- Subsequent infestations were clustered around an initial focus at a distance of 450 m.
- Potential secondary sources fell within the range of the clustering around the primary source.

Moving upscale - including other villages; internal and external sources of reinfestation

- External sources: villages not sprayed and located within 1,500 m of the treated villages.

Recommendation

An effective control program on the community level would entail residual spraying with insecticides of the colonized site, and all sites within a radius of 450 m, and all communities within 1,500 m of the target community in order to prevent the subsequent propagation of T. infestans.
Role of RS/GIS in Chagas study

- Detection and mapping of houses, peridomestic structures, and sylvatic habitats
- Integration of demographic, entomological, and epidemiological data
- Determining sources of colonizing vectors and of T. cruzi infection
- Statistical analysis and modeling of re-infestation and infection processes
- Targeting of NVCP surveillance and control program
- Anthropogenic changes in land cover and land use, and resulting migration and subsistence farming patterns on the department and province levels

Moreno department

T. infestans domestic infestation

Associated with density of rural houses, maximum temperature, elevation and land-cover type (% degraded forest)
3. Spatio-temporal dynamics of Dengue transmission in Cairns, Australia

Collaborators:
- Scott Ritchie – Tropical Public Health Unit Network – Cairns
- Uriel Kitron – Emory University
- Gonzalo Vazquez-Prokopec – Emory University

Dengue in Northern Queensland:
history of multiple introductions

Dengue not endemic in Australia

The “Christmas rush” effect

The 2003 epidemic:
- 383 confirmed cases
- Index case: PNG infective late January
- Delay in notification of 49 days
- Index case misdiagnosed (tested for malaria, retrospectively tested positive for dengue 2)

Methods for analysis

Knox test
(Knox 1963)

- Where: N is the number of cases, \( s_i \) is the space adjacency value, \( t_i \) is the time adjacency value

- We used \( x^2 \) test to determine those pairs of cases that were separated by less than the critical space (100 m) and time (25 days) distances

- Randomness expectation is modeled by Monte Carlo simulations
Space-time analysis

250/383 cases (65%) belonged to 15 space-time clusters.

Progression of cases over space and time

Improving vector control

Recommendations:
• During the “Christmas rush” consider every dengue-like case as dengue and apply rapid response
• Consider spatial heterogeneity when designing and implementing surveillance and control interventions (decision support system)
• Spraying needs to be contextualized according to time since introduction
Vector borne disease transmission dynamics

- Host/reservoir/vector heterogeneity:
  - Genetics, age/sex, location, behavior, reproduction, movement patterns
- Population heterogeneity:
  - Herd immunity, meta-population dynamics, social structure
- Environmental heterogeneity:
  - Gradients, suitable/unsuitable patches, barriers
- Socio-economic factors
  - Exposure, impact, interventions
- Host-pathogen interactions:
  - Parasitism, co-evolution
- Dependent on scale (spatial/temporal) and mode of transmission

Spatial tools - opportunities

- New impetus for ecological research
  - Landscape determinants of disease transmission
- Comprehensive multi-scale picture
  - Local/regional/global epidemiology of infectious diseases or environmental assessments
- Consideration of temporal changes
  - Emerging infectious diseases & effects of climate change
- Interdisciplinary research, integration of molecular, entomological and epidemiological studies and findings

Spatial data - concerns and limitations

- Massive amounts of environmental data
- Paucity of accurate epidemiological data
- Heterogeneity of transmission patterns
- Lack of data readily masked
- Meaning of area boundaries
- Spatial autocorrelation and interpolation
- Meta analysis
Challenges and new studies

- Addressing loss in heterogeneity across scales
- Consideration of social, economic, institutional processes
- Integration of fine scale (biotic factors) with coarse-scale (environmental factors) efforts
- Construction of risk maps that go beyond showing a pattern (pretty picture) to understanding the underlying biological process