Linking vectors, humans, and the environment to understand the spatial dimension of vector-borne disease transmission

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Outline

Vector-borne diseases: a global challenge

Chagas disease
  -Spatial heterogeneity and control

Dengue
  -Spatial transmission dynamics
  -Human movement and virus transmission

West Nile Virus
  -Linking the environment and virus transmission

General conclusions
Requisites for VBD transmission

- Vector presence and survival
- Presence of suitable hosts (reservoirs)
- Pathogen presence and amplification
- Opportunities for human exposure

Vectors: the “weak” link

“We know the cause of it [malaria], and the manner in which it is spread. We know a specific cure for it, and several efficient methods of prevention. It is our own fault then if we do not reduce it as much as possible.”

R. Ross (1910)

 “…The spread of yellow fever can be most effectually controlled with measures directed to the destruction of mosquitoes and protection of the sick against the bites of these insects”

Walter Reed (1911)
Malaria, Chagas, dengue, leishmaniasis, filariasis, lyme disease, plague, yellow fever, west nile virus, EEE, chikungunya, venezuelan equine encephalitis, RVF…

Growing global public health, economic, and ecological impacts.

Linking vectors, pathogens, hosts and the environment

“Much remains to be discovered about the complex biological and ecological relationships among pathogens, vectors, hosts, and their environments.”

“Such knowledge is essential to the development of novel and more effective interventions”

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Conclusions
Most human transmission of *T. cruzi* occurs under the thatched roofs and in the patios of the domiciliary sites. 

**Key problem:** reinfestation of houses by bugs from peridomestic sources.

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**Eco-Epidemiology of Chagas Disease in Argentina**

a. **Vector studies - Reinfestation by triatomine bugs**

b. **Reservoir studies of dogs and cats**

c. **Sylvatic studies of wildlife and bugs**

d. **Scale of study and heterogeneity**

e. **Spraying strategies and cost effectiveness**

f. **Surveillance and control strategy recommendations**

R Gurtler, C Cecere, G Vazquez-Prokopec (Univ. of Buenos Aires); J Cohen (Rockefeller University); C Spillmann (National Vector Control Program); M Lauricella (Argentine Institutes of Health); E Dotson (CDC); JP Dujardin (IRD-CNRS, France); U Kitron (Emory University)

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(NIH – Fogarty)
Reinfestation by *T. infestans* (5 yrs post-spraying)

Subsequent infestations clustered around initial focus up to 450 mts.

Pattern validated by wing geometric morphometrics and molecular markers (microsatellites).
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.

Moving upscale: the Moreno department

Mechanisms responsible of clustering at the village level may not act at the Department level.

How can spatial heterogeneity in bug distribution be quantified and harnessed to improve vector control?
Mapping community infestation

Prevalence of domestic infestation by *T. infestans*

Significant clustering of domestic infestation at 24km.

Factors associated with clustering

Risk map of *T. infestans* domestic infestation based on logistic regression coefficients of significant variables

~16,000 km² --> ~6,000 km²
Spatially-targeted interventions

Transportation-based network model:

- Contiguous interventions (A)
- Interventions targeting high-risk areas first (B)

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Conclusions from Chagas study

- Spatial heterogeneity in bug infestation: a pattern emerging at all scales.
- Spatial contextualization of interventions:
  - Insecticide spraying of all sites within 450 m of a residual foci during spring may help prevent community reinfection by *T. infestans*.
  - Risk maps can help improve delivery and effectiveness of vector control interventions at coarser scales.

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Cost in mobility and personnel:

A = US$51,206
B = US$24,298

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Future Directions

Dengue

Annually:
50-100 million infections
500,000 hemorrhagic
22,000 deaths.

Most important mosquito-borne viral disease in the world (and growing)
Dengue epidemics: explosive and widespread

Neff et al. 1967. American Journal of Epidemiology

Spatio-temporal dynamics of epidemic dengue transmission in Cairns, Australia

Collaborators:
Scott Ritchie – James Cook University and Tropical Public Health Unit Network – Cairns
Uriel Kitron – Emory University

Funders
Emory University
Space-time analysis & modeling

Spatial heterogeneity driven by housing type (queenslander)

IRS coverage: protective at >60%
Recommendations to QH

- During transmission season consider every dengue-like case as dengue and apply rapid response.
- Consider spatial heterogeneity when designing and implementing surveillance and control interventions.
- Spatial unit for control actions – spray only first nearest neighbor houses around each case.
- GIS-based decision support system for NQ.

Need for spatially explicit consideration of exposure and transmission patterns
Human movement and dengue transmission in Iquitos, Peru

Immediate Goal of the Study
Determine the locations most visited by participants and assess the risk of acquiring dengue in such locations

Collaborators
Thomas W. Scott, Amy Morrison, Steven Stoddard – UC Davis
John Elder – San Diego State
Valerie Paz Soldan – Tulane
Gonzalo Vazquez-Prokopec, Uriel Kitron – Emory
Tad Kochel – NMRCD (Navy)

Funded by NIH/NIAID

Considering human behavior when estimating dengue transmission risk

Revisiting the Common Assumption:
Infection occurs in the home

If other locations are important, then:
Human movement needs to be considered when determining exposure and probability of key encounters
Using GPS to track human movements

**International Journal of Health Geographics**

**Methodology**
Usefulness of commercially available GPS data-loggers for tracking human movement and exposure to dengue virus
Gonzalo M Vazquez-Prokopec*, Steven T Stoddard, Valerie Paz-Soldan, Amy C Morrison, John P Elder, Tadeusz J Kochel, Thomas W Scott and Uriel Kitron

**Key features:**
- memory and battery life
- durable and tamper-proof
- light weight
- design widely accepted by participants
- little to no maintenance required of participants
- low cost ($50)

**Accuracy:** 4-10 m

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**Tracking ~600 individuals with GPS**

GPS: latitude, longitude, elevation, time.

- 2,500,000 data points

Sample balanced between ages and sexes.

Goal: estimate mobility parameters of Iquitos residents.
Representing movement data

Contact networks – nodes represent individuals (or locations), links represent relationships allowing pathogen transmission

Bipartite & spatial topology

A dengue contact network
Iquitos study

• Exposure to mosquitoes across activity space necessary to assess entomological risk.

• Identify:
  - sources of infection.
  - key sites
  - Individuals responsible for most transmission?

• Target surveillance & interventions (location &/or people)

  Multi-disciplinary approach

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West Nile virus in urban Atlanta, GA

Collaborators
Thomas Burkot – CDC
Danny Mead – UGA
Rosmarie Kelly – GA-DPH
Gonzalo Vazquez-Prokopec, Luis Chaves, Uriel Kitron - Emory

Combined Sewer Systems and Mosquitoes

Combined Sewage Overflows (CSO) Are Major Urban Breeding Sites for Culex quinquefasciatus in Atlanta, Georgia

Lisa M. Calhoun, Melissa Avery, Lee Ann Jones, Karina Gunarto, Raymond King, Jacquetin Roberts, and Thomas R. Burkot
Division of Parasitic Diseases, Centers for Disease Control and Prevention, Atlanta, Georgia

Does the high mosquito productivity translates into a higher WNV transmission risk?
Combined Sewer Systems

Designed to carry both sewage and storm water.

When flow exceeds the maximum capacity of the sewer systems, it overflows directly into bodies of water with minor treatment.

Atlanta: 7 CSO facilities located in close proximity to residential, commercial and recreational sites.

Research

WNV infection in mosquitoes, birds and humans clustered in close proximity to CSO streams.
Risk factors of WNV infection

Mosquitoes: Distance to CSO, followed by Tree cover range

Humans: Distance to CSO and housing age, followed by median income.

Birds: Distance to CSO and mean tree cover, followed by Median income.

Observational, laboratory, and semi-natural experiments

The role of CSO in mosquito population dynamics.

Oviposition preference
Fitness and behavior
Density dependence

Peavine creek Non-CSO
CDC insectary
Tanyard creek CSO
Monitoring CSO (T) and non-CSO (P) streams

Conclusions from WNV study

- Sewage overflows impair natural streams.
- Reduction of stream richness and diversity (including mosquito predators)
- Increase in *Culex sp.* abundance.
- Abundant bird populations in riparian forests.
- Opportunities for human exposure
- More WNV.
General Conclusions

- Spatial dimension, an essential component of VBD transmission dynamics and control.

- Vector biology and ecology are rich in diversity & have significant impacts on VBD transmission.

- GIScience has dramatically increased our ability of detecting and understanding the linkages between vectors, humans and the environment.

- A multidisciplinary endeavor.
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Questions?