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

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EMORY UNIVERSITY

FOGARTY

USF,
November 4, 2011

Outline

Vector-borne diseases: a global challenge

Chagas disease
- Spatial heterogeneity and control

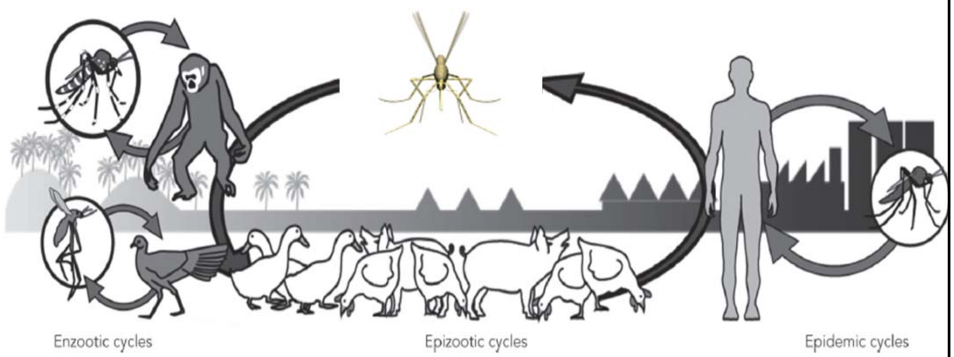
Dengue
- Spatial transmission dynamics
- Human movement and virus transmission

West Nile Virus
- Linking the environment and virus transmission

General conclusions

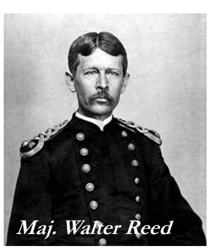
Requisites for VBD transmission

- **Vector presence and <u>survival</u>**
- **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"
<u>R. Ross</u> (1910)

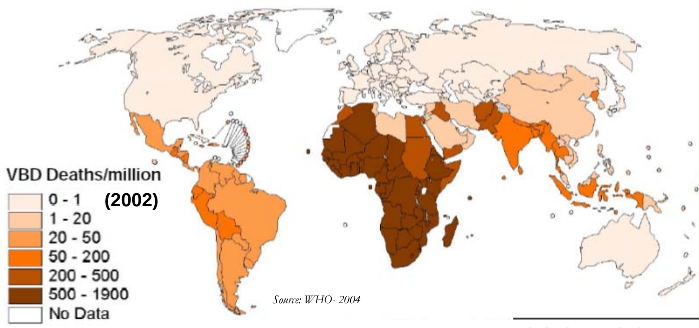


"…The spread of yellow fever can be most effectually controlled with measures directed to the destruction of mosquitoes and protection of the sick against the bites of these insects"
<u>Walter Reed</u> *(1911)*

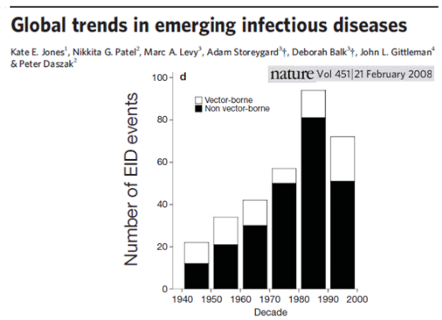
Brazil, circa 1940. Courtesy Joao Carlos Pinto Dias

Keiser et al. 2005 Lancet Inf Dis

Impact of VBD



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



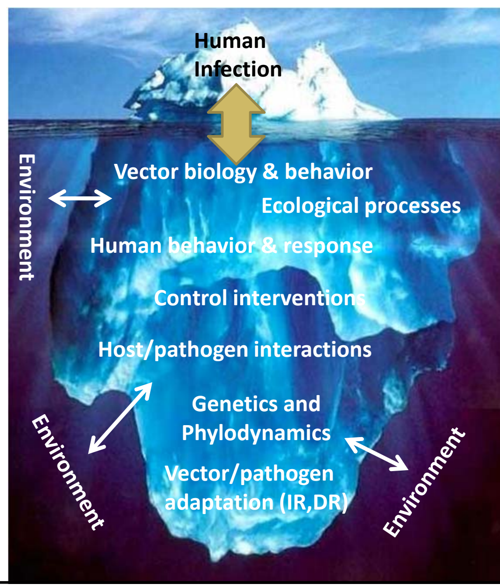
Growing global public health, economic, and ecological impacts.

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"

Forum on Microbial Threats – US Institute of Medicine. 2007.



Outline

<u>Vector-borne diseases: a global challenge</u>

<u>**Chagas disease**</u>
- -Spatial heterogeneity and control

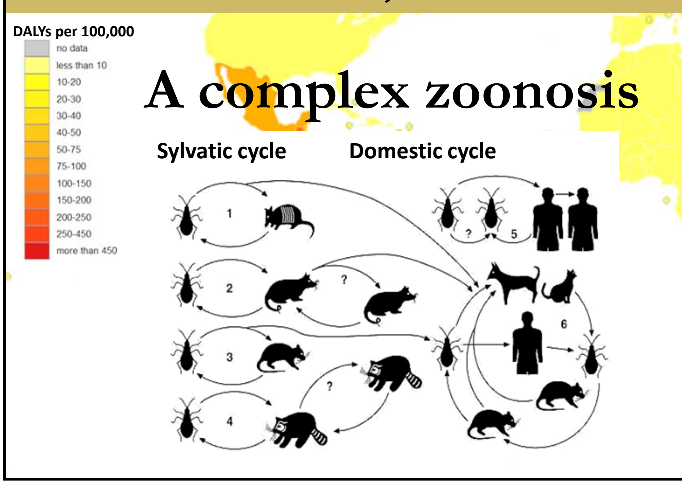
<u>Dengue</u>
- -Spatial transmission dynamics
- -Human movement and virus transmission

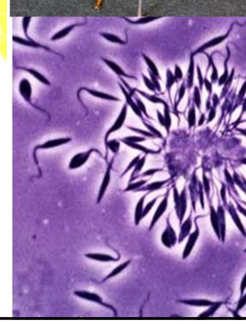
<u>West Nile Virus</u>
- -Linking the environment and virus transmission

<u>Conclusions</u>

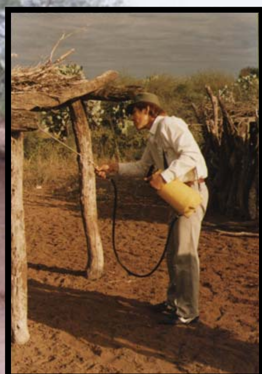
Chagas' disease

Most important VBD in Latin America
15,000 deaths/yr
9-11 million infected, Latin America

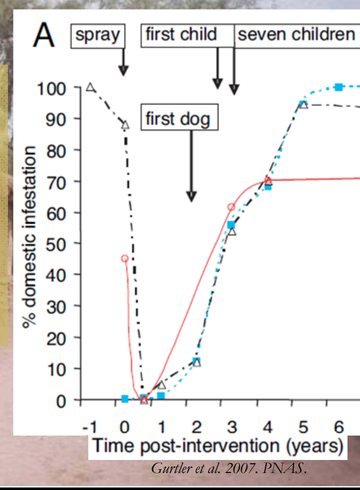




Most human transmission of *T. cruzi* occurs under the thatched roofs and in the patios of the domiciliary sites



<u>Key problem</u>: reinfestation of houses by bugs from peridomestic sources.



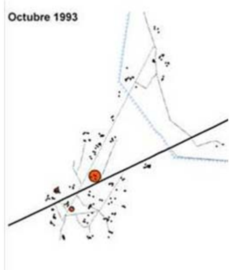
Eco-Epidemiology of Chagas Disease in Argentina

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

<u>R Gurtler</u>, 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>U Kitron</u> (**Emory University**)

Supported by NIH/NSF Ecology of Infectious Disease Program
(NIH – Fogarty)

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



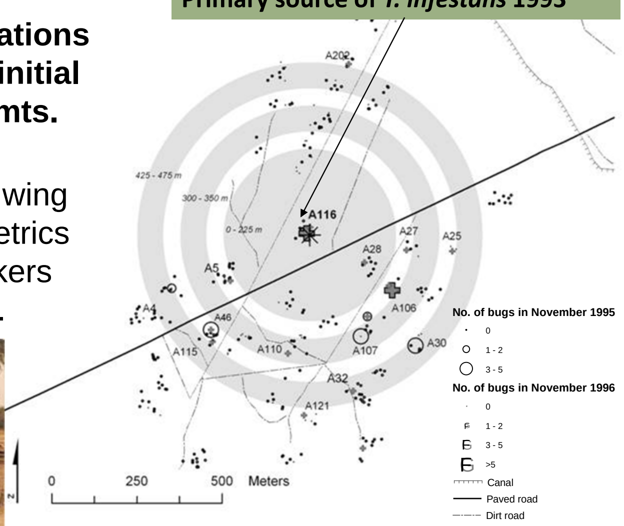
SPATIO-TEMPORAL ANALYSIS OF REINFESTATION BY *TRIATOMA INFESTANS* (HEMIPTERA: REDUVIIDAE) FOLLOWING INSECTICIDE SPRAYING IN A RURAL COMMUNITY IN NORTHWESTERN ARGENTINA

MARÍA C. CECERE, GONZALO M. VAZQUEZ-PROKOPEC, RICARDO E. GÜRTLER, AND URIEL KITRON

Primary source of *T. infestans* 1993

Subsequent infestations clustered around initial focus up to 450 mts.

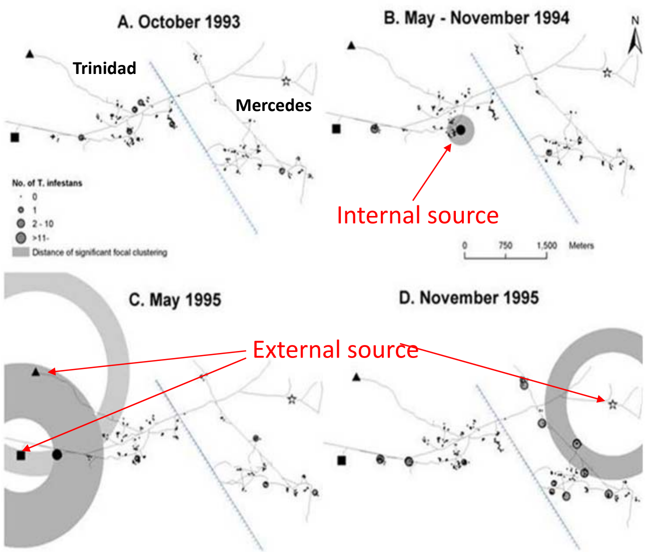
Pattern validated by wing geometric morphometrics and molecular markers (microsatellites).



Am. J. Trop. Med. Hyg., 71(6): 803–810 (2004)

Moving upscale - Including other villages.

Internal and external sources of reinfestation.



Reinfestation Sources for Chagas Disease Vector, *Triatoma infestans*, Argentina

María C. Cecere, Gonzalo M. Vazquez-Prokopec, Ricardo E. Gürtler, and Uriel Kitron†

EID (2006) vol 12

External sources:

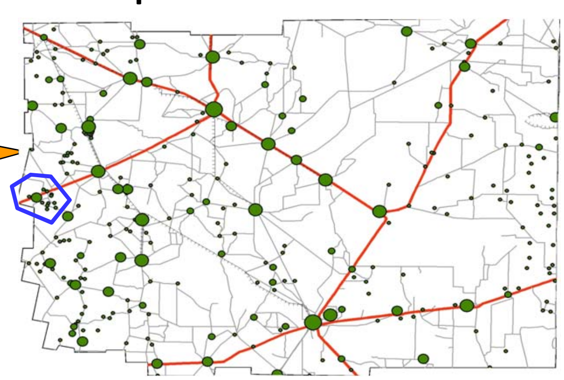
Villages not sprayed and located within 1,500 m of the treated villages.

Moving upscale: the Moreno department

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

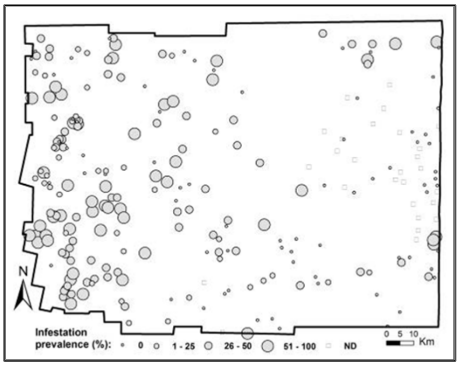
How can spatial heterogeneity in bug distribution be quantified and harnessed to improve vector control?

Change of SCALE of measurement and analysis



Mapping community infestation

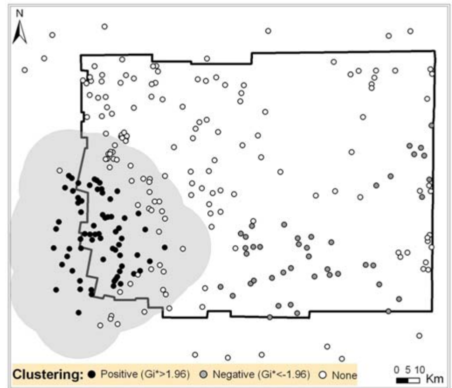
Prevalence of domestic infestation by *T. infestans*



Geographical information systems and tropical medicine

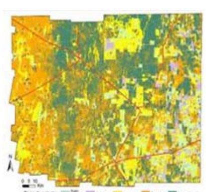
O. A. KHAN*, W. DAVENHALL†, M. ALI‡, C. CASTILLO-SALGADO§, G. VAZQUEZ-PROKOPEC*, U. KITRON*,**, R. J. SOARES MAGALHÃES†† and A. C. A. CLEMENTS††,‡‡

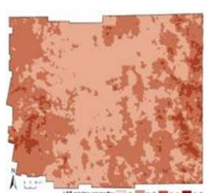
Annals of Tropical Medicine & Parasitology, Vol. 104, No. 4, 303–318 (2010)

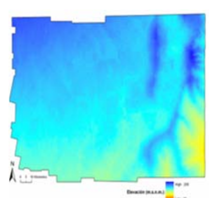


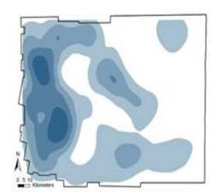
Significant clustering of domestic infestation at 24km.

Factors associated with clustering


Landscape (Landsat TM, classified)

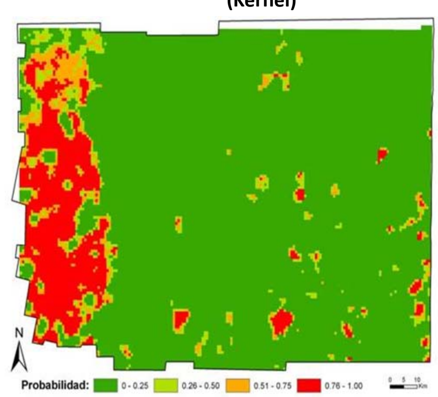

Maximum LST (MODIS)


Elevation (SRTM)


House density (Kernel)

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

~16.000 km^2 --> ~6.000 km^2



Spatially-targeted interventions

Transportation-based network model:

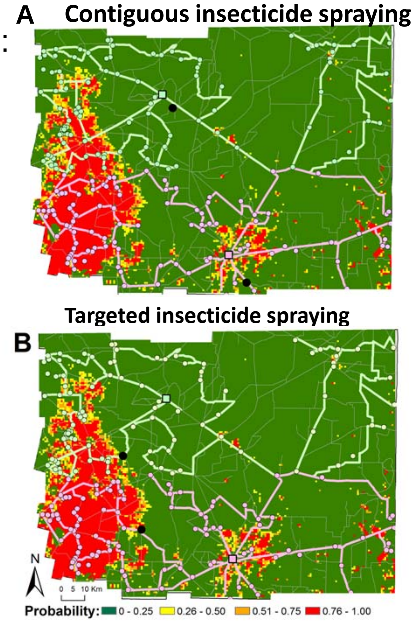
-Contiguous interventions (A)

-Interventions targeting high-risk areas first (B)

Modeled scenario[1]	Location[2]	Distance covered (km)	No. of communities / houses sprayed	Campaign duration (workdays)	Distance, high-risk only (km)[3]	No. of high risk communities/ houses sprayed	Duration, high-risk only (workdays)[3]
Contiguous							
	Tintina	1,048	108 / 1,391	373	1,000	51 / 572	371
	Quimili	1,015	112 / 1,244	332	937	53 / 650	307
	All	**2,063**	**220 / 2,635**	**373**	**1,937**	**104 / 1,222**	**371**
Targeted							
	Tintina	1,022	108 / 1,391	373	301	51 / 572	157
	Quimili	1,084	112 / 1,244	332	359	53 / 650	178
	All	**2,106**	**220 / 2,635**	**373**	**660**	**104 / 1,222**	**178**

[1] Contiguous assumes communities are visited based on the rule of contiguity (i.e. the nearest neighbor first) whereas targeted assumes high-risk communities are visited first. [2] Refers to the city where spraying brigades are based. [3] Estimates effort needed to cover the communities identified as high risk (probability of membership in a cluster > 0.75) of high domestic infestation.

cost in mobility and personnel:
A = US$51,206
B = US$24,298).



Vazquez-Prokopec et al. submitted

Conclusions from Chagas study

- Spatial heterogeneity in bug infestation: a pattern emerging at all scales.

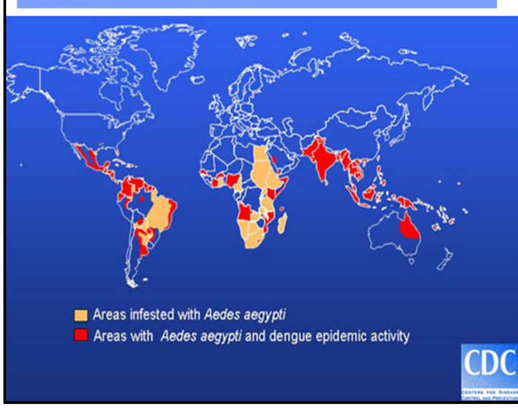
- Spatial contextualization of interventions:
  - Insecticide spraying of all sites within 450 m of a residual foci during spring may help prevent community reinfestation by *T. infestans*.
  - Risk maps can help improve delivery and effectiveness of vector control interventions at coarser scales.

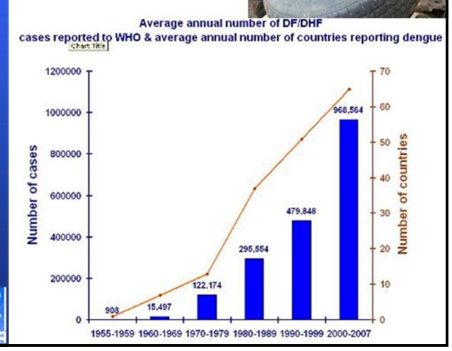
Outline

Dengue

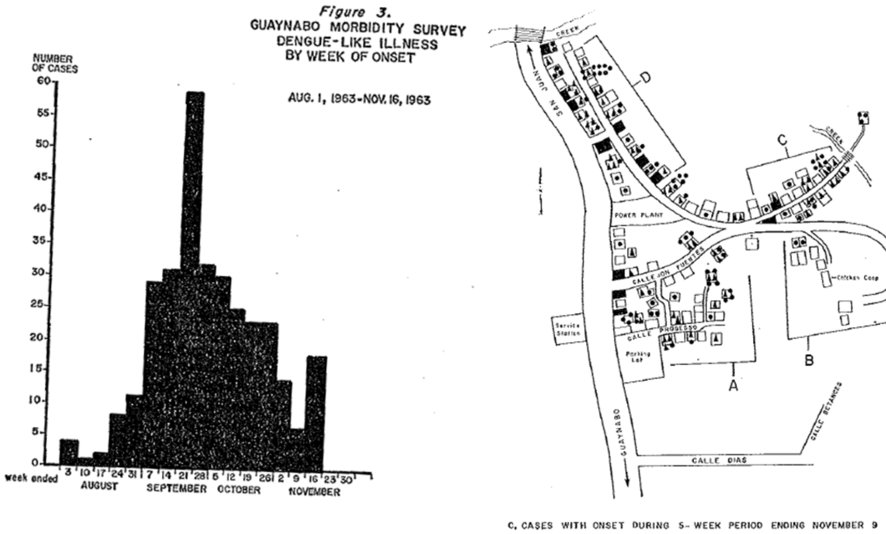
Annually:
50-100 million infections
500,000 hemorrhagic
22,000 deaths.

Most important mosquito-borne viral disease in the world (and growing)





Dengue epidemics: explosive and widespread



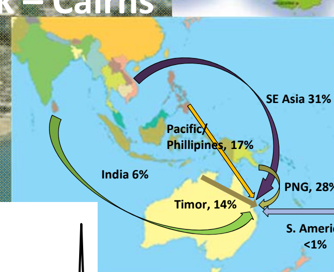
Neff et al. 1967. American Journal of Epidemiology

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

Collaborators:

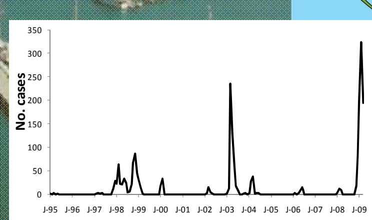
Scott Ritchie – James Cook University and Tropical Public Health Unit Network – Cairns

Uriel Kitron – Emory University



Funders

Emory University



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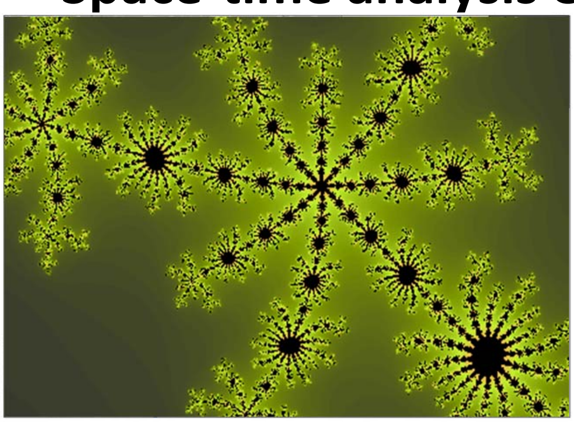
PLoS NEGLECTED TROPICAL DISEASES

Quantifying the Spatial Dimension of Dengue Virus Epidemic Spread within a Tropical Urban Environment

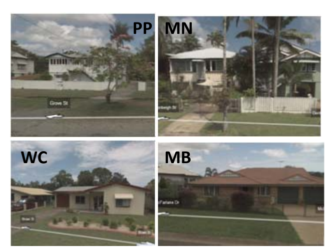
Gonzalo M. Vazquez-Prokopec[1,2]*, Uriel Kitron[1,2], Brian Montgomery[3], Peter Horne[3], Scott A. Ritchie[3,4]

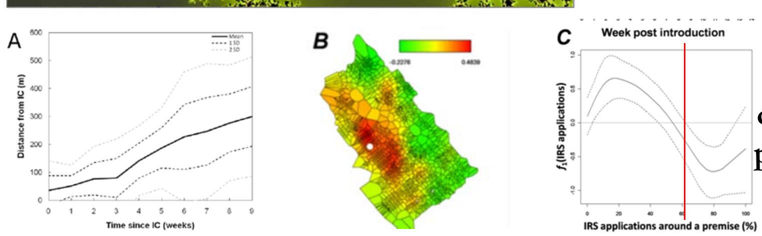
December 2010 | Volume 4 | Issue 12 | e920

Space-time analysis & modeling



Spatial heterogeneity driven by housing type (queenslander)





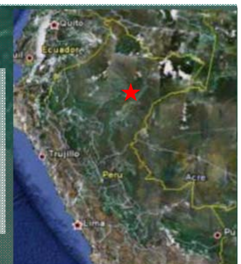
IRS coverage: protective at >60%

Recommendations to QH

- During transmission season consider <u>every dengue-like case</u> as dengue and apply <u>rapid response</u>.
- Consider spatial heterogeneity when designing and implementing surveillance and control interventions.
- <u>Spatial unit for control actions</u> – 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

BioMed Central

Methodology

International Journal of Health Geographics 2009, **8**:68

Usefulness of commercially available GPS data-loggers for tracking human movement and exposure to dengue virus

Gonzalo M Vazquez-Prokopec*[1], Steven T Stoddard[2], Valerie Paz-Soldan[3], Amy C Morrison[2], John P Elder[4], Tadeusz J Kochel[5], Thomas W Scott[2] and Uriel Kitron[1]

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

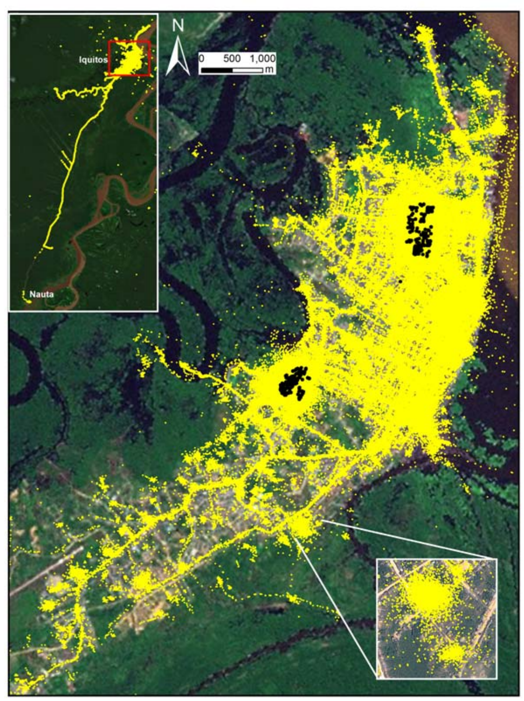
Tracking ~600 individuals with GPS

GPS: latitude, longitude, elevation, time.

2,500,000 data points

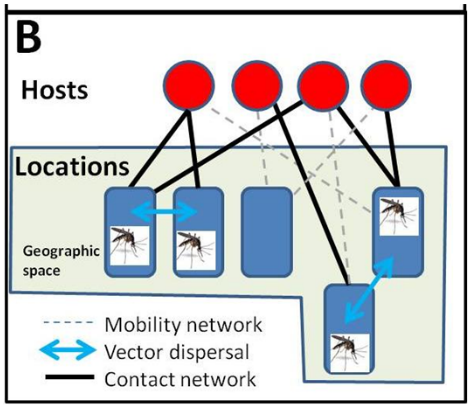
Sample balanced between ages and sexes.

Goal: estimate mobility parameters of Iquitos residents.



Representing movement data

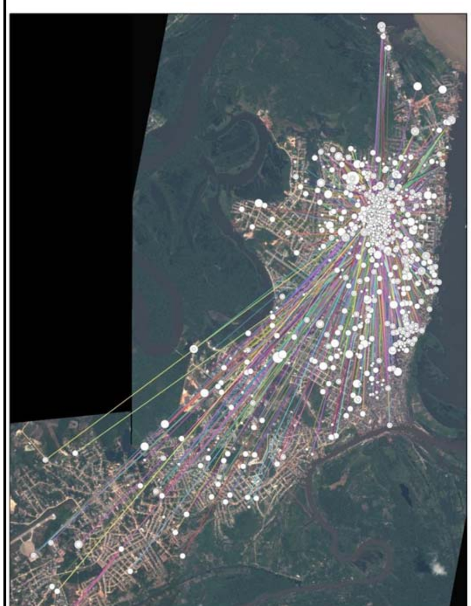
Contact networks – nodes represent individuals (or locations), links represent relationships allowing pathogen transmission

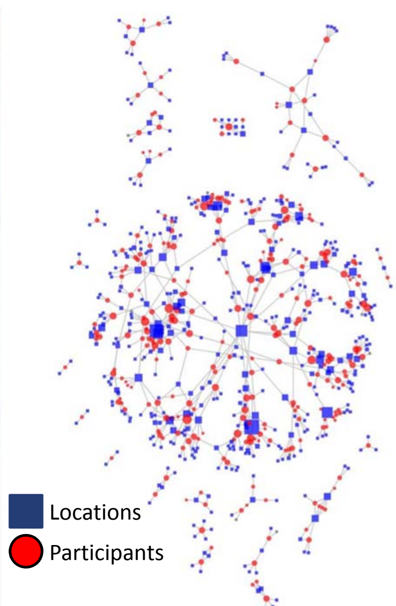


Bipartite & spatial topology

Vazquez-Prokopec & Bansal, in prep.

A dengue contact network

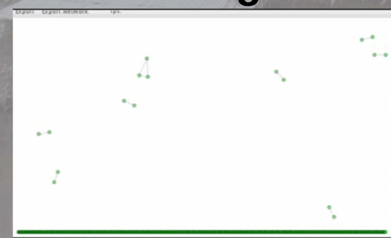




Vazquez-Prokopec et al. in prep.

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

Outline

Vector-borne diseases: a global challenge

Chagas disease

-Vector dispersal as a driver of community reinfestation

Dengue

-Spatial transmission dynamics

-Human movement and virus transmission

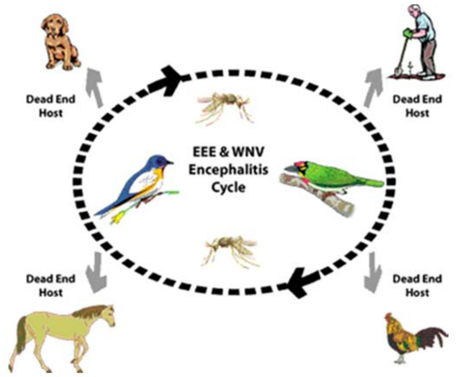
West Nile Virus

-Linking the environment and virus transmission

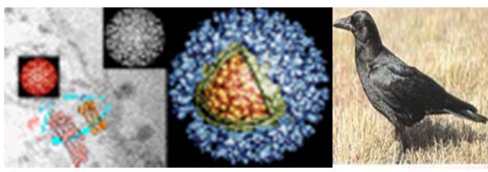
Conclusions

Future Directions

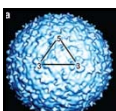
West Nile virus in urban Atlanta, GA



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



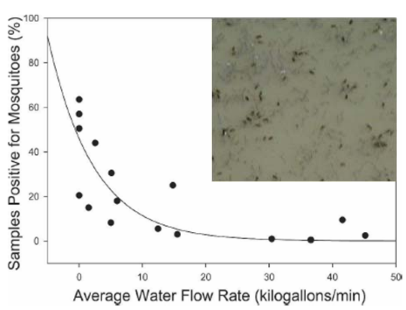
Combined Sewer Systems and Mosquitoes



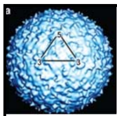
Am. J. Trop. Med. Hyg., 77(3), 2007, pp. 478–484

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

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



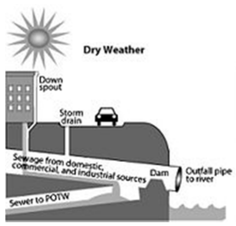
Does the high mosquito productivity translates into a higher WNV transmission risk?

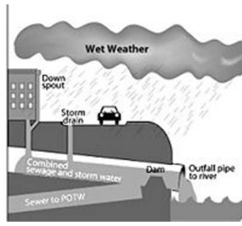


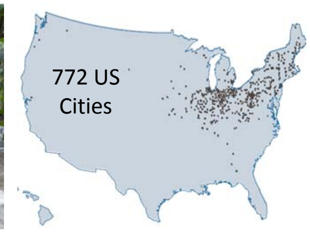
Combined Sewer Systems

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.

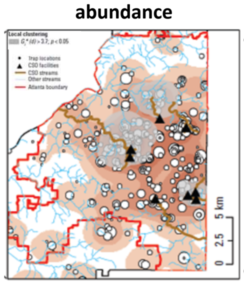
Research VOLUME 118 | NUMBER 10 | October 2010 · ehp ENVIRONMENTAL HEALTH PERSPECTIVES OPEN ACCESS

The Risk of West Nile Virus Infection Is Associated with Combined Sewer Overflow Streams in Urban Atlanta, Georgia, USA

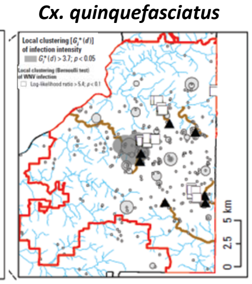
Gonzalo M. Vazquez-Prokopec,[1] Jodi L. Vanden Eng,[2] Rosmarie Kelly,[3] Daniel G. Mead,[4] Priti Kolhe,[5] James Howgate,[5] Uriel Kitron,[1,6] and Thomas R. Burkot[2]

[1]Emory University, Atlanta, Georgia, USA; [2]Centers for Disease Control and Prevention, Atlanta, Georgia, USA; [3]Georgia Division of Public Health, Atlanta, Georgia, USA; [4]University of Georgia, Athens, Georgia, USA; [5]Fulton County Department of Health and Wellness, Atlanta, Georgia, USA; [6]Fogarty International Center, National Institutes of Health, Bethesda, Maryland, USA

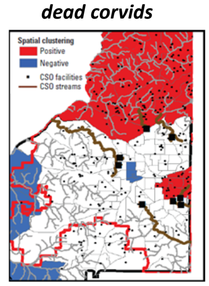
Cx. quinquefasciatus **abundance**



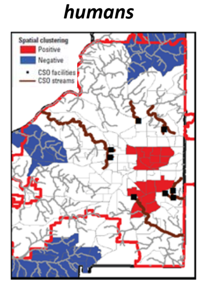
WNV infection in ***Cx. quinquefasciatus***



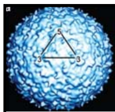
WNV infection in dead corvids



WNV infection in humans



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



Risk factors of WNV infection

Response variable, model[b]	Distance to CSO (m)	Distance to catch basin (m)	Tree cover range (%)	Mean tree cover (%)	Residential use Low (%)	Residential use Medium (%)	Residential use High (%)	Wetland (%)	Forest (%)	Barren land (%)	Elevation (m)	Constant	AIC	ΔAIC	ω_i^c
WNV infection in *Cx. quinquefasciatus*															
1	−6.9E−4*	—	—	—	—	—	—	—	—	—	—	−1.26*	406.2	0.0	0.559
2	−7.5E−4*	2.4E−4	—	—	—	—	—	—	—	—	—	−1.28*	407.83	1.63	0.247
3	—	—	0.04*	0.04	—	—	—	—	—	—	—	−3.70	408.8	2.6	0.152
4	—	—	—	—	1.40	−4.44	0.04	−3.33	3.33	22.19	−0.03	−1.88	412.15	5.95	0.029
5	−2.1E−5	1.3E−4	0.04	1.31	−1.23	1.55	6.51	6.95	−4.07	21.23	−0.01	−4.03	413.9	7.7	0.012
6	—	3.5E−4	—	—	—	—	—	—	—	—	—	−1.51*	419.67	13.47	0.001
$\Sigma\omega_i$	0.81	0.0	0.152	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				

Mosquitoes: Distance to CSO, followed by Tree cover range

Response variable	Model[b]	Mean distance to CSO (m)	Mean distance to catch basin (m)	Mean tree cover (%)	Mean elevation (m)	2000 U.S. Census: Percent houses 1950s–1960s	2000 U.S. Census: Median household income (U.S. dollars)	No. dead corvids	Constant	AIC	ΔAIC	ω_i^c
Human WNV incidence												
	1	−6E−5**	—	−0.0018	—	0.0276*	−1E−5*	−0.0362	3.60*	309.0	0.0	0.817
	2	−6E−5**	5E−5	−0.0012	−0.0018	0.0287*	−2E−5*	−0.032	4.13*	313.1	4.1	0.105
	3	−8E−5*	3E−5	—	—	—	—	−0.117*	2.65*	314.8	5.8	0.04
	4	—	—	—	—	0.0381*	−2E−5*	—	3.58*	316.8	7.8	0.02
	5	—	—	−0.020*	−0.0035	—	—	—	3.75*	316.9	7.9	0.02
	$\Sigma\omega_i$	0.97	0.0	0.02	0.0	0.94	0.92	0.04				
WNV-positive corvid death ratio												
	1	−6E−4*	—	0.194*	—	0.1095	1.0E−5*	—	4.26*	707.0	0	0.913
	2	−6E−4*	2E−5	0.215*	−0.0159	0.1023	−6.0E−5	—	10.46*	711.7	4.7	0.09
	3	—	—	—	—	0.186*	1.4E−4*	—	1.19	728.2	21.2	0.00
	4	—	—	0.172*	−0.0017	—	—	—	4.83	728.4	21.4	0.00
	5	−3E−4	−1E−5	—	—	—	—	—	11.61*	739.9	32.9	0.00
	$\Sigma\omega_i$	1.0	0.0	1.0	0.0	0.0	0.91					

Humans: Distance to CSO and housing age, followed by median income.
Birds: Distance to CSO and mean tree cover, followed by Median income.

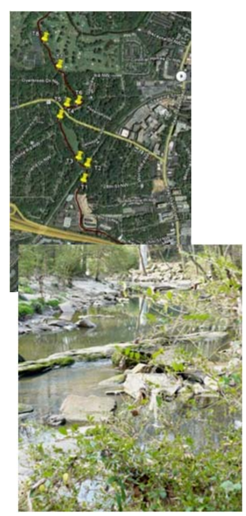
Observational, laboratory, and semi-natural experiments

Peavine creek
Non-CSO

The role of CSO in mosquito population dynamics.

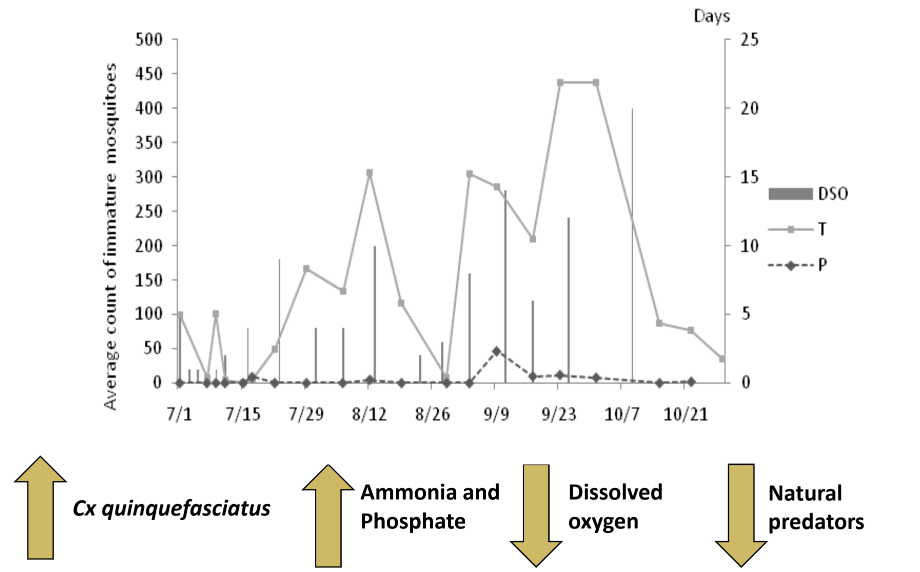
Oviposition preference
Fitness and behavior
Density dependence

CDC insectary



Tanyard creek
CSO

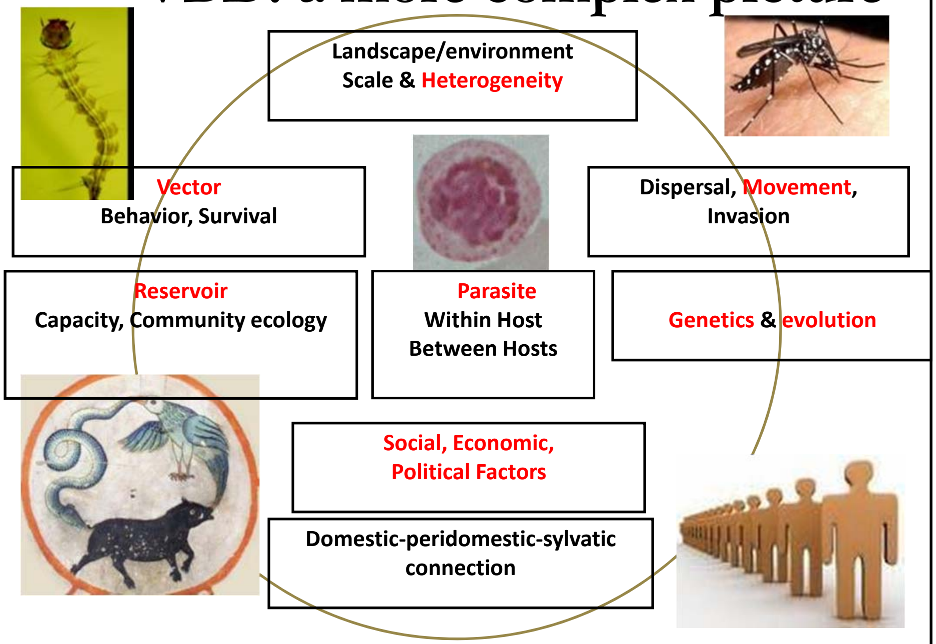
Monitoring CSO (T) and non-CSO (P) streams



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.**

VBD: a more complex picture



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?