Population dynamics of *Aedes aegypti*, vector of Dengue Fever

Cláudia Codeço
Fiocruz, Rio de Janeiro

IFT, São Paulo, 24 janeiro 2012

Ministério da Saúde

FIOCRUZ
Fundação Oswaldo Cruz

Everybody knows *Aedes aegypti*, the dengue vector

AËDES AEGYPTI (L.)

THE YELLOW FEVER MOSQUITO

ITS LIFE HISTORY, BIONOMICS AND STRUCTURE

BY

SIR S. RICKARD CHRISTOPHERS

C.I.E., O.B.E., F.R.S., I.M.S. (retd.)

Member of the Malaria Commission of the Royal Society and Colonial Office, 1899–1902. Late Officer in Charge Central Malaria Bureau, India

CAMBRIDGE

AT THE UNIVERSITY PRESS

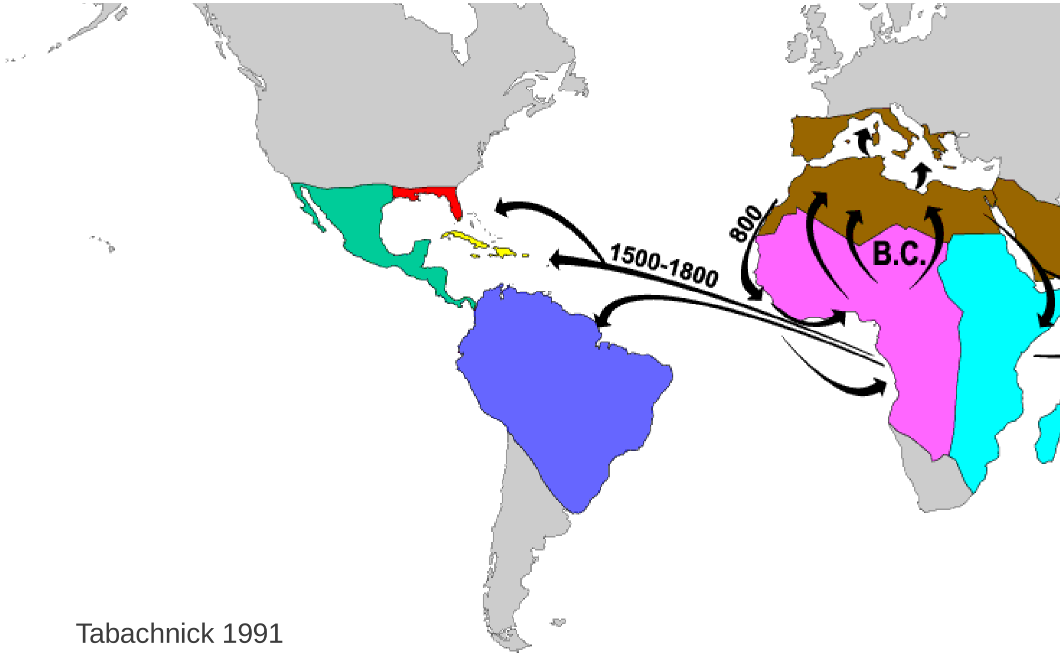
1960

CONTENTS

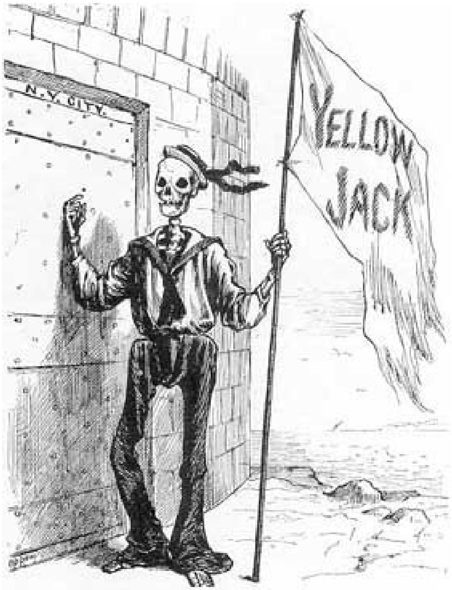
Table 11. *Duration of instar periods*

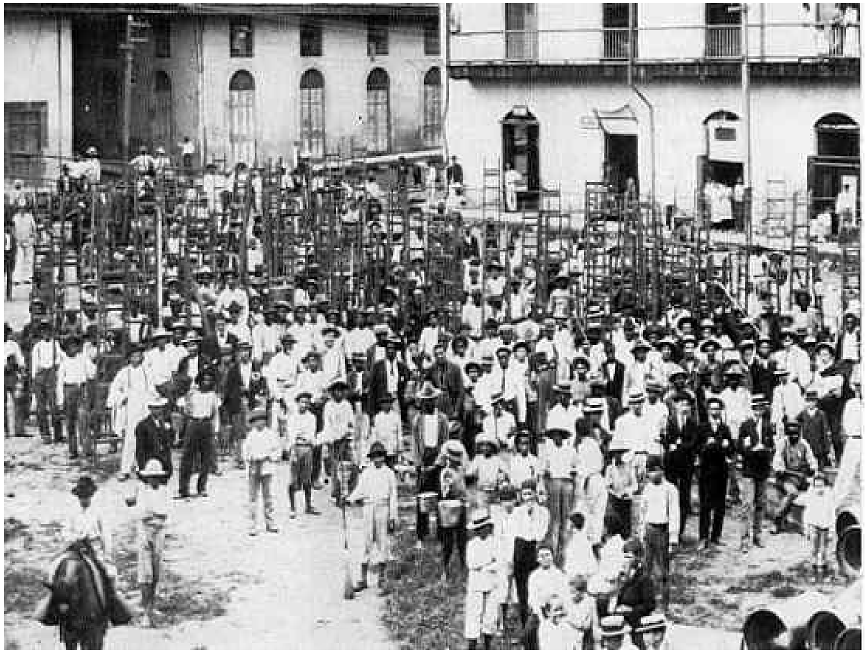
Hours	Instars I	II	III	IV	*P*	Timing of stage
20	100	—	—	—	—	All first instar up to 20 hours
22	100	+	—	—	—	—
23	89	11	—	—	—	—
24	67	33	—	—	—	—
25	56	44	—	—	—	50 per cent ecdysis I–II 25–26 hours
26	44	56	—	—	—	
27	31	69	—	—	—	—
28	3	97	—	—	—	—
30	—	100	—	—	—	—
						All second instar 30–42 hours
42	—	100	—	—	—	—
45	—	74	26	—	—	—
46	—	37	63	—	—	50 per cent ecdysis II–III 46 hours
47	—	17	83	—	—	—
48	—	27	73	—	—	—
49	—	+	100	—	—	—
50	—	15	85	—	—	—
52	—	+	100	—	—	—
54	—	2	98	—	—	—
						All third instar 54–68 hours
68	—	—	100	—	—	—
69	—	—	73	27	—	—
70	—	—	60	40	—	—
71	—	—	58	42	—	50 per cent ecdysis III–IV 71–72 hours
72	—	—	32	68	—	
73	—	—	24	76	—	—
76	—	—	17	83	—	—
78	—	—	—	100	—	—
92	—	—	9	91	—	—
94	—	—	—	100	—	—
96	—	—	6	94	—	—
98	—	—	—	100	—	—
102	—	—	—	100	+	First male pupa 102 hours
117	—	—	9	91	—	—
122	—	—	—	50	50	Bulk of males pupated 122 hours
139	—	—	—	+	100	—
141	—	—	—	12	88	—
144	—	—	—	+	100	Bulk of females pupated 144 hours

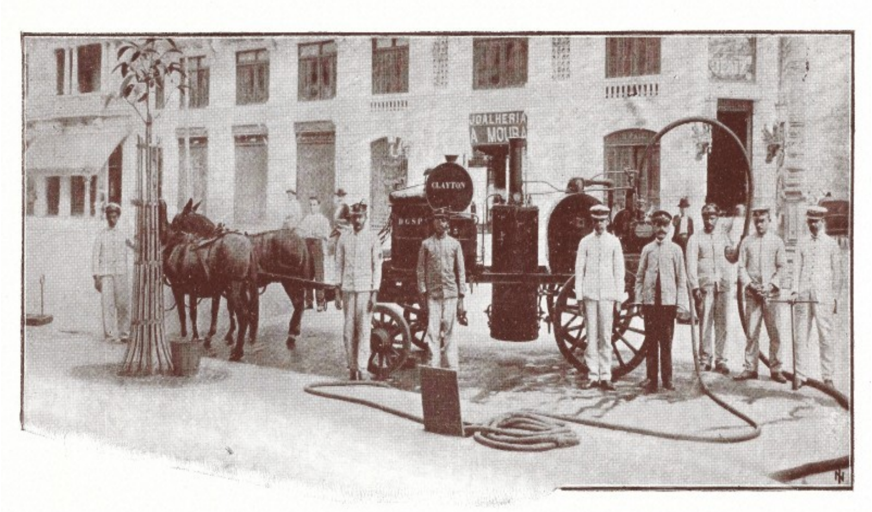
Aedes aegypti : vector of yellow fever



Tabachnick 1991

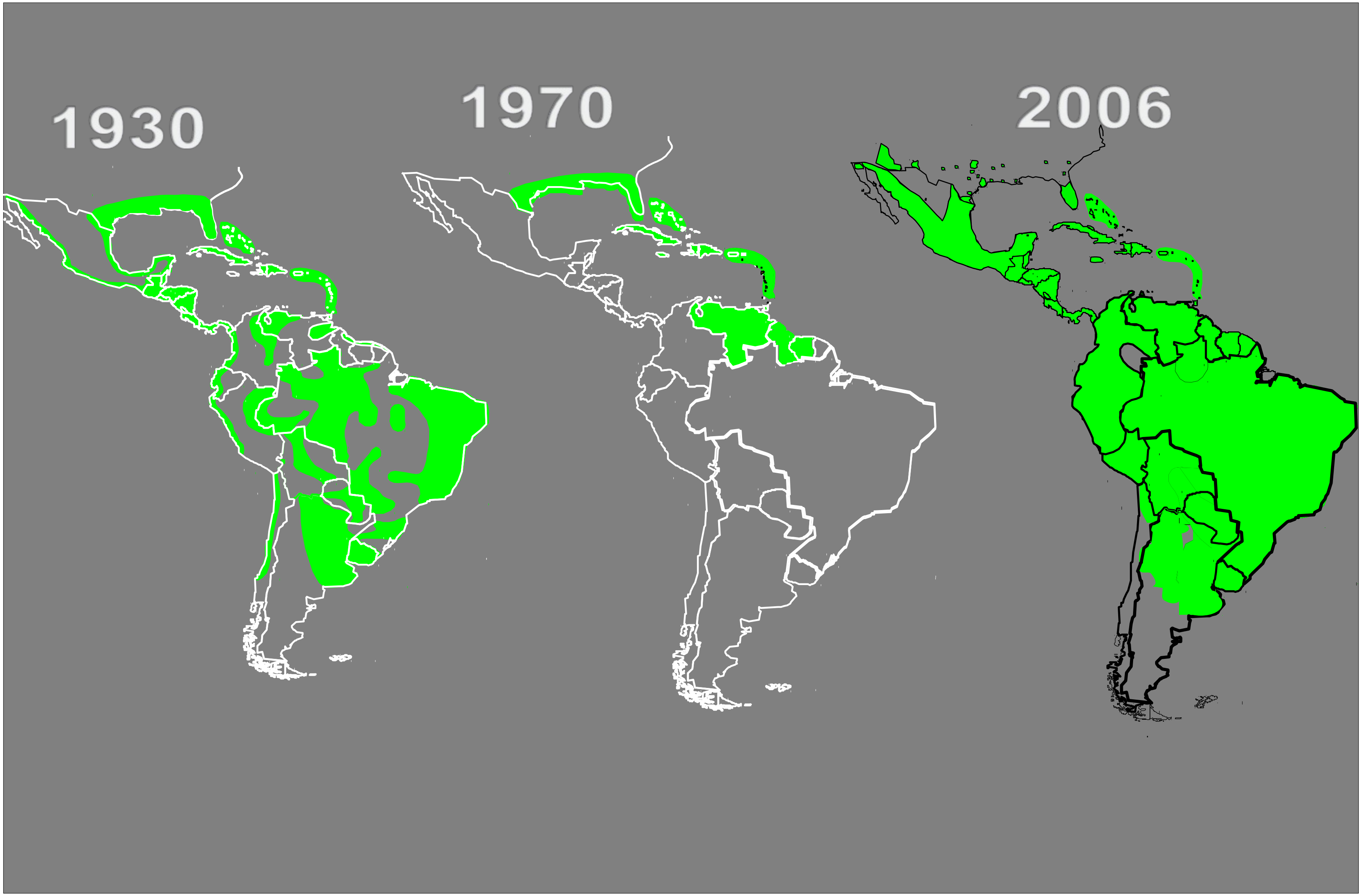




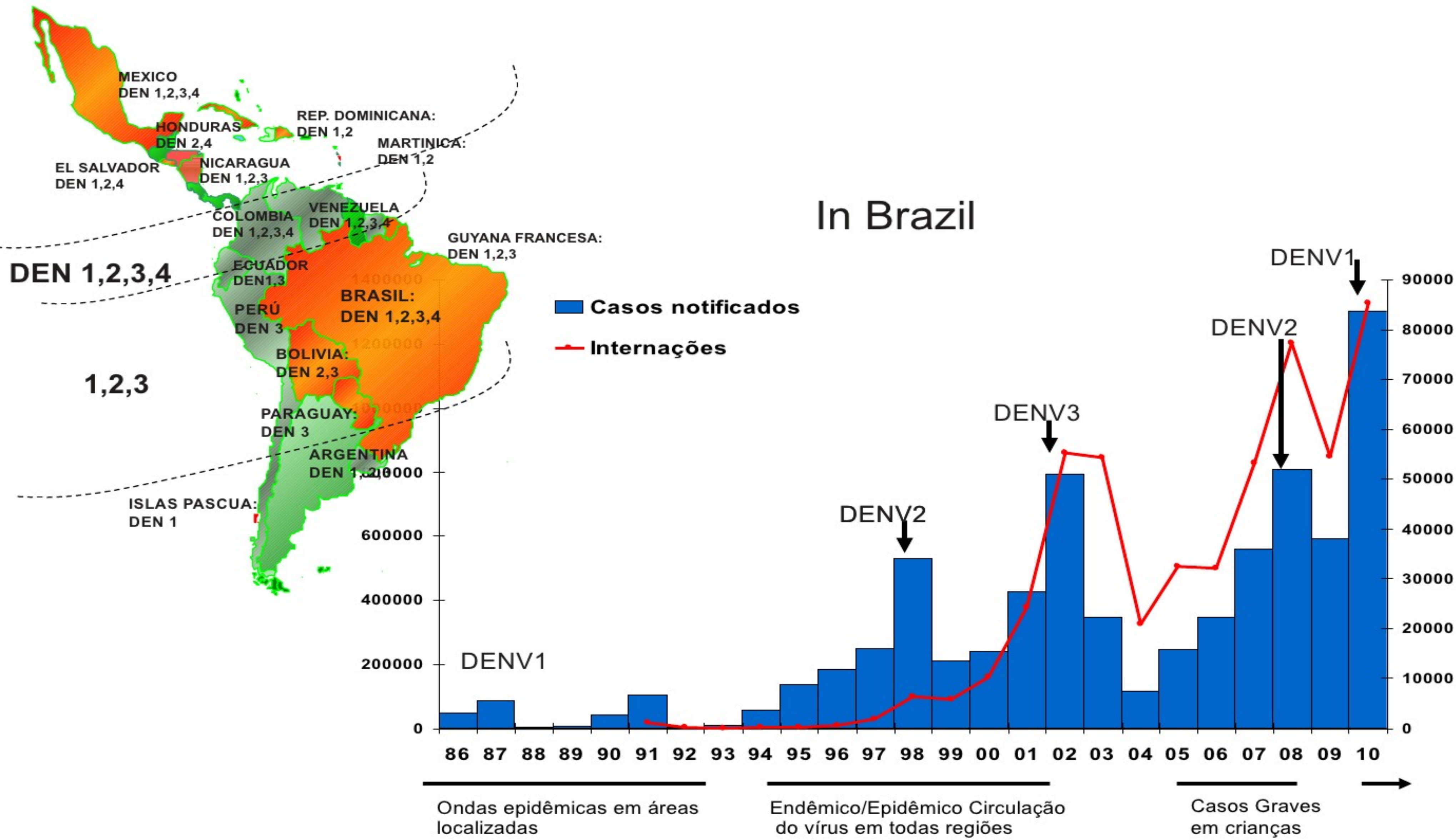


Prophylaxia da febre amarella — Apparelho CLAYTON.

Erradication campaign



Aedes aegypti is again the greatest enemy: as the vector of dengue fever



The tools of Public Health

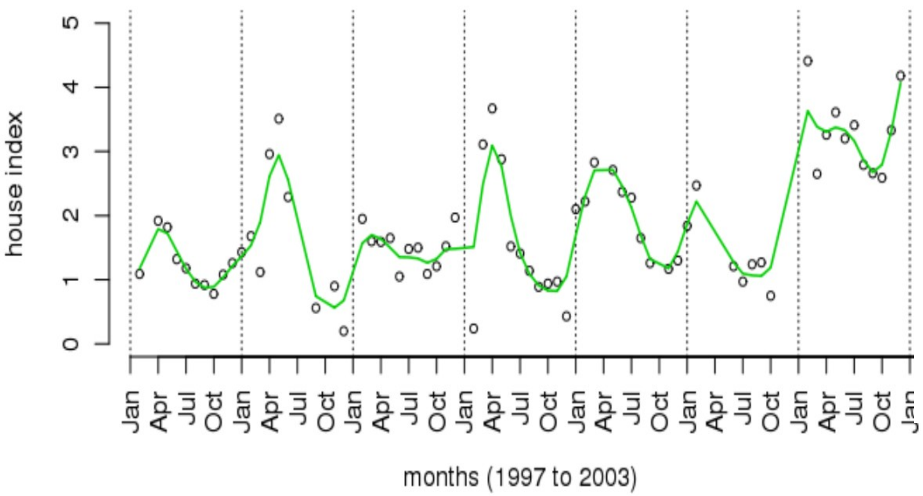
- Surveillance
- Control

The tools of Public Health

- Surveillance
- Control

Clinical cases – time series of cases

Mosquitos – infestation indices



New indices require new models

Trap indices

TARGET	TRAP	INDEX
	 Ovitraps	Eggs/trap % Positive traps
	 Mosquitraps	Adults/trap % Positive traps

The tools of Public Health

- Surveillance

Clinical cases – time series of cases

Mosquitos – infestation indices

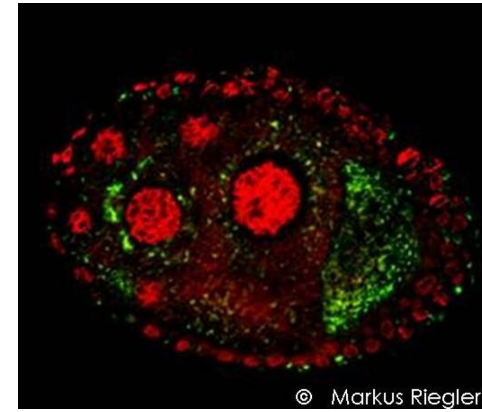
- Control

Vaccine under development
Specific treatments under development

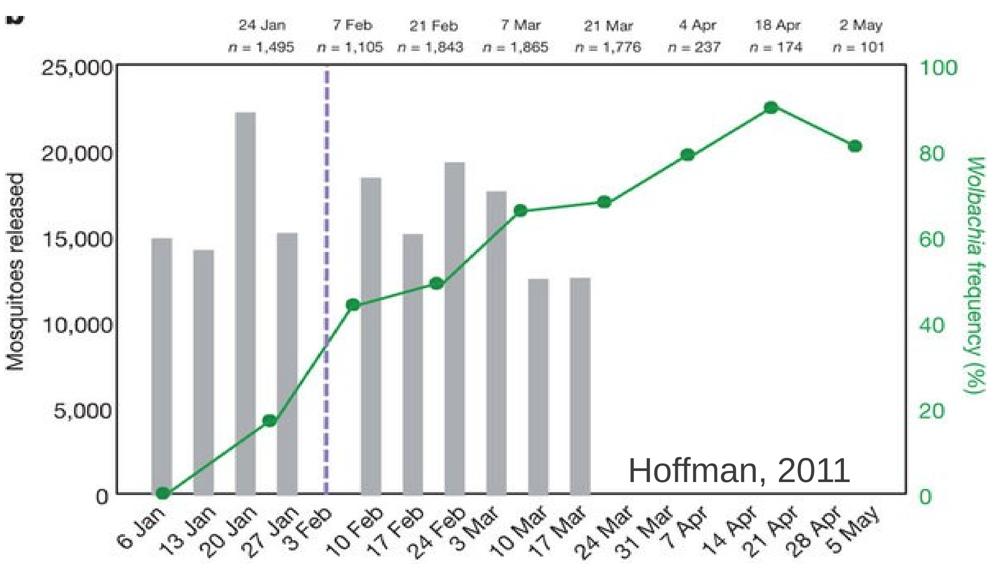
Vector control
- chemical
- removal of breeding sites (education)
- biological control

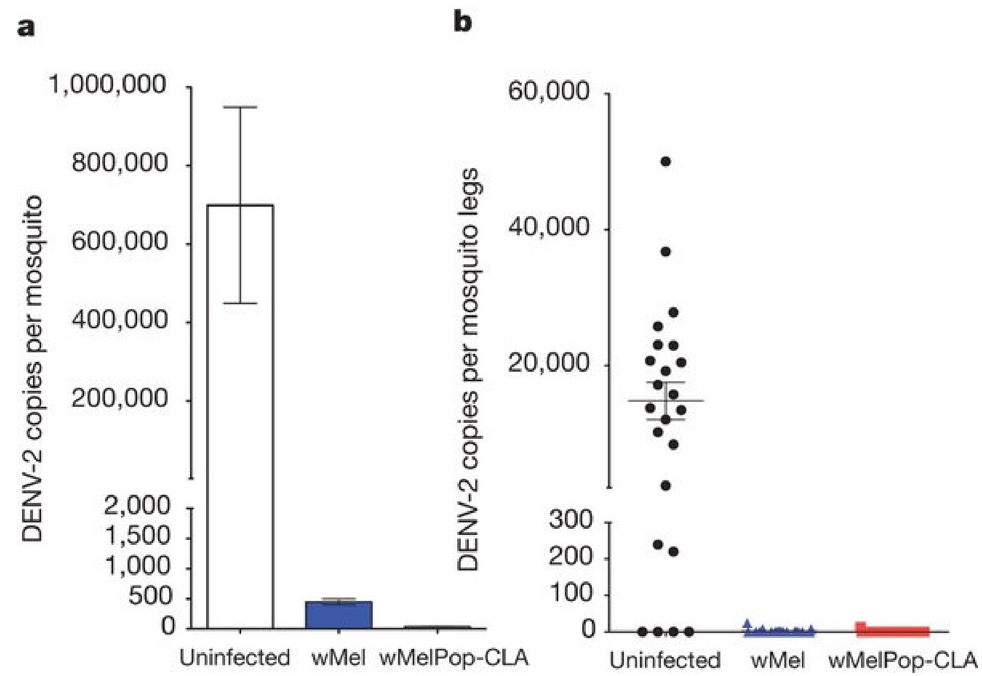
→ New tools demand new models

The most recent technology: Wolbachia Infected mosquitos



In Australia:





In Brazil?? Measuring the probability of success requires Undertanding the dynamics of the wildtype Aedes aegypti.

Modeling Aedes aegypti dynamics: Why?

Optimize vector control strategies

Early warning systems

Predict future Dynamics, p.e., Global warming

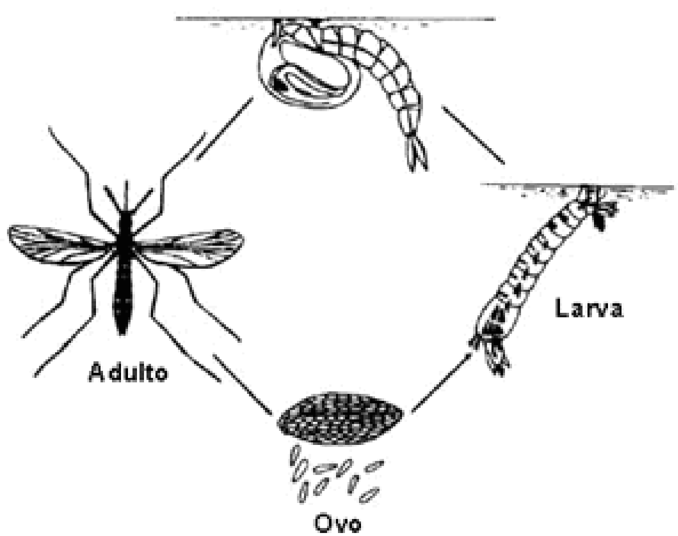
Modeling Aedes aegypti dynamics: Why?

Early warning systems

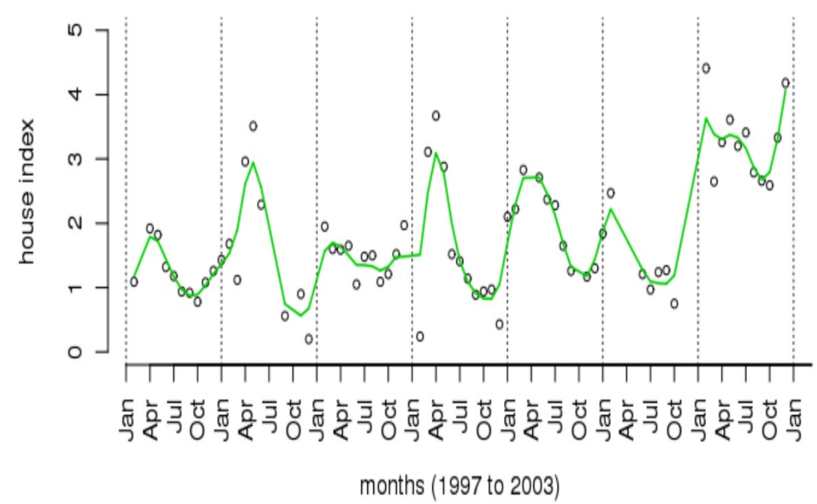
Optimize control strategies

Predict future Dynamics, p.e., Global warming

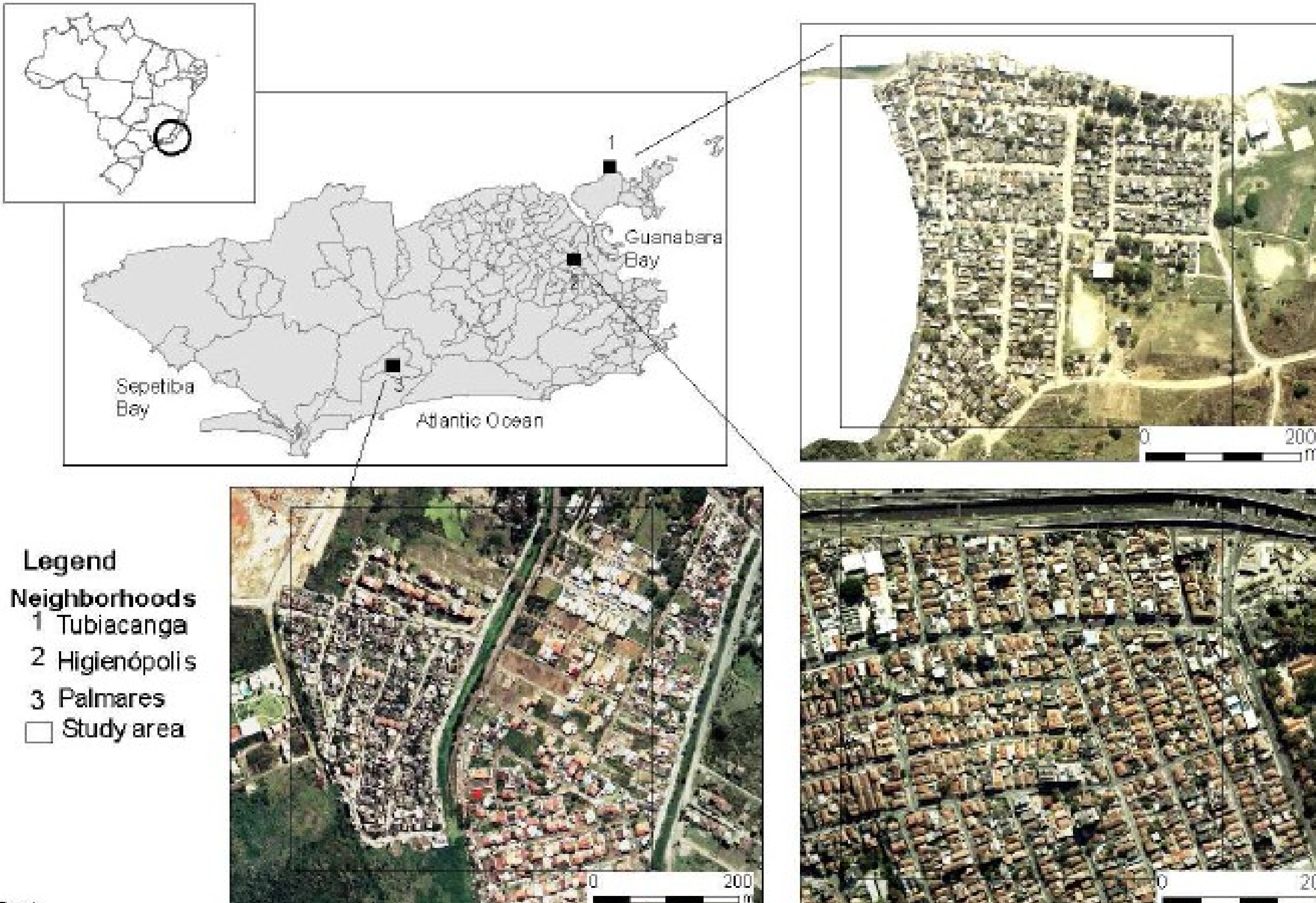
Temperature
Rainfall
humidity



Seasonality
Year-to-year variation

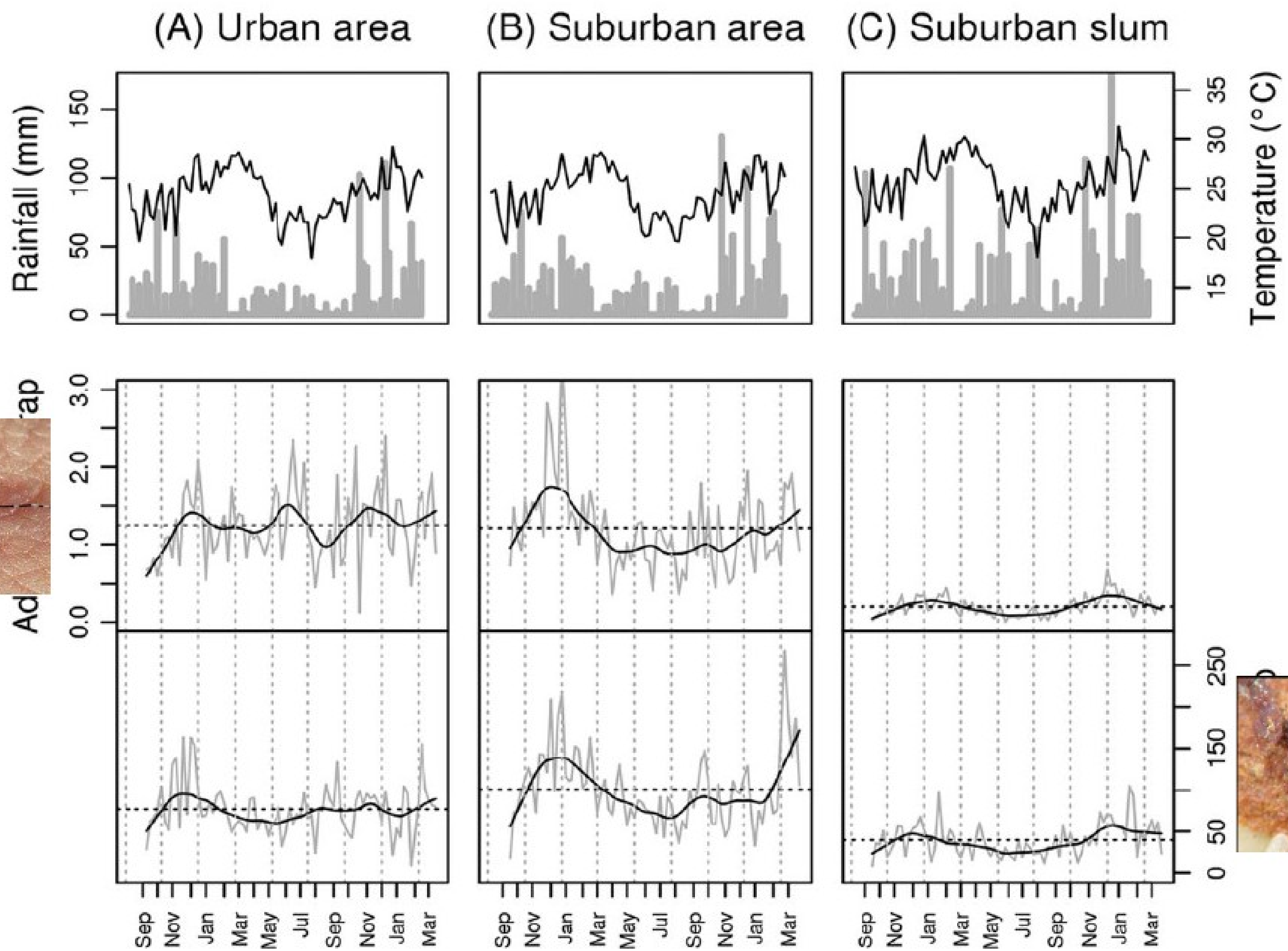


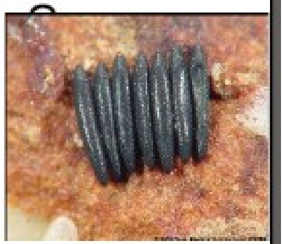
Entomological survey (sept2006 - march 2008)



Font:
Ortophoto: PoratalGeo - IPP- Rio de Janeiro
Digital map: Geoprocessing Laboratory - ICICT/ Fiocruz

The data


(A) Urban area
(B) Suburban area
(C) Suburban slum
Rainfall (mm)
Temperature (°C)
0
50
100
150
15
20
25
30
35
0.0
1.0
2.0
3.0
0
50
150
250
Sep
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar

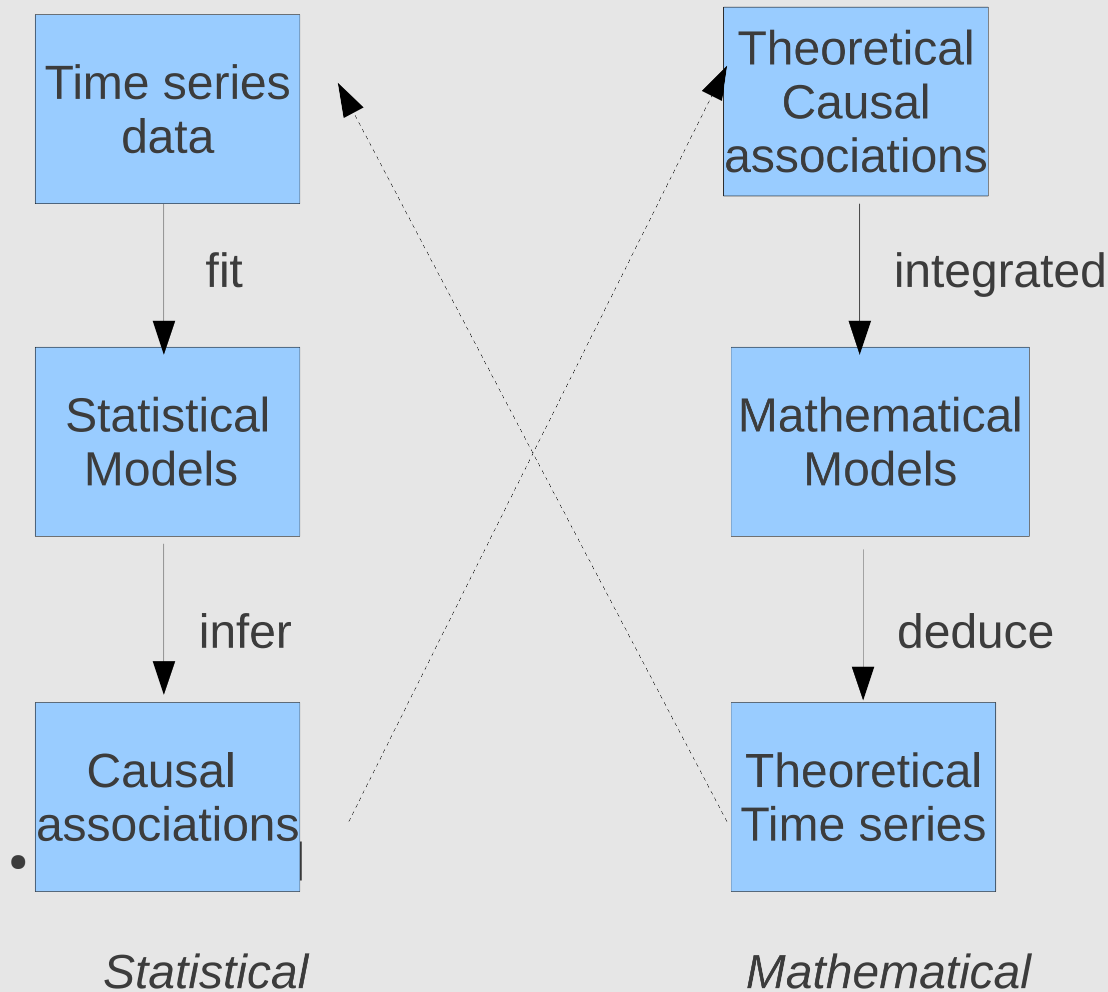


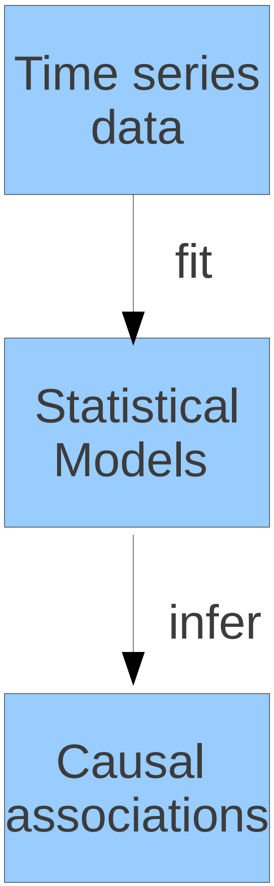
"the mathematical method of treatment is really nothing but the application of careful reasoning to the problems at issue."

Ronald Ross
(1857-1932)

The theoretical framework
A priori & a posteriori pathometry

A priori: (first principles) → model → data
A posteriori: data → model → theory





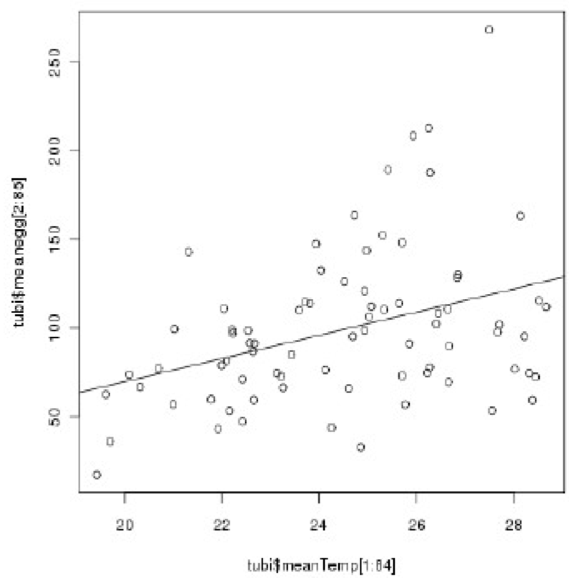
Statistical

General linear modeling: quantitative predictions of the effect of climate on mosquito abundance

Hypotheses:

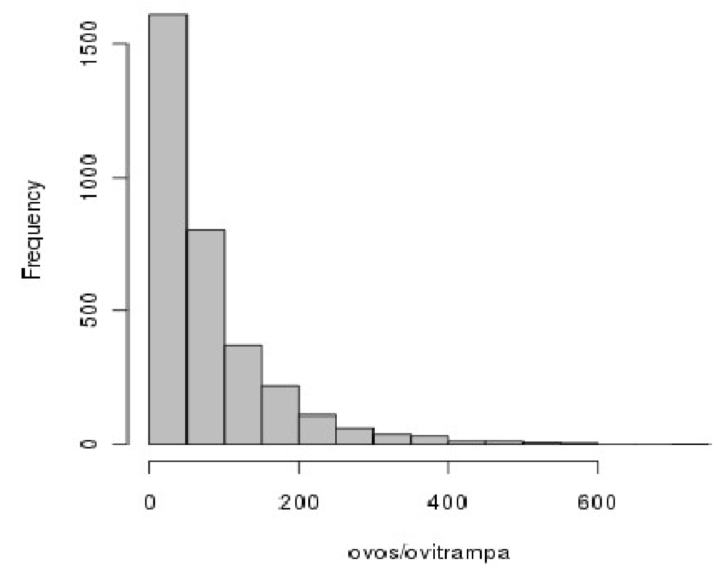
- Higher temperatures imply more mosquitos with a certain delay
- More rainfall imply more mosquitos with a certain delay

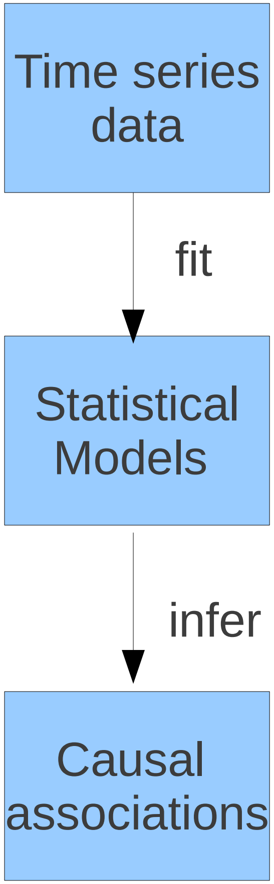
Eggs (t)



Temperature (week-1)

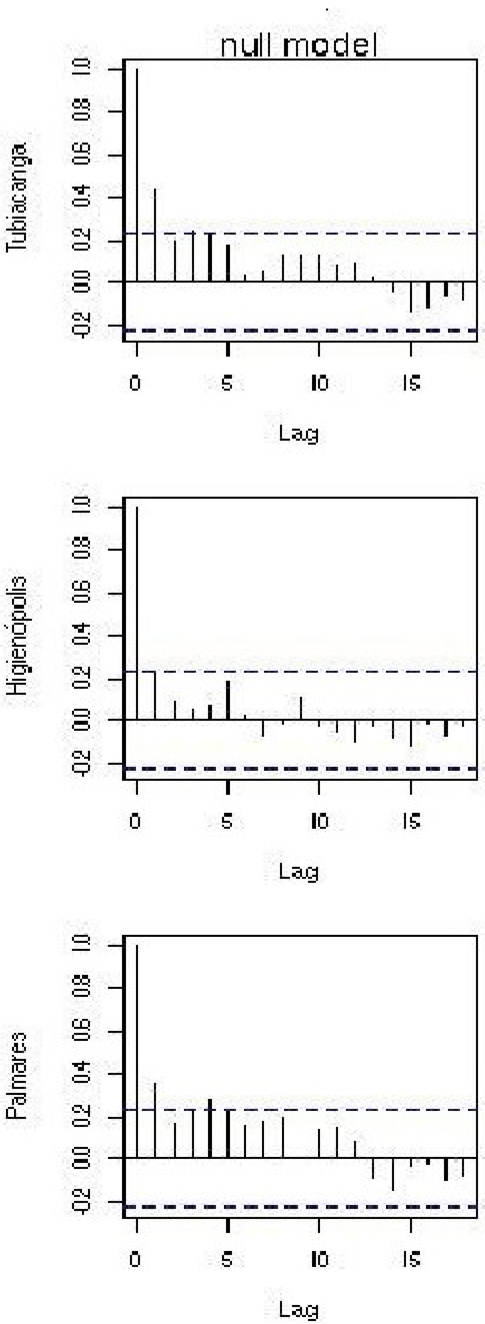
Negative Binomial distribution





Statistical

Auto-correlation structure



Time series data

fit

Statistical Models

infer

Causal associations

Statistical

Models:

$$Y_t \sim NegBin$$

$$E[Y_t] = a_0 \quad \text{null}$$

$$E[Y_t] = a_0 + a_1 Y_{t-1} \quad \text{AR1}$$

$$E[Y_t] = a_0 + a_1 Y_{t-1} + a_2 Temp_{t-m} \quad \text{+ temperature}$$

$$E[Y_t] = a_0 + a_1 Y_{t-1} + a_2 Temp_{t-m} + a_3 Chuva_{t-n} \quad \text{+ rain}$$

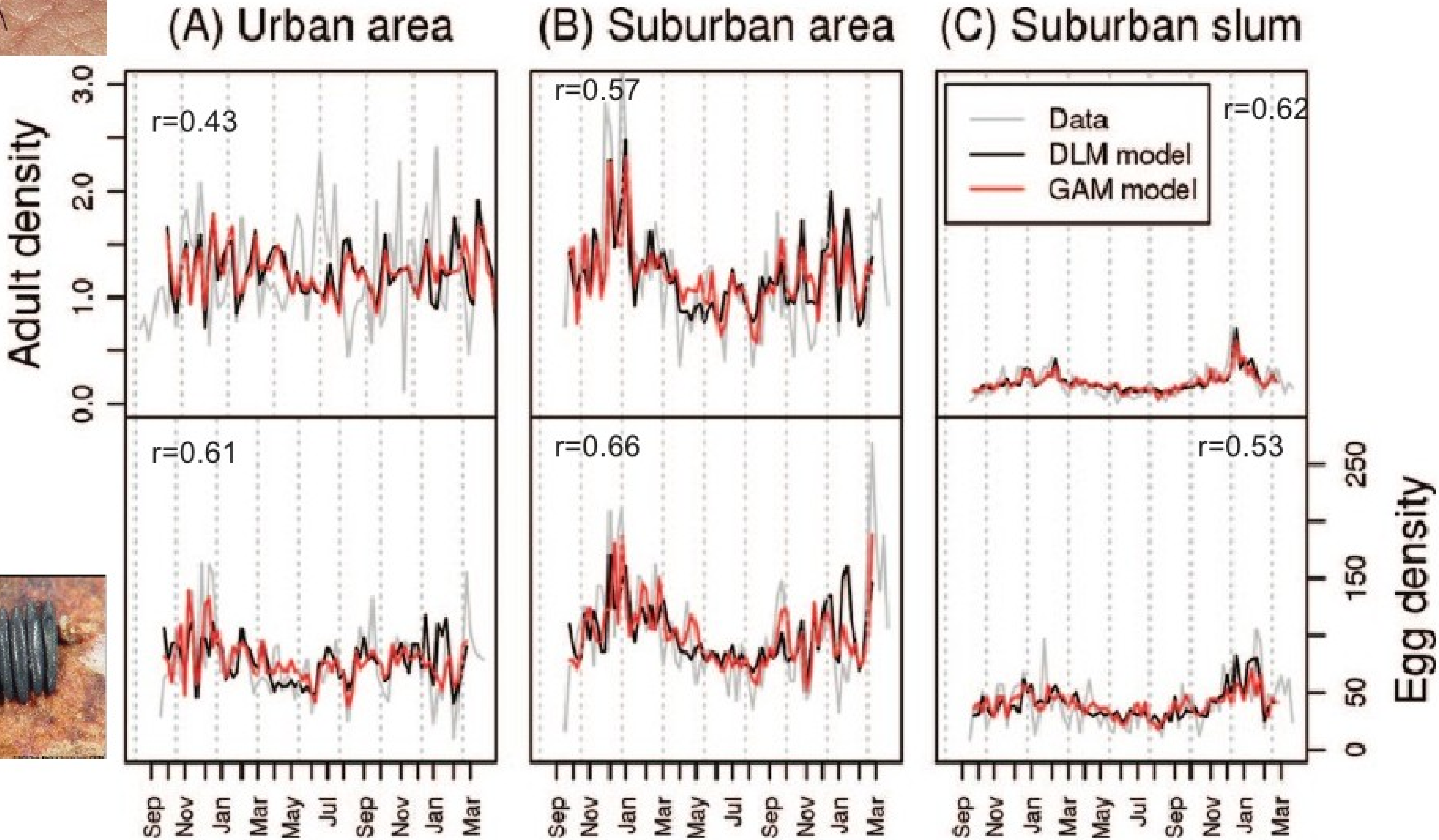
Model comparison

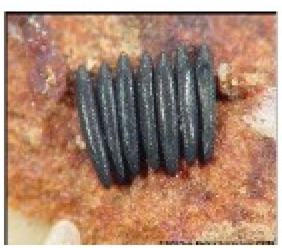
- Likelihhod based criterion (AIC)
- Pearson's correlation
- Residuals

GAM model was required:

Smooth temperature term (non linear)

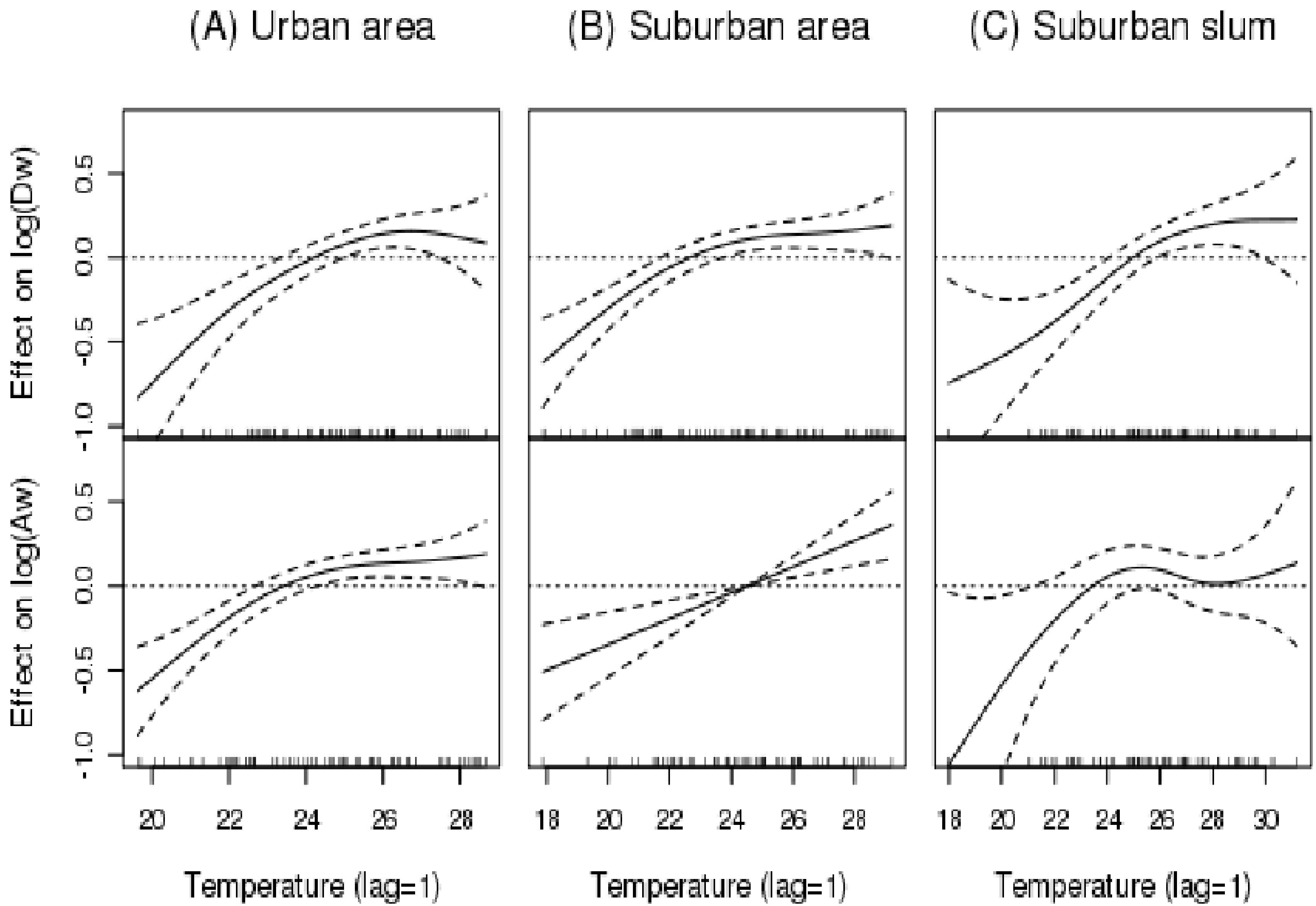
AR(1)+TEMP(1)+CHUVA(4) **AR(1)+TEMP(1)** **AR(1)+TEMP(1)**

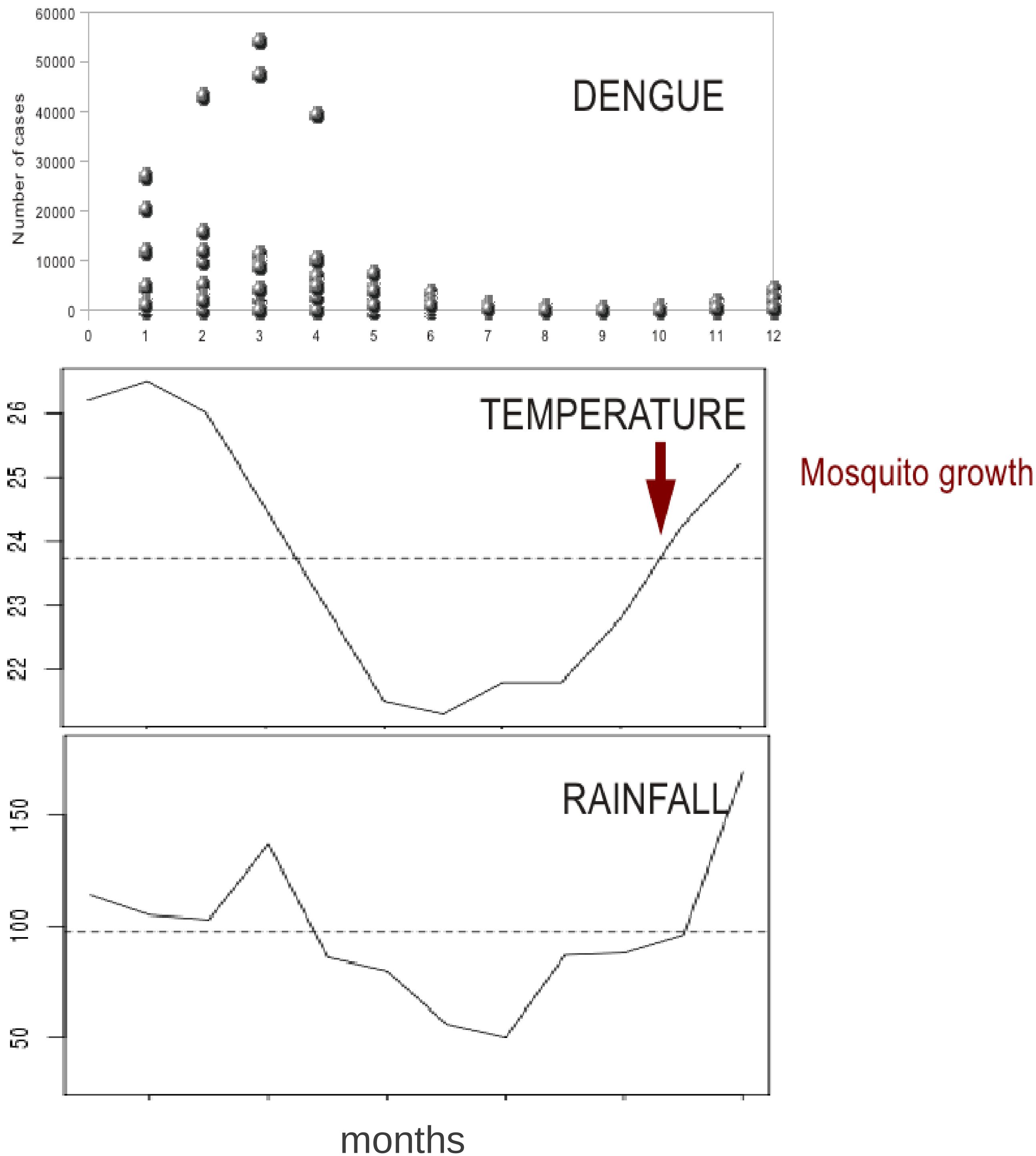




AR(1)+TEMP(1) **AR(1)+TEMP(1)+CHUVA(1)** **AR(1)+TEMP(1)+CHUVA(4)**

Temperature effect is delayed and nonlinear




DENGUE
Number of cases
60000
50000
40000
30000
20000
10000
0
0
1
2
3
4
5
6
7
8
9
10
11
12
TEMPERATURE
26
25
24
23
22
Mosquito growth
RAINFALL
150
100
50
months

Theoretical Causal associations

integrated

Mathematical Model

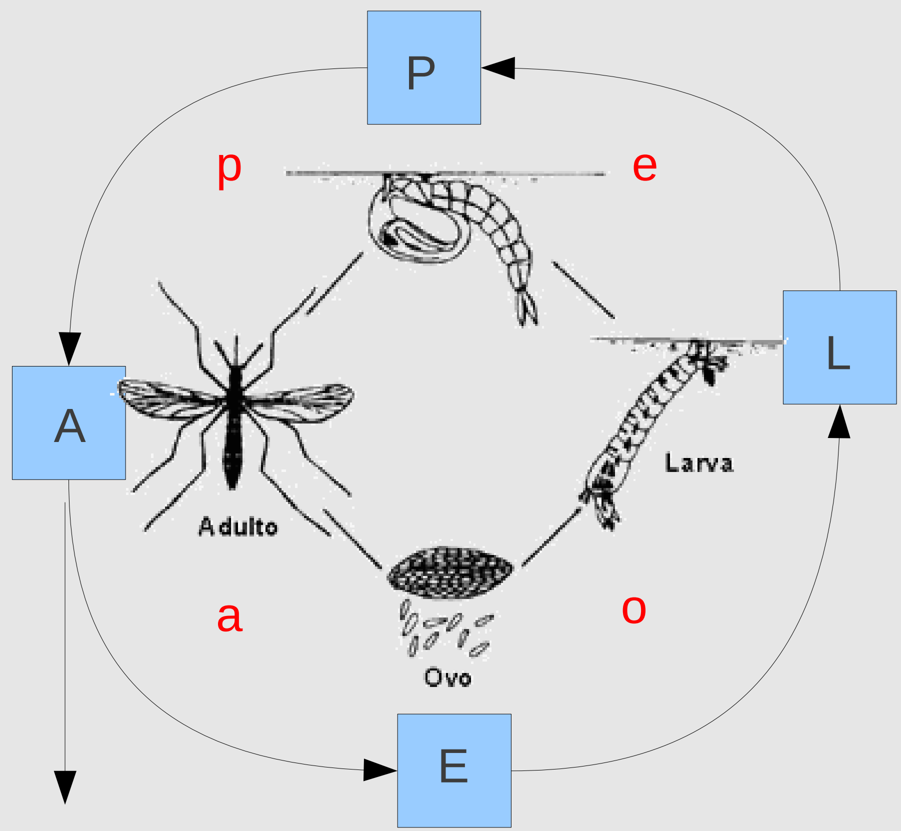
deduce

Theoretical Time series

Mathematical

The mechanistic way...

The population cycle



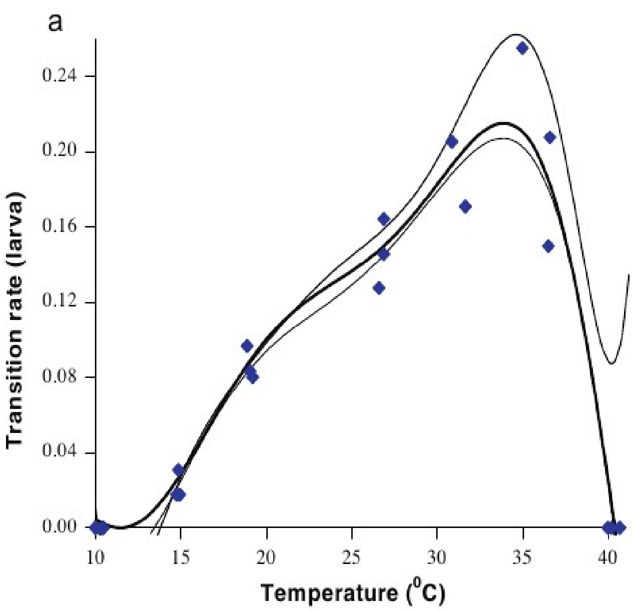
temperature – dependent development

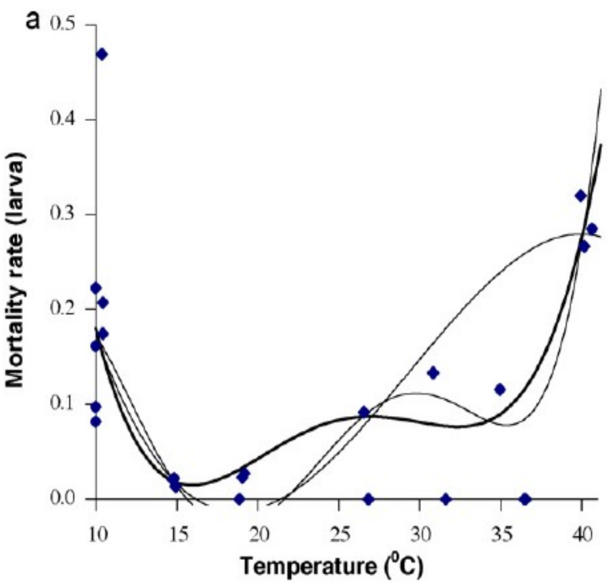
availability of breeding sites affect recruitment (density dep effect)

no predators or other inter-specific Interactions

Follow up estimation of *Aedes aegypti* entomological parameters and mathematical modellings☆

Hyun Mo Yang[a,*,1], Maria de Lourdes da Graça Macoris[b], Karen Cristina Galvani[b], Maria Teresa Macoris Andrighetti[b]





Intra-specific competition during immature stage

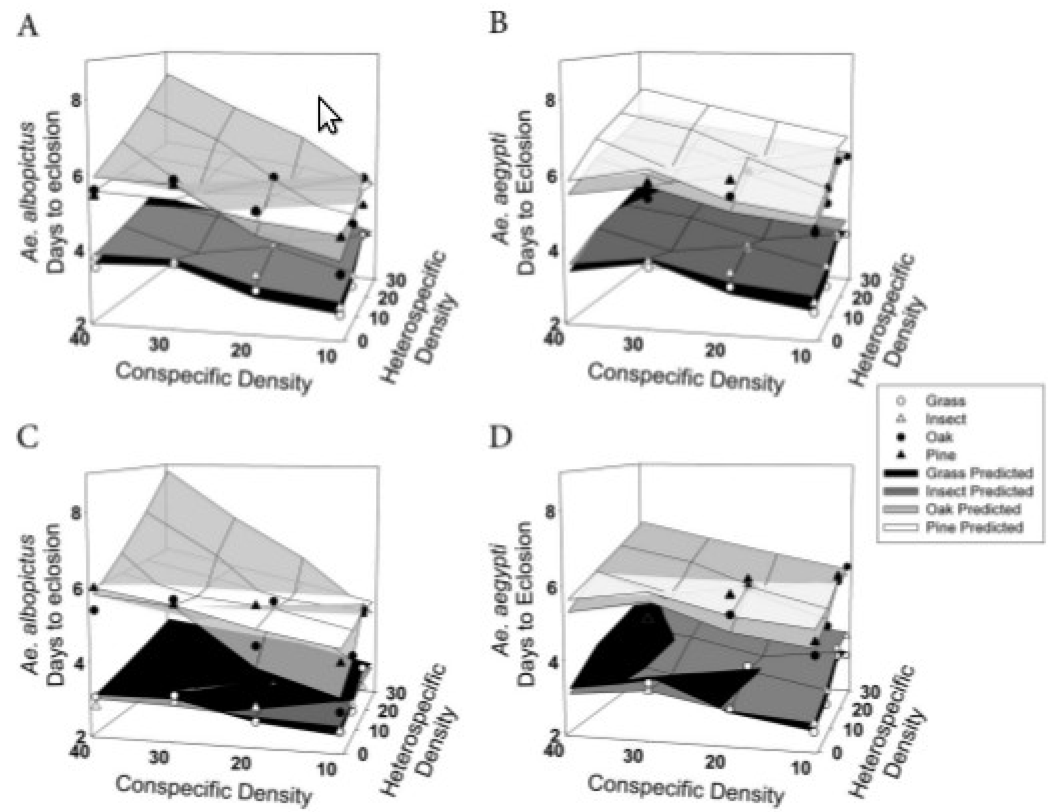


Fig. 5. Median days to eclosion, by detritus type, of adult females (A and B) and males (C and D) of each species, as affected by conspecific and heterospecific densities. As in Fig. 3, scatter plots represent back-transformed means and surfaces represent predicted model values. Apparent nonlinearity is a product of back-transformation of data. Note that colors for this graph have been reversed to better display all detritus types.

Murrel & Juliano, 1998

Aedes aegypti alternative mathematical models

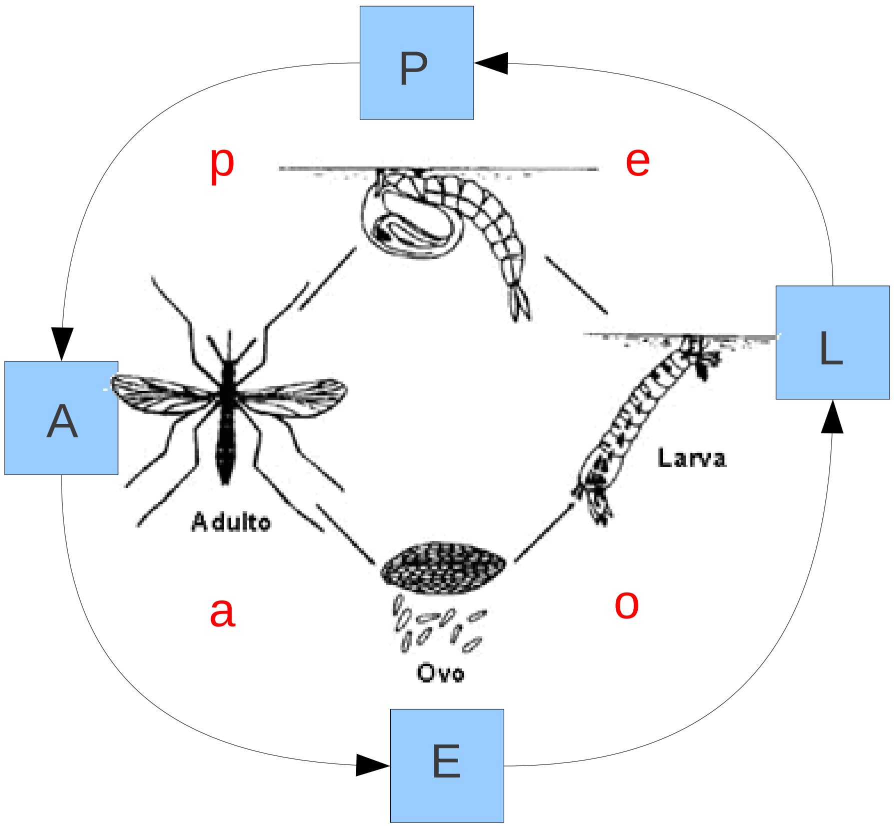
1) Null model: constant rates

$$\frac{dE}{dt} = oA - mE - eE$$

$$\frac{dL}{dt} = eE - mL - pL$$

$$\frac{dP}{dt} = pP - mP - aP$$

$$\frac{dA}{dt} = aP - mA$$



Aedes aegypti alternative mathematical models

1) Null model: constant rates

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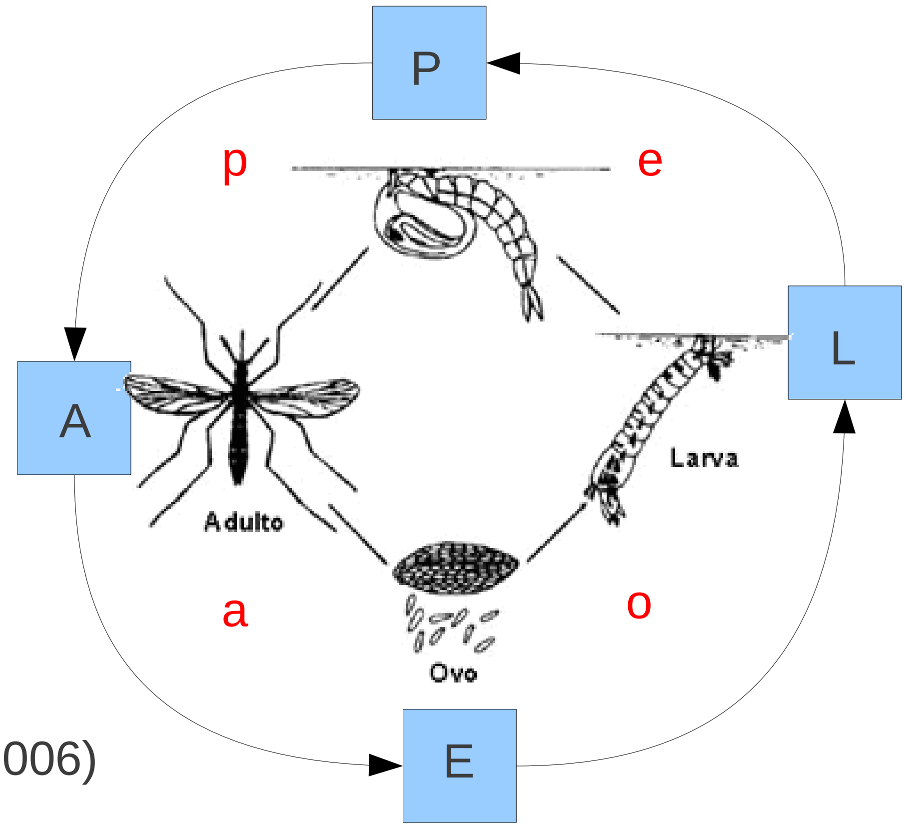
$$\frac{dL}{dt} = e\,E - m\,L - p\,L$$

$$\frac{dP}{dt} = p\,P - m\,P - a\,P$$

$$\frac{dA}{dt} = a\,P - m\,A$$



2) Temperature model

Transition rates are polinomials (Yang, 2011)

Or

Transition rates from thermodynamics (Otero, 2006)

Aedes aegypti alternative mathematical models

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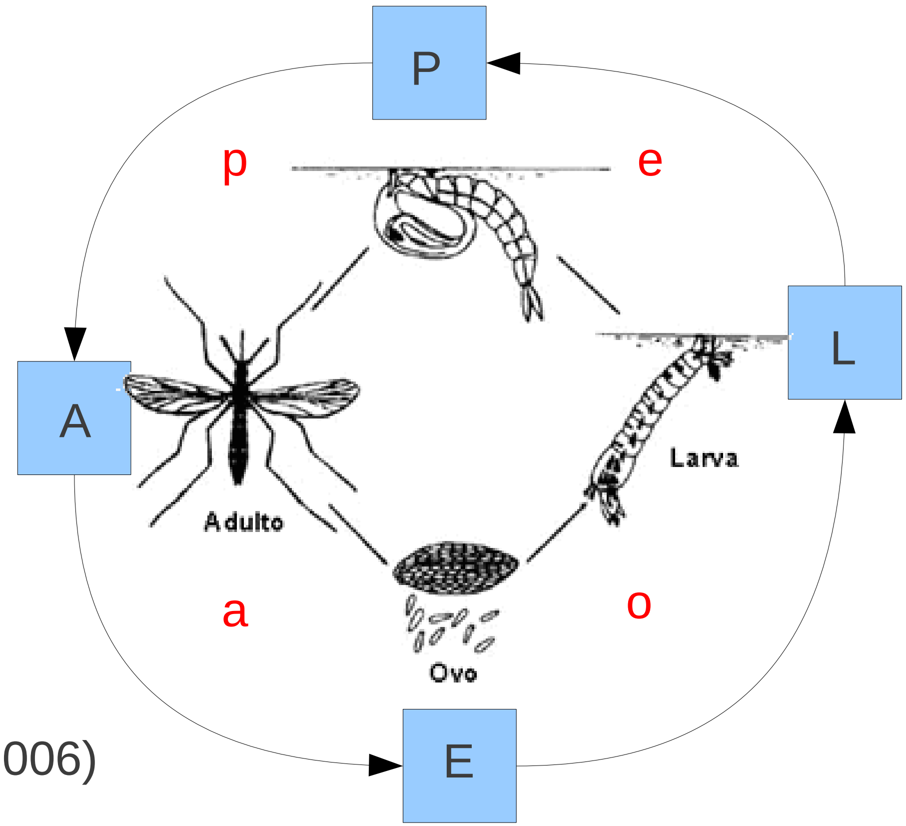
3) Temperature+Competition model

Logistic term in the immature phase (Yang, 2011, Otero, 2006)



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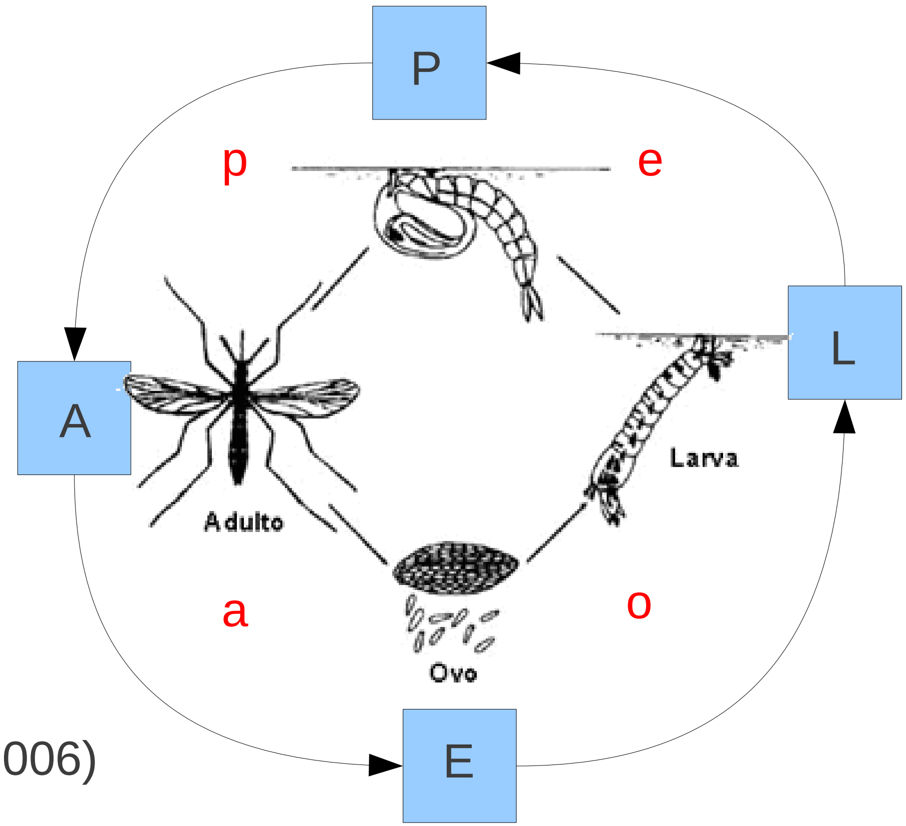
Logistic term in the immature phase (Yang, 2011, Otero, 2006)

4) Temperature + Competition + rainfall

Lower resource limitation during rainy season (high K)



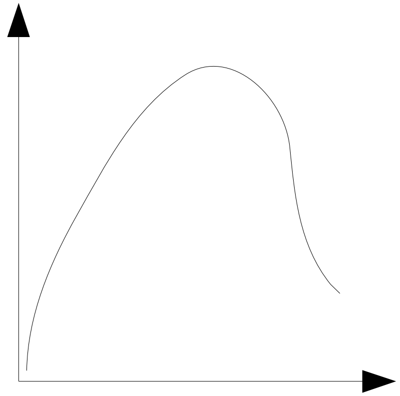
Fitting mathematical models to data

Define range for free parameters → Simulate Many realizations model → Compare fit With time series

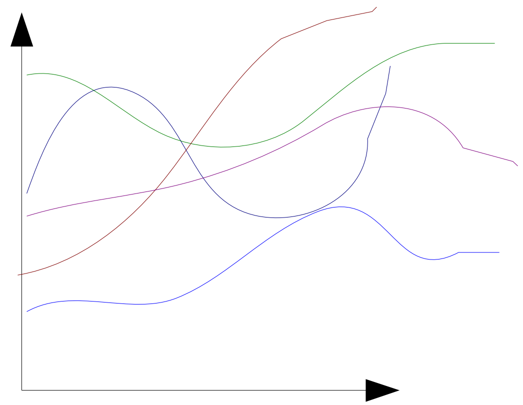
Uniform distribution
Latin hypercube sampling

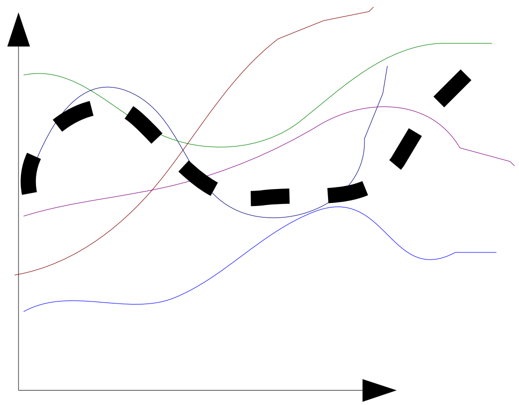
Monte carlo
Markov chain monte carlo

Determination coef
Maximum likelihood



params

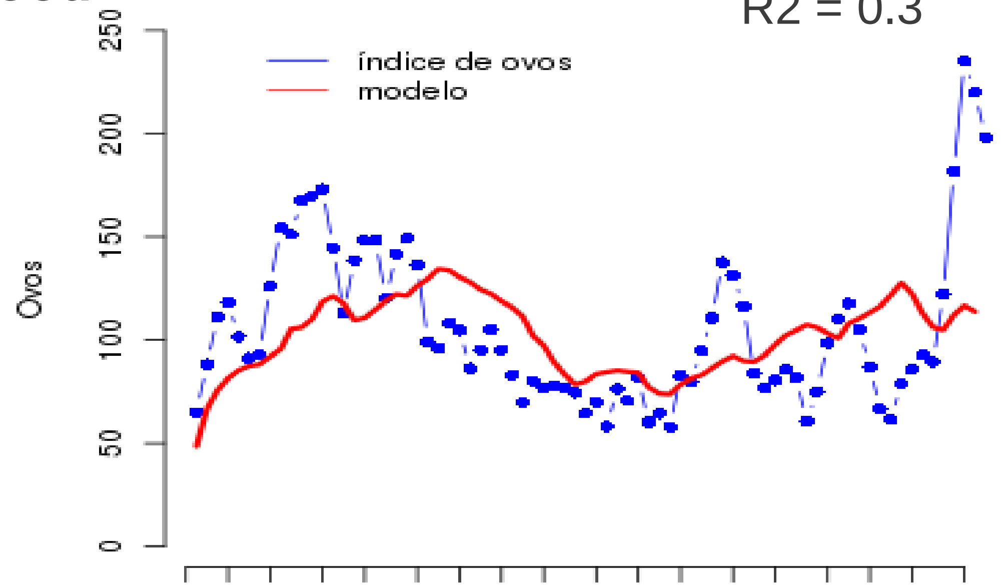




In the sub urban slum and neighborhood

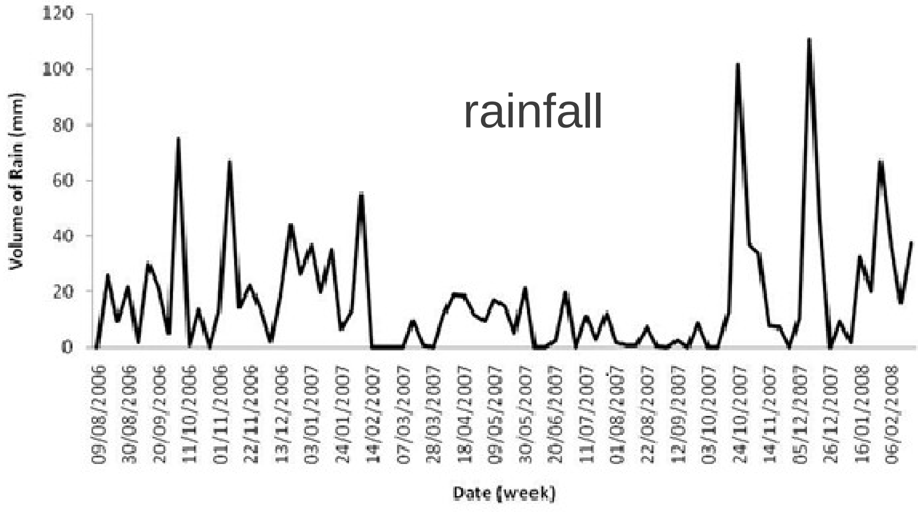
R2 = 0.3

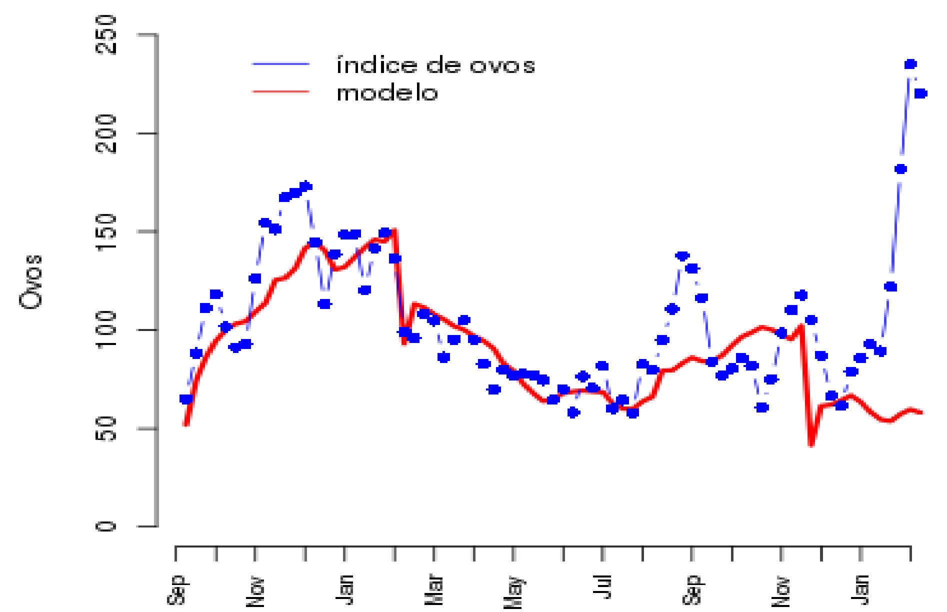
Model 3: Temperature + competition



Model 4: Temperature + competition
+ seasonal carrying capacity

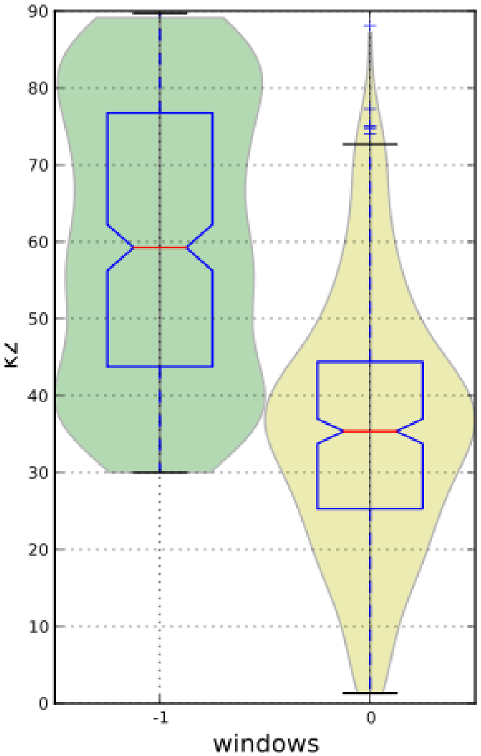
R2 = 0.75



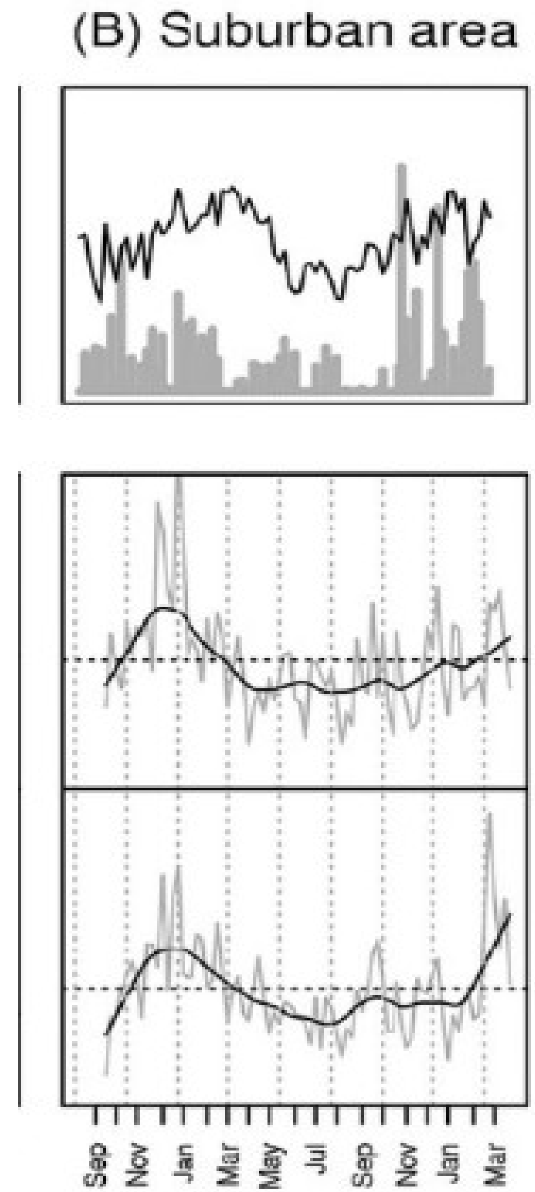


K alto K baixo K alto

Strong breeding sites seasonality



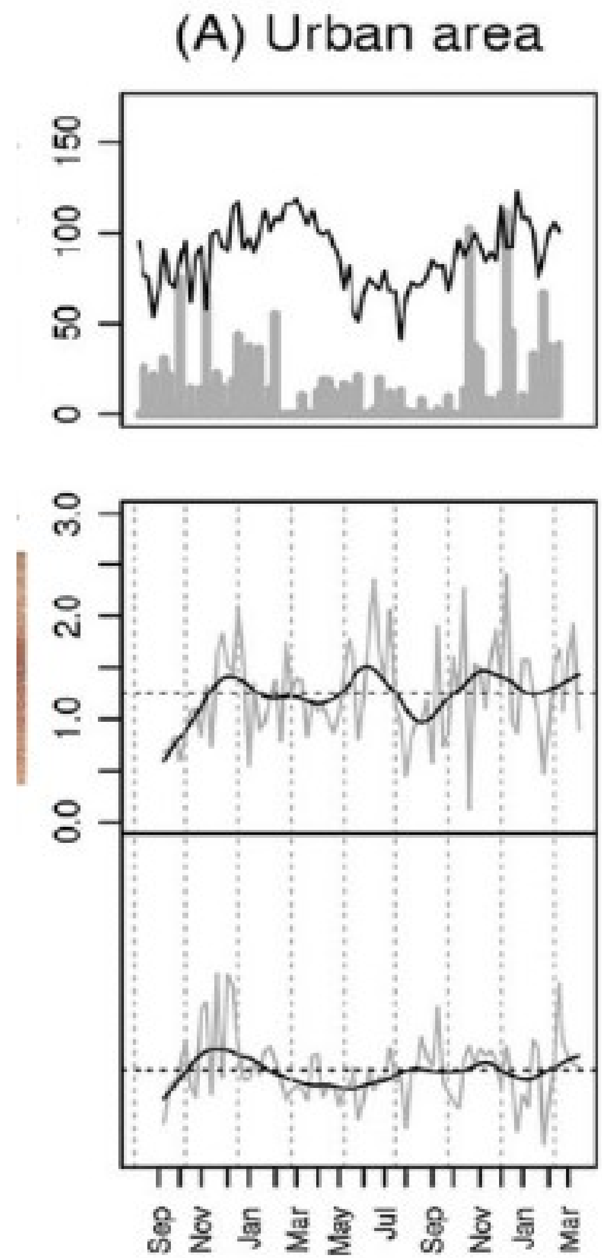
K high K low



In the urban neighborhood

Weak climate effect on dynamics

Validation Data	Higienopolis		P
Models	Spearman's cor	p-value	Spea
Basic (Ba)	-0.07518797	0.5178	0.:
Temperature-dependent (Td)	0.01408066	0.9038	0..
Larva density-dependent (Ldd)	-0.2005468	0.08243	0.:
Temperature-density-dependent (Tdd)	-0.1922898	0.09607	0.:



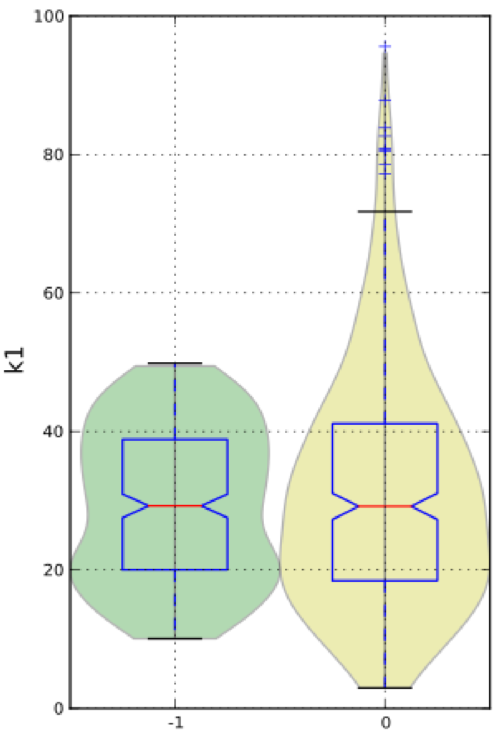


Figura 1 - Aspecto do recipiente artificial do tipo caixa d´água, no qual foram encontradas formas imaturas de Anopheles argyritarsis e Aedes albopictus.

K high K low

In a glance

Statistical model

- Non-linear effect of temperature,

  limiting < 24 degrees
- Weak, heterogeneous effect of rainfall

Mathematical model

- Suggests rainfall effect on breeding site availability, spatially heterogeneous

Acknowledgments

Entomology, Fiocruz:

- Nildimar Honório, Ricardo Lourenço,Denise Valle, Rafael de Freitas,

Modeling, Fiocruz e UFOP:

- Claudio Struchiner, Paula Luz, Arthur Weiss, Flavio Coelho, Raquel Lana, Tiago Carneiro
- **Rede Pronex Modelagem em Dengue CNPq**

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Contato: codeco@fiocruz.br

CNPq

Conselho Nacional de Desenvolvimento Científico e Tecnológico

Acknowledgments

Announcement

Open Positions

Postdoc – control with wolbachia
PostMSc (or 2 ys experience) – dengue control

Rede Pronex CNPq

Www.procc.fiocruz.br (Oportunidades)
A partir de 30 jan

o

OP:

a

Coelho, Raquel Lana, Tiago Carneiro

- **Rede Pronex Modelagem em Dengue CNPq**

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