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

Cláudia Codeço
Fiocruz, Rio de Janeiro

IFT, São Paulo, 24 janeiro 2012
Everybody knows *Aedes aegypti*, the dengue vector.
### Table 11. Duration of instar periods

<table>
<thead>
<tr>
<th>Hours</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>P</th>
<th>Timing of stage</th>
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<tbody>
<tr>
<td>20</td>
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<td></td>
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<td>All first instar up to 20 hours</td>
</tr>
<tr>
<td>22</td>
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<td>25</td>
<td>56</td>
<td>44</td>
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<td>50 per cent ecdysis I–II 25–26 hours</td>
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<td>44</td>
<td>56</td>
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<tr>
<td>30</td>
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<td>All second instar 30–42 hours</td>
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<td>42</td>
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<td>50 per cent ecdysis II–III 46 hours</td>
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<td>All third instar 54–68 hours</td>
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<td>72</td>
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<td>32</td>
<td>68</td>
<td></td>
<td>50 per cent ecdysis III–IV 71–72 hours</td>
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<tr>
<td>73</td>
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</tr>
<tr>
<td>102</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>+</td>
<td>First male pupa 102 hours</td>
</tr>
<tr>
<td>117</td>
<td></td>
<td></td>
<td>9</td>
<td>91</td>
<td></td>
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<tr>
<td>122</td>
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<td></td>
<td></td>
<td>50</td>
<td>50</td>
<td>Bulk of males pupated 122 hours</td>
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<tr>
<td>139</td>
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<td>+</td>
<td>100</td>
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<tr>
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<td>12</td>
<td>88</td>
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</tr>
<tr>
<td>144</td>
<td></td>
<td></td>
<td>+</td>
<td>100</td>
<td></td>
<td>Bulk of females pupated 144 hours</td>
</tr>
</tbody>
</table>
Aedes aegypti: vector of yellow fever

Tabachnick 1991
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**
  - Clinical cases – time series of cases
  - Mosquitos – infestation indices

- **Control**

New indices require new models
## Trap indices

<table>
<thead>
<tr>
<th>TARGET</th>
<th>TRAP</th>
<th>INDEX</th>
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<tbody>
<tr>
<td></td>
<td><img src="image1" alt="Ovitrap Image" /></td>
<td>Eggs/trap</td>
</tr>
<tr>
<td></td>
<td><img src="image2" alt="Mosquitrap Image" /></td>
<td>% Positive traps</td>
</tr>
<tr>
<td></td>
<td><img src="image3" alt="Mosquitrap Image" /></td>
<td>Adults/trap</td>
</tr>
<tr>
<td></td>
<td><img src="image4" alt="Mosquitrap Image" /></td>
<td>% Positive traps</td>
</tr>
</tbody>
</table>
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 Understanding the dynamics of the wildtype Aedes aegypti.
Modeling Aedes aegypti dynamics: Why?

- Early warning systems
- Optimize vector control strategies
- 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

Graph showing house index from January 1997 to January 2003.
Entomological survey (sept 2006 - march 2008)
The data

(A) Urban area
(B) Suburban area
(C) Suburban slum

Rainfall (mm)

Temperature (°C)

Adap

0.0

1.0

2.0

3.0

0

50

100

150

200

250

300

350
The theoretical framework
A priori & a posteriori pathometry

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

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

Ronald Ross
(1857-1932)
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) vs. Temperature (week-1)

Negative Binomial distribution
Time series data

fit

Statistical Models

infer

Causal associations

Statistical

Auto-correlation structure

null model

lag

lag

lag

lag
Models:

\[ Y_t \sim \text{NegBin} \]

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

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

\[ E[Y_t] = a_0 + a_1 Y_{t-1} + a_2 \text{Temp}_{t-m} + \text{temperature} \]

\[ E[Y_t] = a_0 + a_1 Y_{t-1} + a_2 \text{Temp}_{t-m} + a_3 \text{Chuva}_{t-n} + \text{rain} \]

Model comparison
- Likelihood based criterion (AIC)
- Pearson's correlation
- Residuals

**GAM model was required:**

*Smooth* temperature term (non linear)
Temperature effect is delayed and nonlinear

(A) Urban area  
(B) Suburban area  
(C) Suburban slum

Effect on log(Dw)

Effect on log(Aw)

Temperature (lag=1)
The chart shows the number of dengue cases over the months. It also includes graphs for temperature and rainfall, with a note indicating a correlation between mosquito growth and certain environmental factors.
Theoretical Causal associations

Mathematical Model

deduce

Theoretical Time series

The mechanistic way...

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\textsuperscript{a,*,1}, Maria de Lourdes da Graça Macoris\textsuperscript{b}, Karen Cristina Galvani\textsuperscript{b}, Maria Teresa Macoris Andrighetti\textsuperscript{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

\[ \frac{dE}{dt} = o_A - m_E - e_E \]
\[ \frac{dL}{dt} = e_E - m_L - p_L \]
\[ \frac{dP}{dt} = p_P - m_P - a_P \]
\[ \frac{dA}{dt} = a_P - m_A \]
**Aedes aegypti alternative mathematical models**

1) Null model: constant rates

\[
\frac{dE}{dt} = oA - mE - eE
\]

\[
\frac{dL}{dt} = eE - mL - pL
\]

\[
\frac{dP}{dt} = pP - mP - aP
\]

\[
\frac{dA}{dt} = aP - mA
\]

2) Temperature model

Transition rates are polinomials (Yang, 2011)

Or

Transition rates from thermodynamics (Otero, 2006)
Aedes aegypti alternative mathematical models

3) Temperature+Competition model

1) Null model: constant rates

\[
\frac{dE}{dt} = oA - mE - eE \\
\frac{dL}{dt} = eE - mL - pL \\
\frac{dP}{dt} = pP - mP - aP \\
\frac{dA}{dt} = aP - mA
\]

2) Temperature model

Transition rates are polynomials (Yang, 2011)

Or

Transition rates from thermodynamics (Otero, 2006)
**Aedes aegypti** alternative mathematical models

1) **Null model: constant rates**

\[
\frac{dE}{dt} = oA - mE - eE
\]

\[
\frac{dL}{dt} = eE - mL - pL
\]

\[
\frac{dP}{dt} = pP - mP - aP
\]

\[
\frac{dA}{dt} = aP - mA
\]

2) **Temperature model**

Transition rates are polynomials (Yang, 2011)

Or

Transition rates from thermodynamics (Otero, 2006)

3) **Temperature + Competition model**

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

1. Define range for free parameters
2. Simulate Many realizations of the model
3. Compare fit With time series

Uniform distribution
Latin hypercube sampling

Monte carlo
Markov chain monte carlo

Determination coefficient
Maximum likelihood

params
In the sub urban slum and neighborhood

Model 3: Temperature + competition

Model 4: Temperature + competition + seasonal carrying capacity

R2 = 0.3

R2 = 0.75
Strong breeding sites seasonality

K high  K low

(B) Suburban area
In the urban neighborhood

Weak climate effect on dynamics

<table>
<thead>
<tr>
<th>Validation Data</th>
<th>Higienopolis</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Models</td>
<td>Spearman's cor</td>
<td>p-value</td>
</tr>
<tr>
<td>Basic (Ba)</td>
<td>0.07518797</td>
<td>0.5178</td>
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<tr>
<td>Temperature-dependent (Td)</td>
<td>0.01408066</td>
<td>0.9038</td>
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<tr>
<td>Larva density-dependent (Ldd)</td>
<td>-0.2005468</td>
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</tr>
<tr>
<td>Temperature-density-dependent (Tdd)</td>
<td>-0.1922898</td>
<td>0.09607</td>
</tr>
</tbody>
</table>

Fig. 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

Contato: codeco@fiocruz.br
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**Announcement**

**Open Positions**

Postdoc – control with Wolbachia
PostMSc (or 2 yrs experience) – dengue control

Rede Pronex CNPq

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

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Ministério da Saúde

FIOCRUZ
Fundação Oswaldo Cruz