ARBOCARTO(R): AN OPERATIONAL SPATIAL MODELLING TOOL TO PREDICT THE DYNAMICS OF AEDES MOSQUITO SPECIES FROM WEATHER AND ENVIRONMENTAL VARIABLE

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Climate-Sensitive Vector Dynamics Modelling Workshop

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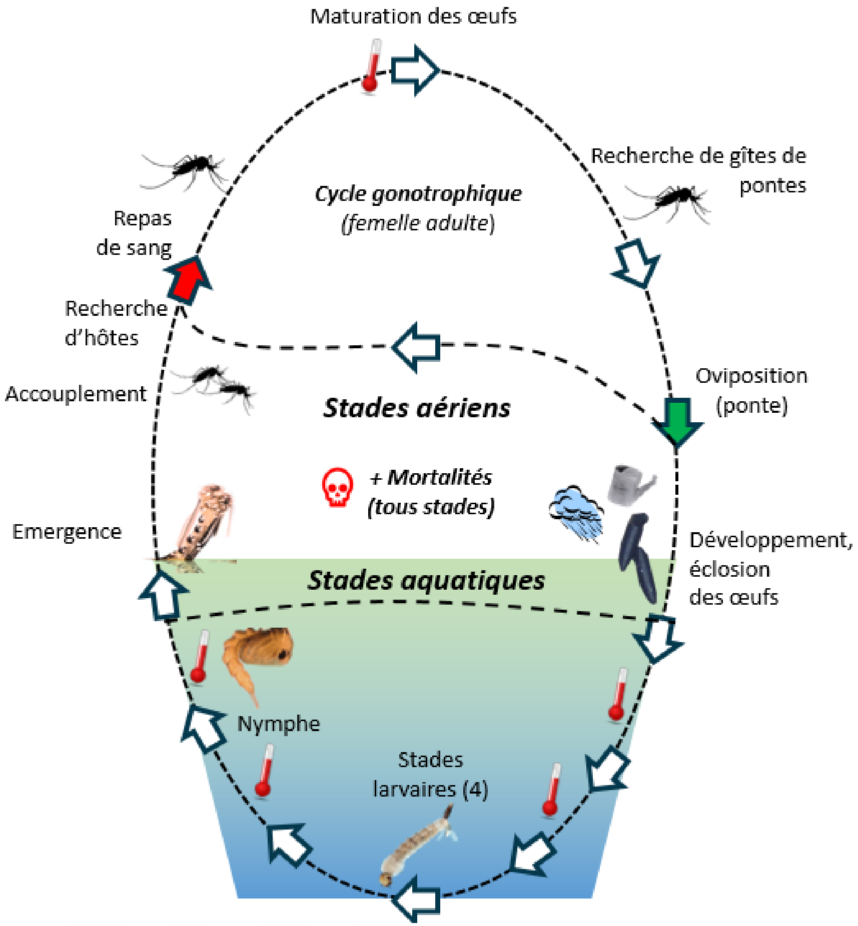
Bologne, Italia

https://www.arbocarto.fr/en

ARBOCARTO

ARBOCARTO project

1. **Observe and describe the biological processes and mechanisms of the species (*Ae. albopictus* and *aegypti*)**
2. **Identify dependence on the environment (temperature, rain, vegetation, human habitats, breeding sites, etc.)**
3. **Select the knowledge of interest, and formalise a mechanistic model (diagrams, "boxes", equations, code)**



- **Differentiate between the "states" of the mosquito life cycle:**
  - aquatic (eggs, larvae, nymphs)
  - aerial (emergent, nulliparous, parous)
- **Order the sequences of important "actions" carried out:**
  - Emerge (males and females)
  - Reproduce (males and females)
  - Search for hosts for the blood meal (females)
  - Produce eggs (females)
  - Search for places to lay eggs (females)

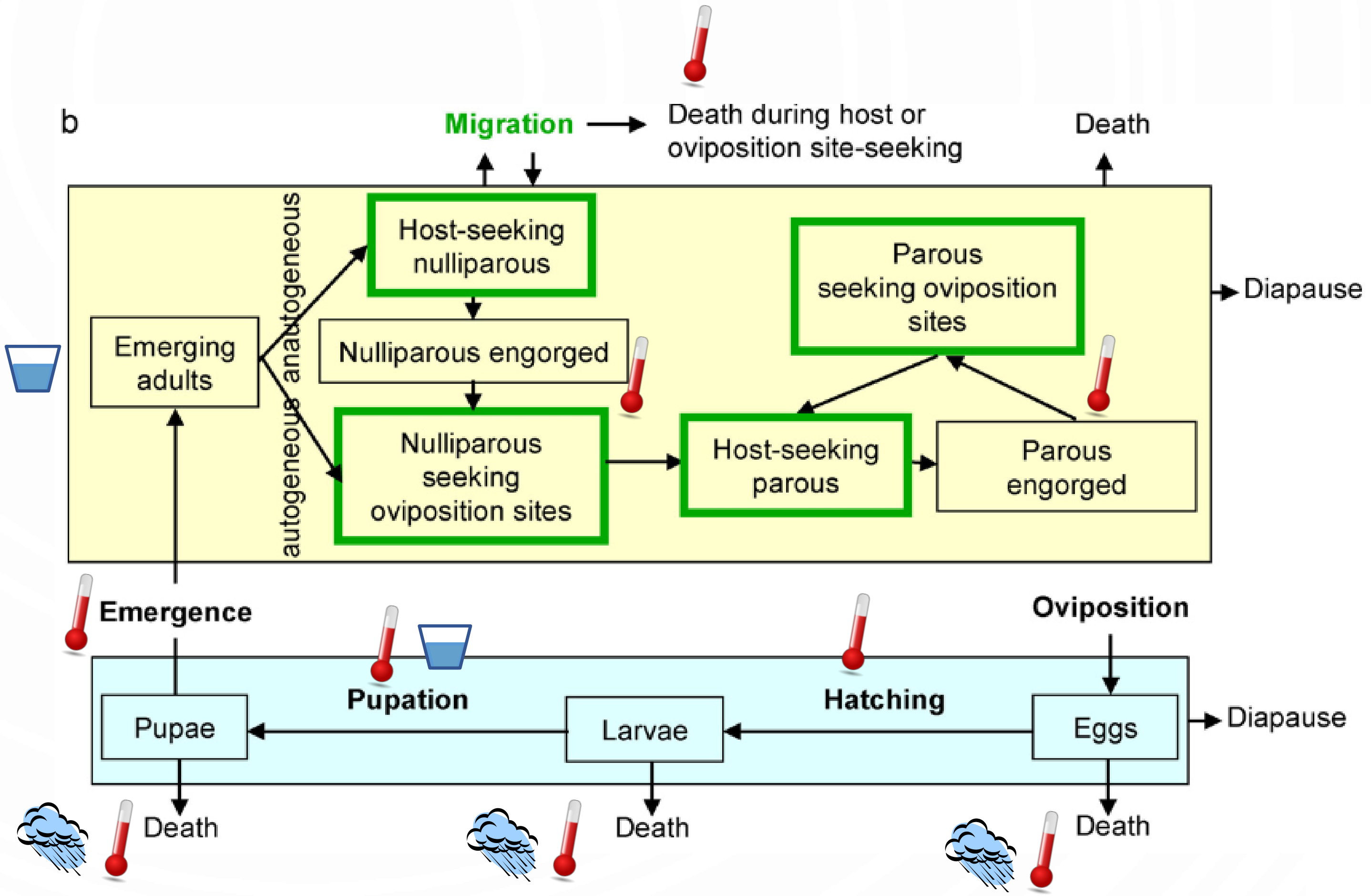
Mosquito population dynamics: compartmental model

Temperature-controlled processes

Rain-driven processes

Environmental carrying capacity

- A way to limit the maximum number of larvae in the larval sites and the number of successful pupae emergences, depending on their respective densities



Tran A et al. ; Int J Environ Res Public Health. 2013;10: 1698–1719. doi:10.3390/ijerph10051698
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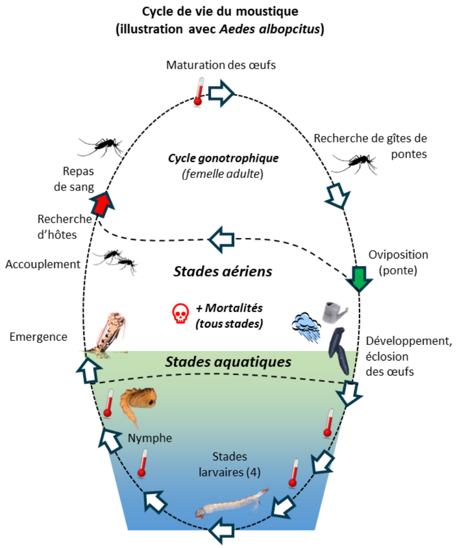
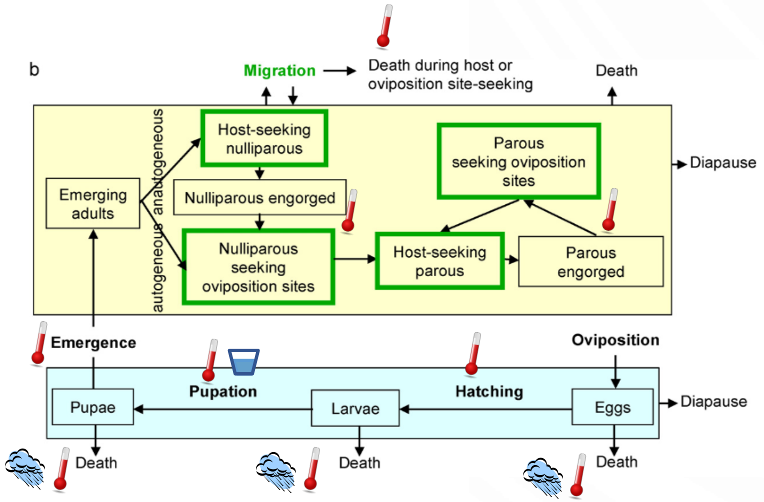
Cailly P. ; These de doctorat, Nantes, Ecole nationale vétérinaire. 2011. https://www.theses.fr/2011ONIR002F

Mosquito population dynamics: compartmental model, described by a system of ordinary differential equations (ODE)





$$\dot{E} = \gamma_{A_{o\to h}}(\beta_1 A_{1o} + \beta_2 A_{2o}) - (\mu_E + z * f_{E\to L})E$$

$$z = \begin{cases} 0 & \text{during diapause} \\ 1 & \text{otherwise} \end{cases}$$

$$f_{E\to L} = \begin{cases} \frac{(T(t) - T_E)}{TDD_E} & \text{if } T(t) > T_E \\ 0 & \text{otherwise} \end{cases}$$

$$\dot{L} = z * f_{E\to L}E - [m_L(1 + \frac{L}{k_L}) + f_{L\to P}]L$$

$$m_L(t) = e^{-(\frac{T(t)}{2})} + \mu_L$$

$$f_{L\to P} = q_1 T^2 + q_2 T + q_3 \quad q_1 = -0.0007,\ q_2 = 0.0392,\ q_3 = -0.3911$$

$$\dot{P} = f_{L\to P}L - (m_p + f_{P\to Em})P$$

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$$\dot{A}_{em} = f_{P\to Em}P * \sigma * e^{-\mu_m(1+\frac{P}{k_P})} - (m_A + \gamma_{A_{em}})A_{em}$$

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Temperature-driven processes

Rain-driven processes

Carrying capacity of the environment (larval stage)

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Aedes albopictus (temperate/tropical environment)

E

Tiger mosquito eggs and larval sites

Aedes albopictus (temperate/tropical environment)

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Tiger mosquito eggs and larval sites

Temperature-driven process

Precipitation-driven process

Environment-driven process

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$$\dot{L} = z * f_{E\to L} E$$

Aquatic stage

Temperature-driven process

Precipitation-driven process

Environment-driven process

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Aquatic stage

Temperature-driven process
Precipitation-driven process
Environment-driven process

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Aquatic stage

Temperature-driven process

Precipitation-driven process

Environment-driven process

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Aquatic stage

Temperature-driven process
Precipitation-driven process
Environment-driven process

Aedes albopictus (temperate/tropical environment)

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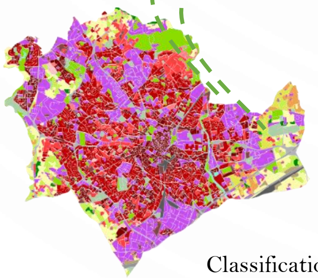
Temperature-driven process

Precipitation-driven process

Environment-driven process

Impoundment of egg-laying sites due to anthropogenic or meteorological actions

K_{FIX}, K_{VAR}



Classification of the urban typology (Urban Atlas)

Additional index (végétation urbaine)

+ Hotspots identified by vector control agents

(abandoned houses, individual gardens, etc.)

Aedes albopictus (temperate/tropical environment)

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Aerial stage: emergence of the adult

Temperature-driven process

Precipitation-driven process

Environment-driven process

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Adult stage

Temperature-driven process

Precipitation-driven process

Environment-driven process

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$$\dot{A}_{1h} = \gamma_{A_{em}}A_{em}$$

Adult stage - host-seeking

Temperature-driven process
Precipitation-driven process
Environment-driven process

Aedes albopictus (temperate/tropical environment)

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$$\dot{A}_{1h} = \gamma_{A_{em}}A_{em} - (m_A + \mu_r + \gamma_{A_{h\to g}})A_{1h}$$

Adult stage - host-seeking (success blood feeding)

Temperature-driven process
Precipitation-driven process
Environment-driven process

Aedes albopictus (temperate/tropical environment)

Adult stage-search for egg-laying sites

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Temperature-driven process
Precipitation-driven process
Environment-driven process

Aedes albopictus (temperate/tropical environment)

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Temperature-driven process

Precipitation-driven process

Environment-driven process

eggs laid
(back to the start of the cycle !)

Aedes albopictus (temperate/tropical environment)

$$\dot{E} = \gamma_{A_{o\to h}}(\beta_1 A_{1o} + \beta_2 A_{2o}) - (\mu_E + z * f_{E\to L})E$$

$$z = \begin{cases} 0 & \text{during diapause} \\ 1 & \text{otherwise} \end{cases}$$

$$f_{E\to L} = \begin{cases} \frac{(T(t)-T_E)}{TDD_E} & \text{if } T(t) > T_E \\ 0 & \text{otherwise} \end{cases}$$

$$\dot{L} = z * f_{E\to L}E - [m_L(1 + \frac{L}{k_L}) + f_{L\to P}]L$$

$$m_L(t) = e^{-(\frac{T(t)}{2})} + \mu_L$$

$$f_{L\to P} = q_1 T^2 + q_2 T + q_3 \quad q_1 = -0.0007,\ q_2 = 0.0392,\ q_3 = -0.3911$$

$$\dot{P} = f_{L\to P}L - (m_p + f_{P\to Em})P$$

$$m_P(t) = e^{-(\frac{T(t)}{2})} + \mu_P$$

$$f_{P\to Em} = q_1 T^2 + q_2 T + q_3 \quad q_1 = 0.0008,\ q_2 = -0.0051,\ q_3 = 0.0319$$

$$\dot{A}_{em} = f_{P\to Em}P * \sigma * e^{-\mu_m(1+\frac{P}{k_P})} - (m_A + \gamma_{A_{em}})A_{em}$$

$$k_X(t) = \kappa_{X_{Fix}} + \kappa_{X_{var}} * P_{norm}(t) \quad \text{X in \{L; P\}}$$

$$\dot{A}_{1h} = \gamma_{A_{em}}A_{em} - (m_A + \mu_r + \gamma_{A_{h\to g}})A_{1h}$$

$$\dot{A}_{1g} = \gamma_{A_{h\to g}}A_{1h} - (m_A + f_{A_{g\to o}})A_{1g}$$

$$f_{A_{g\to o}} = \begin{cases} \frac{(T(t)-T_{Ag})}{TDD_{A_g}} & \text{if } T(t) > T_{Ag} \\ 0 & \text{otherwise} \end{cases}$$

$$\dot{A}_{1o} = f_{A_{g\to o}}A_{1g} - (m_A + \mu_r + \gamma_{A_{o\to h}})A_{1o}$$

$$\dot{A}_{2h} = \gamma_{A_{o\to h}}(A_{1o} + A_{2o}) - (m_A + \mu_r + \gamma_{A_{h\to g}})A_{2h}$$

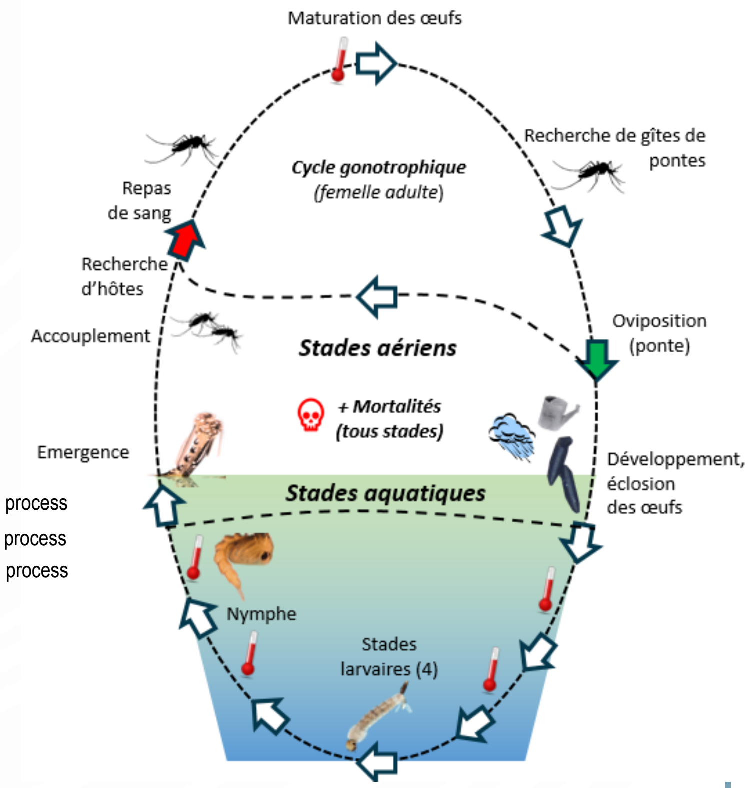
$$m_A(t) = \max_t\{\mu_A, 0.04417 + 0.00217 * T(t)\}$$

$$\dot{A}_{2g} = \gamma_{A_{h\to g}}A_{2h} - (m_A + f_{A_{g\to o}})A_{2g}$$

$$\dot{A}_{2o} = f_{A_{g\to o}}A_{2g} - (m_A + \mu_r + \gamma_{A_{o\to h}})A_{2o}$$

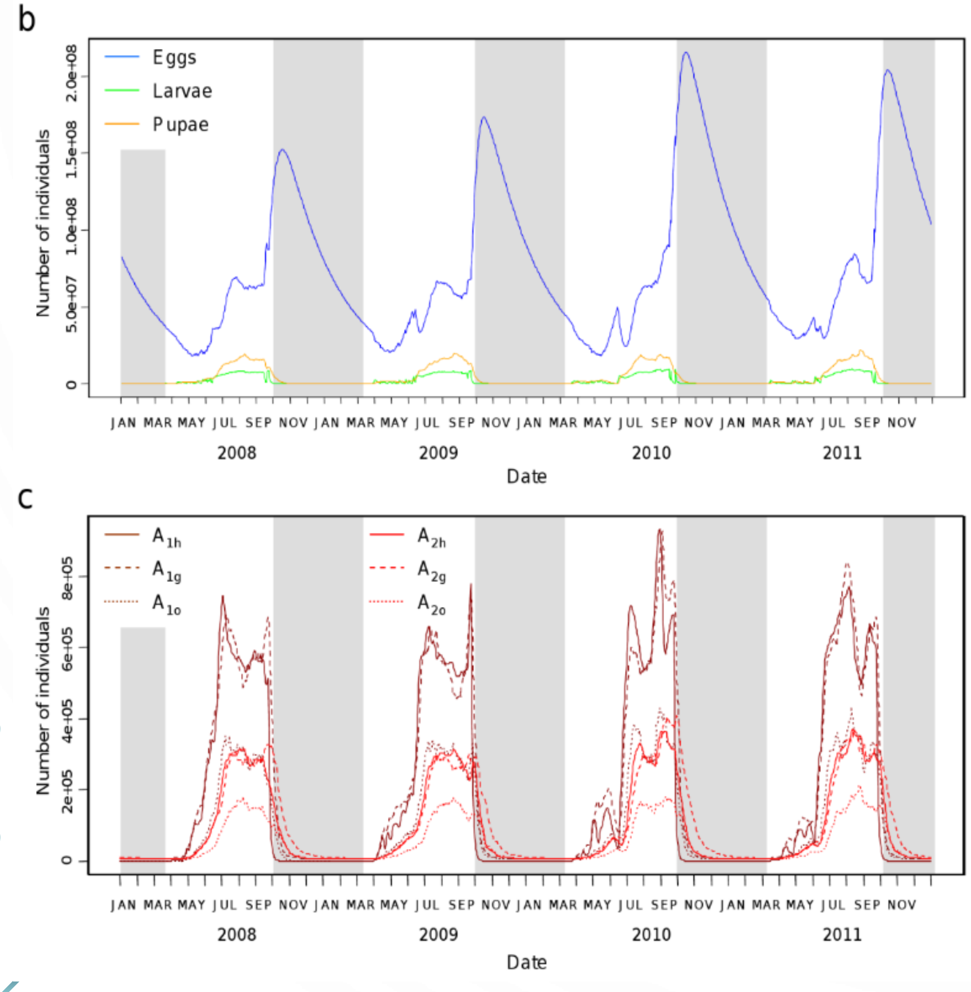
- Temperature-driven process
- Precipitation-driven process
- Environment-driven process

eggs laid
(back to the start of the cycle !)



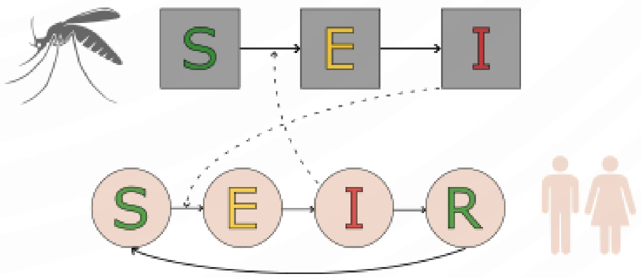
From the mosquito population dynamics to the epimiological model

Mosquito population dynamics model



Epidemiological models

- Deterministic R0
  (Benkimoun S et al ; Results in Physics. 2021;29: 104687. doi:10.1016/j.rinp.2021.104687)
- Stochastic epidemiological simulations



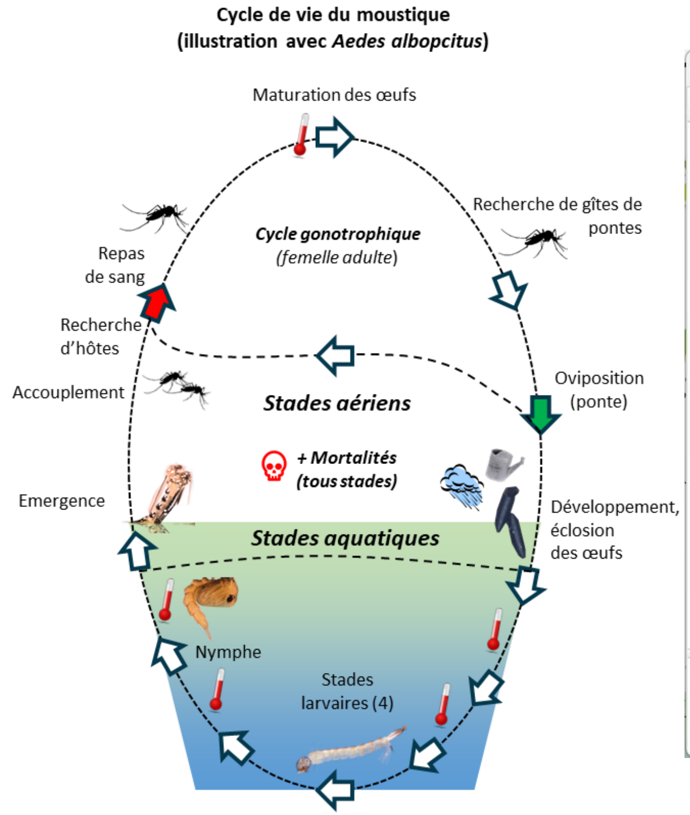
Tran A et al. ; Int J Environ Res Public Health. 2013;10: 1698–1719. doi:10.3390/ijerph10051698

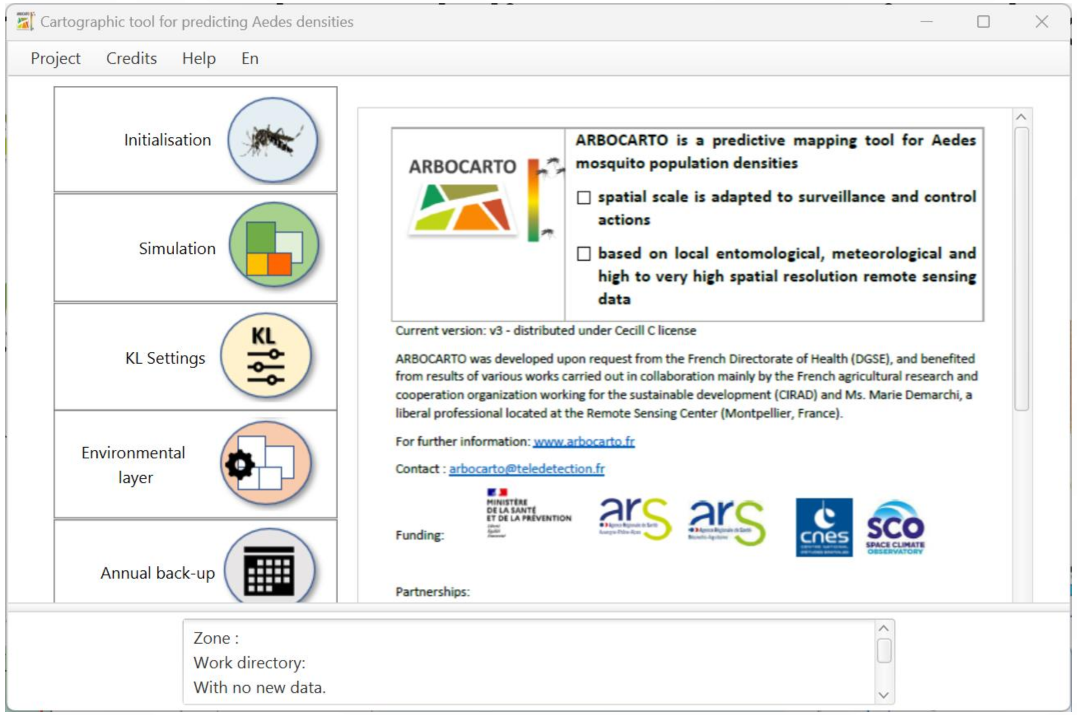
MOOD

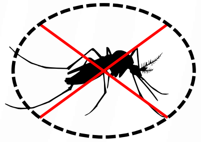
From research modeling to operational tool

ARBOCARTO

A (java-based) Software interface between an *Aedes* mosquito population dynamics model and vector control operators in France







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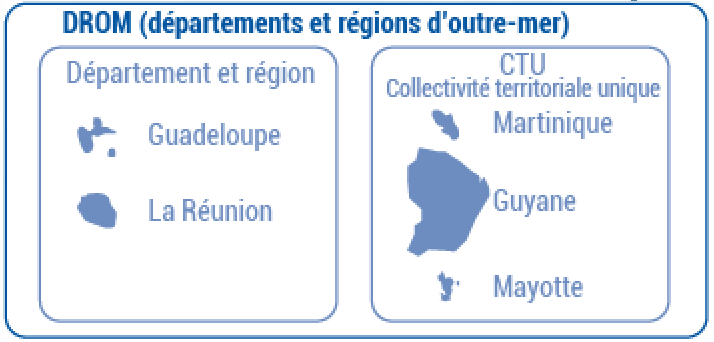
Liberté Égalité Fraternité

ars Agence Régionale de Santé

EID MÉDITERRANÉE OPÉRATEUR PUBLIC EN ZONES HUMIDES



From research modeling to operational tool

An **R package and associated Shiny** application to simulate the spatio-temporal dynamics of *Aedes (albopictus* and *aegypti)* mosquito populations **and the transmission dynamics of three arboviroses: dengue, zika and chikungunya.**

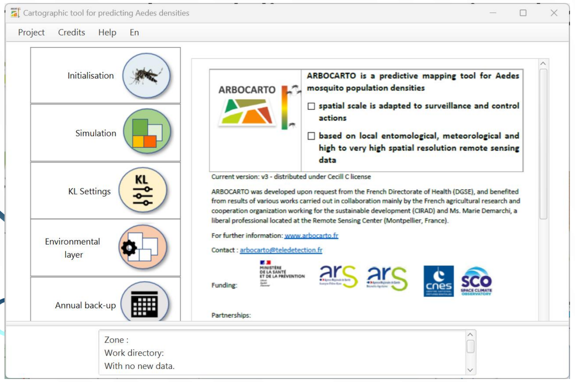
Application: **https://shiny.sk8.inrae.fr/app/sa-astre-arbocarto-r-app**

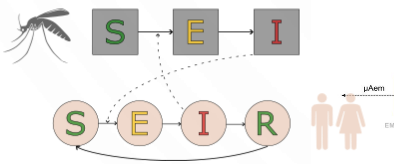
Reload if necessary

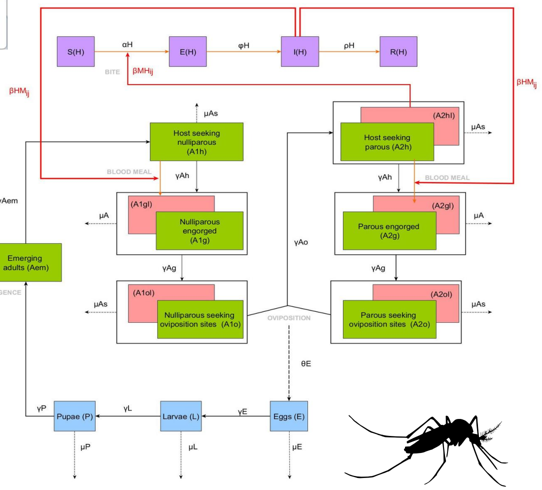
Sources

Package: **https://forgemia.inra.fr/umr-astre/arbocartoR**

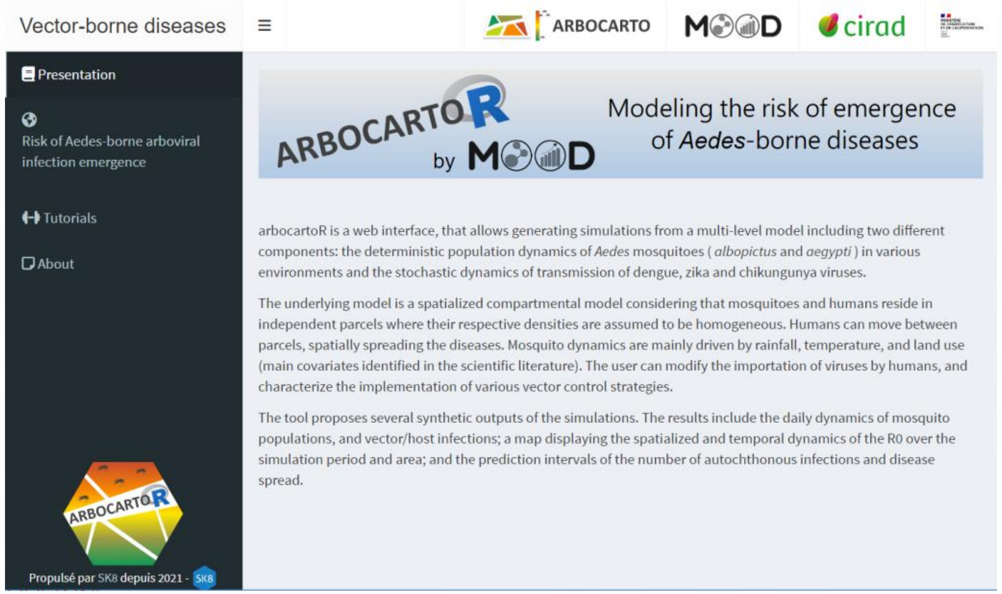
Application: **https://forgemia.inra.fr/sk8/sk8-apps/sa/astre/arbocarto-r-app**







users



arbocartoR application

Divers outputs

Epidemiological indicators (median [95% prediction interval])

With control

9/10 simulations had secondary cases

17 [1-466] autochtonous infection(s)

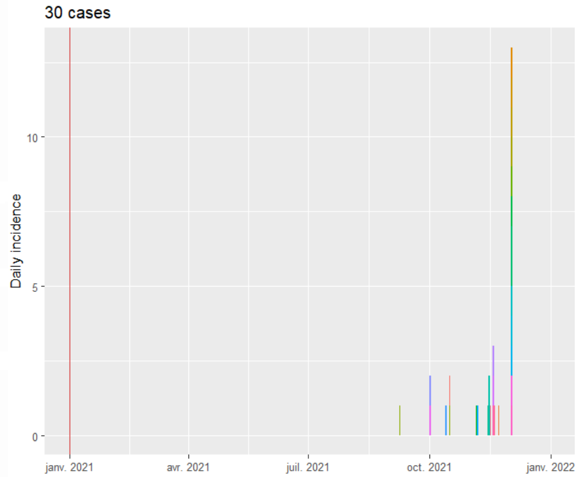
14 [1-236] infected patch(s)

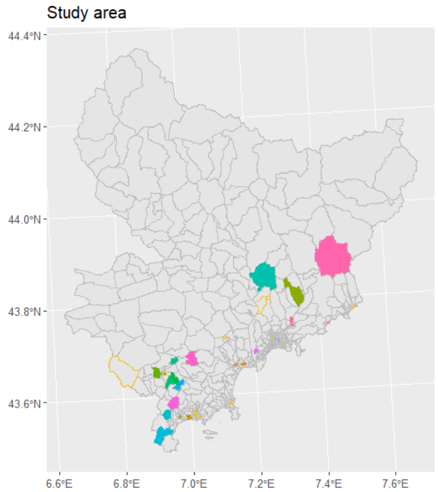
Without control

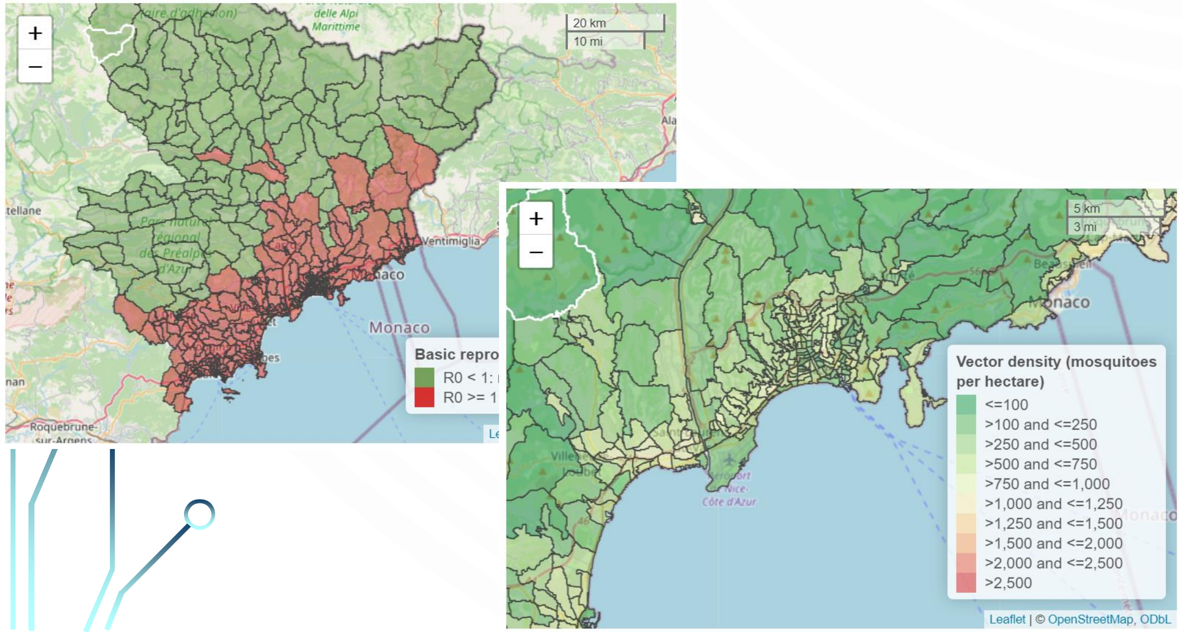
10/10 simulations had secondary cases

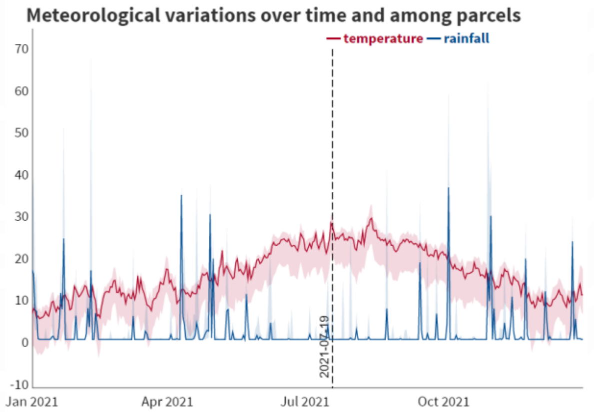
82 [2-595] autochtonous infection(s) - without control

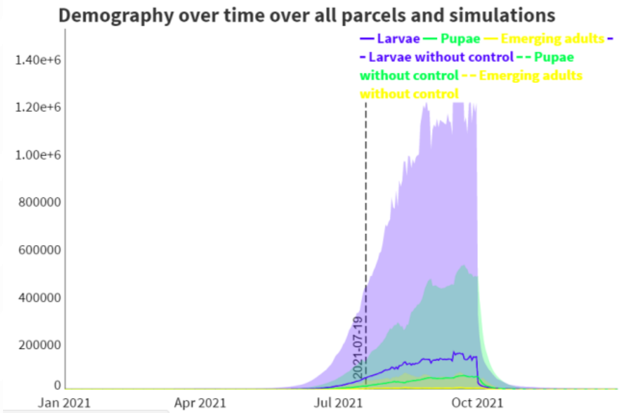
64 [2-279] infected patch(s) - without control











Arbocarto(R) application

Limits & Perspectives

ERGONOMICS

- PDF reports / logs
- Facilitating the acquisition of meteorological data
- Facilitate load capacity estimation
- Facilitate comparison with field data
- …

RESEARCH & DEVELOPMENT

- Favourable period triggering
- SIT
- Developing the co-circulation of different strains
- Developing the co-circulation of different vector species
- Assessing the impact of climate change
- Integrating other vector/pathogen pairs
- …

Take home message

- Powerful modelling approach – generic & adaptable
- Main limit: carrying capacity/breeding sites estimation

- Modelers community:

open source codes (Ocelet – arbocarto ; R package – arbocatoR)

- Non modelers community:

User friendly and dynamic interfaces developped upon request **of** the users, **for** the users and **with** the users (co-creation)

- ➢ java-based software (arbocarto)
- ➢ Rshiny interface (arbocartoR)

THANK YOU FOR YOU ATTENTION

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arbocarto@teledetection.fr

https://mood-h2020.eu/

https://www.arbocarto.fr/en

https://shiny.sk8.inrae.fr/app/sa-astre-arbocarto-r-app

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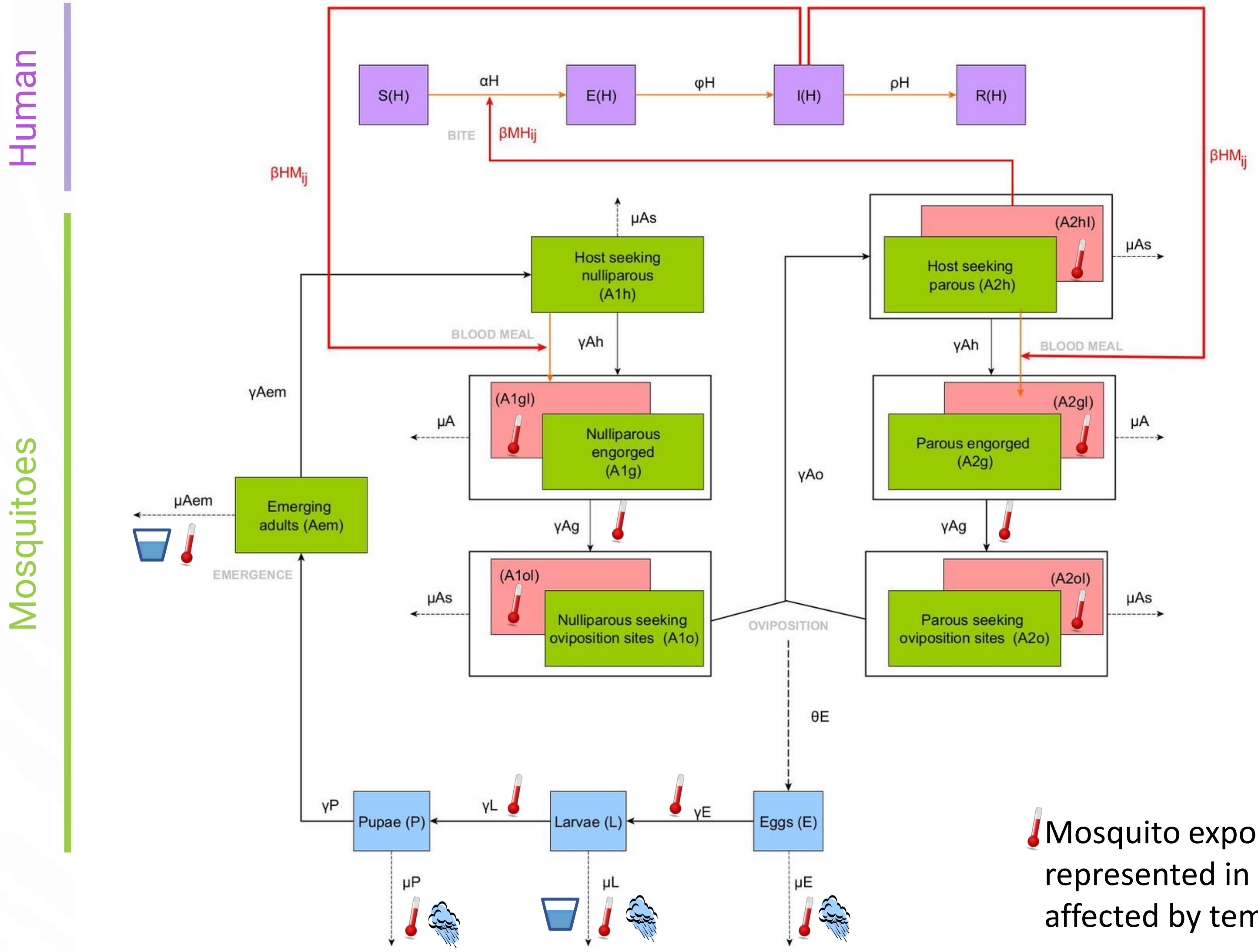
Updated compartmental model: deterministic and stochastic events



Mosquito exposed stages are not represented in this diagram (duration affected by temperature)

Diagram designed by Ewy Ortega