Vector-borne disease outbreak control via instant vector releases

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Congrès Nationale d’Analyse Numérique
Evian-les-Bains

June 14th, 2022
Aedes mosquitoes: A public health problem

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- No efficient vaccine, nor antiviral drugs.

- Expansion of vector’s habitat (trade, global warming, reduction of predator populations ...)

![World map showing distribution of Aedes mosquitoes](image-url)
How to fight it? Two methods

- **Wolbachia** method
  - Reduction of the vector capacity.
  - Cytoplasmic incompatibility.
  - *Wolbachia* vertical transmission.
  - Population replacement.

![Diagram of Wolbachia method](image)

Source: [http://www.elimatedengue.com/our-research/Wolbachia](http://www.elimatedengue.com/our-research/Wolbachia)
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- **Wolbachia** method
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  - Wolbachia vertical transmission.
  - Population replacement.

- Sterile insect technique
  - Population suppression.
  - Recurrent intervention

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The model

\[ S'_H = b_H H - \frac{\beta_M}{H} I_M S_H - b_H S_H \]
\[ E'_H = \frac{\beta_M}{H} I_M S_H - \gamma_H E_H - b_H E_H \]
\[ I'_H = \gamma_H E_H - \sigma_H I_H - b_H I_H \]

\[ M' = b_M M \left(1 - \frac{M}{K}\right) - d_M M \]
The model

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Impulsive control: \( u(t) = \sum_{i=1}^{n} c_i \delta(t - t_i) \)   Constraint: \( \sum_{i=1}^{n} c_i = C \)
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**Impulsive control:** \( u(t) = \sum_{i=1}^{n} c_i \delta(t - t_i) \)

**Constraint:** \( \sum_{i=1}^{n} c_i = C \)

**Goal:** Minimise \( J(u) \) during an outbreak

\[ J(u) := \int_0^T I_H(t) dt \]
Numerics

We compute $\frac{\delta J(u)}{\delta t_i}$ and $\frac{\delta J(u)}{\delta c_i}$ and we implement a numerical algorithm.

- For the $t_i$: Gradient descent
- For the $c_i$: Uzawa algorithm to deal with the constraint $\sum_{i=1}^{n} c_i = C$. 
Results: Wolbachia

- $C < G(\theta)$: release before the outbreak reaches its peak.
- $C > G(\theta)$: Release at $t = 0$.

$C = 10000$
Reduction: 2.0%

$C = 20000$
Reduction: 80.3%

$G(\theta) \approx 14800$
Results SIT: 10 releases

\[ C = 7.5 \cdot 10^7 \]
Reduction: 12.3%

\[ C = 1.5 \cdot 10^8 \]
Reduction: 49.1%
Results SIT: 20 releases

\[ C = 7.5 \cdot 10^7 \]
Reduction: 13.9%

\[ C = 1.5 \cdot 10^8 \]
Reduction: 99.9%
Conclusions
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- **Wolbachia:**
  - Optimal strategy: One single release
  - If we have enough mosquitoes to trigger a population replacement: release as soon as possible.
  - If we don’t have enough: release before the peak of the outbreak.
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- **Sterile mosquito:**
  - Strategy and results depend highly on the number of jumps at first.
  - After $\sim 20$ jumps almost no improvement.
  - With few mosquitoes: spaced releases around the peak.
  - With a lot of mosquitoes: spaced releases from the beginning.
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Thank you for your attention