Slightly Less Simple Mosquito Modeling

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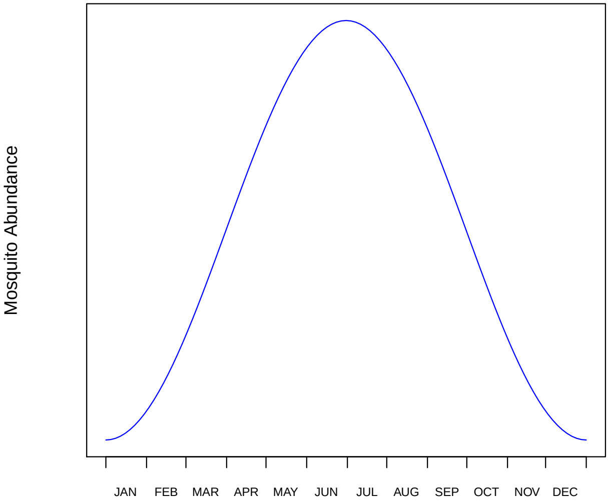
What's this talk really about?

- finding low-hanging fruit,
- expression with models,
- simple analytical approaches,
- a little dimensional analysis,
- how to connect those with experiments and get higher up the tree, and
- a little about work habits and tools

A Not Atypical Model of Vector Population



But. . .

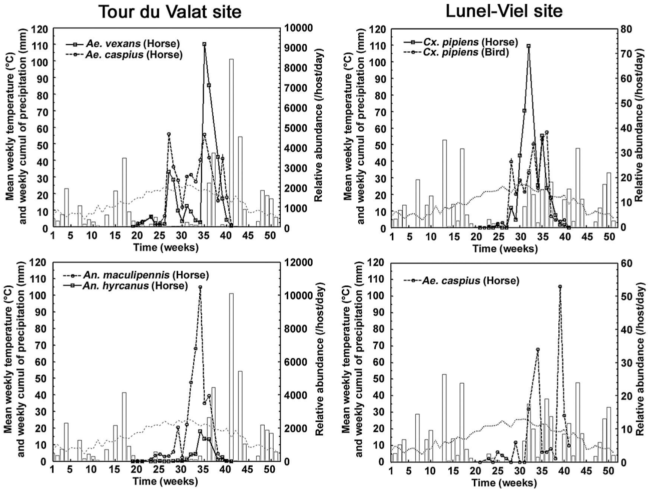


Figure: Bicout et al. "Horse-, Bird-, and Human-Seeking Behavior and Seasonal Abundance of Mosquitos in a West Nile Virus Focus of Southern France". J. Med. Entomol. 43(5): 936-946 (2006)

So, a Disconnect.

Specifically, it is impossible to match features like peak population, total population over a year, and turnover rate with a functional form

$$M(t) = C \sin(\omega t + \theta)$$

. . . and these features can be critical to predicting transmission dynamics, and thus planning interventions.

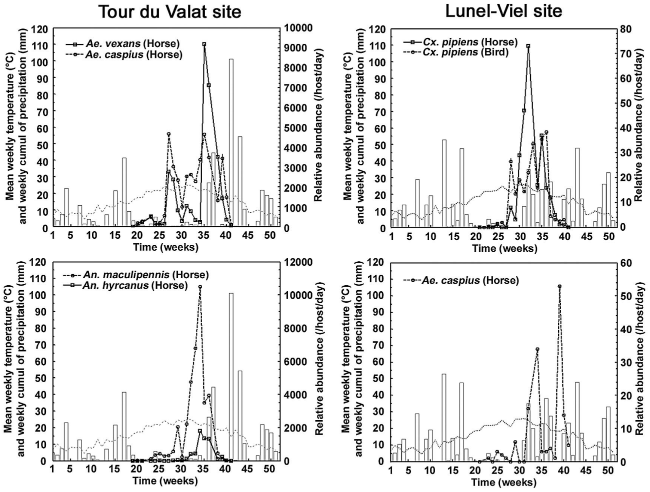
Do Better, But Keep It Simple

What's appealling about this trigonometric representation?
Simplicity:

- two parameters
- no spatial features
- "easy" analytical form

Possible to identify alternatives that *can* match salient features, but still retain these features?

What are those salient features? Let's look again.



Tour du Valat site
Lunel-Viel site
Ae. vexans (Horse)
Ae. caspius (Horse)
Cx. pipiens (Horse)
Cx. pipiens (Bird)
An. maculipennis (Horse)
An. hyrcanus (Horse)
Ae. caspius (Horse)
Mean weekly temperature (°C) and weekly cumul of precipitation (mm)
Relative abundance (/host/day)
Time (weeks)

- every year,
- over a relatively short duration,
- the mosquito population rapidly increases,
- sits at a high level of activity,
- then rapidly declines,
- apparently connected with resource availability & environmental suitability

What's present in the trigonometric formulation?

- every year, **CHECK!** . . . *but not the rest of:*
- over a relatively short duration,
- the mosquito population rapidly increases,
- sits at a high level of activity,
- then rapidly declines,
- apparently connected with resource availability & environmental suitability

What does the last point tell us? That we need to stub out a connection to an external force. So, instead of just stating that mosquito populations oscillate, let's propose something else, $E(t)$, does and consider what that means for mosquito population*. *I.e.*, consider solutions to:

$$\dot{M}(t) = E(t) - \lambda M(t)$$

*and also just guess that mosquitos, like many other ecological phenomena, decay exponentially when their external resource supply is removed.

Picking Candidates

We want to meet those criteria, which mostly amount to “spikey” function options, since the sharpness in $E(t)$ will carry over to $M(t)$. There are a variety of functions to satisfy that.
What else would need to ensure?

Alternatives I

$$E(t) = \begin{cases} \dfrac{M_+}{\Delta t} & t \in \Delta t \\ 0 & \text{otherwise} \end{cases} \tag{Step}$$

$$E(\rho, t) = \begin{cases} \dfrac{2M_+}{\Delta t(2-\rho)} & t \in \Delta t(1-\rho) \\ \dfrac{2M_+}{\Delta t(2-\rho)\rho}\left(1 - \dfrac{2|t|}{\Delta t}\right) & t \in \rho\Delta t \\ 0 & \text{otherwise} \end{cases} \tag{Modified Step}$$

$$E(t) = \frac{2M_+}{\Delta t}\sqrt{\frac{2}{\pi}}e^{-\dfrac{8t^2}{\Delta t^2}} \tag{Approximate δ}$$

Alternatives II

$$E(t) = \frac{M_+}{\Delta t}\sqrt{\frac{2}{\pi}}e^{-\dfrac{\sin^2 \omega t}{\omega^2 \Delta t^2}} \quad (\omega = \frac{\pi}{T}) \quad \text{(Trig. Approximate } \delta\text{)}$$

$$E(t) = \frac{M_+}{T}\left(1 + \cos\left(\frac{2\pi}{T}t\right)\right) \quad \text{(Trig.)}$$

$$E(t) = \frac{(2^n n!)^2}{(2n)!}\frac{M_+}{T}\cos^{2n}\left(\frac{4\pi}{T}t\right) \quad (n = \lfloor 2^{-1}\sin^{-2}\frac{\pi \Delta t}{2T}\rfloor) \quad \text{(Proper Trig.)}$$

$$E(c,t) = \frac{M_+}{\Delta t}\left[\frac{1}{1+e^{-c(t+\Delta t/2)}} - \frac{1}{1+e^{-c(t-\Delta t/2)}}\right] \quad \text{(Double Logistic)}$$

Aside: Dimensional Analysis

Those equations have a lot of parameters, as do the resulting integral solutions.

Fortunately, everything you learned in engineering coursework can apply here as well.

So, how can remove the scales?

Scale-free Alternatives I

$$\tilde{E}(\rho, \tau) = \begin{cases} \frac{1}{\rho} & |\tau| \le \rho/2 \\ 0 & \text{otherwise} \end{cases} \qquad \text{(Step)}$$

$$\tilde{E}(\rho, \rho_\Delta, \tau) = \begin{cases} \frac{2}{\rho(2-\rho_\Delta)} & \tau \in \rho(1-\rho_\Delta) \\ \frac{2}{\rho(2-\rho_\Delta)\rho_\Delta}\left(1 - \frac{2|\tau|}{\rho}\right) & \tau \in \rho\rho_\Delta \\ 0 & \text{otherwise} \end{cases} \qquad \text{(Modified Step)}$$

$$\tilde{E}(\rho, \tau) = \frac{2}{\rho}\sqrt{\frac{2}{\pi}}e^{-\frac{8}{\rho^2}\tau^2} \qquad \text{(Approximate } \delta\text{)}$$

Scale-free Alternatives II

$$\tilde{E}(\rho,\tau) = \frac{1}{\rho}\sqrt{\frac{2}{\pi}}e^{-\frac{\sin^2 \pi\tau}{\pi^2\rho^2}} \qquad \text{(Trig. Approximate } \delta\text{)}$$

$$\tilde{E}(\tau) = (1+\cos 2\pi\tau) \qquad \text{(Trig.)}$$

$$\tilde{E}(\rho,\tau) = \frac{(2^n n!)^2}{(2n)!}\cos^{2n} 4\pi\tau \quad (n = \lfloor 2^{-1}\sin^{-2}\frac{\pi\rho}{2}\rfloor) \qquad \text{(Proper Trig.)}$$

$$\tilde{E}(\tilde{c}=cT,\rho,\tau) = \frac{1}{\rho}\left[\frac{1}{1+e^{-\tilde{c}(\tau+\rho/2)}} - \frac{1}{1+e^{-\tilde{c}(\tau-\rho/2)}}\right] \qquad \text{(Double Logistic)}$$

The Resulting Mosquito Populations

The analytical work to get exact $M(t)$ is... tedious. Thankfully, there are numerical integrators!

Which gives us a window to qualify these alternatives rapidly, and then decide which to thoroughly investigate.

TODO insert poster figs

Thoughts?

What do *you* think about the options?

Back To Oversimplification Question

Are these alternatives still too simple?

They are all built assuming a stable driver, which is inaccurate.

But: this framework presents an easy way to consider $E(t)$ changes as perturbations. That is, given the stable solution at the start of a period, how do changes to the driver in that period transform the end-of-period outcome?

So What?

What does this basic analysis give us?

- rough boundaries as input to other models,
- where more complex approaches are needed (agent-based, spatially explicity, *etc.*)
- a cog for ranges where this kind of model is good (or good enough [for now])

“New” Habits and Tools

The general arrow of scientific work has been towards increased specialization and collaboration, and to increasingly digitally-based components.

This presents a few challenges to getting work done:

- lashing together methods from different fields,
- getting genuine peer-review, and
- the purely mechanical handling of different people simultaneously working on the same “thing”

How can we address these issues?

“New” Habits and Tools

Fortunately, there’s a whole industry that’s continuously tackling this exact problem: software development, and more specifically open-source software projects.

What tools and habits can we adopt from this field? What risks are associated with that? What’s still missing?

The Good

- version control systems,
- collaborative tools on top of those,
- preference for code documentation leading to
  - bite-sized parts,
  - modularity,
  - re-usability, and
  - verifiability (a/k/a unit testing)
- open availability of all source,
- combines with version control to provide complete history of work product

The Bad

- openness can make for opportunity to be "scooped",
- can focus more on process than product,
- learning curve for most scientists

The Ugly

- university contracts' intellectual property clauses,
- academic institutions don't "get" these tools,
- community adoption?

Why bring this up?

It's a little bit advocacy, and I built this presentation using this work model.