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How can we track mosquitoes? (And why!)

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Abstract

Mosquitoes aren't just annoying, they can carry deadly diseases as well. The main way to control these diseases is by controlling mosquito populations. In order to do that we have to study the *ecology of these populations*; we have to track the mosquitoes. *Mark-release-recapture* (MRR) is a great method to estimate the population's size and other information. Mosquito MRR experiments, however, have some limitations as these insects are really small and have short lives. We present mathematical models which address these limitations. Our results indicate a good estimation of the population *abundance* (number of mosquitoes in a given area).

Introduction

Are you afraid of sharks? You shouldn't be. The chances of being killed by a shark are miniscule compared to dying from encountering another animal roaming the world - some types of mosquito carry *pathogens* (bacteria, viruses or microbes) that can cause deadly diseases! Mosquito bites result in the death of more than 1 million people every year. What makes mosquitoes so deadly? Mosquitoes are *vectors* (they carry the pathogens that cause a disease) for devastating diseases – from malaria to dengue, Zika and chikungunya (Fig. 1).

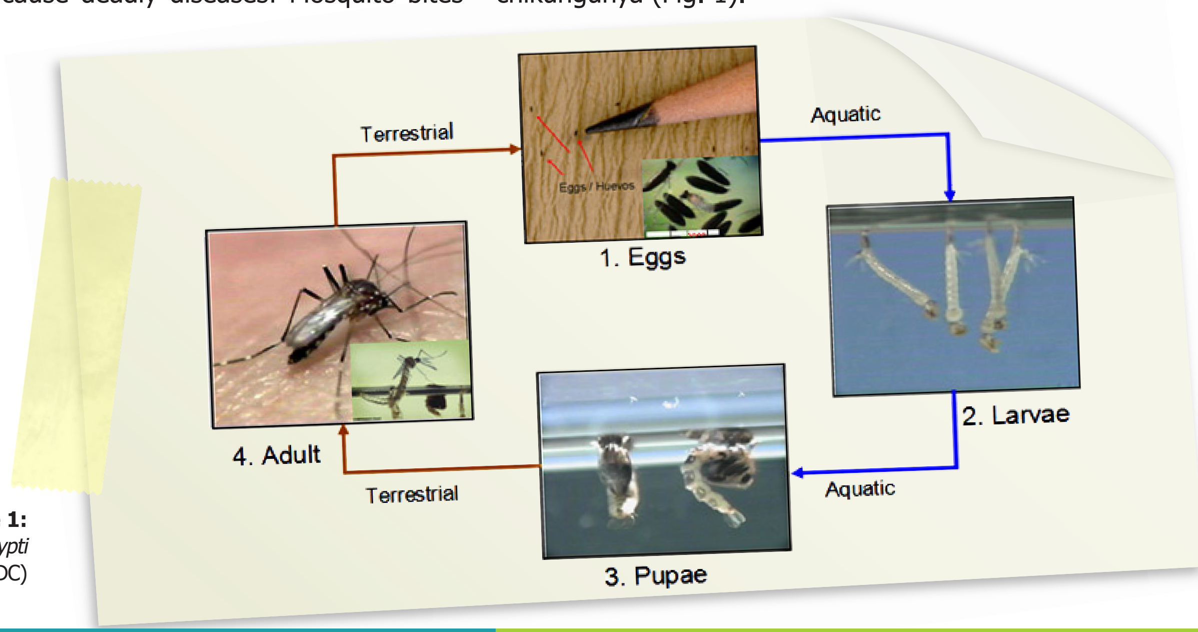


Figure 1:
Life cycle of *Aedes aegypti* (and other) mosquitoes (CDC)

How can we control these diseases? Vaccine development is never easy, takes a lot of time and is sometimes not even possible (at least for now). Controlling mosquito populations is another option. But to do that we have to study mosquitoes and their populations – we have to know where they are, how many there are, how long they live, and where they lay their eggs. We can study mosquito (and other) populations by the *mark-release-recapture method* (MRR) – in short, researchers capture, mark and then release a portion of the population. Later, the researchers capture another portion of the population and count the marked and the unmarked individuals, allowing them to estimate the population size.

Mosquito MRR experiments have some limitations though:

1) Once captured, mosquitoes often don't survive
2) A mosquito's life-span is short
3) Researchers may recapture only a few of the marked mosquitoes
4) Because mosquitoes are really small, individual marking is difficult (so researchers won't know if they capture the same mosquitoes over and over again)

What we wanted to do was to create reliable mathematical models to estimate mosquito population measures like population size, *survivorship* (the proportion of the population surviving to a given age) and *recruitment* (increase in a population due to births or new mosquitoes travelling to an area), which would take these limitations into account.

Methods

We used the data from one of our previous studies: We had collected mosquito eggs in a neighbourhood of Rio de Janeiro, Brazil using traps which attract mosquitoes seeking to lay eggs. We raised adult mosquitoes (*Aedes aegypti*) from these eggs. We had then marked these mosquitoes with *fluorescent dust* before releasing them. Having released the mosquitoes, we then collected mosquitoes in our study area using traps (the traps attract mosquitoes seeking to feed on the blood of an animal or human) for a period of 8 days.

We used five different models (Fig. 2) which combine observed data and different assumptions (factors or situations we suppose to be true) to estimate the population size, survivorship and recruitment of the mosquitoes.

Besides field data, we also used computer simulations to test these models. In each simulation we input varying population size, number of releases, and chances of survival. We then compared the results from our own estimations with the numbers used in the computer simulated data. This allowed us to check the accuracy of our models as we would expect the results to be the same.

Model	What it counts	What it estimates
M_0	Number of recaptures	Abundance
M_1	Number of recaptures, survivorship	Abundance and survivorship
M_2	Number of recaptures, survivorship, the individuals which we remove when we capture them	Abundance and survivorship
M_3	Number of recaptures, the individuals which we remove when we capture them, recruitment	Abundance, survivorship,
M_4	Number of recaptures, survivorship of marked and unmarked, the individuals which we remove when we capture them, recruitment, number of immature mosquitoes	Abundance, survivorship, recruitment

Figure 2:
Description of the models we used. The first three models (M_0 – M_2) are based on previous research; we built the last two models (M_3 and M_4).

Results

We estimated the abundance of female *Aedes aegypti* in the neighborhood of Rio de Janeiro using our five models (Fig. 3A). We also used the relevant models to estimate recruitment and survivorship. For example, Models M_1 - M_4. kept survivorship in mind (Fig. 3B).

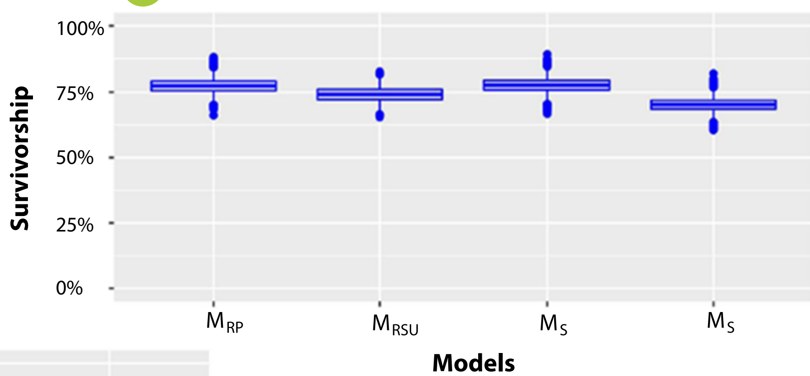
In our simulated studies model M_4 gave the most promising results. However, when we simulated much higher abundance (i.e. 8000), model M_4 underestimated it (gave lower results than it should).

Our simulation studies also showed that:

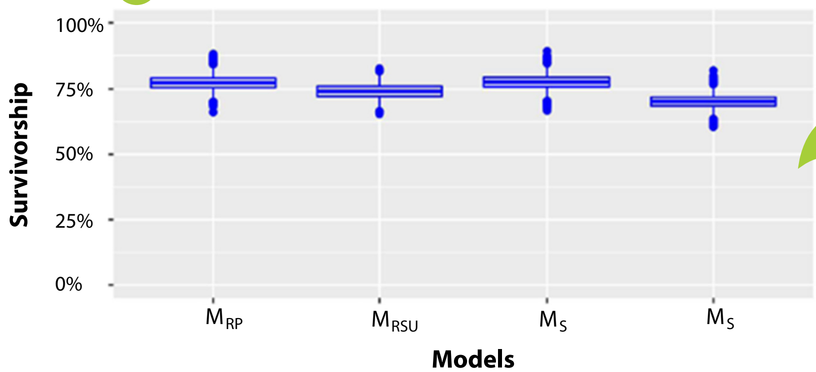
1. We need to mark at least 1000 mosquitoes to estimate the abundance accurately
2. The fewer mosquitoes the traps capture, the more uncertain the results are. Therefore, *capture efficiency* rates should be high.

Which model shows the largest abundance?

A.



B.



Why is the M_0 model missing from figure 3B? Is there any significant difference between the results obtained from models M_1 - M_4 regarding survivorship?

Figure 3:
Estimation of (A) the mosquito abundance and (B) survivorship in an area in Rio de Janeiro, Brazil.

Discussion

When we used the 5 different models to estimate the abundance of female mosquitoes (*Aedes aegypti*) in an area in Rio de Janeiro they showed very different results. This is why it's important to choose an appropriate model which bears mosquito biology in mind: to estimate abundance we have to know how many mosquitoes leave and enter the population. In our simulation studies model M_4 gave the best results because it took into account not only the mosquitoes' survival rates but also the recruitment rates and the number of collected immature mosquitoes. Model M_4 also distinguishes the survival rate of marked and unmarked individuals (marked mosquitoes are more likely to die) which makes it more accurate than the other model for estimating recruitment (model M_3).

All models, however, require the marking of at least 1000 mosquitoes. If the number of mosquitoes released from the traps is lower than that, the estimations become very uncertain. As mentioned above, capture efficiency rates must be high for the models to work. These rates usually vary between 5 and 10% of mosquitoes in an area, which according to our simulations, are good enough for abundance estimation.

Conclusion

Mathematical models shouldn't be confused with truth since reality is always more complicated. Nevertheless, models can be really useful. The models we built can contribute to better mosquito control, which will lead to the control of diseases, by revealing the most mosquito abundant area. Health authorities can then target this area with measures to control the mosquito populations, for example: eradicating the mosquitoes with chemical substances or deploying biological methods such as fish that feed on mosquito larvae.

Glossary of Key Terms

Abundance – the number of members of a species (like the mosquito) in a given area. E.g. There is a high abundance of mosquitoes in heavily infested trees.

Aedes aegypti – a species of mosquito, sometimes called the Yellow fever mosquito, which can spread dengue, Zika, chikungunya and other viruses. It originated from Africa but has now spread to other tropical and subtropical regions of the world.

Capture efficiency – how well the traps attract the female mosquitoes and how many of the attracted mosquitoes get trapped.

Ecology of these populations – Population ecology is a branch of ecology that studies how population sizes change over time and how populations interact with their environment. For example, issues that might be studied within population ecology could be the growth of the human population and how this alters the environment which in turn impacts other species' populations.

Fluorescent dust – or powder, tiny particles of fluorescent dye which researchers use to mark insects and other arthropods externally (on the outside of the body). Usually fluorescent dust is visible to the naked eye; sometimes a UV light is needed. (See Fig. 4.)

Mark-release-recapture – A method used in ecology to estimate the size of an animal population in which a subset of the animals is captured, marked (with a tag or some other mark), then released. Later, another group of the animals is captured and the number of marked animals within the second group is counted to estimate the overall size of the population.

Figure 4: A mosquito marked with fluorescent dust

Pathogens – Small organisms (usually bacteria, microbes or viruses) that make people or animals sick.

Recruitment – the addition of new individuals into the population. For example, pupae survive, transform into adults, and thus enter the population. Mosquitoes migrating from neighbouring zones into our study area is also considered recruitment.

Survivorship – the probability that an individual will survive beyond a specified time. For example, younger animals are more likely to survive for longer than old ones.

Vector – an animal or insect that spreads a disease by carrying the pathogens that cause it. For instance, many tropical diseases like malaria, Zika, and dengue are spread by mosquito vectors. Other diseases can be spread by mammals like rats, squirrels, foxes or even cats and dogs.

REFERENCES

Villela DAM, Garcia GdA, Maciel-de-Freitas R (2017) *Novel inference models for estimation of abundance, survivorship and recruitment in mosquito populations using mark-release-recapture data.* PLoS Negl Trop Dis 11(6): e0005682.

https://doi.org/10.1371/journal.pntd.0005682

The American Mosquito Control Association: Mosquito-borne diseases

http://www.mosquito.org/page/diseases

Centers for Disease Control and Prevention: Help control mosquito populations
https://www.cdc.gov/zika/pdfs/control_mosquitoes_chikv_denv_zika.pdf

Check your understanding

1. If mosquitoes are so bad why don't we just kill all of them?

2. How can we prevent mosquito-borne diseases?

3. Can you use MRR (mark-release-recapture) to estimate fish abundance in a lake?

4. Why do you think Model M_0 revealed a much larger mosquito abundance than the other 4 models?