Mosquito Model

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**Introduction & Motivation**

This model explores the eradication of Aedes aegypti mosquitoes through the use of genetically modified (GMO) male mosquitoes. The Aedes aegypti has turned to a significant public health threat. It is a vector of several for transmitting ZIKA and other tropical fevers. Conventional control methods have failed to control the population of mosquitoes so far. Novel genetics-based strategies offer a promising alternative or aid towards efficient control of this mosquito.

Current genetics-based strategies have two different methods, Bi-sex RIDL and fs-RIDL (female specific). Bi-sex RIDL will cause that both male and female offspring die before adulthood. This method requires continuous releases of the GMO mosquitoes to the wild. It could significantly reduce the population but hard to eradicate the mosquitoes. On the other hand, fs-RIDL (female specific) targets on the female offspring ensuring they fail to survive until adulthood. Meanwhile, male offspring will grow up with the lethal gene and continue to mate with other wild female. In favorable circumstances, modified gene is spread automatically.

This model focuses exclusively on the fs-RIDL method. The goal of this model is to help the user choose the ideal locations and quantity of GMO mosquitoes to release while providing the most effective results for the practice.

The advantage of using ABMS to modeled this system is that ABMS could show the characteristic of different mosquito in the model. In the real wild environment, every difference mosquito’s life time, mate times, reproduce number and many other variables is a different number. In addition, release GMO mosquitoes at difference location will cause difference result. Using a model with some equations could not show the real situation in a wild environment. Therefore, design and operation an ABMS model to simulate this system is the best way which would help us to find the most efficiency way of using novel genetics-based strategies.

**Operating Instructions**

Prior to Setup, the initial release locations should be set using the initial-release-locations slider. This sets the number of GMO deployment locations ranging from 0 to 10. These deployment locations are represented by red boxes in the environment.

Next simulation initialization is invoked using the SETUP button. This creates the aforementioned deployment locations as well as three bodies of water represented by cyan colored patches. Within these patches are an initial random (0-49) amount of wild (non-GMO) eggs.

To start the simulation, the GO button is pressed. This button has the forever option selected to keep the simulation running continuously until subsequent pressing of the GO button. Once running, eggs will hatch producing adult mosquitoes. These mosquitoes will attempt to reproduce as detailed in the previous sections.

While the simulation is running the user can position the release locations for the genetically modified mosquitoes by dragging each red box using the mouse to place them anywhere in the environment.

The number of GMO male mosquitoes to be released per location is set using the gmo-release-per-deployment slider, ranging from 0 to 100. Note, this is per location so multiply this number by the total number of locations to get the total number of GMO males that will be deployed each time the Release GMO button is pressed.

Once release settings are configured, press the Release GMO button. This can be pressed any number of times. Each press will release the set number of GMO mosquitoes from the current locations. Locations and gmo-release-per-deployment can be changed through out the simulation run.

Survival rate of wild (non GMO) and GMO mosquitoes are controlled by the wild-survival-rate and gmo-survival-rate respectively. This is the success rate that a hatched egg will produce an adult mosquito. This represents the reality that not all eggs laid result in adult mosquitoes that are able to reproduce in their own rite.

On the bottom left side you will find several counters display the total tally of wild (non-GMO) egg, GMO eggs, uninfected adult mosquitoes, and adult mosquitoes that have been infected with the mutated gene.

On the right side there are two plots that historically track the eggs and mosquito populations. The plot titled Eggs plots wild (non-GMO) egg in blue and GMO eggs in red. The plot titled Mosquitoes plots wild (non-GMO) mosquitoes in blue and GMO mosquitoes in red.

**Model Description & Technical Implementation**

Mosquitoes hatch from eggs in bodies of water represented by cyan colored patches. Once hatched, the adult mosquitoes attempt to mate with compatible mosquitoes of the opposite sex. Genetically modified (GMO) male mosquitoes are released by the user who controls release locations, quantities, and number of releases. The mosquito agents fly around in the open, unbound world, interacting with others, testing compatibility, and attempting to mate.

Successful mating requires a non-pregnant, fertile female and a male within a radius of 3 units of the female. There is a compatibility variable (0-9) that must match for the female and male to mate successfully. This represents the variable frequency used for mosquitoes to find a mate. Once a suitable mate is found, the fertilized female seeks out the nearest water patch within her field of view (180 degree, 10 distance). After waiting a rest period of 5 ticks, she lays 0 to 300 eggs. The eggs laid are of type wild (non-GMO) or GMO depending on the genetic makeup of her male partner. Females can get pregnant a random number of times (1 - 3). After eggs have been laid, the female resumes seeking a mate.

Male mosquitoes have a life span, randomly set, ranging from 3 to 10 ticks. The life span of females is also a random number between 3 and 10 but with a random multiplier between 2 and 5. This represents the fact that female mosquitoes can live up to 5 times longer than males.

On each tick each water patch, if applicable, hatches 1 egg. If both wild (non-GMO) and GMO eggs exist on said patch, one is chosen at random. A user controlled survival rate for both wild (non-GMO) and GMO determines the odds that the egg will successfully hatch. Since females produced from GMO eggs do not survive to adulthood, only GMO males are produced. The new generations of mosquitoes then proceed to seek mates, thus continuing the cycle.

The code demonstrates many examples of sprouting turtles from a patch.

The code also demonstrates the use of the watch, subject, and reset-perspective primitives in conjunction with mouse-down and mouse coordinates to automatically pause model and allow user to select and drag a turtle.

The model shows how to leverage the in-cone reporter to create a field of vision then uses max-one-of and face to find the closest water patch.

**Experiments, Results, and Observations**

If the survival rate of GMO mosquitoes is higher than the survival rate of wild (non GMO) mosquitoes, the extinction will happen very fast. If GMO mosquitoes and wild (non GMO) mosquitoes have the same survival rate, with the same release number, it will take a much longer time to generate a complete eradication. In a wild environment, the survival rate of wild mosquitoes is about 20%.

Changing the position of deployment points, such as put them together, or put them far from each other, would not significantly affect the result. However, putting deployment points near the water could accelerate the eradication time, especially when the number of deployment points is low.

Try different values for the INITIAL-RELEASE-LOCATIONS, GMO-REALEASE-PER-DEPLOYMENT, WILD-SURVIVAL-RATE, and GMO-SURVIVAL-RATE sliders. How do they affect the number of eggs and number of mosquitoes?

Try to drag the DEPLOYMENT POINT. Does it affect the eradication process?

Is there a significant change in results when pressing the Release GMO button multiple time to simulate multiple deployments?

**TEST 1**

Initial-release-location: 1

Gmo- release-per-deployment: 100

Wild-survival-rate: 20%

Gmo-survival-rate: 40%

Gmo release number: 1000

Gmo release ticks: 1496

Put the location near the water

Extinction at ticks: 60925

Total mated: 9505



**TEST2: put release location far from the water**

Initial-release-location: 1

Gmo- release-per-deployment: 100

Wild-survival-rate: 20%

Gmo-survival-rate: 40%

Gmo release number: 1000

Gmo release ticks: 1563

Put the location far from the water

Extinction at ticks: 119258

Total mated: 17763



**TEST 3: Lower the gmo survival rate to 20%**

Initial-release-location: 1

Gmo- release-per-deployment: 100

Wild-survival-rate: 20%

Gmo-survival-rate: 20%

Gmo release number: 1000

Gmo release ticks: 1465

Put the location near the water

Extinction at ticks: 167893

Total mated: 26282



**TEST 4: increase release location number to 5**

Initial-release-location: 5

Gmo- release-per-deployment: 20

Wild-survival-rate: 20%

Gmo-survival-rate: 40%

Gmo release number: 1000

Gmo release ticks: 1460

Put the release location randomly

Extinction at ticks: 50237

Total mated: 7282



**TEST 5: put release location near the water**

Initial-release-location: 5

Gmo- release-per-deployment: 20

Wild-survival-rate: 20%

Gmo-survival-rate: 40%

Gmo release number: 1000

Gmo release ticks: 1491

Put all the release location near the water

Extinction at ticks: 74846

Total mated: 10688



**TEST 6: Lower the gmo survival rate to 20%**

Initial-release-location: 5

Gmo- release-per-deployment: 20

Wild-survival-rate: 20%

Gmo-survival-rate: 20%

Gmo release number: 1000

Gmo release ticks: 1504

Put the release location randomly

Extinction at ticks: 241024

Total mated: 23542



**TEST 7: increase release location number to 10**

Initial-release-location: 10

Gmo- release-per-deployment: 10

Wild-survival-rate: 20%

Gmo-survival-rate: 40%

Gmo release number: 1000

Gmo release ticks: 1495

Put the release location randomly

Extinction at ticks: 79211

Total mated: 10149



**TEST 8: put release location near the water**

Initial-release-location: 10

Gmo- release-per-deployment: 10

Wild-survival-rate: 20%

Gmo-survival-rate: 40%

Gmo release number: 1000

Gmo release ticks: 1438

Put all the release location near the water

Extinction at ticks: 53408

Total mated: 6645



**TEST 9: Lower the gmo survival rate to 20%**

Initial-release-location: 10

Gmo- release-per-deployment: 10

Wild-survival-rate: 20%

Gmo-survival-rate: 20%

Gmo release number: 1000

Gmo release ticks: 1480

Put the release location randomly

Extinction at ticks: 167397

Total mated: 20255



**TEST 10: release 1000 gmo in one time**

Initial-release-location: 10

Gmo- release-per-deployment: 100

Wild-survival-rate: 20%

Gmo-survival-rate: 40%

Gmo release number: 1000

Gmo release ticks: 1608

Put the release location randomly

Extinction at ticks: 50877

Total mated: 4347



**TEST 11: release 1000 gmo in one time, lower the gmo survival rate to 20%**

Initial-release-location: 10

Gmo- release-per-deployment: 100

Wild-survival-rate: 20%

Gmo-survival-rate: 20%

Gmo release number: 1000

Gmo release ticks: 1508

Put the release location randomly

Fail to Extinction

Release only time may cause none gmo mosquitoes could survive, and the mission will fail



**TEST 12: maximum the release number**

Initial-release-location: 10

Gmo- release-per-deployment: 100

Wild-survival-rate: 20%

Gmo-survival-rate: 40%

Gmo release number: 10000

Gmo release ticks: 1470

Put the release location randomly

Extinction at ticks: 45721

Total mated: 4395



**TEST 13: maximum the release number and lower the gmo survival rate to 20%**

Initial-release-location: 10

Gmo- release-per-deployment: 100

Wild-survival-rate: 20%

Gmo-survival-rate: 20%

Gmo release number: 10000

Gmo release ticks: 1473

Put the release location randomly

Extinction at ticks: 88609

Total mated: 9848



**Conclusion & Potential Extensions**

From all the tests above, we could find several phenomena:

1. With the same GMO release number, putting deployment points near the water could accelerate the eradication time, especially when the number of deployment points is low.
2. With several release locations, increase the location number would not significantly affect the eradicate efficiency.
3. The eradication speed is faster when the survival rate of GMO mosquitoes is higher than the survival rate of wild (non GMO) mosquitoes.
4. With the same GMO release number, increase the release times would increase the possibility of eradication, but not significantly affect the eradicate efficiency
5. Increase the GMO release number from 1000 to 10000 would give us a decrease return to scale, it is not efficiency.

Therefore, the most efficiency way to release the GMO mosquitoes is that, set about 5 release locations, we could put them randomly, but not too far from water source will better, set GMO release number equal to 5%-10% of wild mosquitoes, and release GMO mosquitoes about 10 times.

Consider that in a wild environment, the survival rate of wild mosquitoes is about 20%, and we could not expect that the GMO survival rate would higher in wild, so set both survival rate at 20% is closer to reality.

There are a number of ways to alter the model, so it will make the model closer to reality. Some will require new elements to be coded in or existing behaviors to be changed.

Add more user control of different species of mosquitoes. This somewhat implied by the compatibility variable but could be expanded upon.

Add hatch time to closer resemble the developmental stages of the mosquito, from egg to adulthood.

Add agent predation behavior. In reality, female mosquitoes need feeding on blood, which they need to mature their eggs. This feature embeds a full life cycle in the model. This could incorporate additional factors that decrease mosquito populations such as bats and spray treatments.

Add and track a variety of diseases such as Zika virus, West Nile Virus, Malaria, and Dengue Fever.

Modified layouts including building structures and different water sources to closer resemble a target environment of study.

**References & Credits**

[https://www.megacatch.com/mosquito-faqs/mosquito-facts/](https://www.megacatch.com/mosquito-faqs/mosquito-facts/" \t "_blank)

[http://www.livescience.com/5976-mosquitoes-harmonize-find-mate.html](http://www.livescience.com/5976-mosquitoes-harmonize-find-mate.html" \t "_blank)

<https://github.com/seancoogan/netlogo-mosquito>

**Appendix A - Model Design**

Design process

Decisions (sean and haotian)

Assumptions (sean)

Agent ID (Sean)

Rule determination (sean)

Agent relationships (haotian)

V&V

Verification – “is the model correct” (sean)

Validation – “is it the correct model” (haotian)

**Appendix B - Code**

Code screen shots (sean)

**Other appendices as needed**