A Climate-Driven Approach to Modeling Mosquito Larval Habitats

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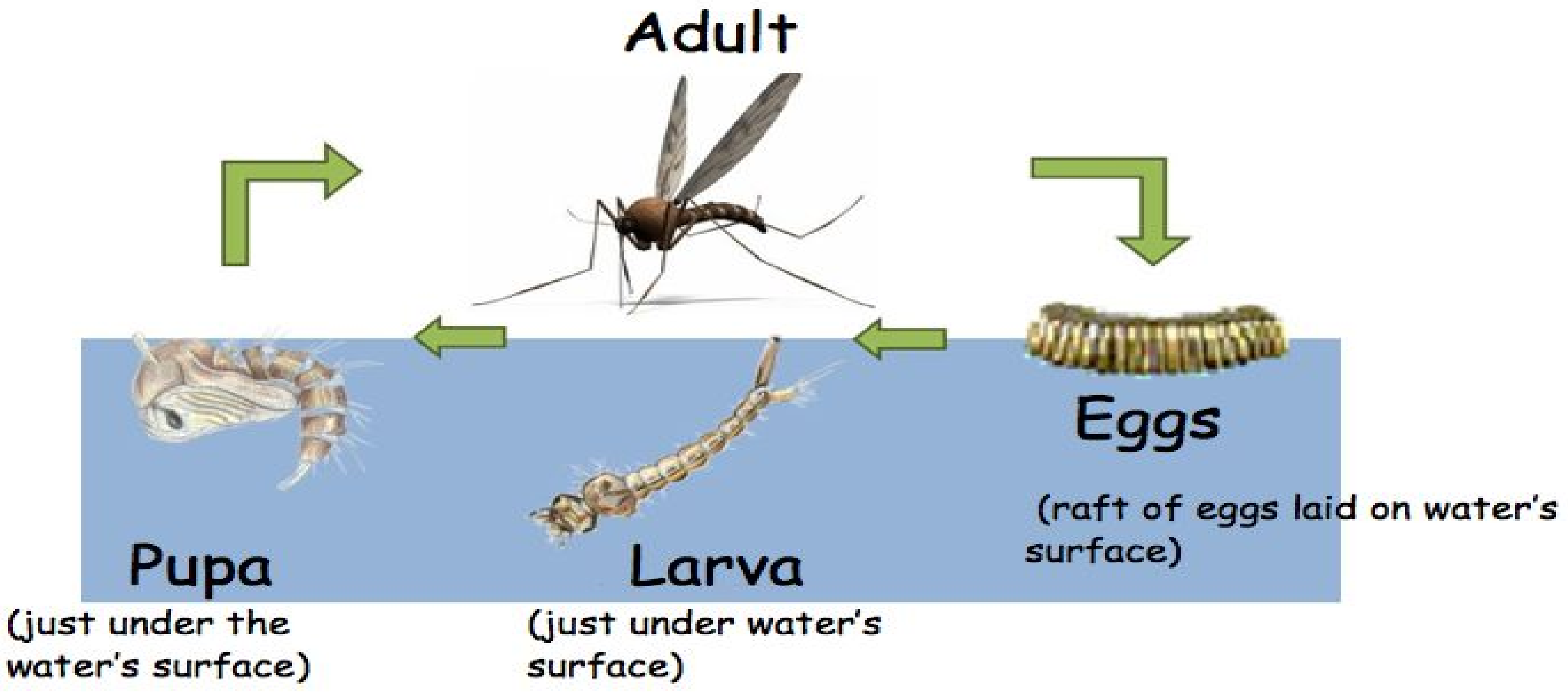
Motivation

- In the absence of major interventions:
  - Disease transmission rates are mainly determined by mosquito biting rates
  - Biting rates are mainly determined by the adult female mosquito population
  - Adult mosquito populations are mainly determined by the carrying capacity of the local larval habitats

Motivation



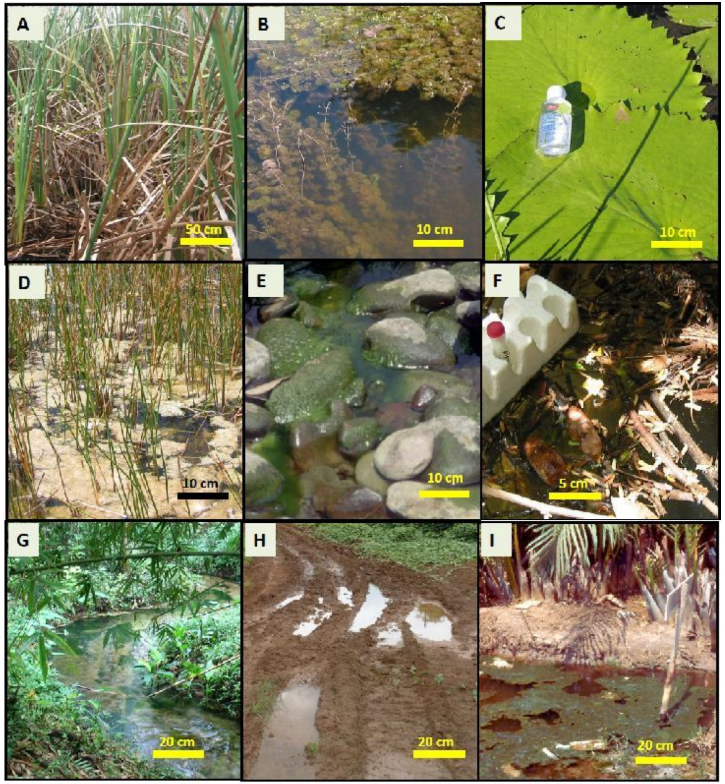
http://www.stsd.org/webpages/animal/mosquitoes.cfm?subpage=938198

Need for New Habitat Model in EMOD

- Current models don’t take into account several factors that affect larval habitats
- Combinations of current habitats are sometimes required to get accurate adult mosquito populations
- Some real habitats are difficult to model accurately with current available habitats and combinations
- Current habitat implementation requires habitats to be attached to mosquitos species rather than the location

New Habitat Overview

- Mathematical model uses new water gain/loss equations and a larger environmental parameter set to handle more types of habitats
- Habitat is more general-purpose to allow for more locations
- Habitat inputs are defined more intuitively for researchers



New Larval Habitat Model

- Food and Agriculture Organization of the UN's Penman-Monteith (FAO ET_0)
  - For EvapoTranspiration equation
- Estimated Cloud Cover (CC)
  - As part of Net Radiation equation
- Interception, Infiltration, and Runoff (IIR)
  - For Quick Environmental Water Loss equation

FAO ET_0 Equation

- Recommended by the UN as the sole method for determining evapotranspiration [1]
- Given specific environmental inputs, can determine climate-based water loss for almost any location [2]

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + \gamma\left(\frac{C_n}{\left(T + 273.16\right)}\right)u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + C_d u_2\right)}$$

CC and IIR Equations

- Cloud Cover used within FAO Penman-Monteith equation to assist with solar radiation calculation
  - Uses humidity and location to estimate hours of sunlight hitting the habitat [3]
- Interception calculated with vegetation [4]
- Infiltration calculated with soil [5]
- Runoff calculated with slope [6]

Inputs Needed for Equations

- Several inputs required from user for new habitat
    - Should not be too difficult to acquire by user
    - May be mostly automatically gathered in the future
- Types of input needed
    - Climate
    - Location
    - Vegetation
    - Soil
    - Slope
    - Minimum/Maximum Water

Inputs: Climate

- Daily Rainfall (mm)
- Daily Air Temperature (°C)
- Daily Relative Humidity (%)
- Daily Net Radiation (J)
  - Can be estimated if missing data
- Daily Wind Speed (m/s^2)
  - Can be estimated if missing data
- Note: Unlike other inputs, climate is shared across all habitats in the modeled location.

Inputs: Location

- Center Point (Latitude and Longitude)
  - e.g. 12.433789, 9.181599
- Elevation (m)
  - e.g. 377
- Area (m^2)
  - e.g. 1250
- Can be found or estimated online based on location and satellite data.

Inputs: Vegetation

- Two needed inputs
  - Vegetation type
    - e.g. “Grass”
    - e.g. “Trees”
  - Vegetation coverage as a percentage
    - e.g. 20
- Vegetation type expected to be easily acquired by local/researcher. Vegetation coverage can be acquired through satellite data.

Inputs: Soil

- As a standard name (USDA or International)
  - e.g. “Loamy Sand”
- As a percentage of the three basic types
  - Clay, Silt, Sand
  - e.g. 15, 15, 70
- Can be acquired through satellite data at a shallow depth (~2cm).
- Note: USDA and International names do not match in all instances

Inputs: Slope

- As a standard phrase (USDA or International)
  - e.g. “Nearly Flat”
  - e.g. “Hilly”
- As a percentage of steepness
  - e.g. 5
  - e.g. 60
- Acquired through hydrology or topology data. Otherwise, expected to be easily estimatable by local/researcher, especially with categorical values.

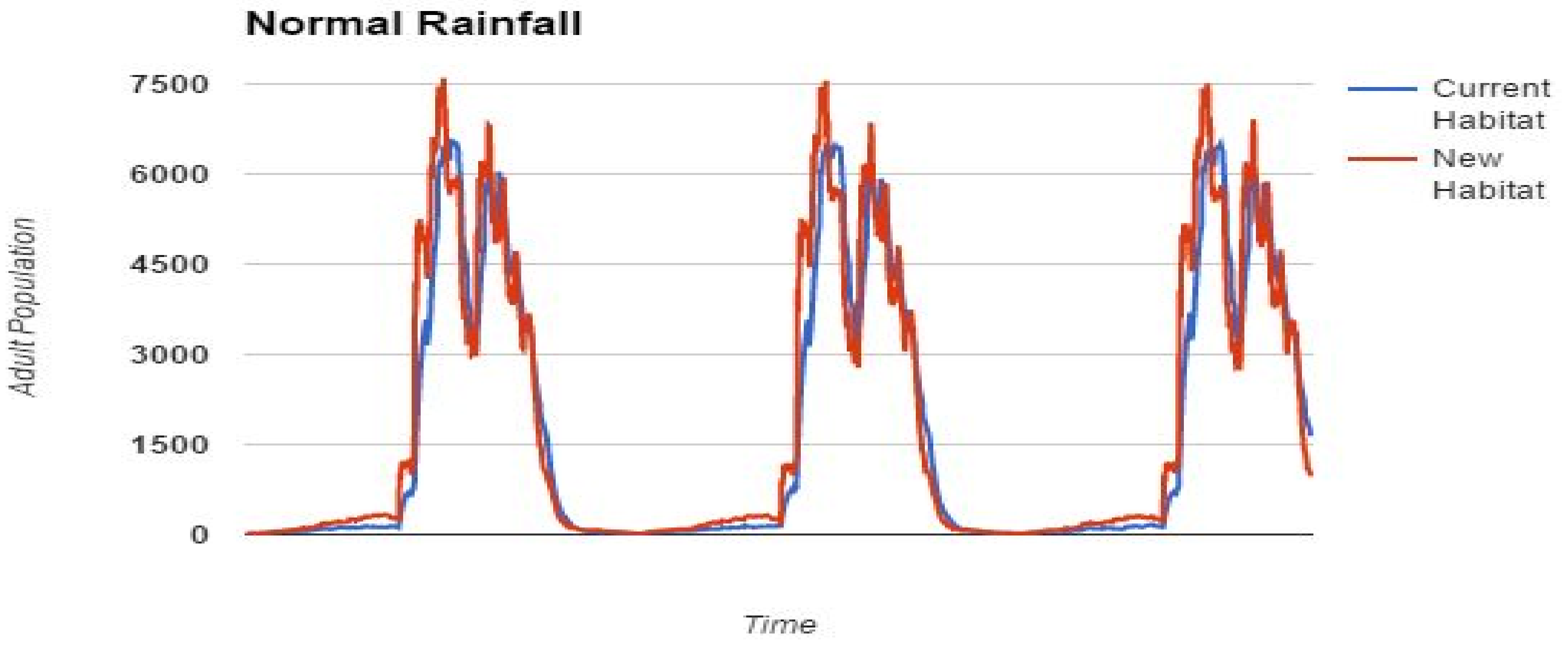
Inputs: Minimum/Maximum Water

- Base amount of water in mm
  - e.g. 0
  - e.g. 100
- Most amount of water in mm (causes overflow when passed)
  - e.g. 5
  - e.g. 1000
- Possibly acquired through carefully checking satellite data throughout the year (focusing on driest and wettest times). May need to be estimated by user.

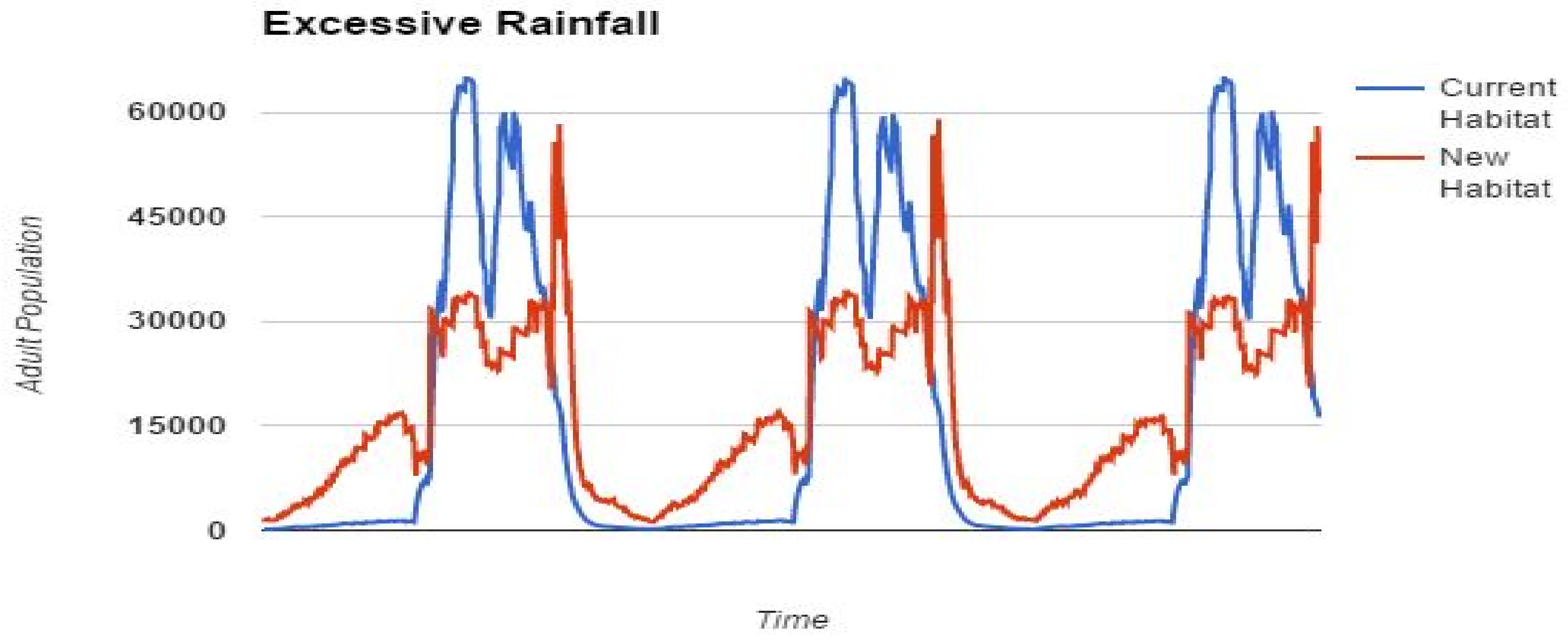
Prototype in EMOD

- Modified EMOD v2.0 with the new inputs and habitat as a proof-of-concept
- Current habitats remained in simulations for testing
- Used the Garki - Single Node tutorial simulation as base for preliminary results validation
- Anopheles gambiae used as primary vectors
- Two different climates used:
    - Normal Rainfall
    - Excessive Rainfall

Results: Normal Rainfall



Results: Excessive Rainfall



Summary of New Habitat Model

- New mathematical model
  - Additional environmental factors accounted for
  - Climate is still primary driver
- New input definitions
  - Habitats are defined separate from mosquito species
  - No simulation-wide habitat properties
- Prototype gives preliminary validation of usefulness of new model and habitats in simulations

Future Work

- Further validation of Climate-Driven habitat
- Add other habitat types
  - Human-Driven
  - Agriculture-Driven
  - Non-Driven
- Full implementation of new habitats in EMOD v2.5
- Add habitat-specific interactions
  - Interventions
  - Surveillance

References

- [1] FAO Corporate Document Repository. “Crop evapotranspiration - Guidelines for computing crop water”.
- [2] Zotarelli, Lincoln, et al. “Step by Step Calculation of the Penman-Monteith Evapotranspiration (FAO-56 Method)”.
- [3] Depinay, Jean-Marc, et al. “A simulation model of African Anopheles ecology and population dynamics for the analysis of malaria transmission”.
- [4] Savenije, Hubert. “The importance of interception and why we should delete the term evapotranspiration from our vocabulary”.
- [5] Tarboton, David. “At a Point Infiltration Models for Calculating Runoff”.
- [6] The COMET Program. “Runoff Processes: International Edition”.

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Thank you!

Questions?