New methods for modeling *Anopheles gambiae s.l.* movement with environmental and genetic data

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Abstract

Models that simulate the effects of interventions on malaria vectors and transmission make assumptions about how mosquitoes move in the environment, such as isotropic behavior and no sex-related differences. These are applied to dispersal between households and villages and processes such as host-seeking and oviposition. Most models use mathematically convenient dispersal kernels based on these assumptions given the paucity of available data to better parameterize mosquito movement and the increase in complexity required. Consequently, there are few available methods to explore the effects of landscape and environmental factors on dispersal patterns. Understanding these patterns is key to optimizing control strategies, particularly for genetic control methods that involve releasing modified mosquitoes that compete with the natural mosquito population. We present a framework for modeling *Anopheles gambiae s.l.* movement mechanistically using available mark-release-recapture, biological, and ecological data and describe how it can be tailored for different locations and scenarios. We demonstrate its use for São Tomé and Príncipe and the Comoros, two candidate field sites for genetic control trials. Furthermore, we show the effects on these islands of elevation, land use, village/city proximity, and wind on predicted dispersal kernels and the implications for mosquito population dynamics. The resultant dispersal kernel is unique to the landscape of interest and is easily calibrated to field data measurements. Finally, we compare these results with genetic methods for inferring dispersal and connectivity between different mosquito populations on the islands and suggest future directions for the synthesis of these two data streams.

Methods

The steps of the framework are as follows:

1) Define the landscape of interest / movement range of mosquitoes

   In our simulations, we are modeling the islands of São Tomé and Príncipe and the Comoros (Grande Comore [Njazidja], Mohéli [Mwali], and Anjouan [Nzwani])

2) Extract landscape features that act as barriers or catalysts to mosquito movement and convert to a simulation space (rasterize)

   We use elevation (DEM) and land use information for all of the islands in addition to the general landform polygons and water features to create our simulation spaces. We classify these features and gradients as barriers or catalysts based on the research literature and primary field experience by collaborators.

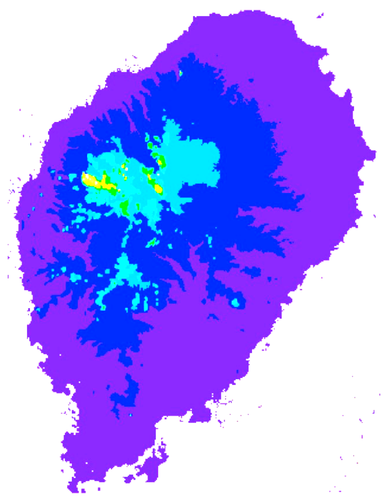
3) Define movement patterns and starting locations of mosquitoes.

   For São Tomé and Príncipe, we use biological parameters for *Anopheles coluzzii* and the São Tomé and Príncipe census data for determining nodes. For the Comoros, we use biological parameters for *Anopheles gambiae s.s.* and OpenStreetMap and other open source GIS data to derive nodes.

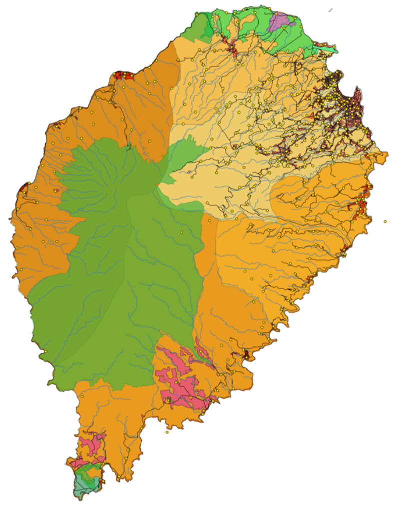
4) Run simulations and calibrate for the following free parameters of interest:

   1) Flight time 3) Maximum flight distance
   2) Flight speed 4) Likelihood of being trapped / detected

São Tomé and Príncipe



(a) Elevation map for São Tomé

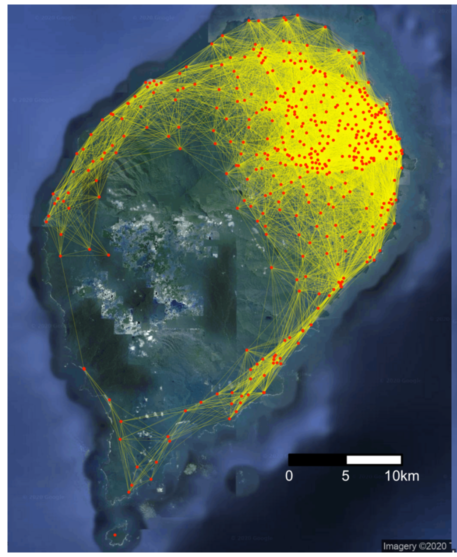


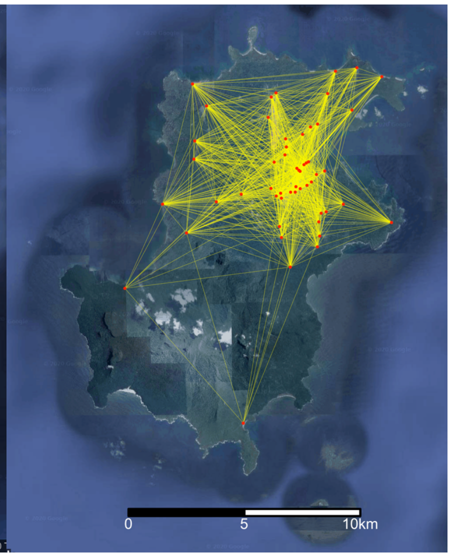
(b) Land use map for São Tomé

Above (a) and (b) show the input layers to the MRRSim mosquito movement modeling framework. Below (c) and (d) show a visualization of the output – the connectivity between nodes that is possible by the simulated *Anopheles coluzzii*. Notably, there is a large barrier caused by the national park and more mountainous area in the southwest part of São Tomé that prevents easy connection between the southern and western parts of the island. Most movement and mosquito activity is concentrated near the capital in the northeast. Príncipe, which is much smaller, has a network of connected nodes and a few distant ones that are reached with low probability.

(c) Simulated mosquito movement kernel for São Tomé

(d) Simulated mosquito movement kernel for Príncipe

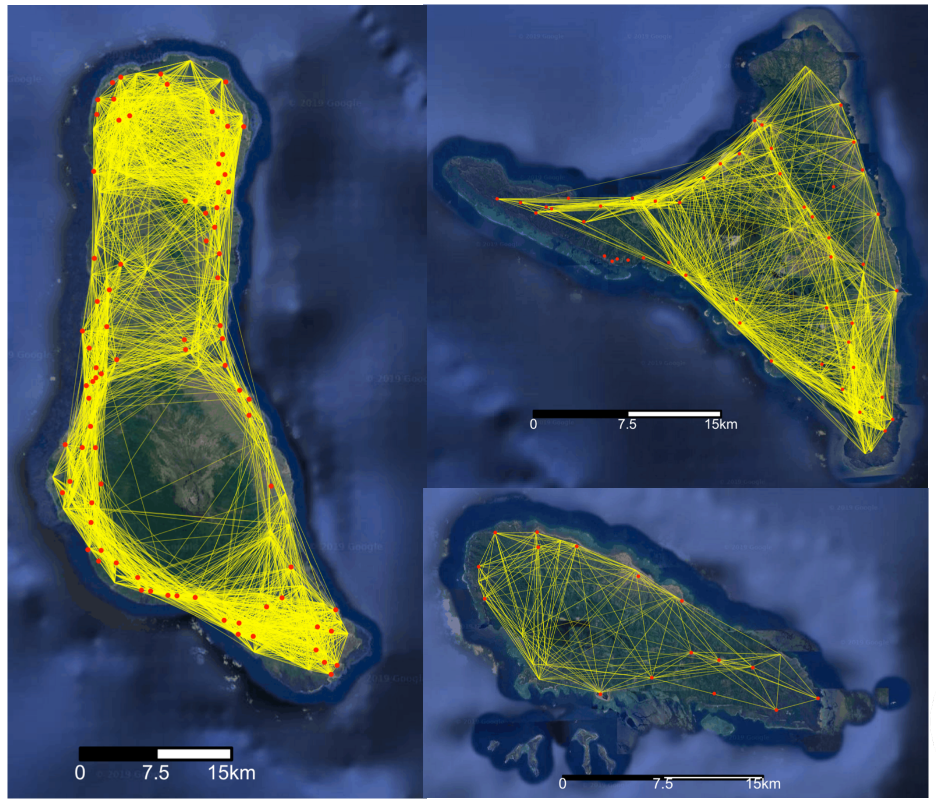




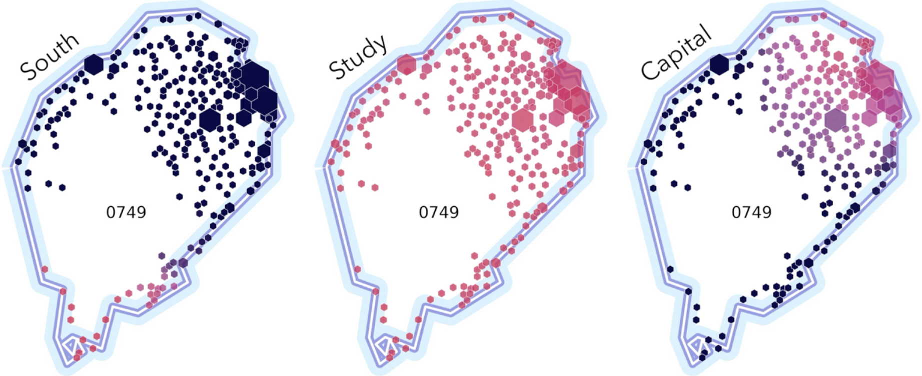
Comoros

Above are example mosquito movement trajectories on Mohéli. Each color is a unique mosquito in the simulation space for the island. Only elevation data was available for this island.

Below are the simulated mosquito movement kernels for Grande Comore (left), Anjouan (upper right), and Mohéli (lower right). Generally, the simulated mosquitoes are more easily able to move along the coast and avoid crossing the more mountainous interiors of the islands, particularly on Grande Comore.



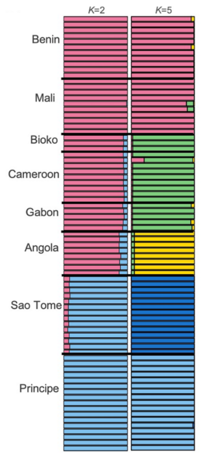
Impact on larger models



The figures above shows a MGDrivE simulation (in progress) for a theoretical gene drive release on São Tomé, with dark purple representing wild-type (the "original") and pink representing the drive (the "release"). All three releases represent an equivalent number of mosquitoes. The South release strategy (left) spreads slowly. The Study release strategy (center, showing fewer mosquitoes released at more locations) spreads the fastest, and the Capital release strategy (right, in the northeast) is in-between. The patterns of spread are determined in large part by the dispersal kernel derived and visualized using the methods described.

Genetic data

Recent work (shown at right from Figure 2(b) in Campos et al. 2020) uses population genomic analyses to compare population structure and relatedness among mainland and island mosquito populations. The admixture results show relative isolation on the islands from the mainland and between the islands of São Tomé and Príncipe. In the future, we hope to gain further insights from genetic data about movement within and between the islands to calibrate and validate the results from MRRSim.



Key References:

Melina Campos, Mark Hanemaaijer, Hans Gripkey, et al. (2020). The origin of island populations of the African malaria mosquito, Anopheles coluzzii. *Authorea.*

Héctor M. Sánchez C., Sean L. Wu, Jared B. Bennett, et al. (2020). MGDrivE: A modular simulation framework for the spread of gene drives through spatially-explicit mosquito populations. *Methods in Ecology and Evolution.*

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