Towards spatially explicit malaria risk models for the Peruvian Amazon

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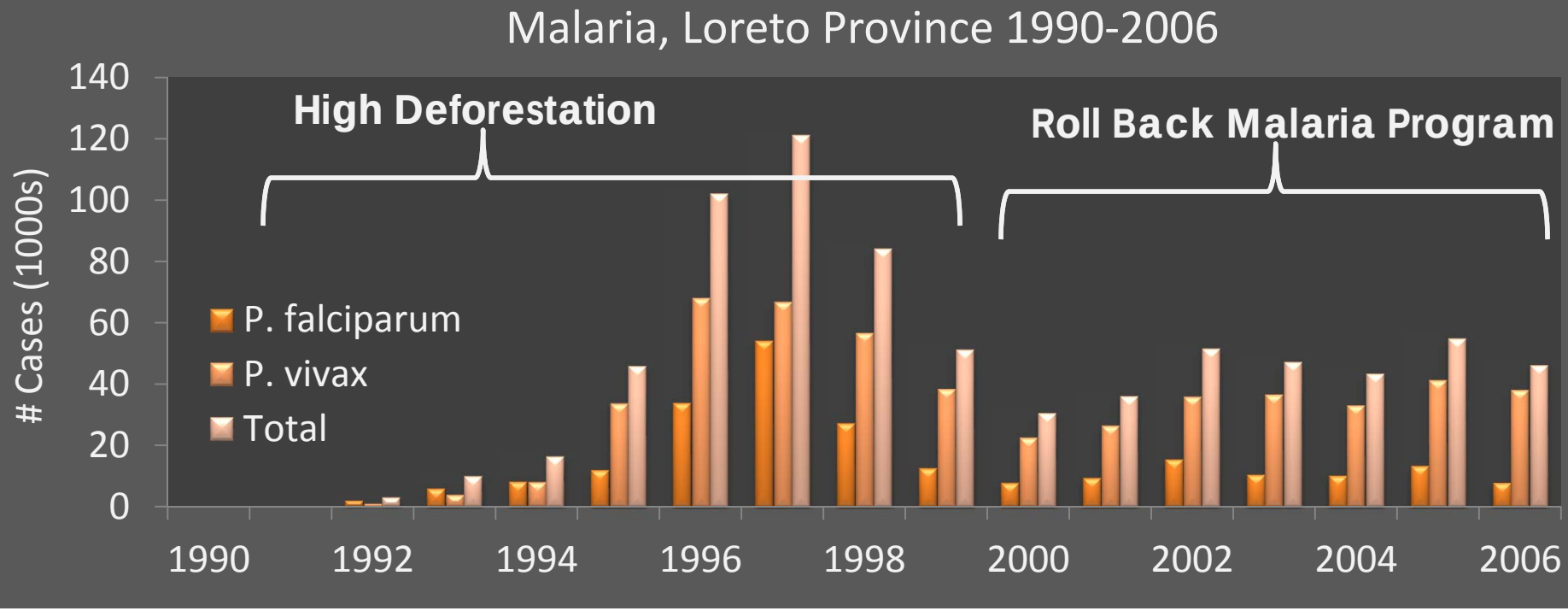
Motivation

- Almost 90% of malaria in the Western Hemisphere is located in the Amazon
- 25% of the malaria burden in the Americas is in 12 municipalities of Peru, Brazil and Venezuela
- 60% of cases in Peru are in the Department of Loreto

Motivation

- Relationships between land use, mosquito ecology, climate, human activity, and malaria risk are complex

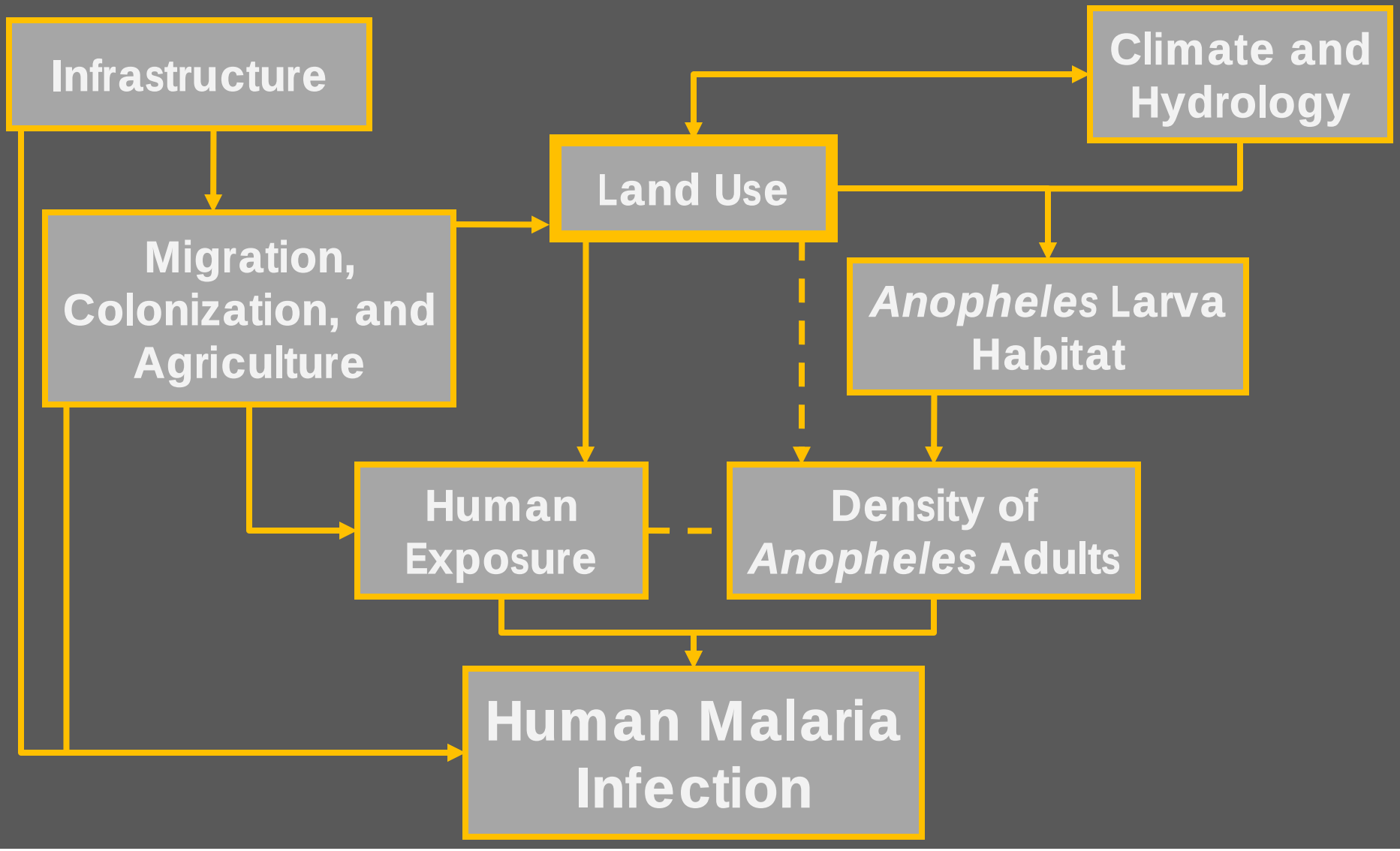


Motivation

- Relationships between land use, mosquito ecology, climate, human activity, and malaria risk are complex

- But strong biophysical links exist, and they can be monitored and addressed through integrated analysis

Malaria on the Amazon Frontier



Process of Land Use Change

Infrastructure Expansion

- Oil Exploration
- Highway construction
- Urban growth

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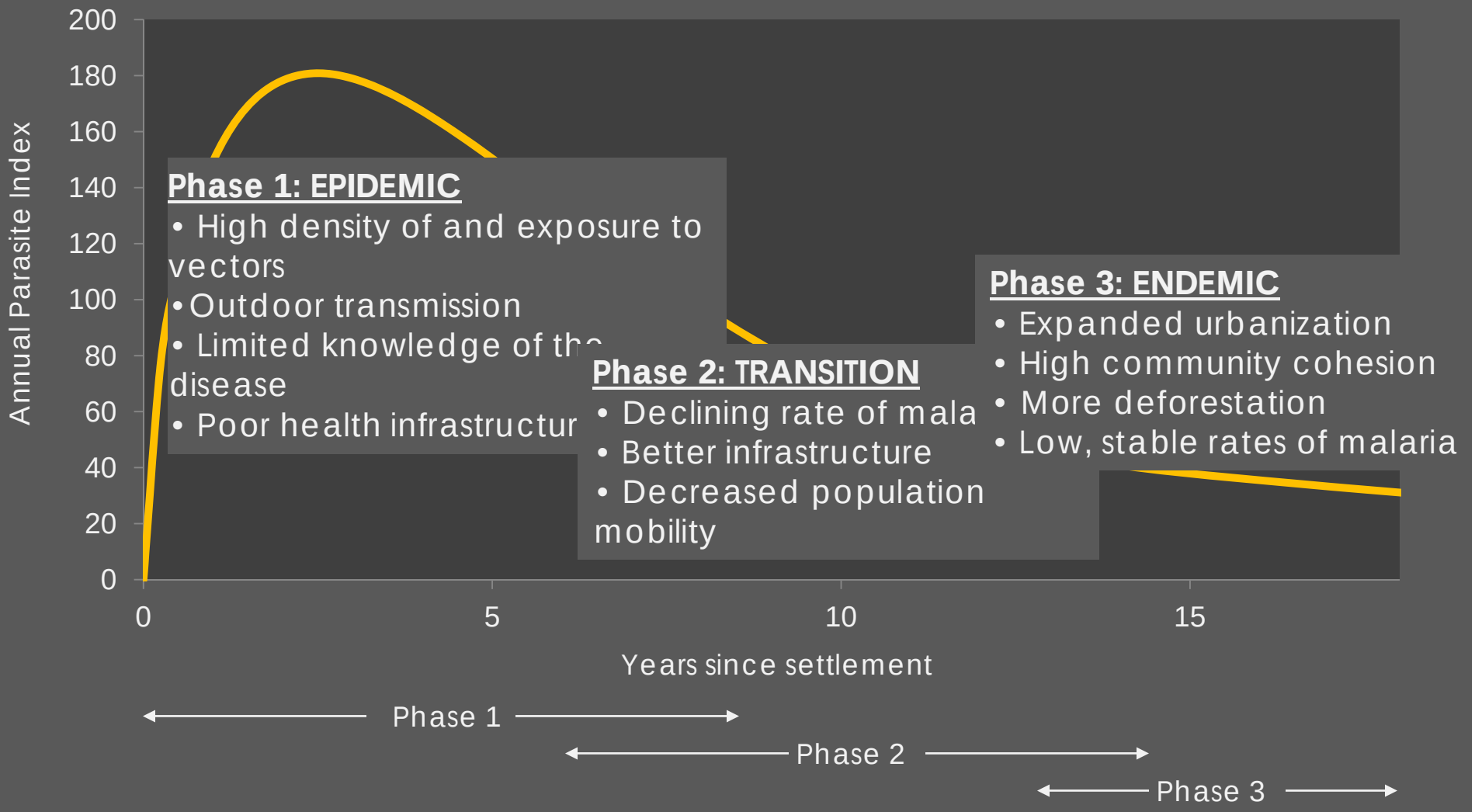
Migration, Colonization, and Phases of Agriculture Development

Annual Crops

Perennial Crops

Pastures

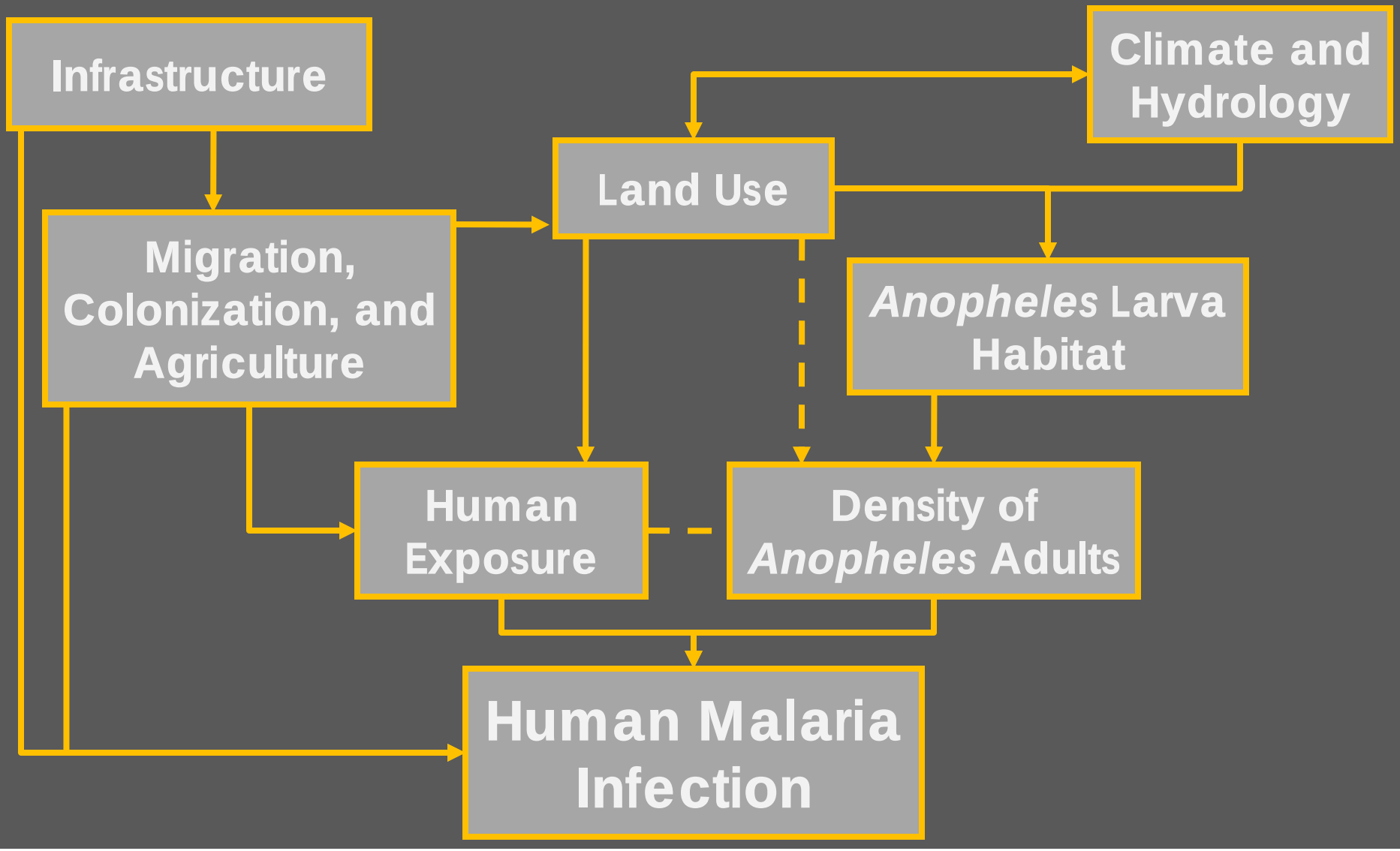
Frontier Malaria Hypothesis



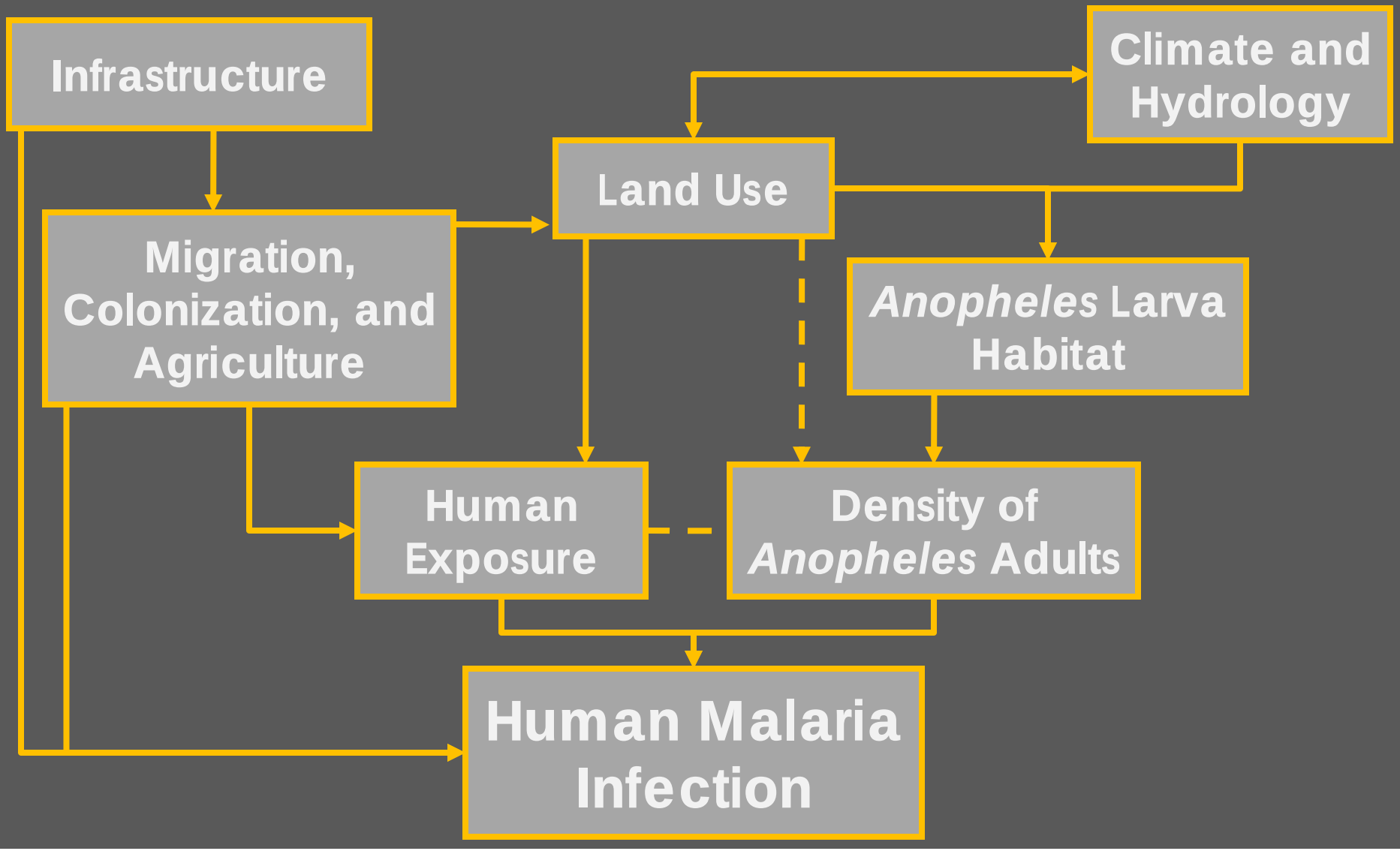
Research Questions

- How do physiography, land use, climate and hydrology interact to influence patterns of *Anopheles* density? How does this differ by species?
- What is the temporal relationship between land clearance and rates of malaria?
- What is the spatial structure of association between biophysical conditions and mosquito density?
- How do human settlement and migration patterns contribute to existing patterns of transmission risk, and how do they drive the evolution of risk zones?

Malaria on the Amazon Frontier



Malaria on the Amazon Frontier

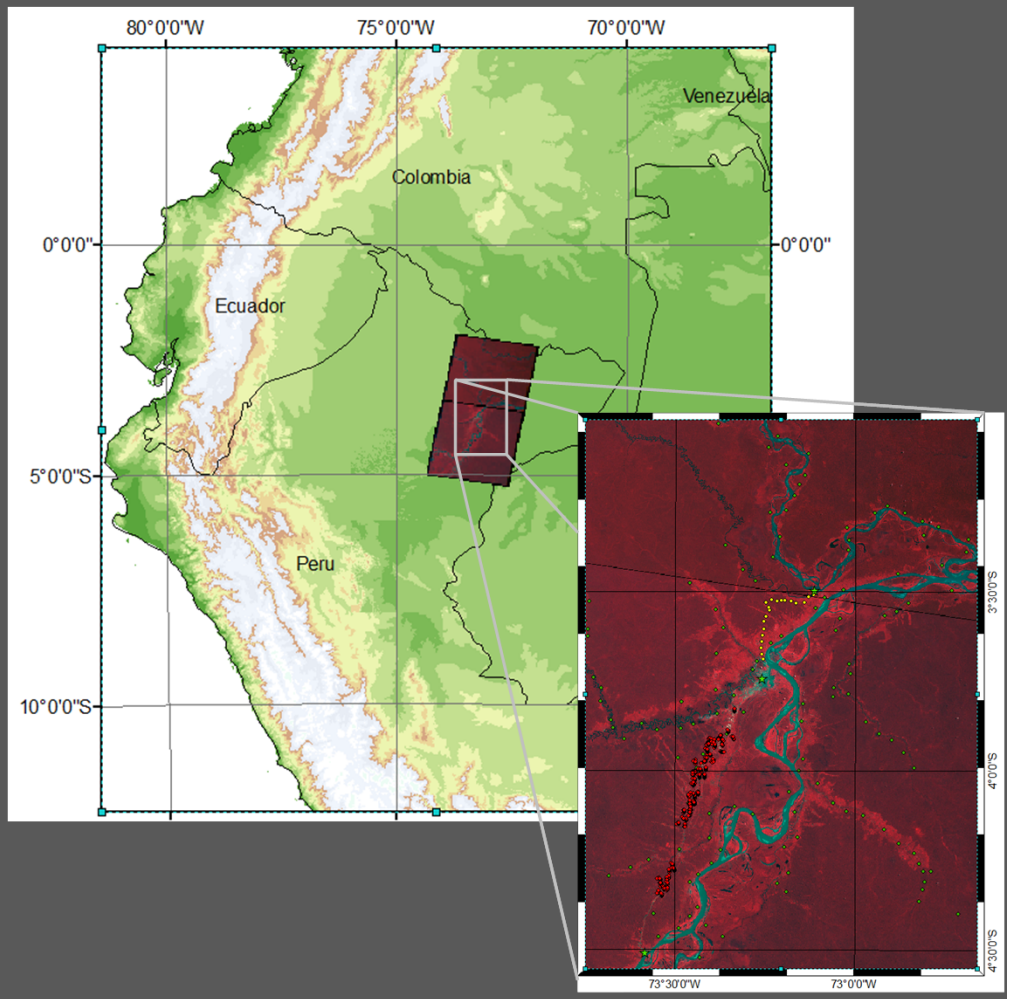


Approach

- Spatio-temporal Ecological *Anopheles* model
  - Input 1: Satellite-based land cover maps
  - Input 2: Meteorological data
  - Input 3: Land Data Assimilation System
- Human Activities and Settlements Map
  - Input 1: Satellite and *in situ* mapping
  - Input 2: Census and Economic data
- Eco-epidemiological Malaria Transmission Model
  - Application: Risk monitoring and prediction

Methods:
Land Cover Mapping

- Deforestation and forest disturbance in Peru can be subtle
- Primary tool: Landsat, multi-temporal analysis
- Supplemented with commercial high resolution imagery
- Extensive ground truth



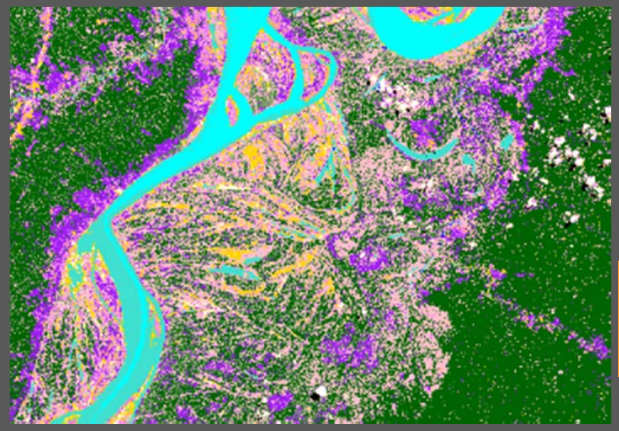
Methods:
Land Data Assimilation System

- A **Land Data Assimilation System (LDAS)** is a computational tool that merges **observations** with **numerical models** to produce **optimal estimates** of land surface states and fluxes.

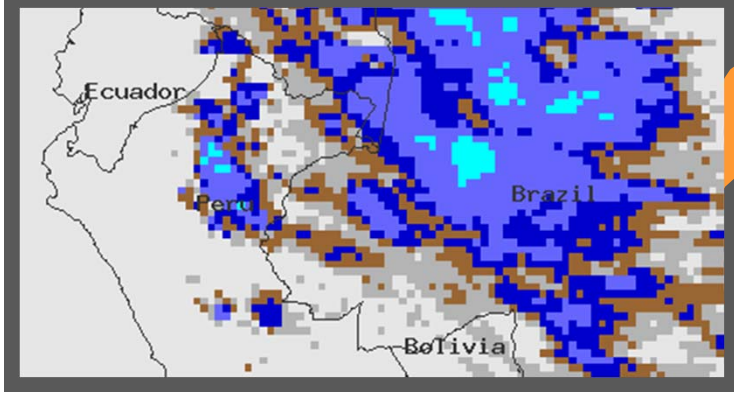
Methods:
Land Data Assimilation System

Update Observations

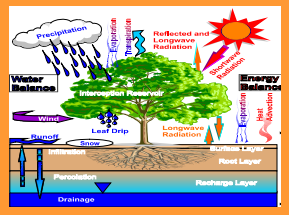
Landscape Information



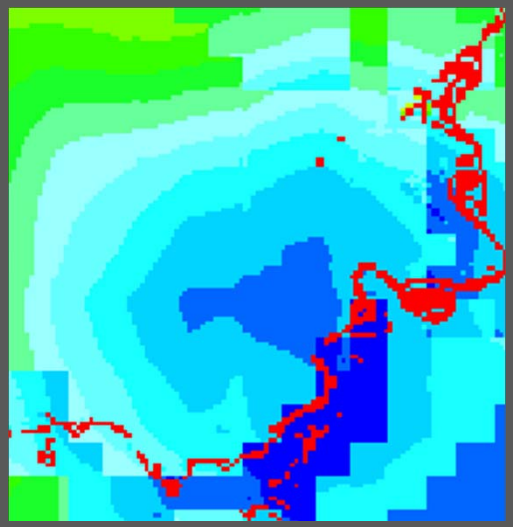
Meteorological Data



Numerical Model

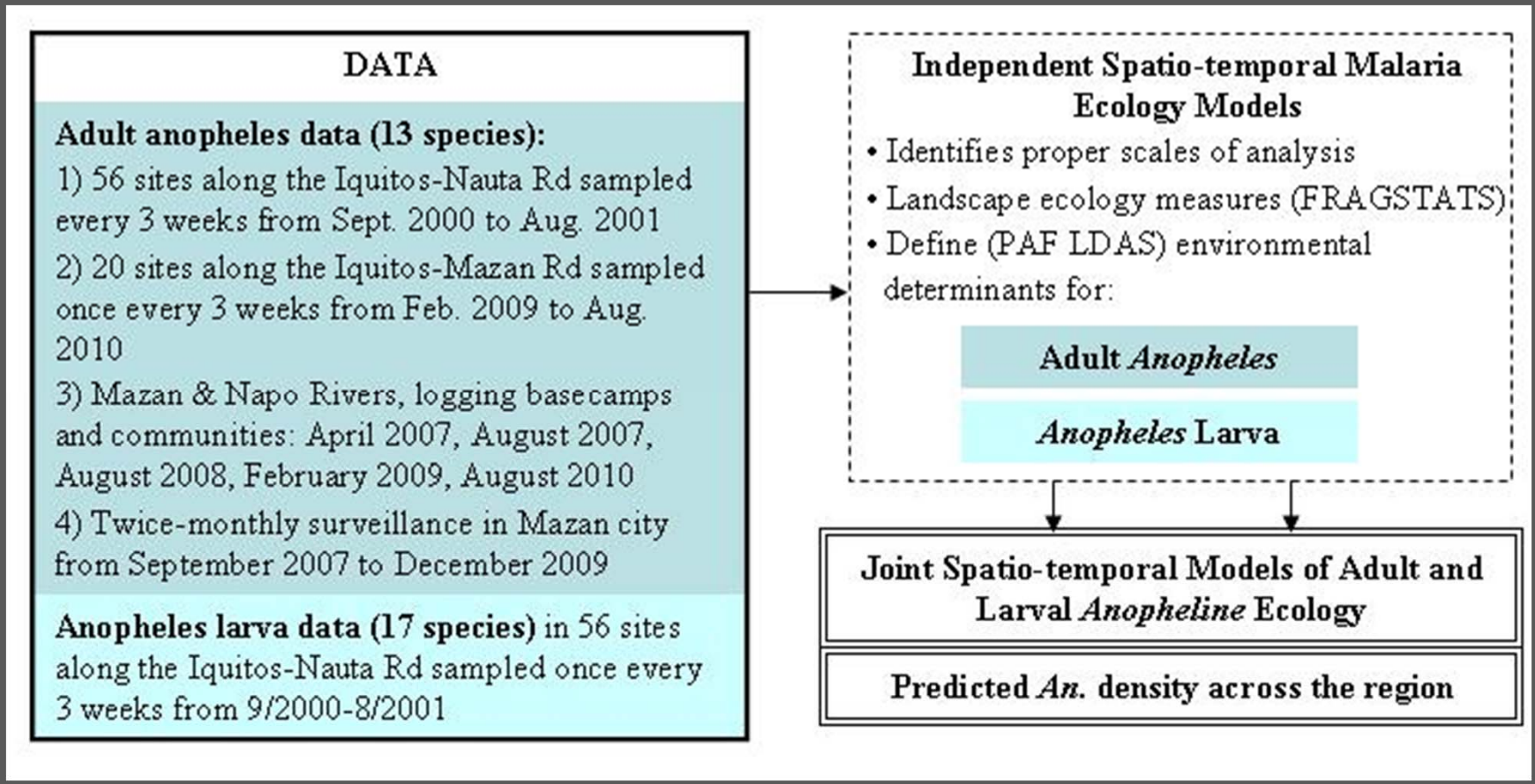


LDAS Output

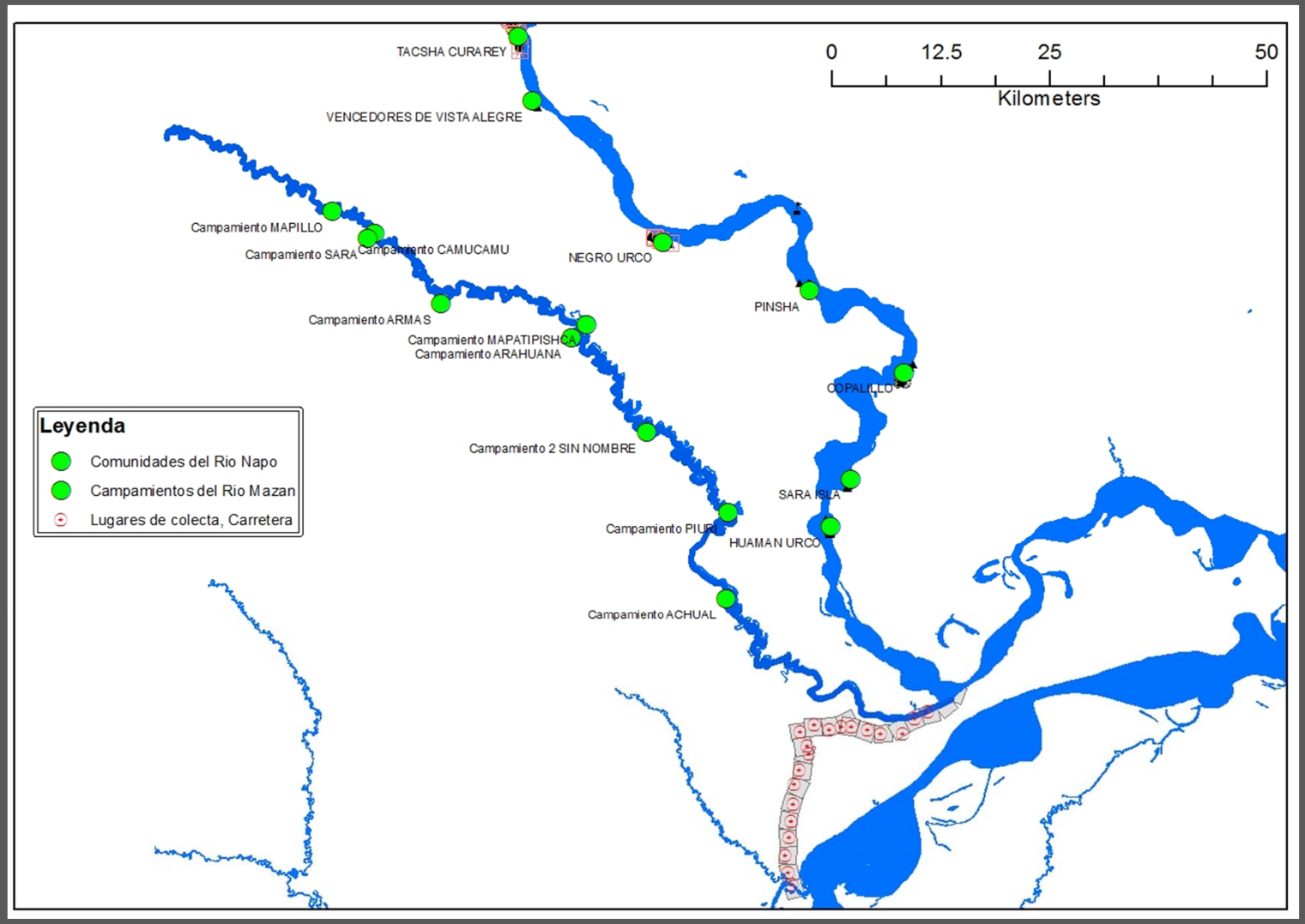


- Hydrological fluxes and storage
- Localized meteorology
- Surface energy balance

Methods:
Spatially explicit *Anopheles* Model



Methods:
Human Activities & Settlement Maps



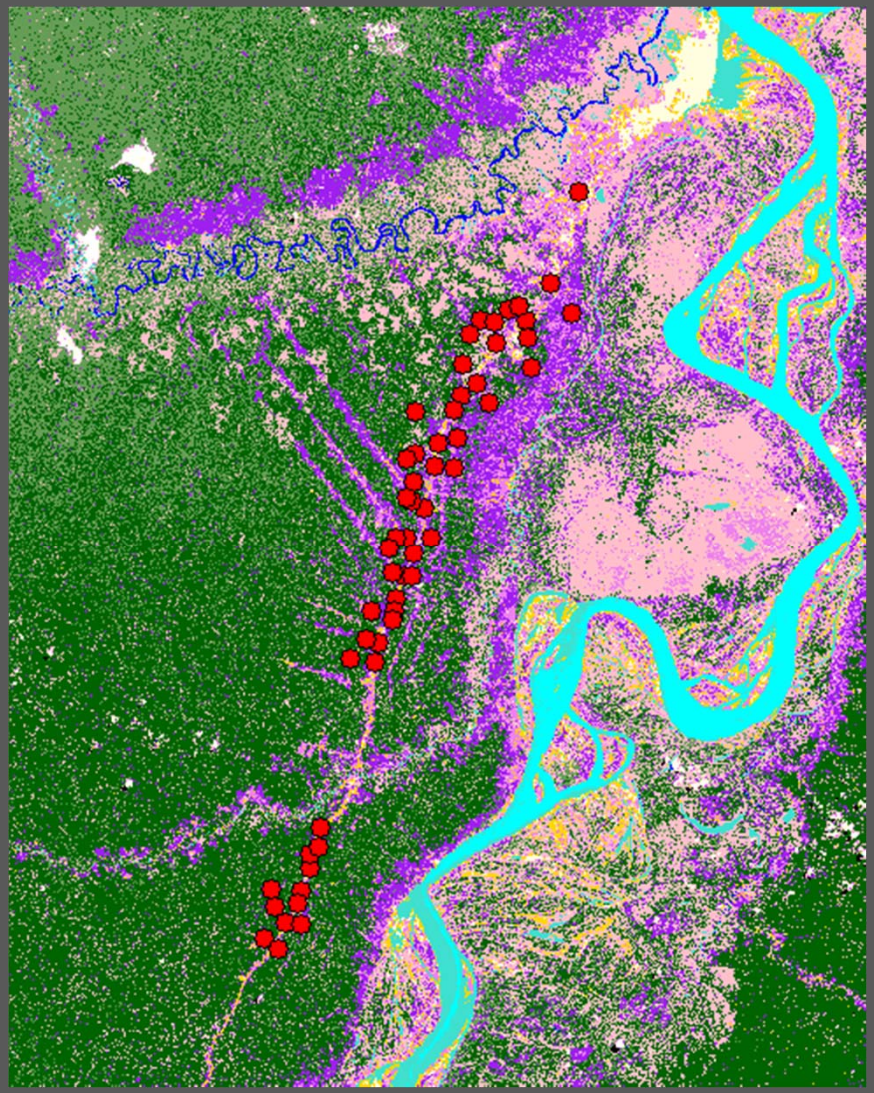
Methods:
Transmission Risk Monitoring

The study is developing four spatially explicit risk factors:

- Human biting rate, a function of the number of mosquitoes per human and the human feeding rate
- Sporozoite rate, the % of mosquitoes with sporozoite in their salivary glands
- Stability index, the expected number of human bites taken by a vector over its lifetime
- Parasite ratio, the number prevalence of infection in humans

Results: Land Cover Analysis

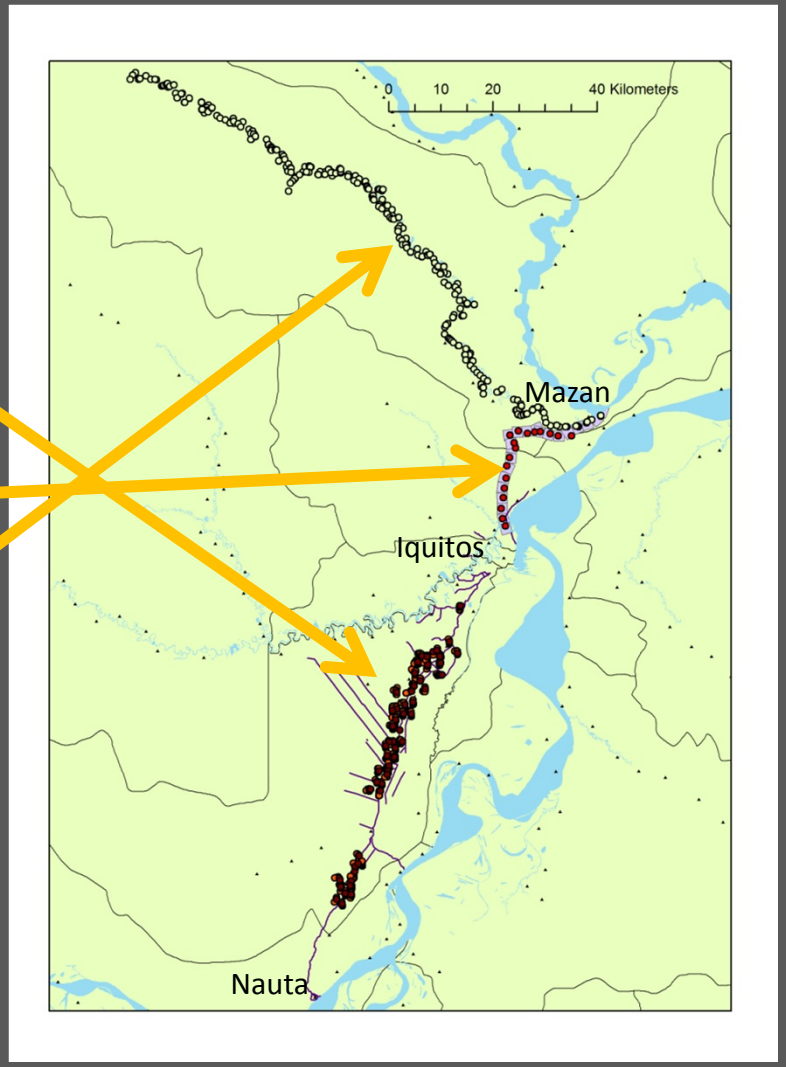
- 12 class supervised classification
- Nauta-Iquitos road in 2001and Iquitos-Mazan road in 2009
- Distinction between forest and non-forest appears to be adequate
- Identification of secondary forest is not



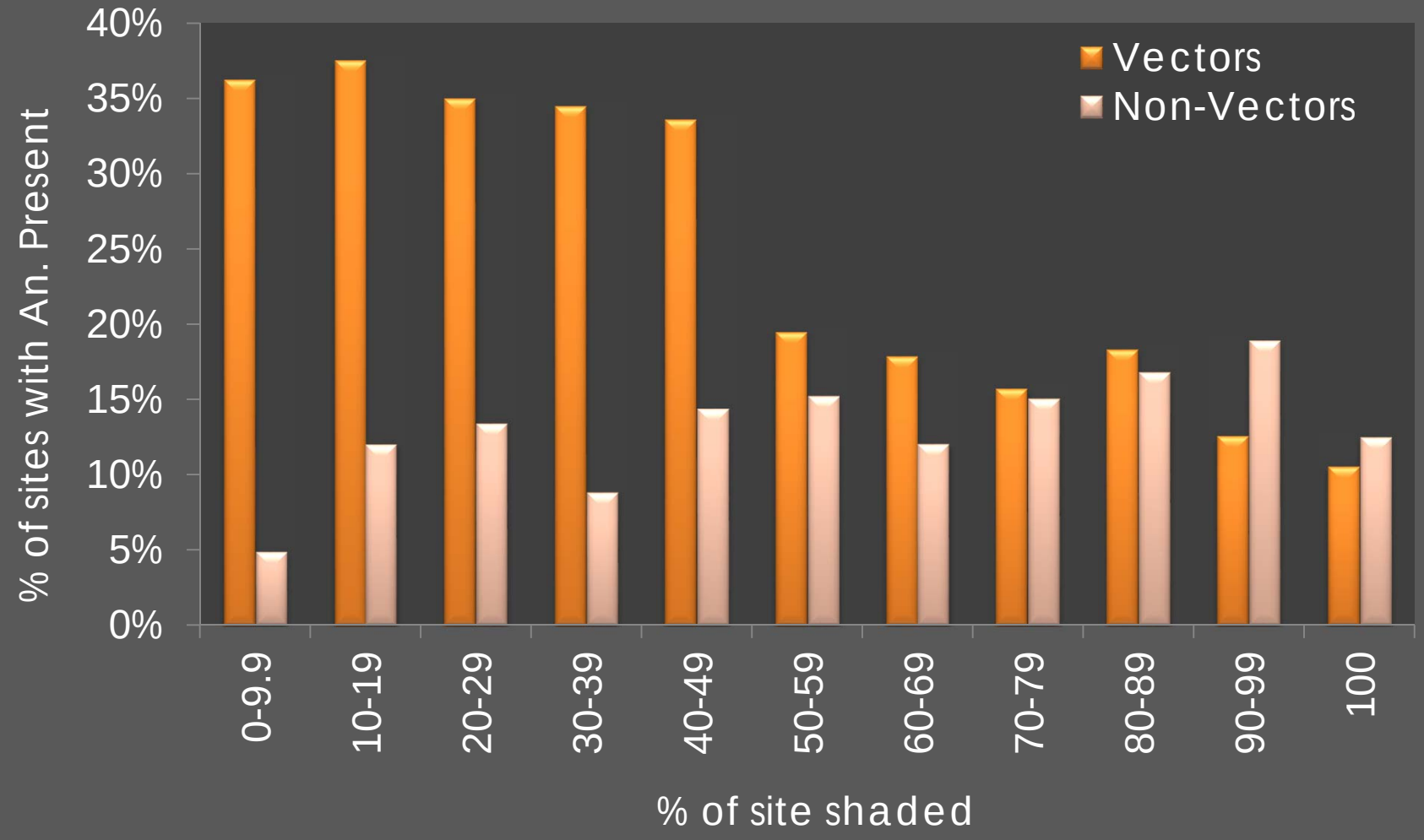
Results: *Anopheles* Analysis

Mosquito Collection

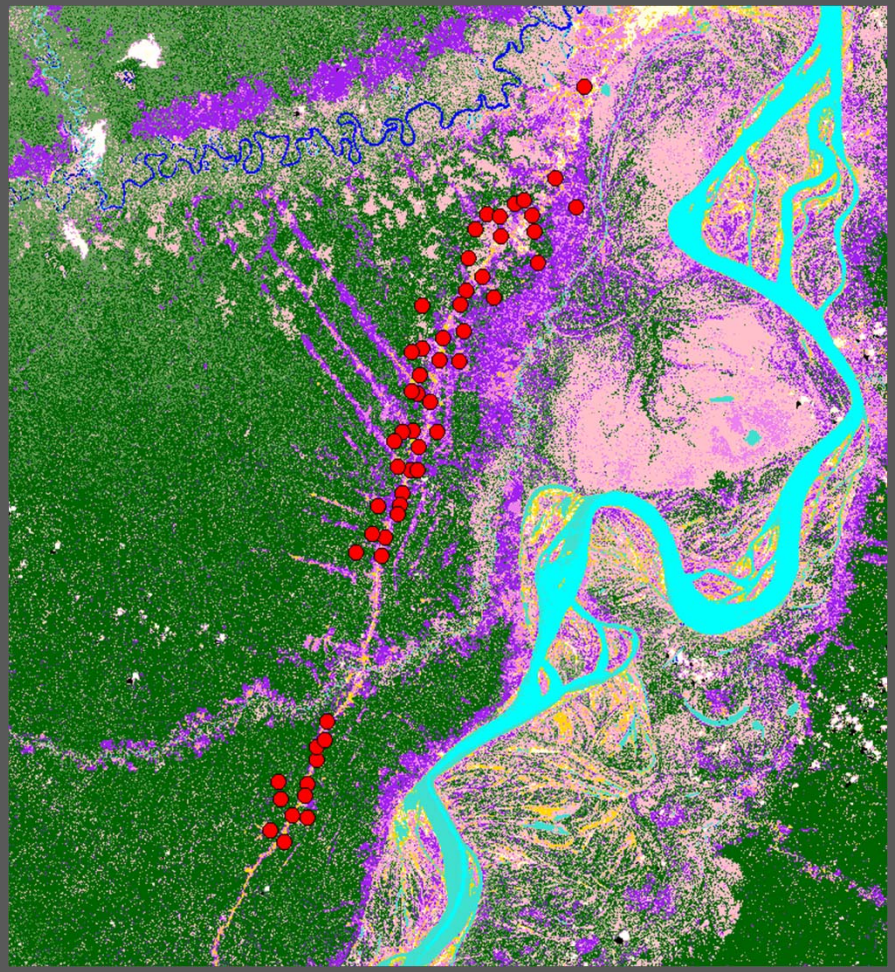
- Iquitos-Nauta road: 1999-2001
- Iquitos-Mazan road: 2007-2011
- Additional survey of logging camps



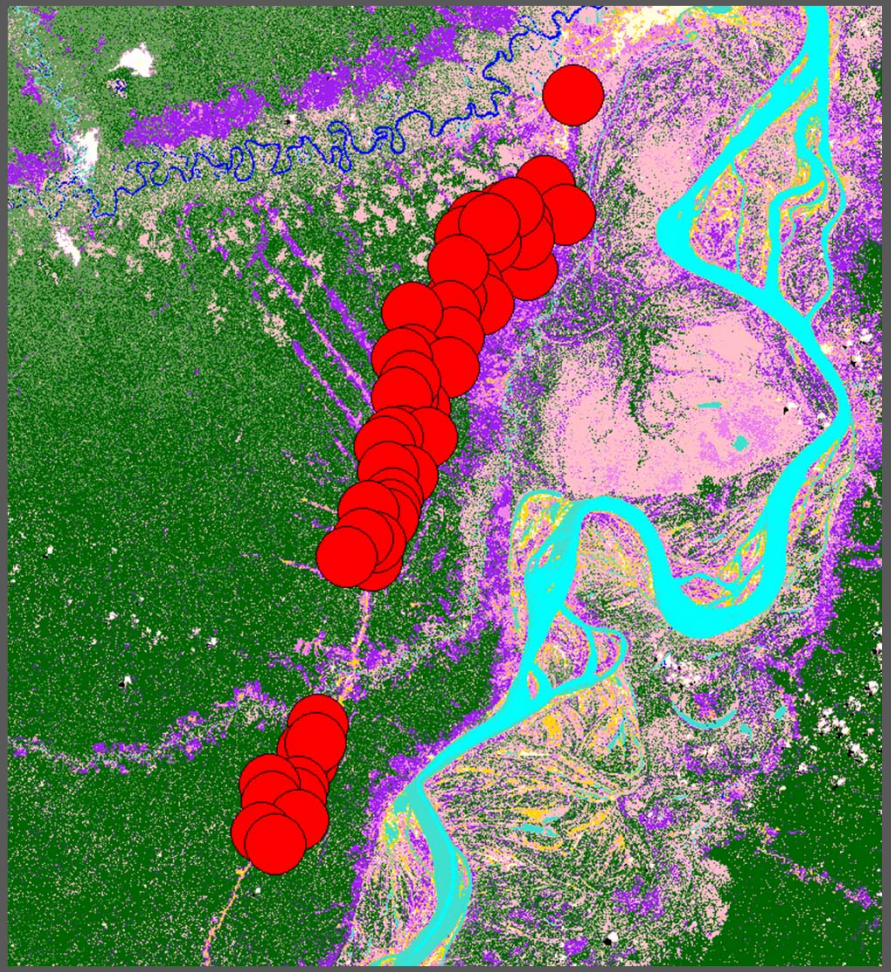
Results: *Anopheles* analysis



Results: *Anopheles* analysis

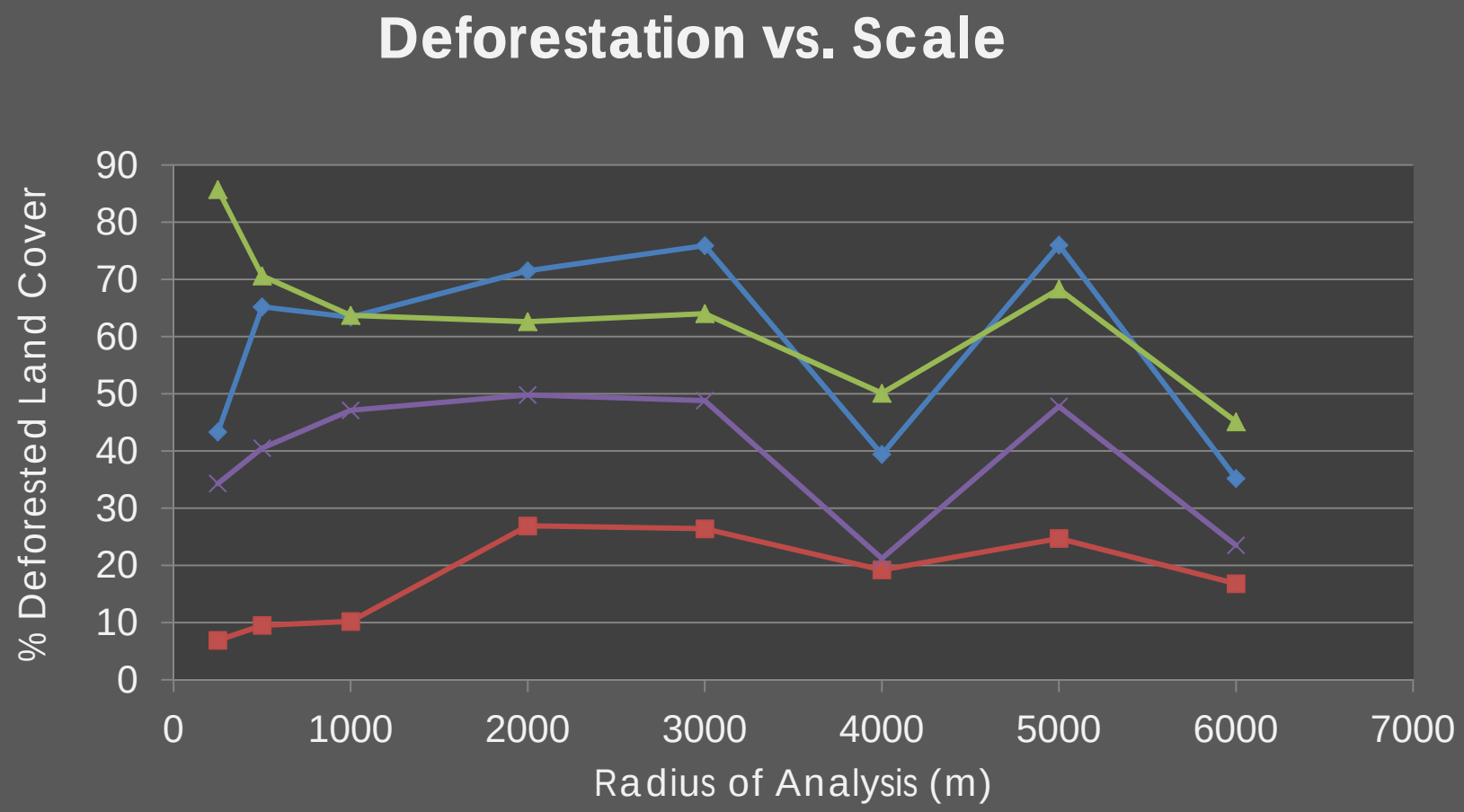


250 m radius

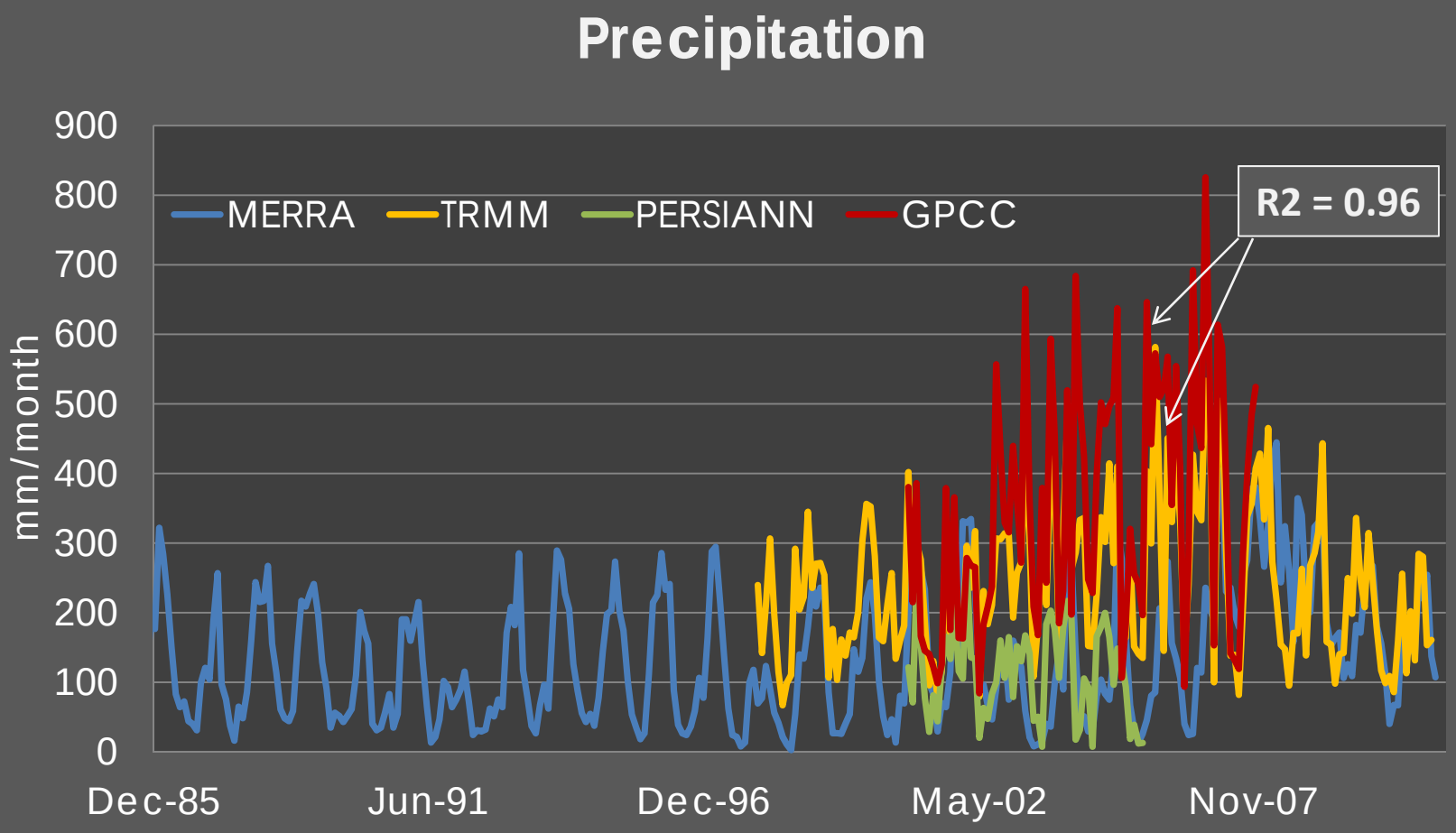


1000 m radius

Results: *Anopheles* analysis



Results: LDAS



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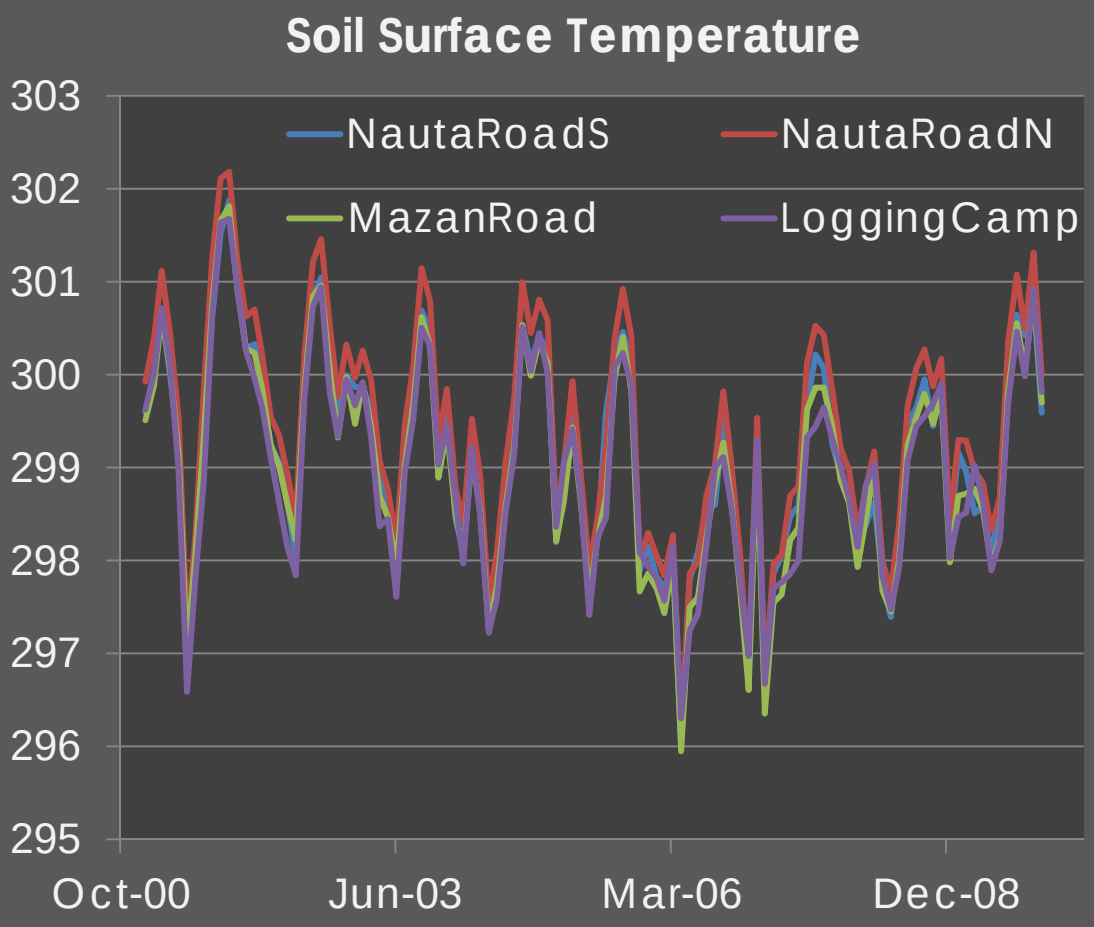

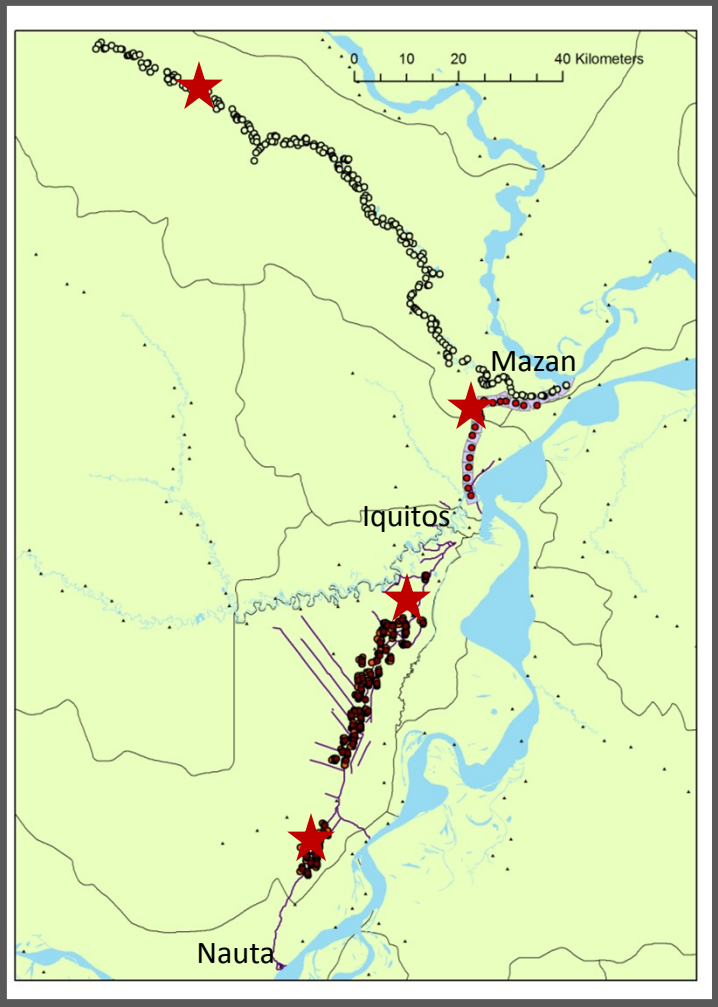

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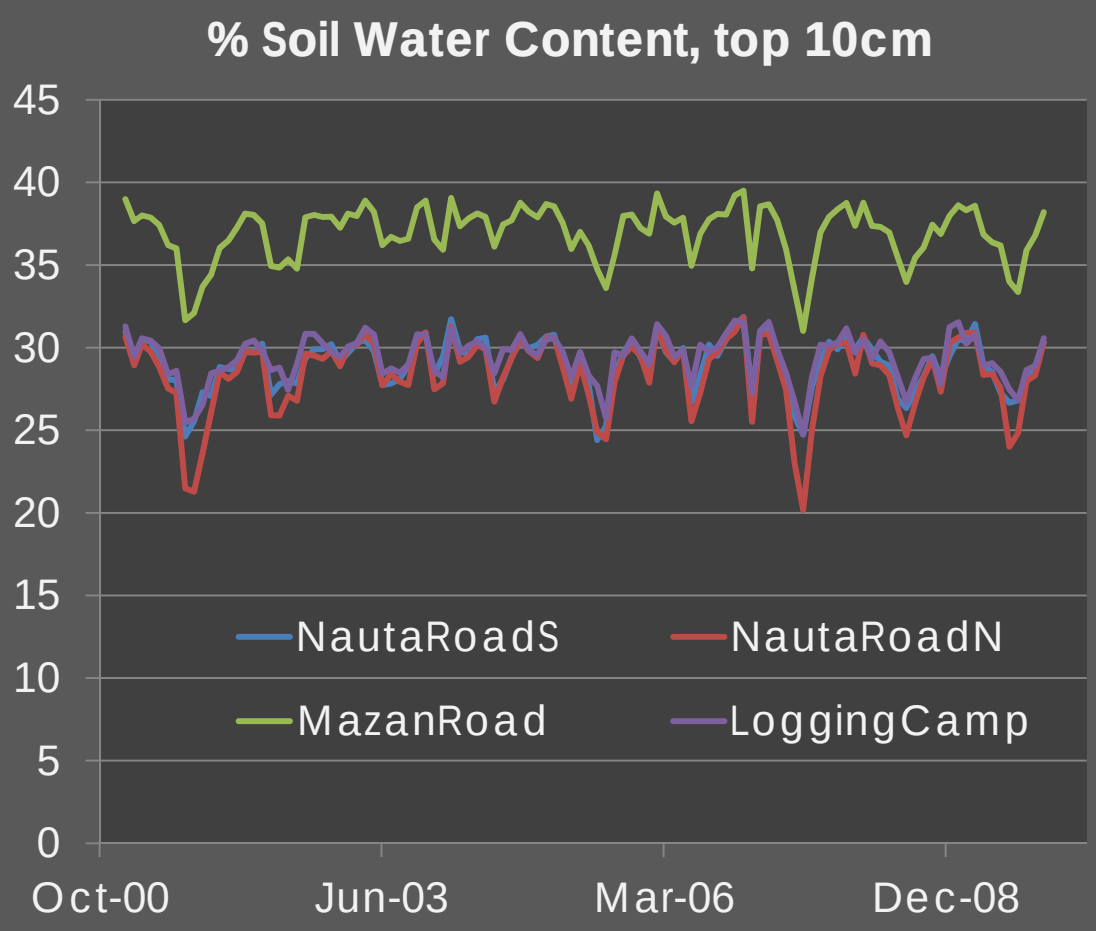

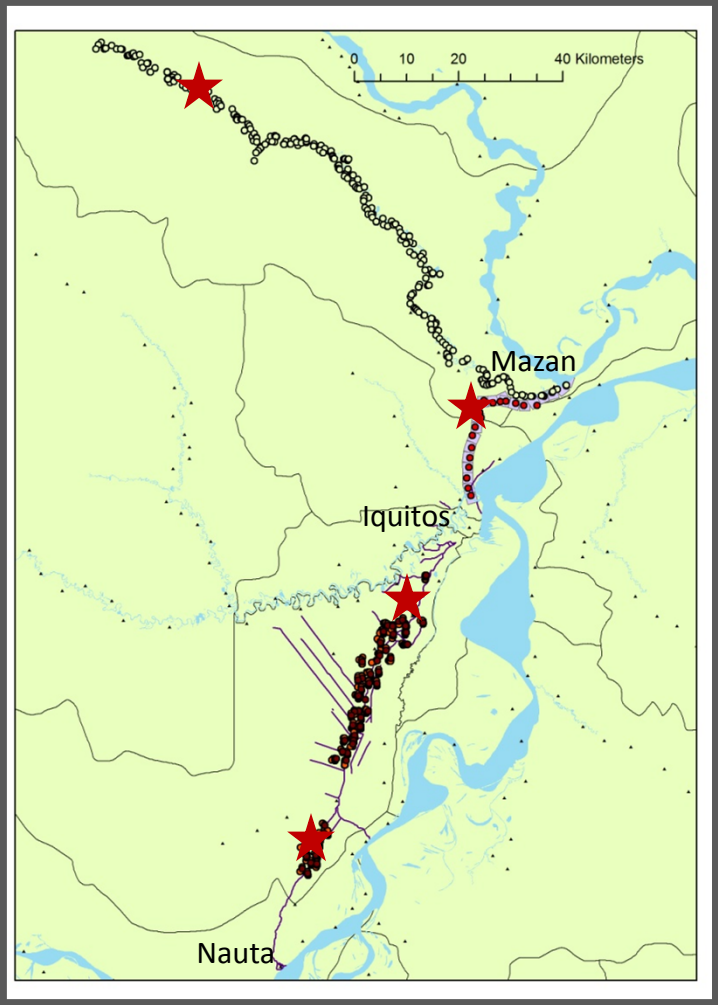

Conclusions

- Land Surface Model simulations show strong potential to inform predictions of *Anopheles* distribution
  - Active data assimilation not yet tested
- The relationship between land cover and mosquito distribution is robust and species-specific, and it appears to be strongest at 3-5km radius of influence

Next Steps

- Integrate LDAS results to *Anopheles* distribution models
- Compile Human settlements and activities map
- Continued and enhanced mosquito collection and malaria monitoring
- Work with end-user partners to ensure that the products are taking on a useful form
- Constant cross-examination of accepted hypotheses regarding what governs malaria risk in this region

THANK YOU