

# MODELING IN PRACTICE: THE LIFE CYCLE OF A MODELING PROJECT, FROM CONCEPTION TO PUBLICATION

- The example of Buruli ulcer in Cameroon -



Andrés Garchitorená

Researcher, Institut de Recherche pour le Développement

Research Advisor, PIVOT Madagascar

*E<sup>2</sup>M<sup>2</sup> Workshop  
Ranomafana, January 2019*

## Steps in a modeling project

1. *Development of the study concept and question*
2. *Literature review*
3. *Data collection*
4. *Construction of model framework*
5. *Model analyses and selection*
6. *Model validation*
7. *Manuscript writing and submission*



- What is your question?
- Why is it interesting?
- Who is interested?
- Can it be narrowed down to a question about specific quantitative relationships?

# Literature review

- Who has tried to answer this before and how did they do it?
  - Empirical studies
  - Modeling studies
- What are these studies short-comings?
- Are there already parameter estimates or data sets to help you answer

Alegana et al. International Journal of Health Geographics 2012, 11:6  
<http://www.i-jhgeographics.com/content/11/1/6>



## RESEARCH Open Access

### Spatial modelling of healthcare utilisation for treatment of fever in Namibia

Victor A Alegana<sup>1\*</sup>, Jim A Wright<sup>2</sup>, Usiku Pentrina<sup>1</sup>, Abdusalan M Noor<sup>1,4</sup>, Robert W Snow<sup>1,4</sup> and Peter M Atkinson<sup>2</sup>

#### Abstract

**Background:** Health care utilization is affected by several factors including geographic accessibility. Empirical data on utilization of health facilities is important to understanding geographic accessibility and defining health facility catchments at a national level. Accurately defining catchment population improves the analysis of gaps in access, complexity of service delivery and disease incidence. Here, empirical household survey data on treatment of acute fevers were used to model the utilization of public health facilities and define their catchment areas and populations in northern Namibia.

**Methods:** This study uses data from the Malaria Indicator Survey (MIS) of 2009 on treatment seeking for fever among children under the age of five years to characterize facility utilization. Probability of attendance of public health facilities for fever treatment was modelled against a theoretical surface of travel times using a three parameter logistic model. The fitted model was then applied to a population surface to predict the number of children treated at health facilities.

**Results:** Overall, from the MIS survey, the prevalence of fever among children was 17.6% (16.0–19.1) (40) of 2,263 children while public health facility attendance for fever was 51.1% (95% CI: 46.2–56.0). The coefficient of the logistic model of travel time against fever treatment at public health facilities were all significant ( $p < 0.001$ ). From this model, probability of facility attendance remained relatively high up to 180 minutes (3 hours) and thereafter decreased steadily. Total public health facility attendance population of children under the age five was estimated to be 1,052,286 in northern Namibia.

**Conclusion:** This study demonstrates the potential of routine household surveys to empirically model health care utilization for the treatment of childhood fever and define catchment populations enhancing the possibilities of accurate commodity needs assessment and calculation of disease incidence. These methods could be extended to other African countries where detailed mapping of health facilities exists.

**Keywords:** Namibia, Fevers, Treatment, Spatial, Utilisation, Malaria

#### Background

Understanding population health care utilization and defining the catchment sizes of health providers are important for efficient planning and resource allocation [1,2]. Understanding as a function of health services and is affected by geographical accessibility, alongside

many other factors [3–9]. In low income countries, such as those of the African continent where the burden of ill health is greatest [10–14], adequate information on the location of populations, health services, facility utilization and the spatial distribution of health care characteristics are rarely available to develop high resolution utilization models nationally [15,16]. Available data on health care utilization are mainly from routine national household surveys undertaken every 3 to 5 years [17], while few countries have a spatial database of health service providers [18,19]. Recent developments in

International Journal of Epidemiology, 2017, 36(4), 708–718  
 doi: 10.1093/ije/dyw317  
 Advance Access Publication Date: 8 September 2016  
 Original article

## REVIEW

### Health services modifies the effect of pneumococcal vaccine on risk among children less than 2 in Bohol, Philippines

Victor A. Alegana,<sup>1</sup>\* Marilla Lucero,<sup>2</sup> Hanna Nohynek,<sup>3</sup> Rebecca Allo,<sup>2</sup> Socorro P Lupisan,<sup>2</sup> Dionele M Sanvictores,<sup>2</sup> Eric AF Simões,<sup>4</sup> for the ARIVAC Team

<sup>1</sup>Division of Epidemiology, Ohio State University, Columbus, OH, USA, <sup>2</sup>Medical Mission Manila, Philippines, <sup>3</sup>Department of Vaccination and Immunization for Health and Welfare, Helsinki, Finland, <sup>4</sup>Institute of Health Services and Policy Research, University of Washington, Seattle, WA, USA and <sup>5</sup>Children's Hospital of Philadelphia, Philadelphia, PA, USA

\*Correspondence: [valegana@osu.edu](mailto:valegana@osu.edu)

© The Author(s) 2017. This article is published with open access at <http://www.i-jhgeographics.com>. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

International Journal of Health Geographics, 2015, 14:69  
 DOI: 10.1186/s13034-015-0141-0

## ARTICLE

### Physical access to health services in rural Ethiopia

Emily L. Webb<sup>1</sup> and Karen M. Edmond<sup>1,2</sup>

<sup>1</sup>Women and Girls in Development, University of Michigan, Ann Arbor, MI, USA and <sup>2</sup>Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA

\*Correspondence: [karen.edmond@jhu.edu](mailto:karen.edmond@jhu.edu)

© The Author(s) 2015. This article is published with open access at <http://www.i-jhgeographics.com>. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Munangarwe et al. Reproductive Health 2016, 13(Suppl 1):S1  
 DOI: 10.1186/s12978-016-0141-0

## RESEARCH

### Barriers and facilitators to health seeking behaviours in pregnant women in southern Malawi

Khatia Munangarwe<sup>1,2\*</sup>, Helene Boen<sup>1</sup>, Marianne Vidler<sup>3</sup>, Cassim M. Pretorius-Tatenda Makanga<sup>2,3</sup>, Rahat Qureshi<sup>4</sup>, Eusebio Matete<sup>1,3</sup>, and Esperanza Sevane<sup>1,4</sup>

<sup>1</sup>Department of Community Medicine, University of Malawi, Blantyre, Malawi, <sup>2</sup>Department of Community Medicine, University of Malawi, Blantyre, Malawi, <sup>3</sup>Department of Community Medicine, University of Malawi, Blantyre, Malawi, <sup>4</sup>Department of Community Medicine, University of Malawi, Blantyre, Malawi

\*Correspondence: [khatia.munangarwe@unimail.ch](mailto:khatia.munangarwe@unimail.ch)

© Munangarwe et al. 2016. This article is published with open access at <http://www.i-jhgeographics.com>. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

All Tahir et al. International Journal of Health Geographics 2010, 9:38  
<http://www.i-jhgeographics.com/content/9/1/38>



## RESEARCH

### Physical accessibility and utilization of health services in Yemen

Abdullah Al-Tahir<sup>1,4</sup>, Allan Clark<sup>2</sup>, Joseph C Longenecker<sup>3</sup> and Christopher JM Whitty<sup>2</sup>

#### Abstract

**Background:** Assessment of physical access to health services is extremely important for planning. Complex methods that incorporate data inputs from road networks and transport systems are used to assess physical access to healthcare in industrialized countries. However, such data inputs hardly exist in many developing countries. Straight-line distances between the service provider and resident population are easily obtained but their relationship with driving distance and travel time is unclear. This study aimed to investigate the relationship between different measures of physical access, including straight-line distances, road distances and travel time and the impact of these measures on the protection of children in Yemen.

**Methods:** Coordinates of houses and health facilities were determined by GPS machine in Urban and rural areas in Taiz province. Road distances were measured by an odometer of a vehicle driven from participants' houses to the nearest health centre. Driving time was measured using a stop-watch. Data on children's vaccination were collected by personal interview and recorded by a handheld device.

**Results:** We found correlation between straight-line distances, driving distances and driving time (straight line distances vs. driving distance:  $r = 0.92$ ,  $p < 0.001$ ; straight line distances vs. driving time:  $r = 0.73$ ,  $p < 0.001$ ; driving distance vs. driving time:  $r = -0.83$ ,  $p < 0.001$ ). Each measure of physical accessibility showed strong association with vaccination of children after adjusting for socio-economic status.

**Conclusion:** Straight-line distances, driving distances and driving time are strongly linked and associated with vaccination uptake. Straight-line distances can be used to assess physical access to health services where data inputs on road networks and transport are sparse. Impact of physical access is clear in Yemen, highlighting the need for efforts to target vaccination and other preventive healthcare measures to children who live away from health facilities.

#### Background

Access to health services is difficult to define. It is a multidimensional process that in addition to the quality of care, involves geographical accessibility, availability of the right type of care for those who need it, financial accessibility and acceptability of service [1]. Geographic accessibility, the distance that must be travelled in order to use a health facility, may present an important barrier to access to health services [2,3]. Previous studies have presented strong evidence that physical proximity of health service can play an important role in the use of primary healthcare [2–12].

In Yemen, we have demonstrated that driving distance and driving time are important predictors for developing severe malaria in comparison to mild malaria [13]. It is hypothesized that long distance can be a significant obstacle to trying to seek medical help. The recent advances of Geographic Information Systems (GIS) have provided an important tool for health care planning particularly in measuring access to health services. Major progress was made in industrialized countries where the detailed data inputs such as detailed road networks and transport systems are available [14]. Shelly used cost path analysis in order to determine the minimum travel time and distance to the closest hospital via road network in New Zealand [16]. More recently there was an attempt to produce a single index for overall physical access to health services based on physical access to the resources and the amount of resources available [17]. Application of such methods in developing countries, however, remained constrained by the lack of

mild malaria [13]. It is hypothesized that long distance can be a significant obstacle to trying to seek medical help.

The recent advances of Geographic Information Systems (GIS) have provided an important tool for health care planning particularly in measuring access to health services. Major progress was made in industrialized countries where the detailed data inputs such as detailed road networks and transport systems are available [14].

Shelly used cost path analysis in order to determine the minimum travel time and distance to the closest hospital via road network in New Zealand [16]. More recently there was an attempt to produce a single index for overall physical access to health services based on physical access to the resources and the amount of resources available [17]. Application of such methods in developing countries, however, remained constrained by the lack of

# Introduction

\*Correspondence: [valegana@osu.edu](mailto:valegana@osu.edu)  
 © The Author(s) 2017. This article is published with open access at <http://www.i-jhgeographics.com>. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

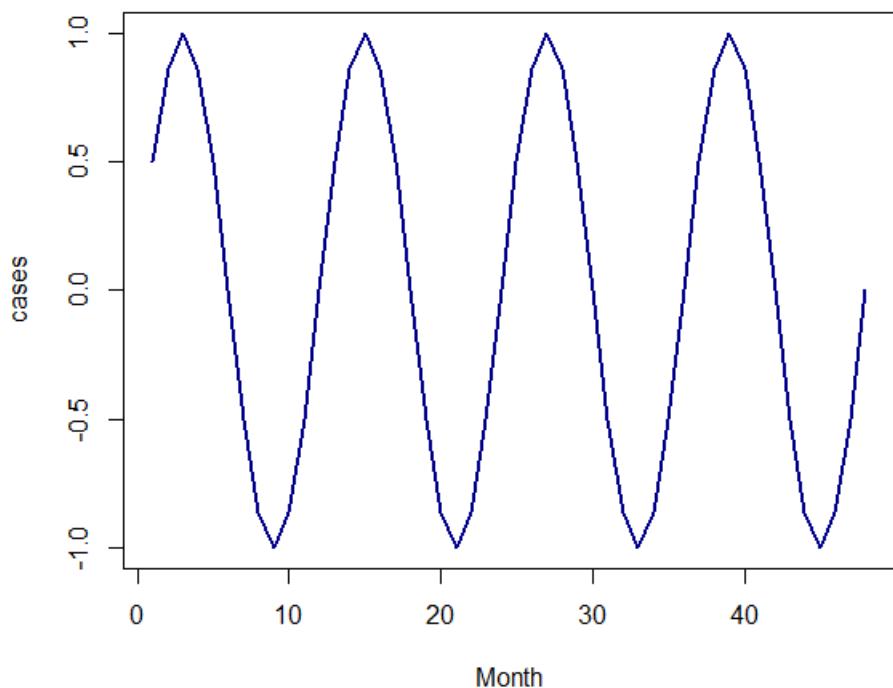
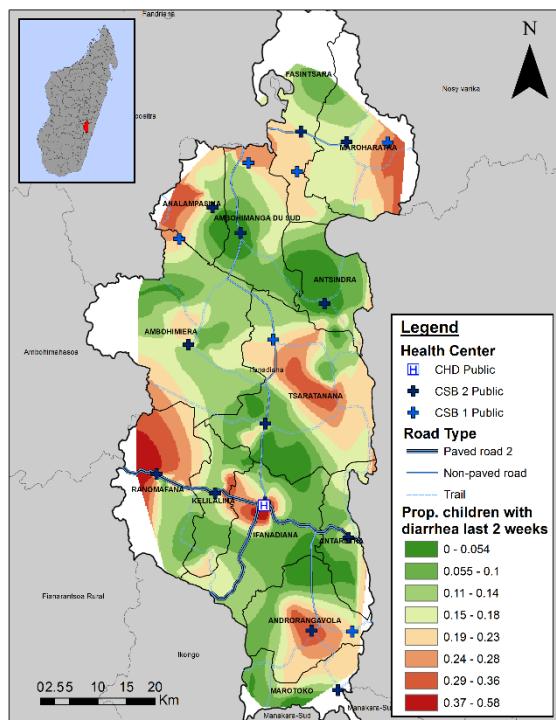
<sup>1</sup>Centre for Health Services and Population Research, Malaria and Health & Epidemiology Group, Centre for Geographic Medicine Research – Kisumu, Kenya Medical Research Institute/Walter Reed School of Medicine, Kisumu, Kenya  
 Full list of author information is available at the end of the article

Correspondence: [al-tahir@zcu.ac.za](mailto:al-tahir@zcu.ac.za)  
 © All Tahir et al. Licensee BioMed Central. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.



# Data collection

- What do you need to characterize?
  - Spatial and/or temporal dynamics
  - Relationships between parameters or systems

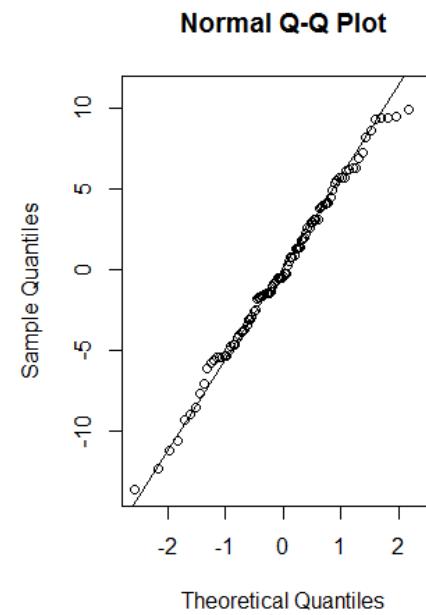
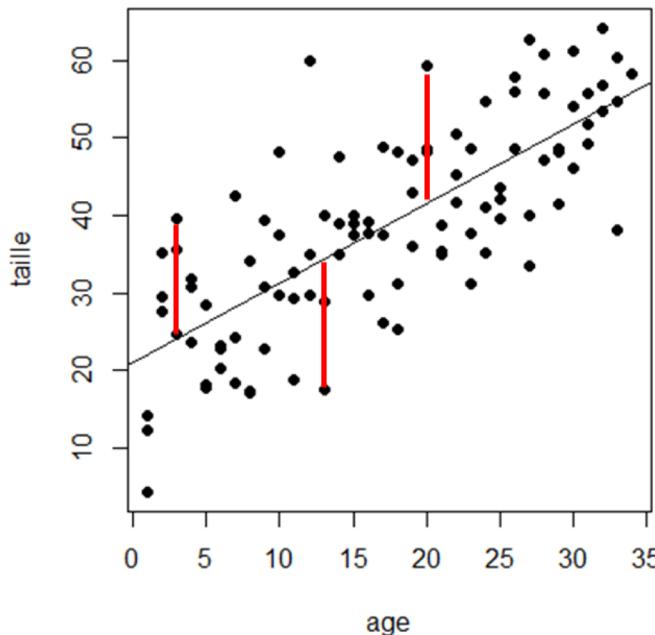


## Construction of model framework

- What drawbacks of previous studies can I mitigate?
- What type of modeling is necessary to answer my question?
  - Statistical: GLM, spatial, time-series, etc.
  - Mathematical: population based, individual based
- What modeling elements are necessary for my question?
  - Stochasticity
  - Compartments and complexity

# Model analysis, selection and validation

- What model(s) best fit my data and explain my question?
  - Comparison of alternative models and application of selection procedures
- Does the selected model suffer from any substantial drawbacks?
  - Statistical models: verification of model assumptions
  - Mathematical models: sensitivity analyses and out-of-sample predictions



# Types of modeling studies

## Without data collection

1. Purely theoretical studies
2. Parametrization based on published studies
  - Systematic reviews and meta-analyses
  - Experimental and field studies

1. Development of the study concept
2. Literature Review
3. Data collection
4. Construction of model framework
  - Dynamic equations and code
  - Relationships between parameters
5. Model analyses and selection
  - Parametrization
  - Simulations and debugging
6. Model validation
  - Model validation
  - Sensitivity analyses
7. Manuscript writing and submission

# Types of modeling studies

1. Development of the study concept
2. Literature Review
- 3. Data collection**
4. Construction of model framework
  - Statistical vs. Mathematical model
  - Model better adapted to our data
5. Model analyses and selection
  - Descriptive, univariate and multivariate
  - Parametrization and simulations
6. Model validation
  - Model validation, comparison
  - Sensitivity analyses
7. Manuscript writing and submission

## With data collection

1. Data already collected for other purposes
  - Focus only on analyses
  - Need to understand data limitations and quality
  - Need to adapt modeling to the available data
2. Data collected for the modeling project
  - Very time consuming
  - Modeling is generally more straightforward

Buruli-ulcer  
ecology Malaria

infectious-diseases

Environmental-changes

populations traps

modelling health

feedbacks Poverty M.ulcerans public

Deforestation links

Disease-Prevalence

---

# THE EXAMPLE OF BURULI ULCER IN CAMEROON

# Buruli ulcer



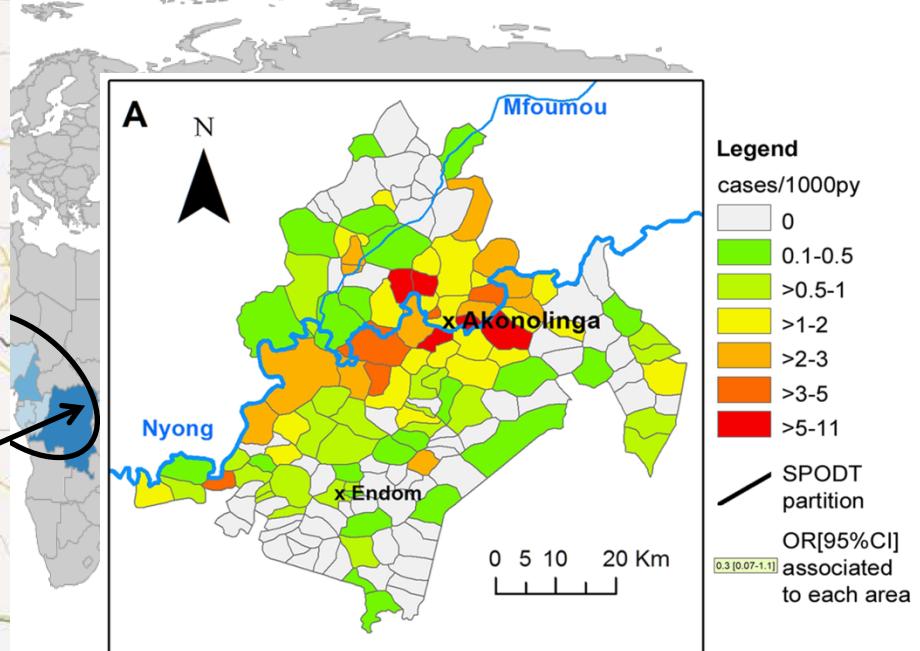
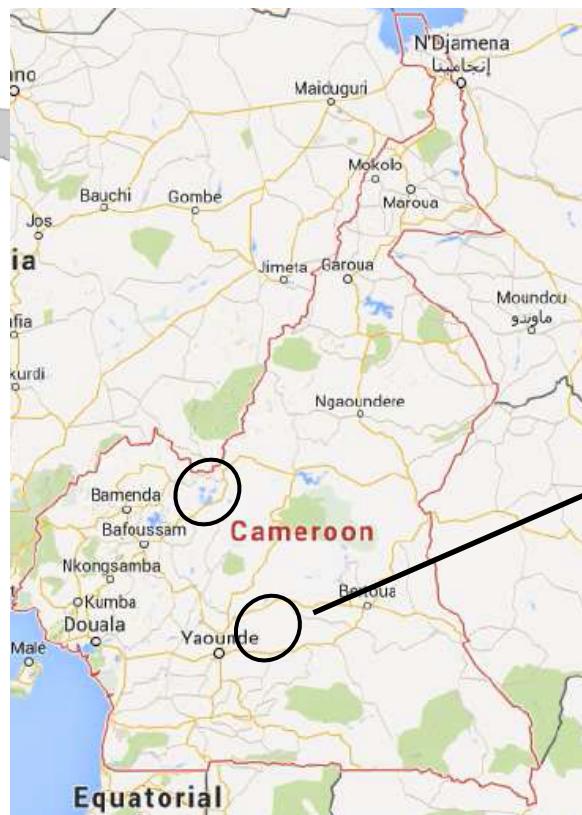
Most affected : Children <15 years

25% cases with functional limitations



Source of images: [www.who.int](http://www.who.int) (2014)

# Buruli ulcer: an emergent and neglected disease



WHO meeting on BU control and research (2013)

Landier *et al.* (2014, *PLoS NTDs*)

Cases in more than 30 countries

Focal distribution

Around 5000 new cases each year

What is my question?

Why is it interesting?

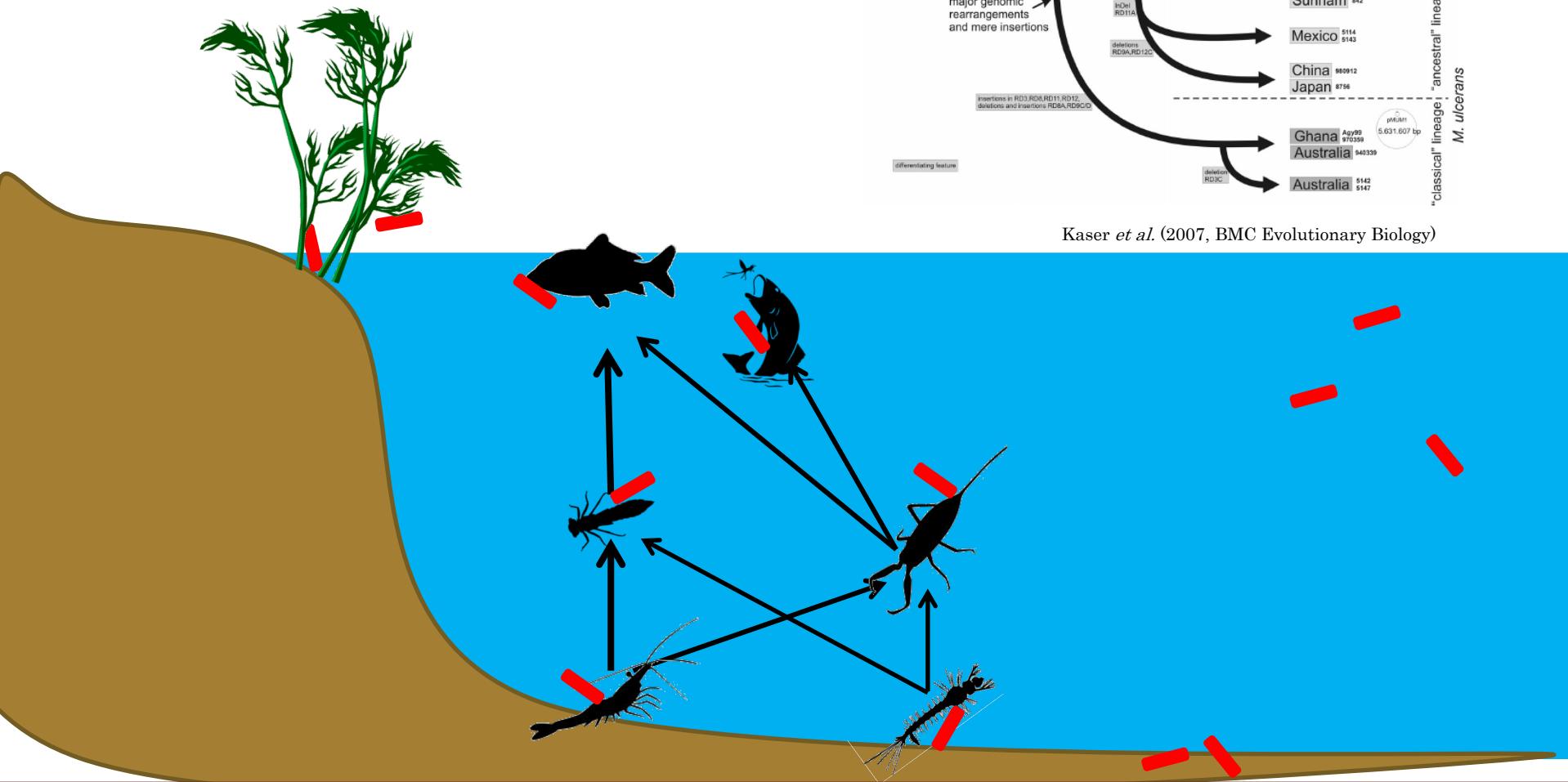
Who has tried to answer this before and how?

What are these studies short-comings?

# 1. LITERATURE REVIEW & IDENTIFICATION OF THE PROBLEM

# *Mycobacterium ulcerans*: generalities

Multi-host  
&  
Environmentally persistent



# Buruli ulcer: a disease linked to aquatic ecosystems

## BU Risk factors

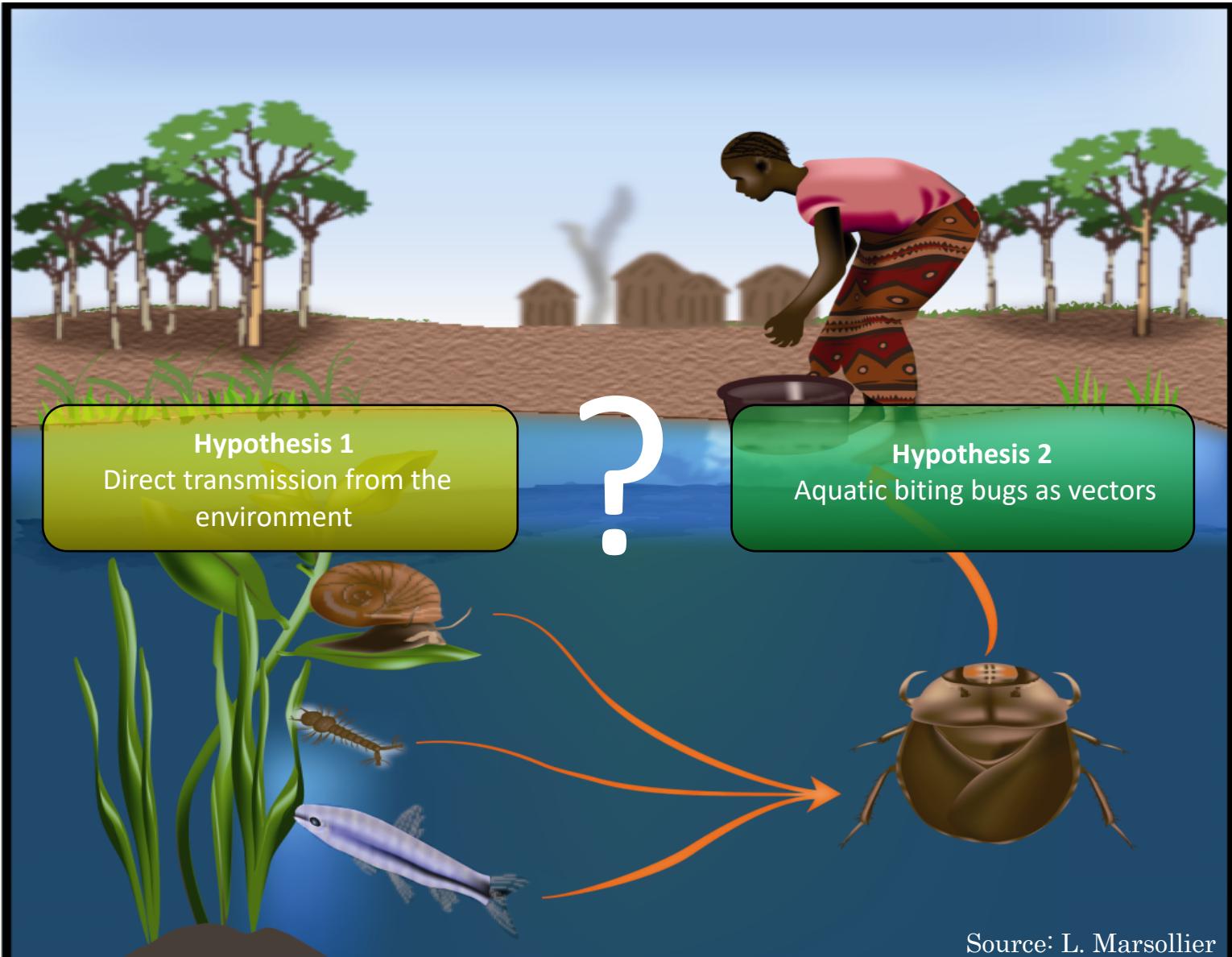
Proximity to stagnant or slow flowing waters

Activities near water

*M. ulcerans*



# Buruli ulcer: a mysterious disease



Source: L. Marsollier

# Objectives of the project

## General objective

To gain insights on the ecological determinants of Buruli ulcer disease.

## Specific objectives

1

To understand the effects of environmental factors on *M.ulcerans* ecology

2

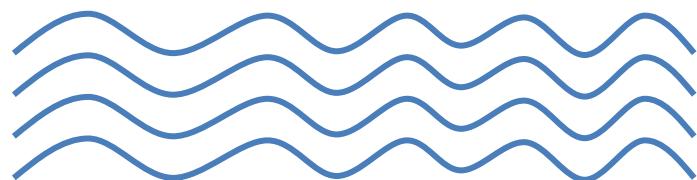
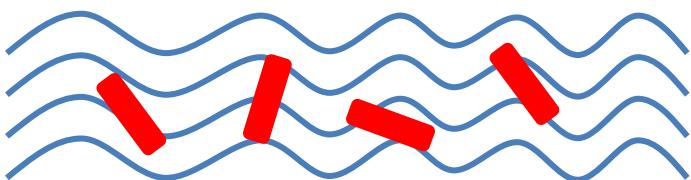
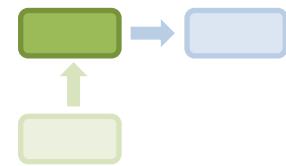
To study the transmission of *M.ulcerans* from the aquatic environment to humans

What do I need to characterize?

Spatial and/or temporal dynamics?

Relationships between parameters or systems?

# DATA COLLECTION & DESCRIPTIVE ANALYSES



# Regions of study

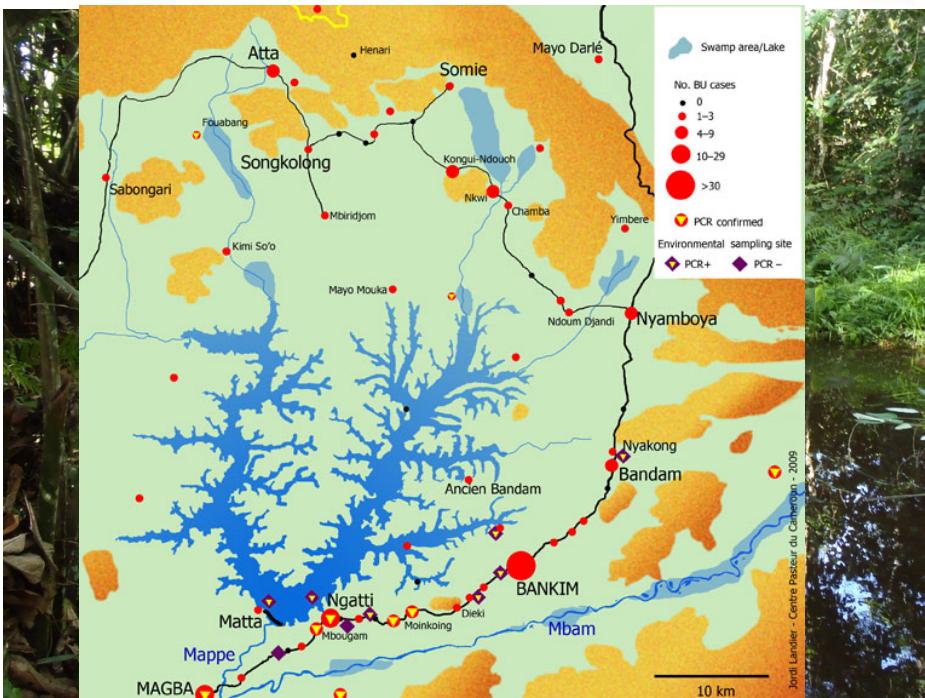
## Akonolinga

- Landscape: Tropical rainforest
- Historically endemic area (>40 years)



## Bankim

- Landscape: Savannah-Forest
- New endemic area (10 years)



Marion et al. (2011, EID)



Landier et al. (2014, PLoS NTDs)

## 1. Fieldwork: Environmental sampling



## 2. Laboratory (CPC): Taxonomic identification & Pool composition

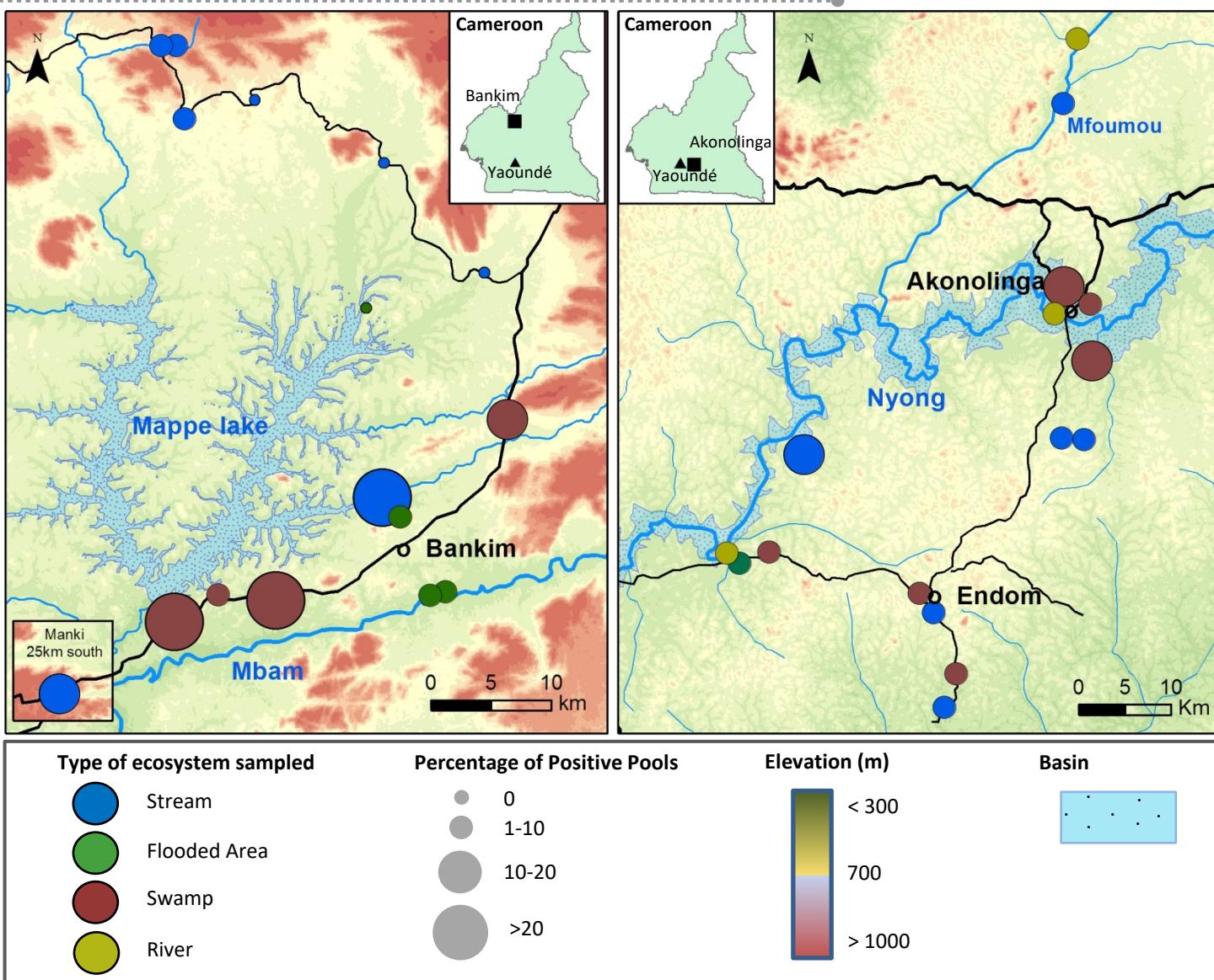
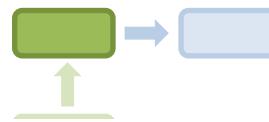


## 3. Laboratory (Angers): DNA extraction & Amplification



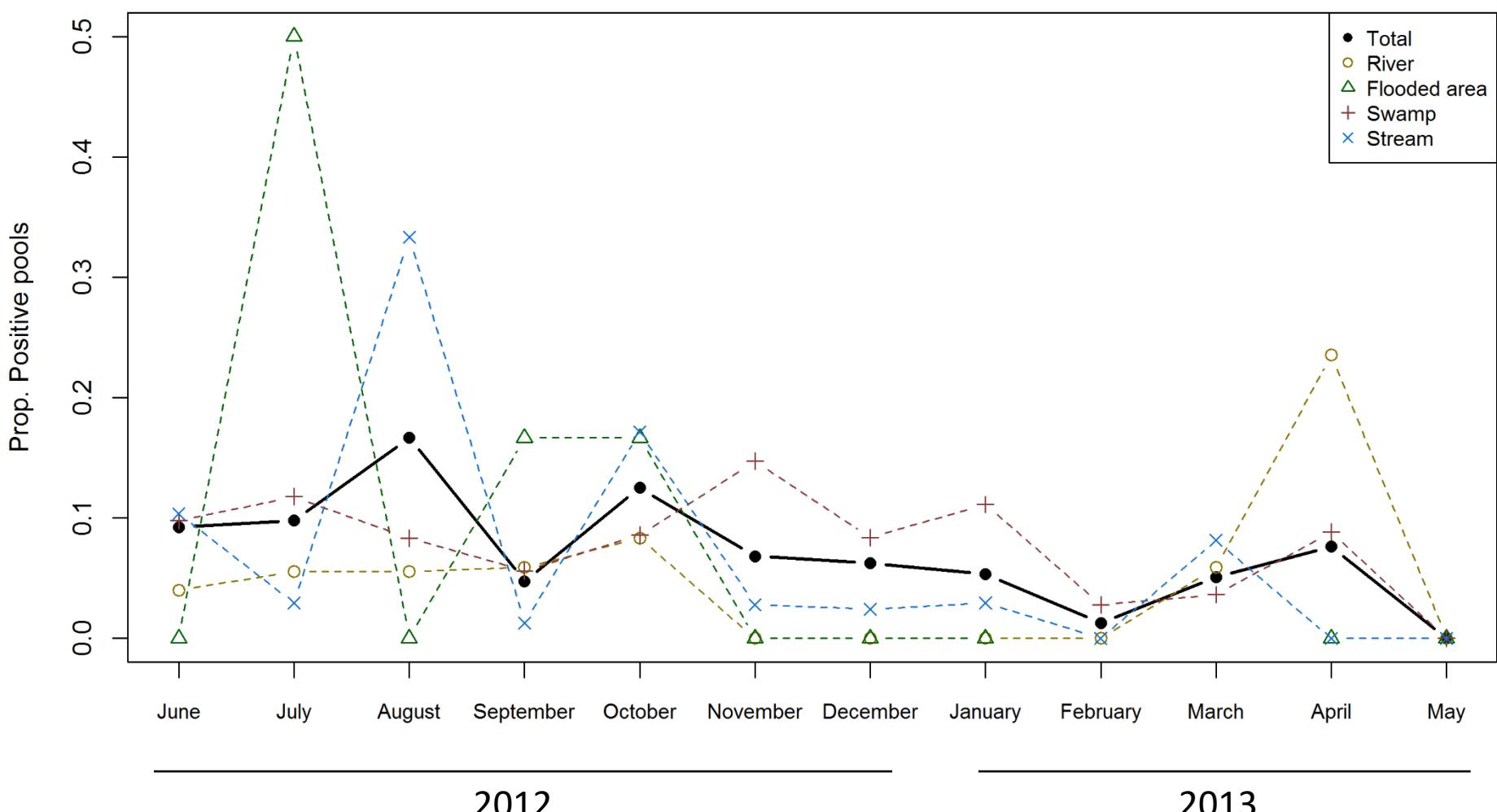
Characterization of MU in the environment

# *M. ulcerans* geographical distribution



Gachitoren et al. (2014, *PLoS NTDs*)

# Seasonal fluctuations of *M. ulcerans* in freshwater ecosystems

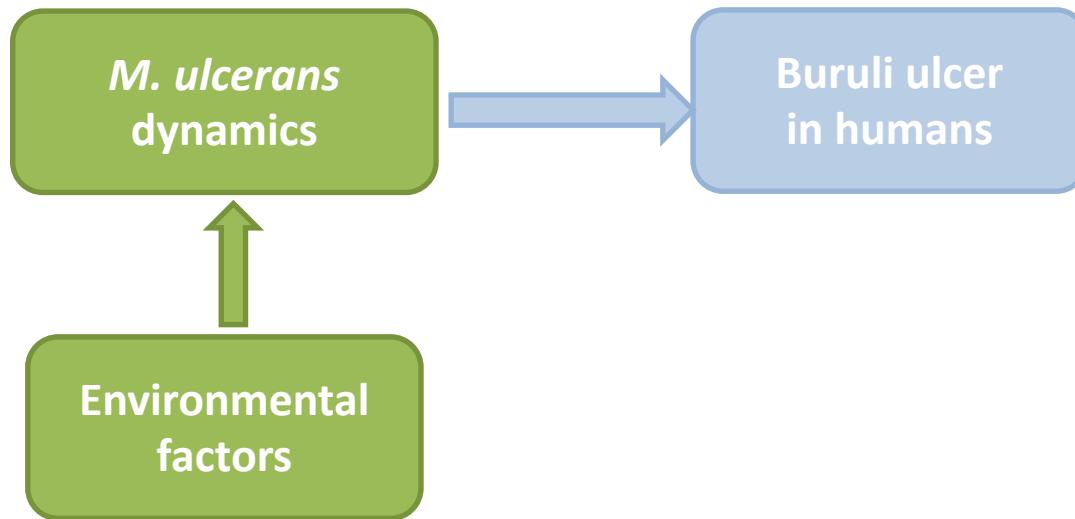


2012

2013

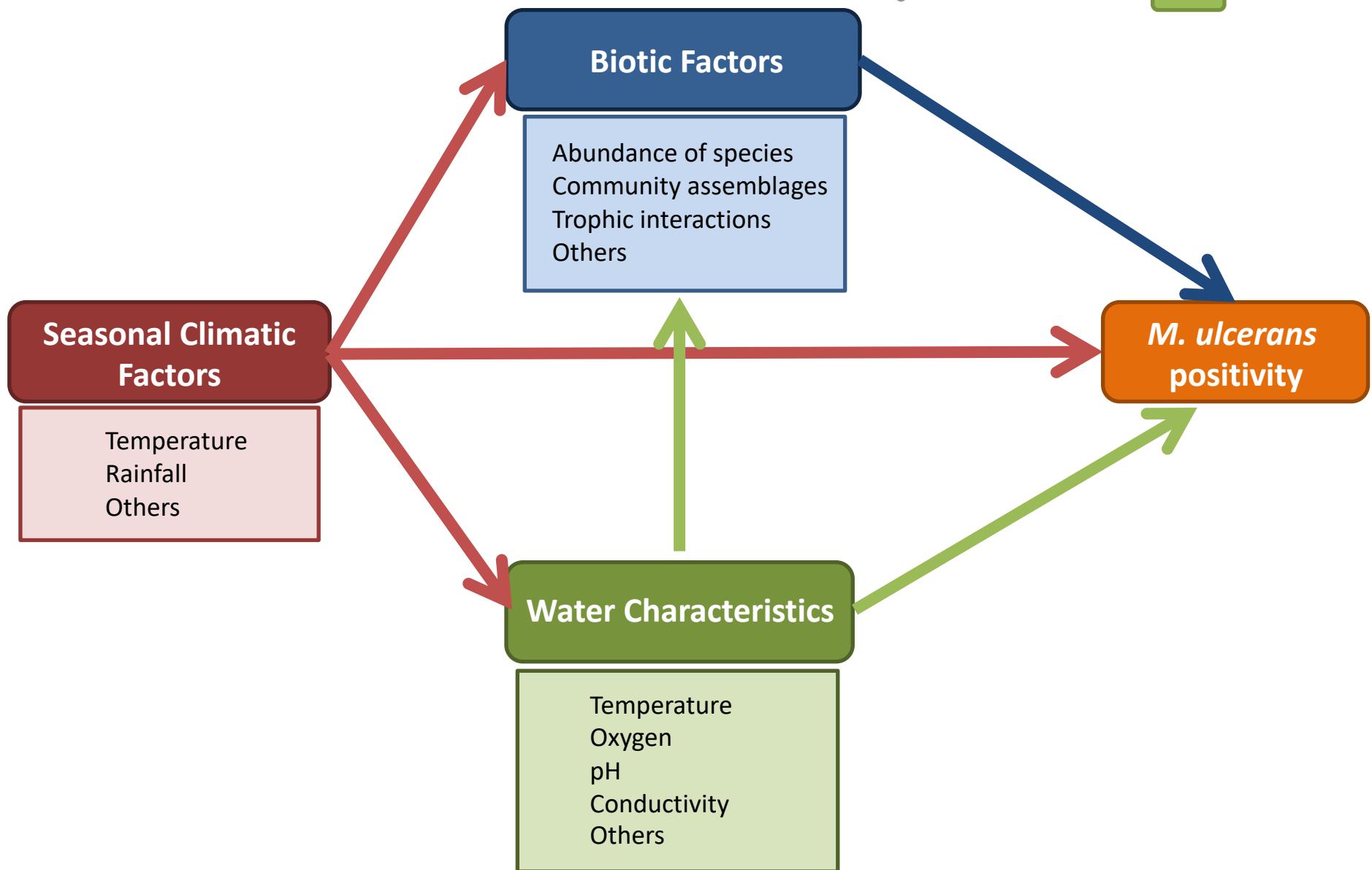
Gachitorená et al. (2014, *PLoS NTDs*)

What type of modeling is necessary to answer my question?

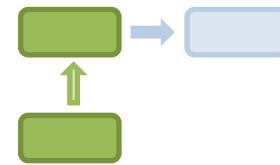


# STATISTICAL ANALYSES TO UNDERSTAND M. ULCERANS ECOLOGY

## Environmental drivers of *M. ulcerans*

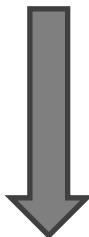


# Methodology: Multi-model approach



## Model Definition

- Generalized linear mixed model (binomial)
- **Random effect:** Sample site

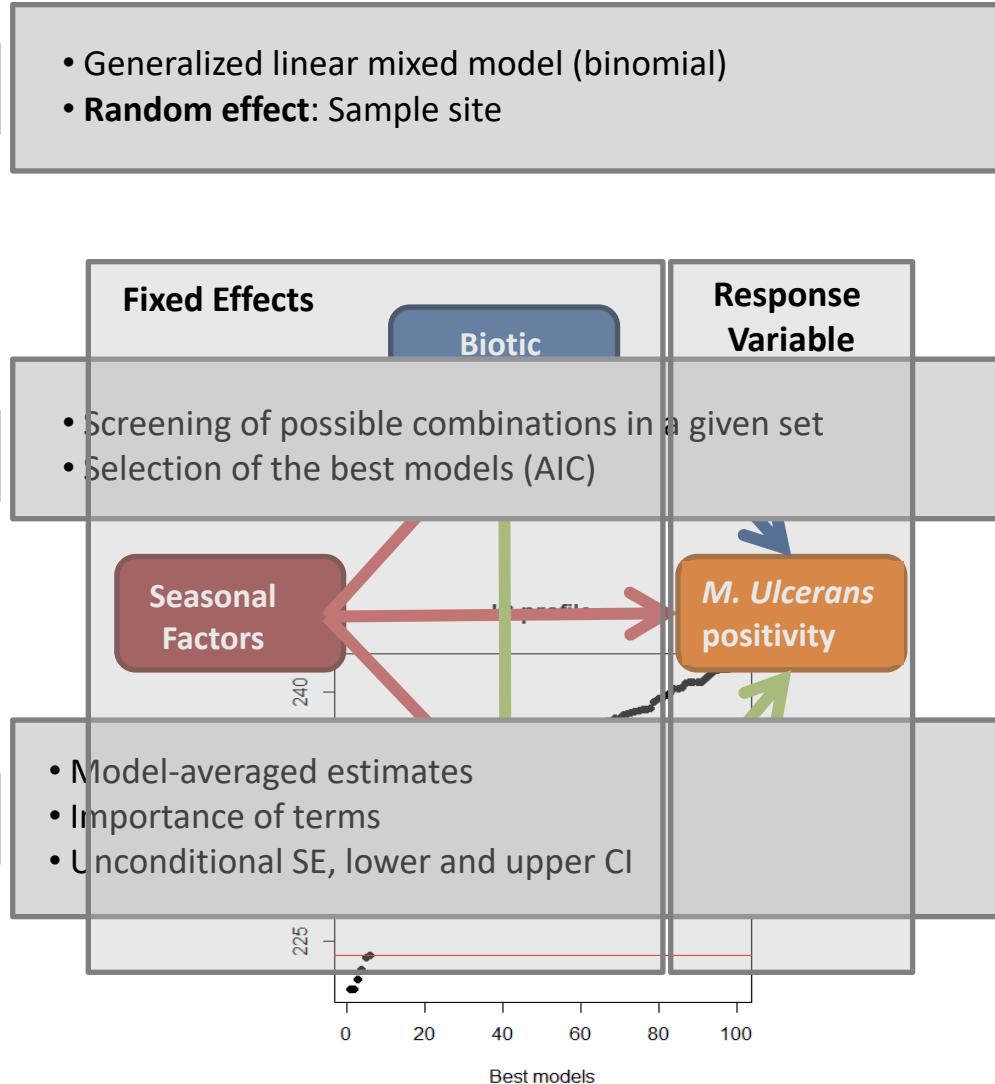


## Multi-model Selection

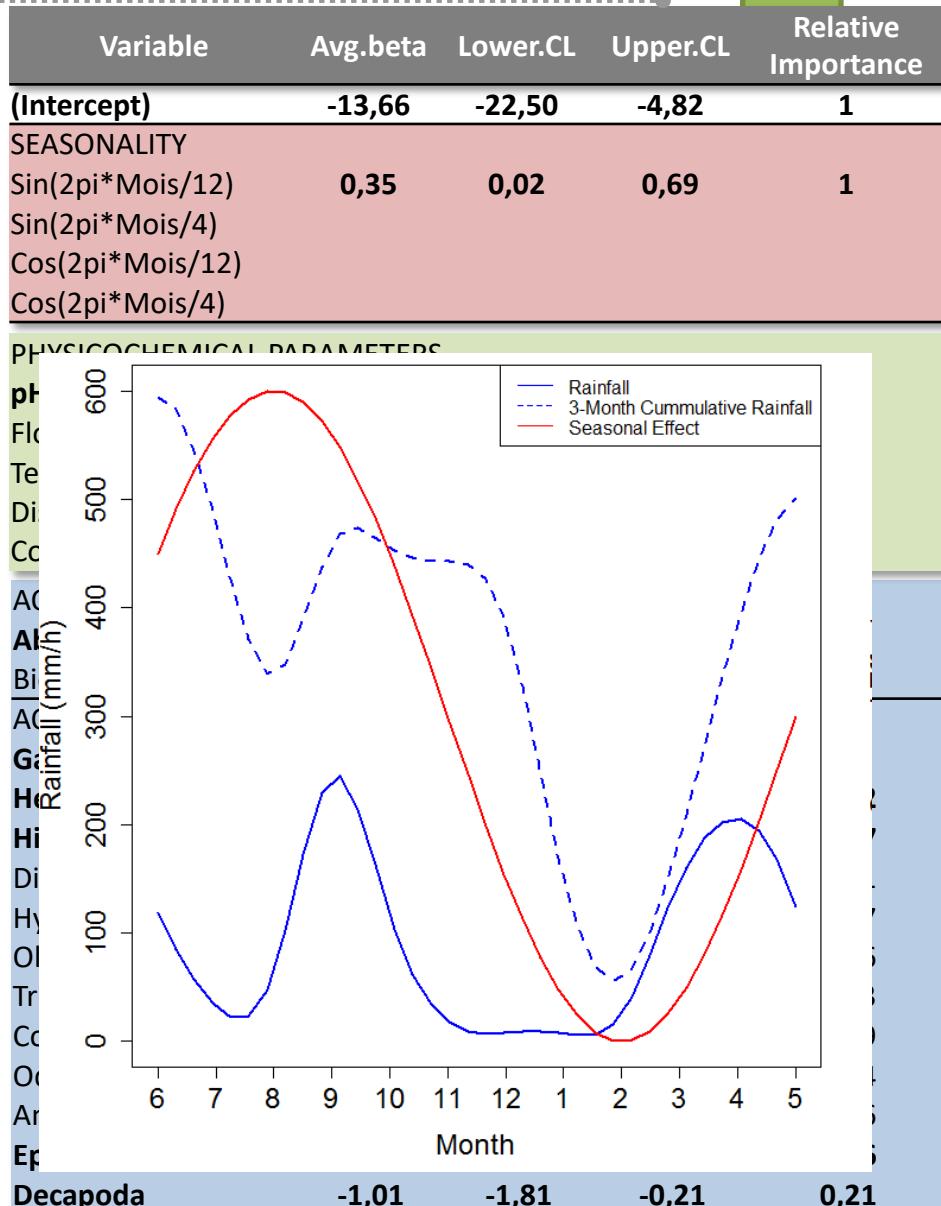
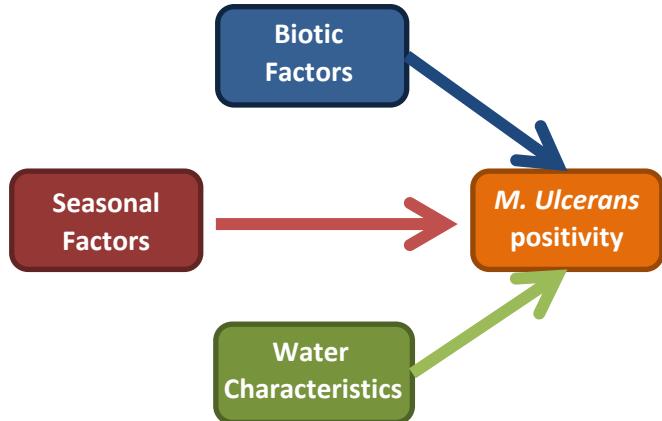
- Screening of possible combinations in a given set
- Selection of the best models (AIC)

## Multi-model Inference

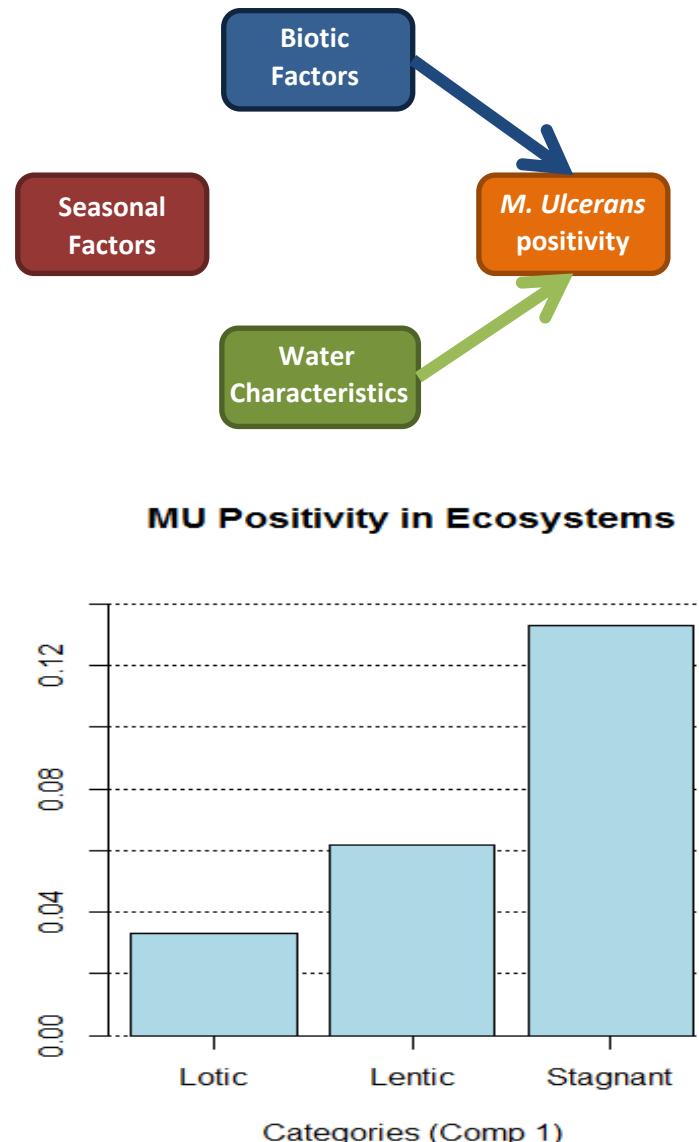
- Model-averaged estimates
- Importance of terms
- Unconditional SE, lower and upper CI



# Environmental drivers of *M. ulcerans*: Akonolinga

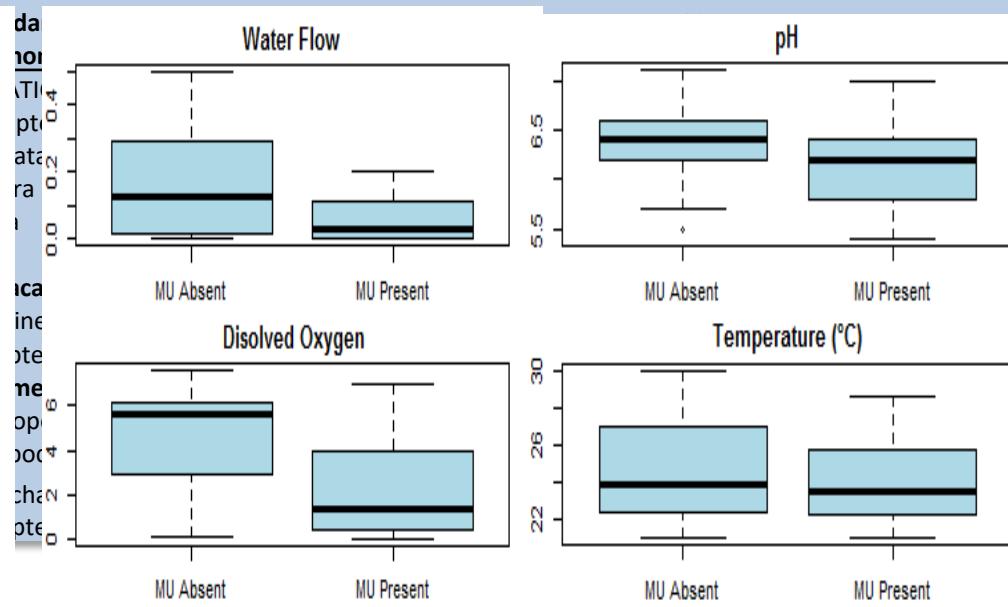


# Environmental drivers of *M. ulcerans*: Bankim

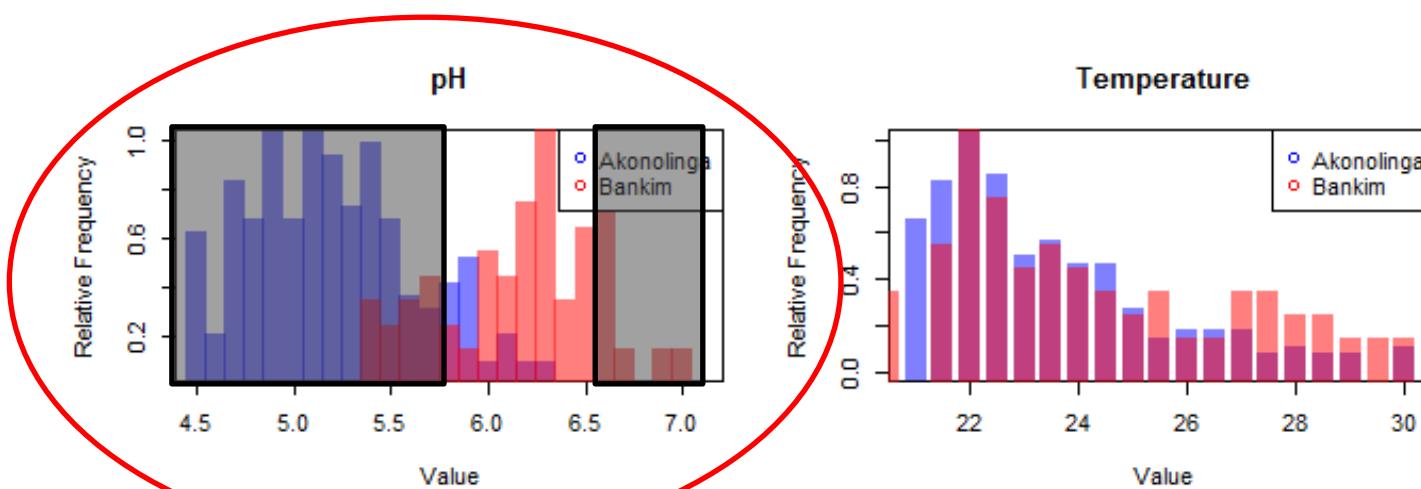
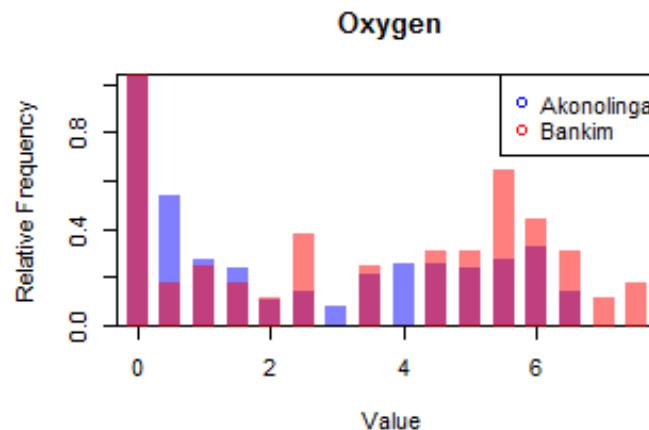
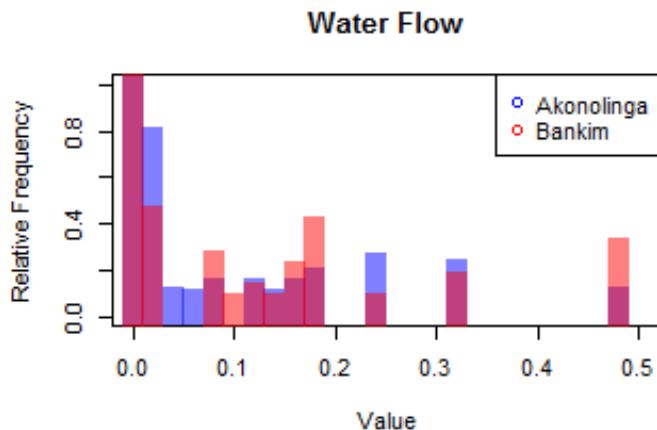
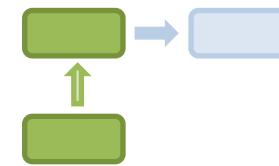


Variable	Avg.beta	Lower.CL	Upper.CL	Relative.Importance
(Intercept)	-10,13	-18,94	-1,32	1
<b>PHYSICO-CHEMICAL PARAMETERS</b>				
Water Flow (lentic)	-1,91	-3,25	-0,57	1
Water Flow (lotic)	-2,86	-4,38	-1,33	1
pH	-5,52	-15,64	4,61	0,02
Temperature				
Dissolved Oxygen				
Conductivity				
Comp3	0,24	-0,57	1,06	0,05
Comp1	0,34	-0,24	0,92	0,02
Comp2	-0,16	-0,85	0,53	0,01

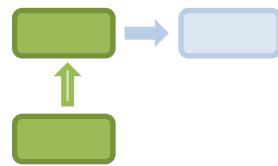
## COMMUNITY



# Why the two regions are so different?

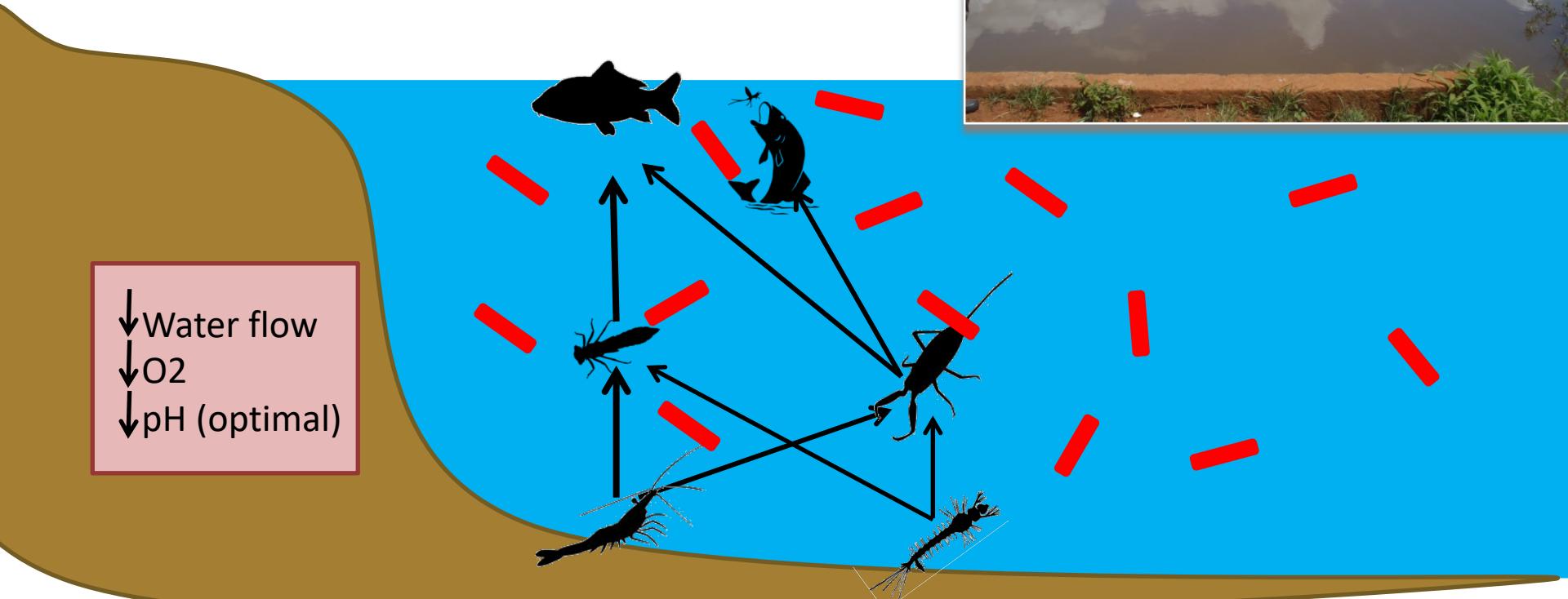


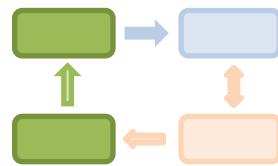
Optimal *pH* for MU [5.8-6.5]



### Scenario 1: Favourable physico-chemical conditions

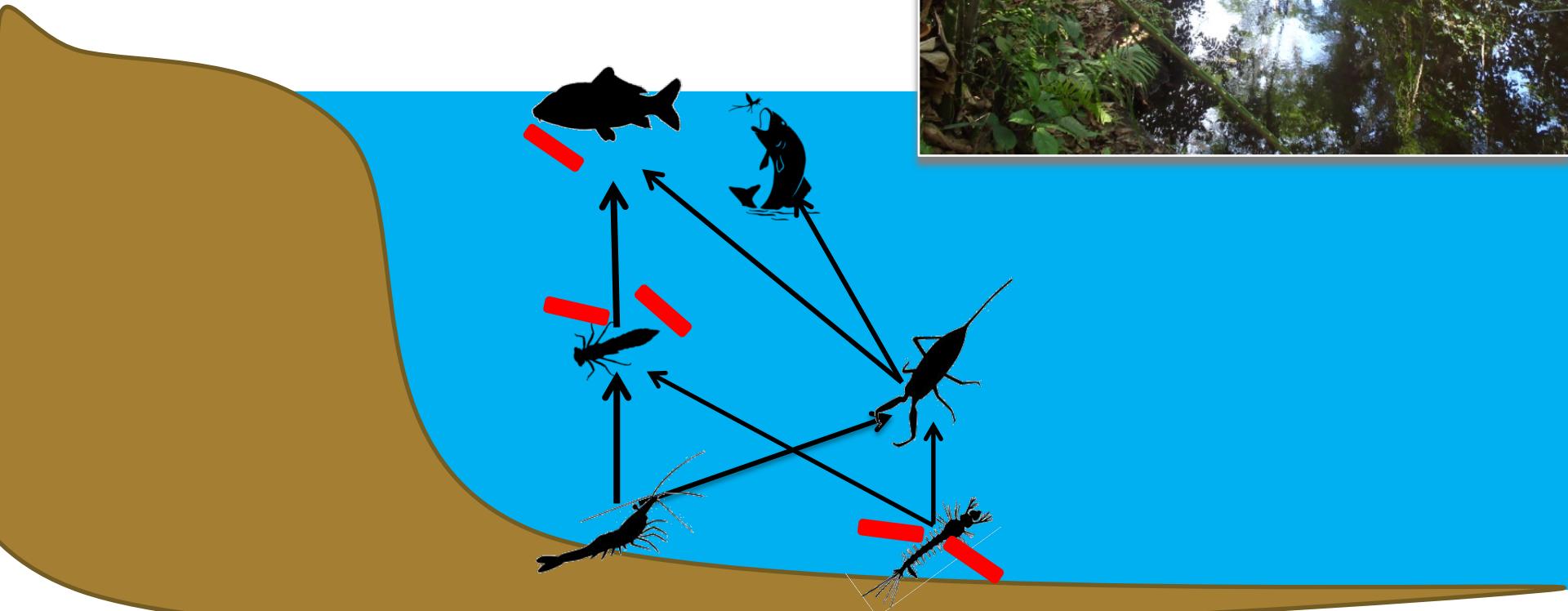
Free living stages  
&  
Environmental transmission to aquatic organisms



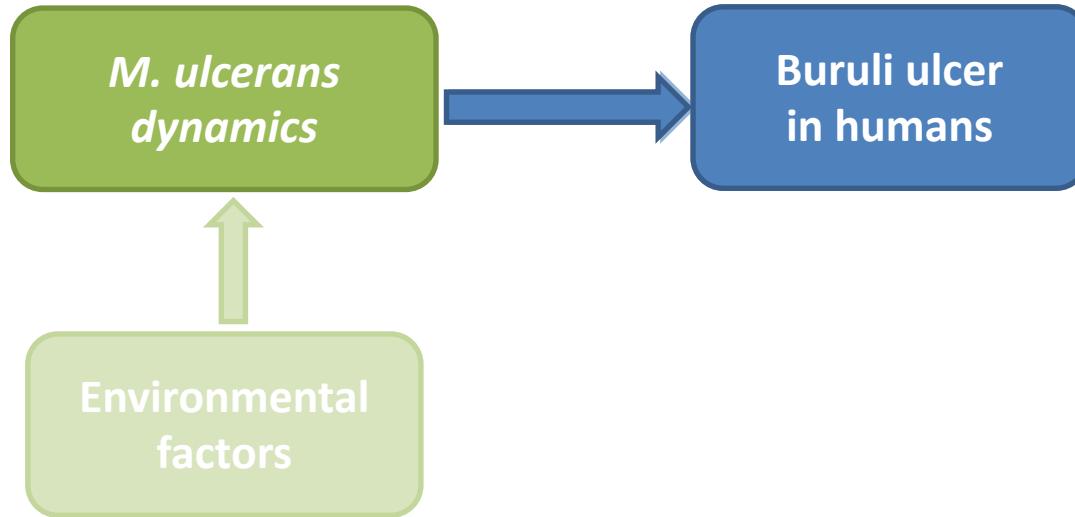


### Scenario 2: Adverse physico-chemical conditions

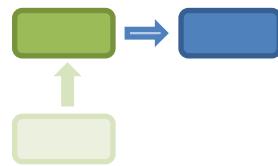
Mostly intra-host  
&  
Trophic transmission



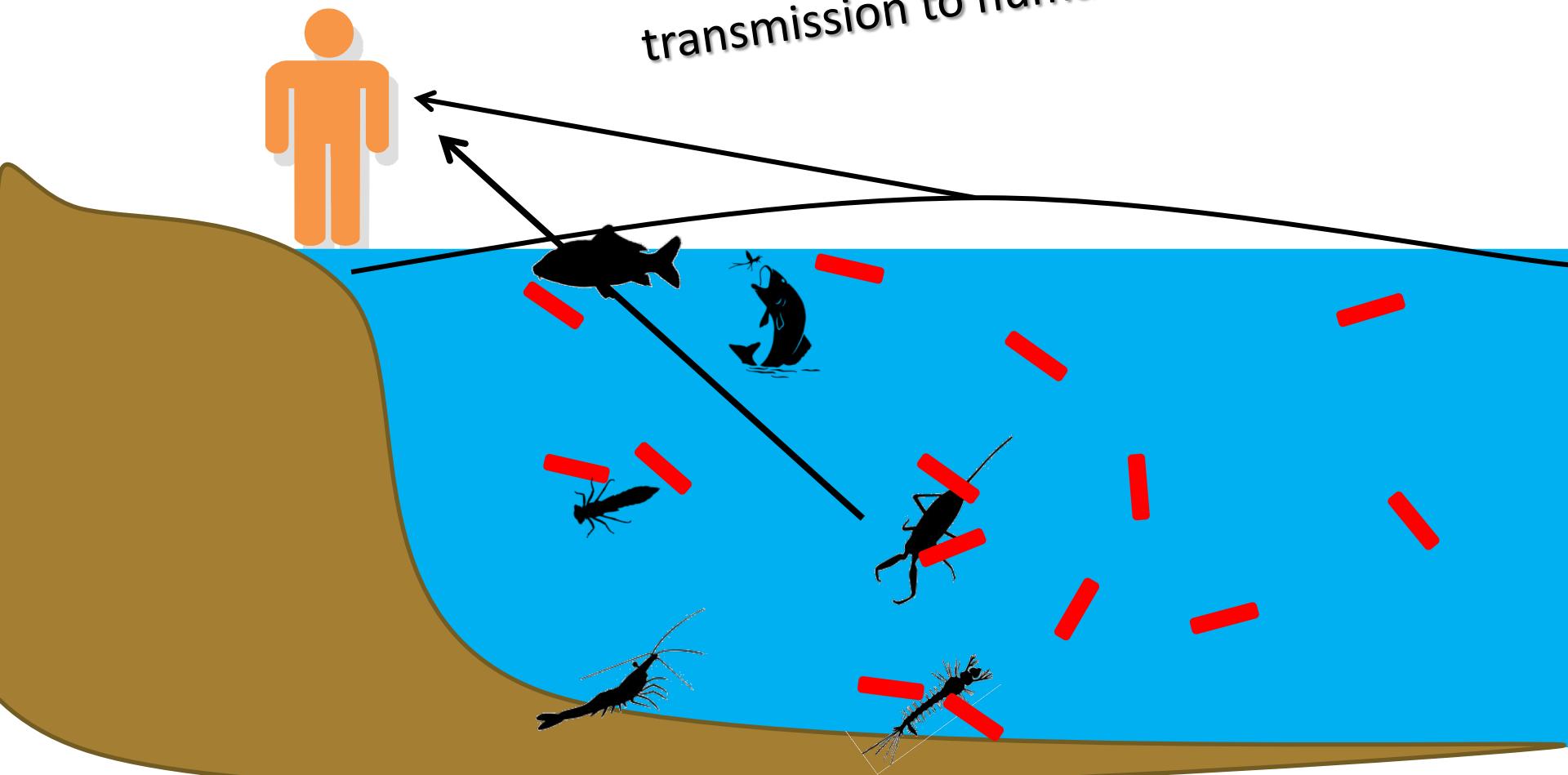
What type of modeling is necessary to answer my question?



# MATHEMATICAL MODELING TO UNDERSTAND BU TRANSMISSION

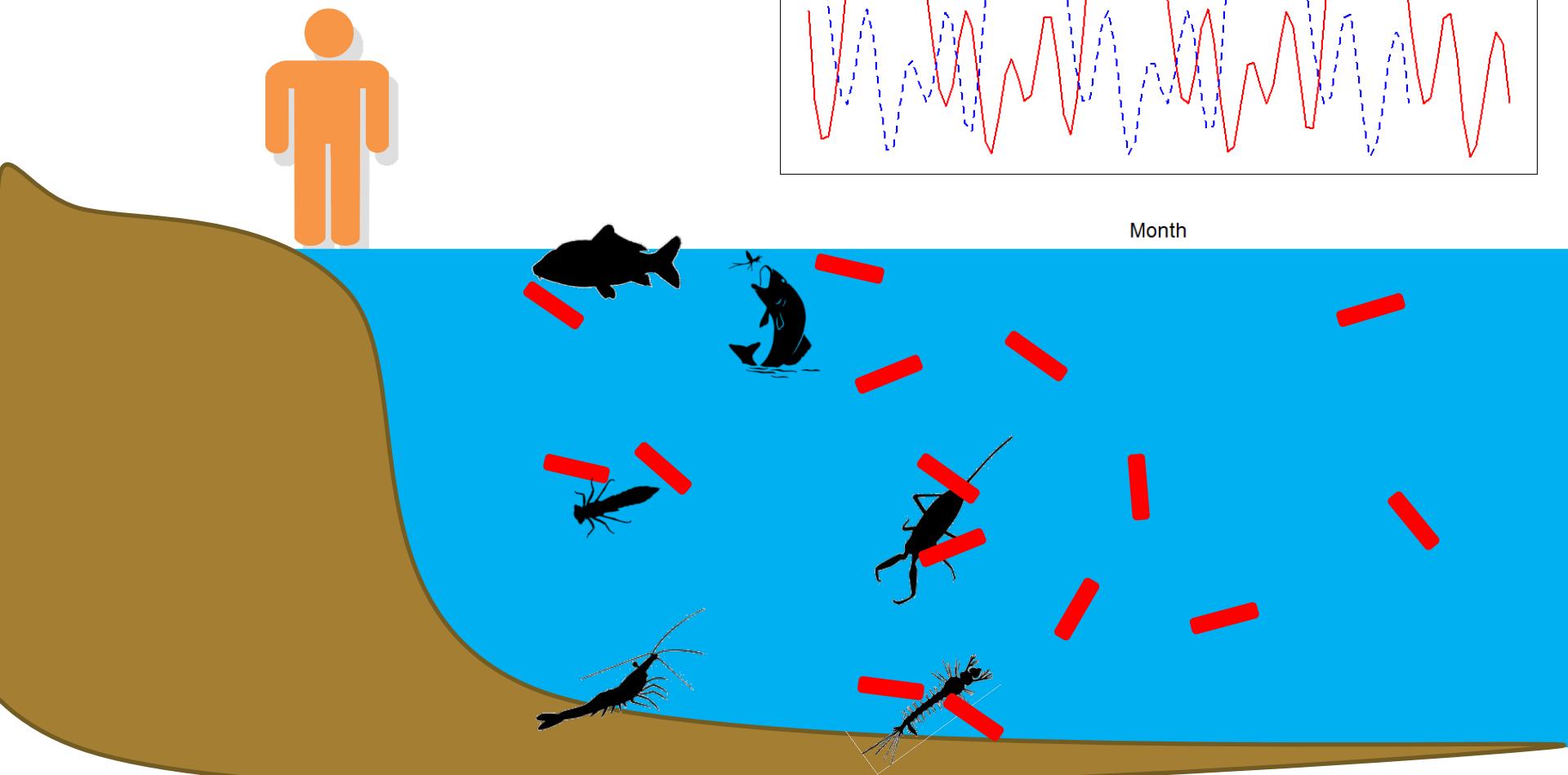


2 possible routes of transmission to humans

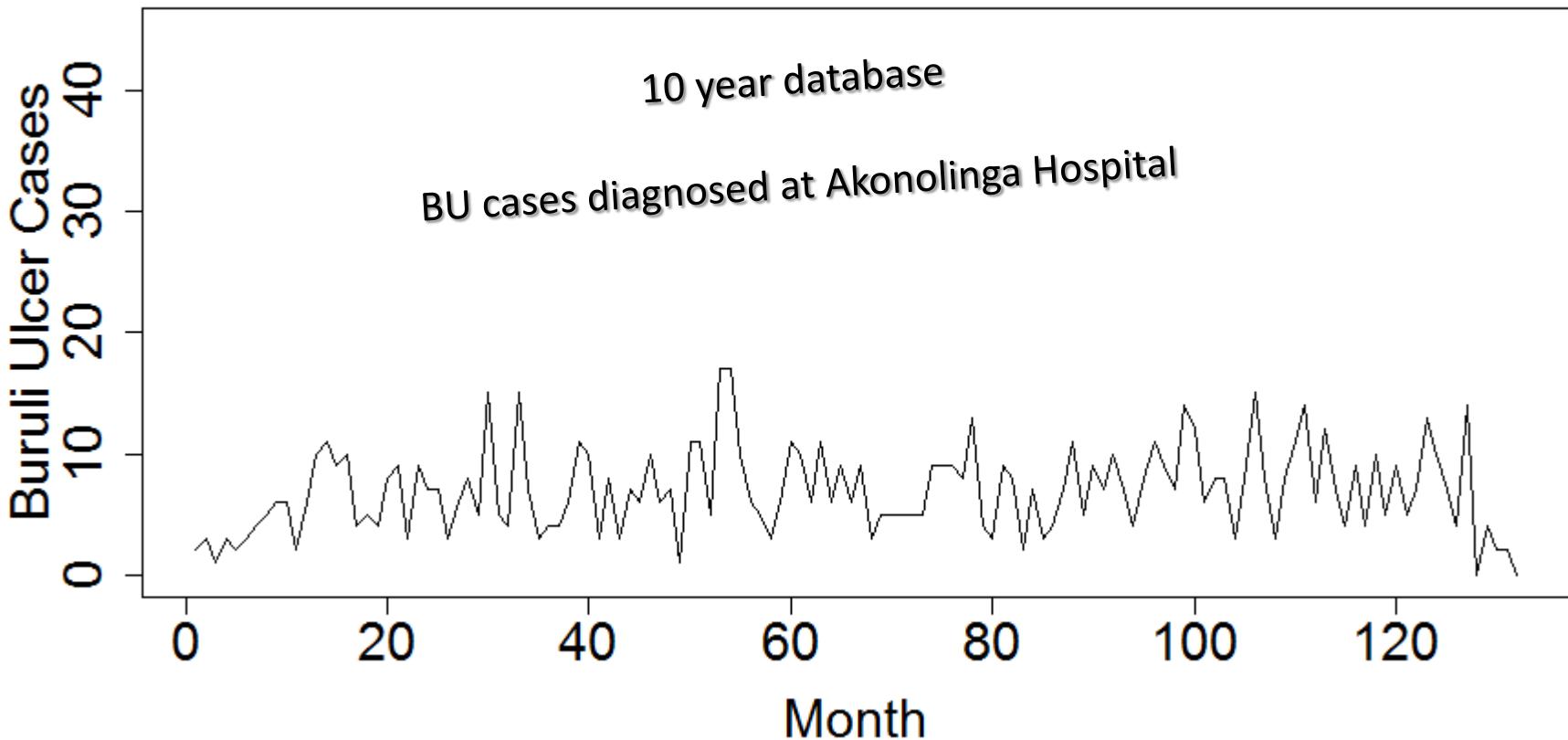
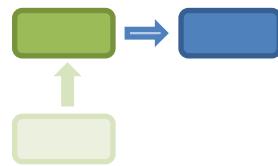


# Introduction

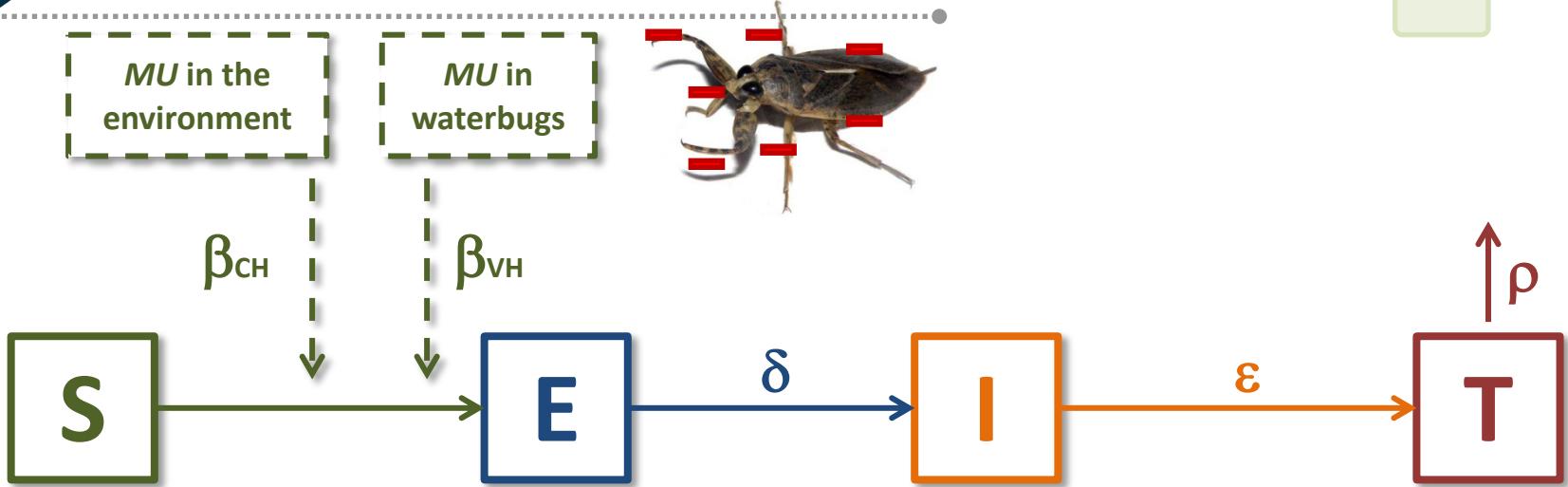
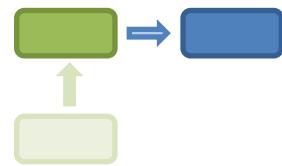
## Dynamic model



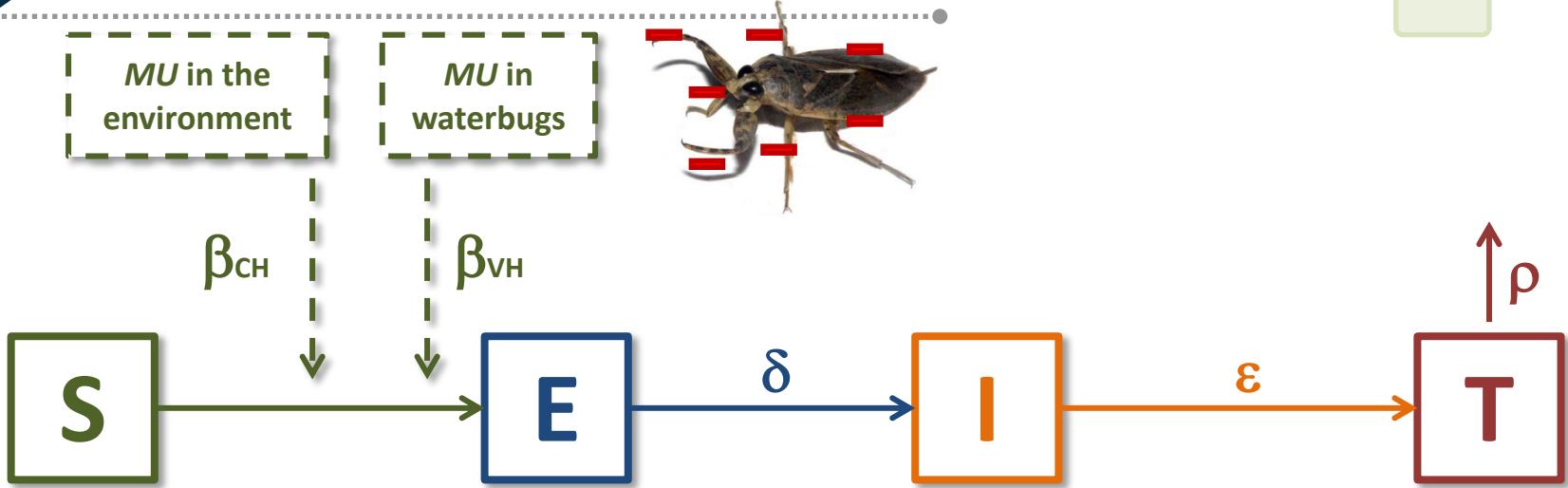
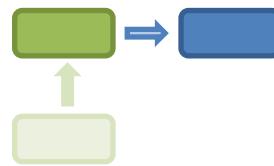
Transmission of MU to humans



# Mathematical model framework



# Mathematical model framework



## Mathematical Model

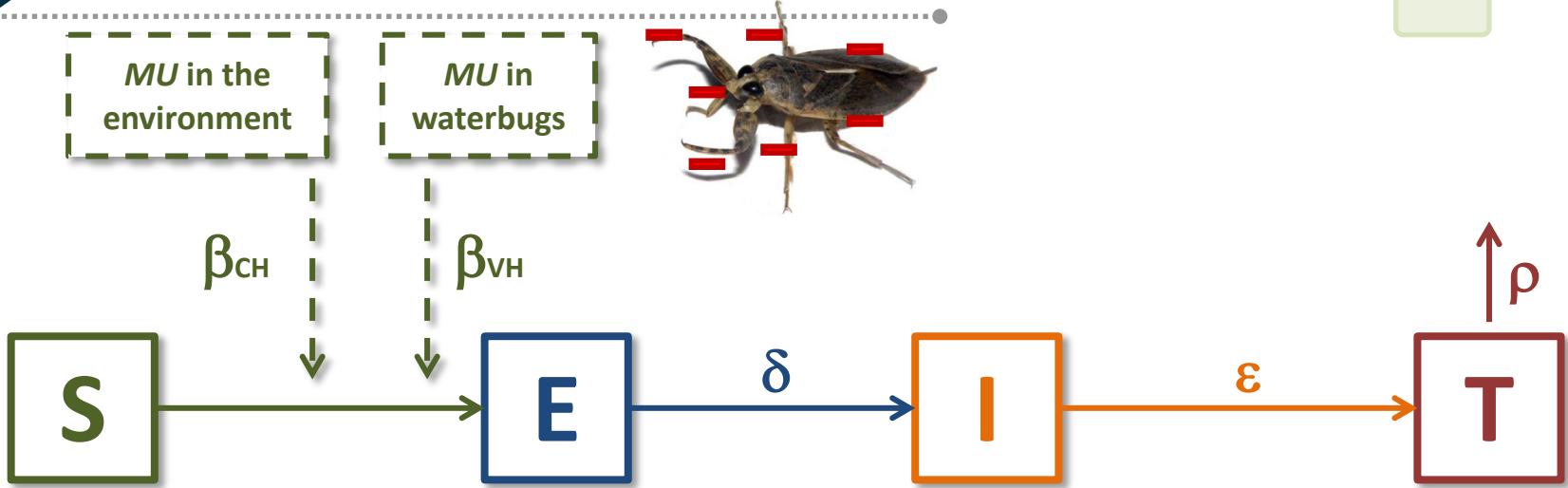
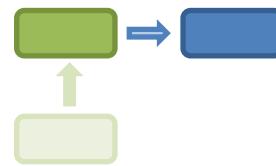
$$\frac{dS}{dt} = \mu N - \lambda_{CH}(Month_i) S - \lambda_{VH}(Month_i) S - \mu S$$

$$\frac{dE}{dt} = \lambda_{CH}(Month_i) S + \lambda_{VH}(Month_i) S - \sigma E - \mu E$$

$$\frac{dI}{dt} = \sigma E - \varepsilon I - \mu I$$

$$\frac{dT}{dt} = \varepsilon I - \gamma T - \mu T$$

## Mathematical model framework

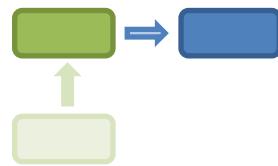


### Model simulations to account for:

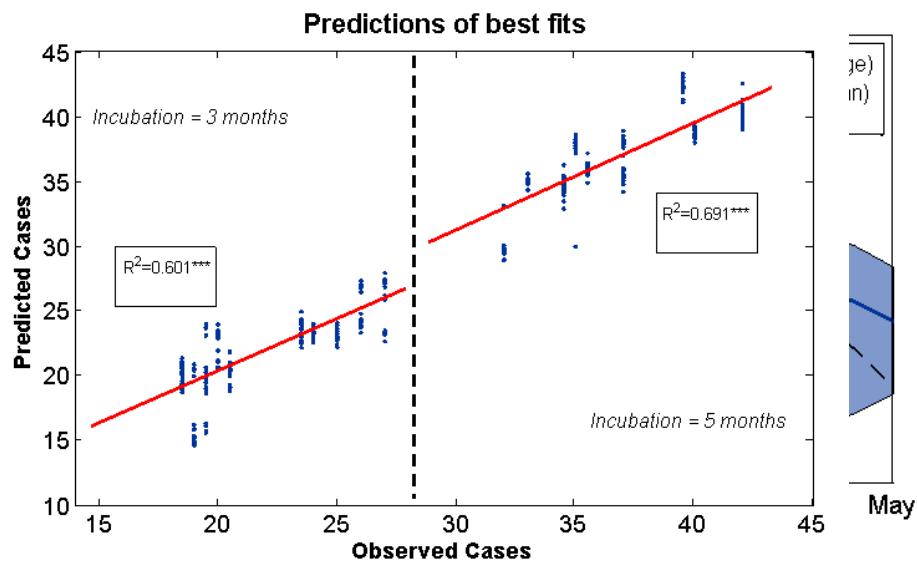
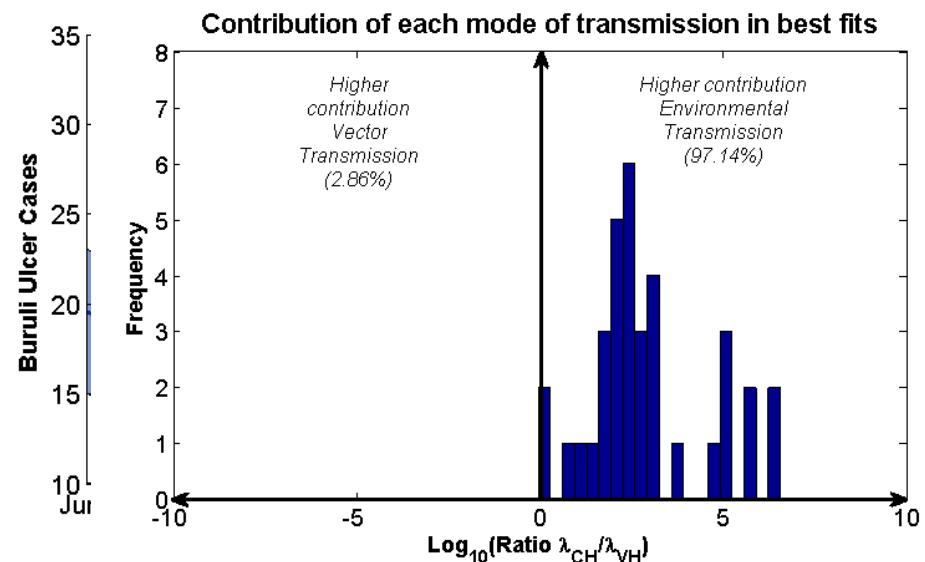
- A range of initial parameters
- Uncertainties in rates of incubation ( $\delta$ ) and seeking treatment ( $\epsilon$ )
- Different proxies of waterbug transmission and environmental transmission
- Linear risks or thresholds in the relationship MU-BU

**Comparison of model fit using AIC and selection of best performing (2 AIC)**

# Results for Buruli ulcer temporal dynamics



## Best temporal fit



Environmental transmission >>> water bug transmission

MU environmental concentration as linear predictor of BU cases

**AT THIS STAGE WE ARE ALMOST DONE...**

- What are the main results that provide the answer to my question?
  - 1 to 3 graphs
  - 1 to 3 tables
- What is the journal that best fits my study?
  - Scope, audience, impact factor, math focus
- How do I present my manuscript?
  - Introduction: set the stage to your question
  - Methodology: describe explicitly all steps for replicability
  - Results: clear and concise
  - Discussion: explain how your study improves previous knowledge

# MODELING IN PRACTICE: THE LIFE CYCLE OF A MODELING PROJECT, FROM CONCEPTION TO PUBLICATION

- The example of Buruli ulcer in Cameroon -



Andrés Garchitorená

Researcher, Institut de Recherche pour le Développement

Research Advisor, PIVOT Madagascar

*E<sup>2</sup>M<sup>2</sup> Workshop  
Ranomafana, January 2019*