E^2M^2: Ecological and Epidemiological Modeling in Madagascar

Looking back: How far have we come?
Rétrospective : où en sommes-nous ?

Hotel Cyperus

Andasibe, Madagascar

May 2025

- **Programming**
- **Data**
- **Models**
- **Research Development**

Saturday: R Bootcamp

- Intro to R and R Studio
- Data Manipulation in R
- Exploring and Visualizing Data in R

Sunday: "Travel Day"

- Travel MBC → Andasibe
- Downloading packages
- Night walk at VOI

Monday: "Getting Started with the Basics"

- Data and Models
- **Formulating Research Questions**
- Simple Mathematics and Statistics
- Dynamical Fever

Tuesday: "Exploring Types of Models"

- Linear Regression
- Linear Regression Tutorial
- Mechanistic Modeling
- Mechanistic Modeling Tutorial
- Formulating Research Questions
- Epidemic Cards Game

Wednesday: "Fitting Models to Data"

- Refining Research Questions for Modeling
- Reading a Model-Focused Research Paper
- Model Fitting in Practice
- Model Fitting Tutorial
- Model Fitting with Epidemic Cards

Thursday: "Modeling Different Types of Data"

- Hike at VOI
- Spatial Analysis and Visualization
- Spatial Analysis Tutorial
- Model Comparison

Friday: "Using Models in Practice"

- Model Comparison Tutorial
- Phylogenetic Analysis
- Phylogenetic Analysis Tutorial
- Research Seminar
- Model Telephone

Saturday: Travel

Monday: "Sharing Your Work"

- Final student presentations

Saturday: R Bootcamp

- Intro to R and R Studio
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R Bootcamp for E2M2

We R
R User Group
Madagascar

Taratra D. Raharison
CEO - We R
taratra.d.raharison@gmail.com

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What is science?

C’est quoi la science?

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What is science?
C’est quoi la science?

the **systematic observation** of natural events and conditions in order to **discover facts** about them and to **formulate laws and principles**

l'observation systématique des événements et des conditions naturelles afin de découvrir des faits à leur sujet et de formuler des lois et des principes fondés

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What are data?

Quelles sont les données?

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What are data?
Quelles sont les données?

evidence to support a claim
preuves à l'appui d'une réclamation

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What is a model?

C’est quoi un modèle?

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What is a model?
C’est quoi un modèle?

an abstract representation of a phenomenon

une représentation abstraite d'un phénomène

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C’est quoi un modèle?

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Statistical Statistique	Mechanistic Mécaniste

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What is a model?
C'est quoi un modèle?

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Statistical Statistique	Mechanistic Mécaniste
Correlation Corrélation	Causation Causalité
What? Que?	How? Comment?

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Formulating research questions
Formuler des questions de recherche

Statistical: What factors explain the geographic distribution of plague infection in Rattus rattus in Madagascar?

Mechanistic: Can the Malagasy black rat (Rattus rattus) population independently maintain transmission of the plague bacterium, Yersinia pestis?

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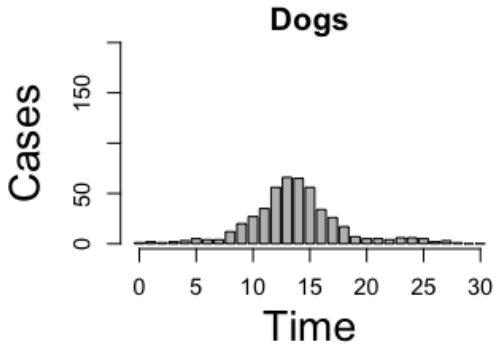
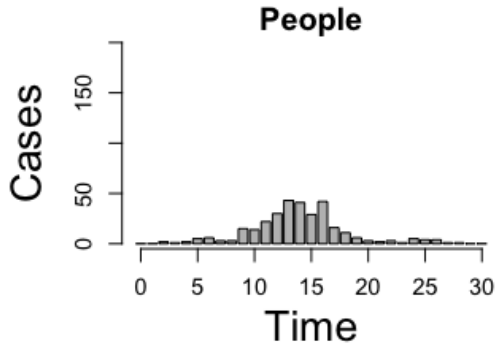
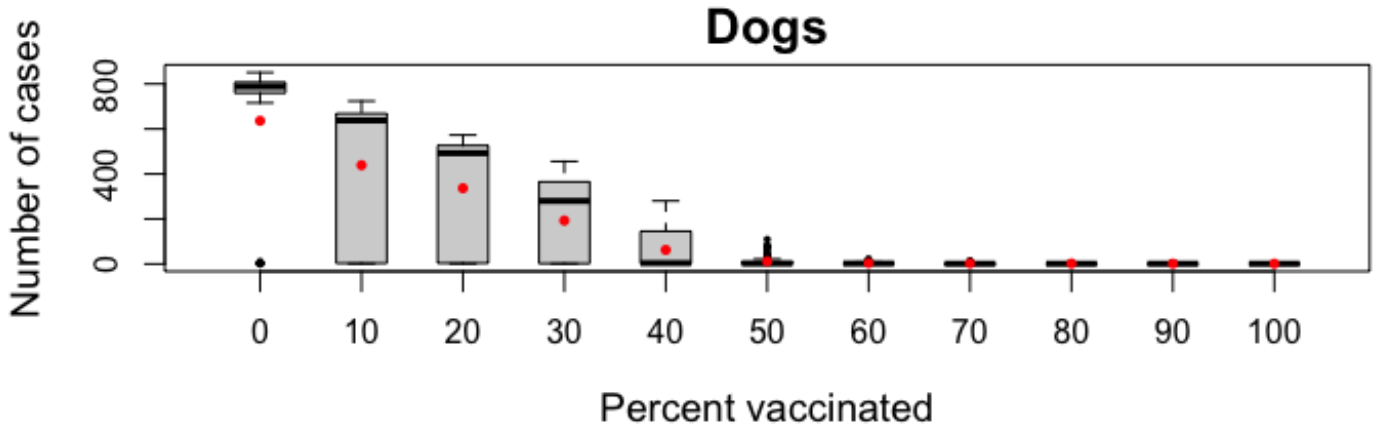
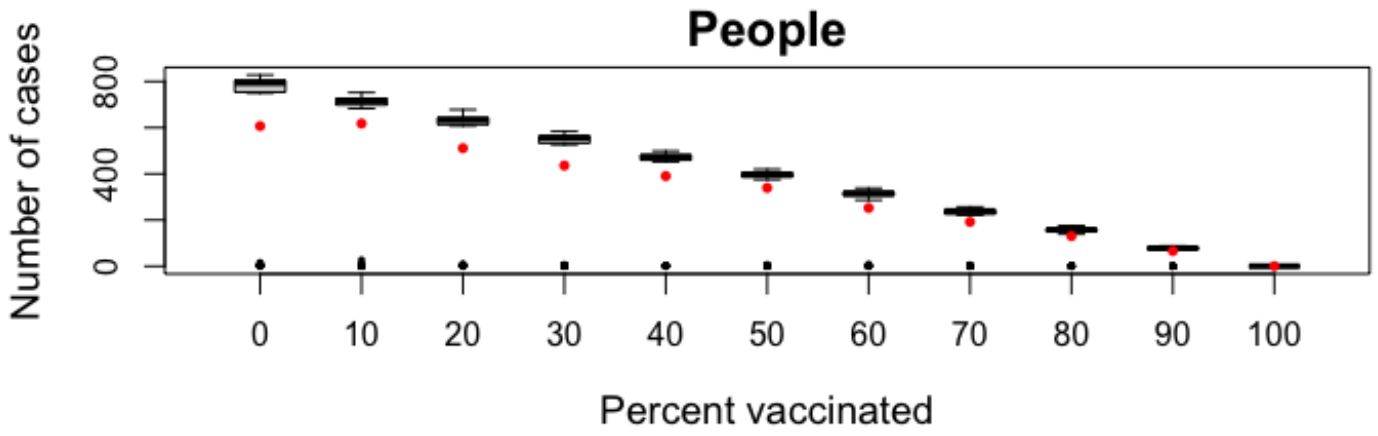
Dynamical Fever
Fièvre dynamique









$$P_V = 1 - \frac{1}{R_0}$$

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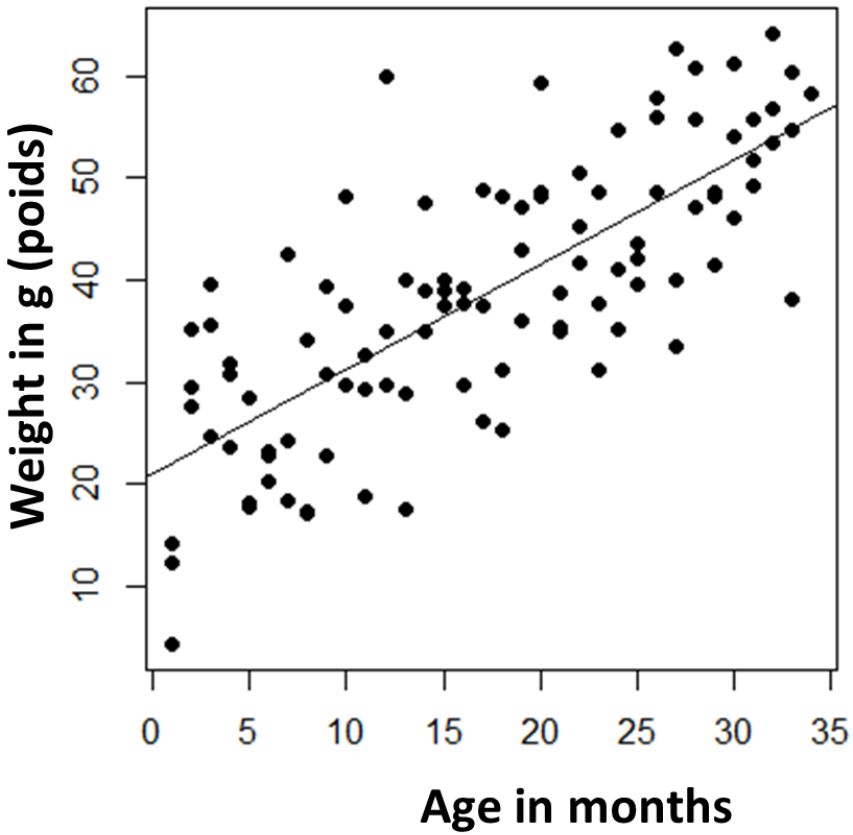
Linear Regression
Régression linéaire



$$y = \alpha + \beta x + \varepsilon$$

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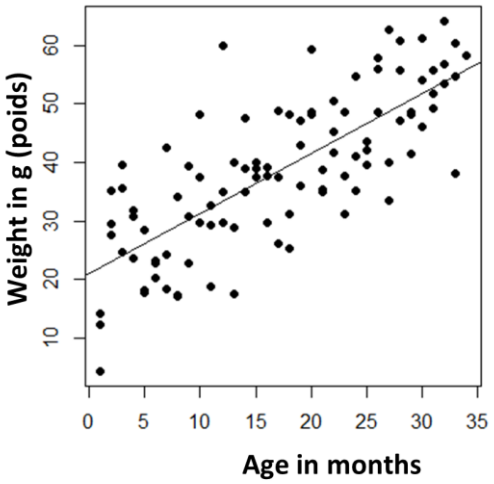

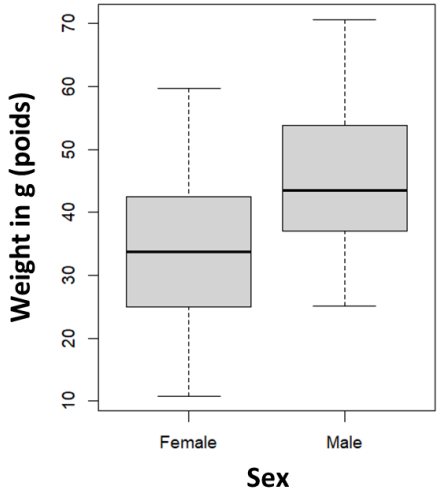

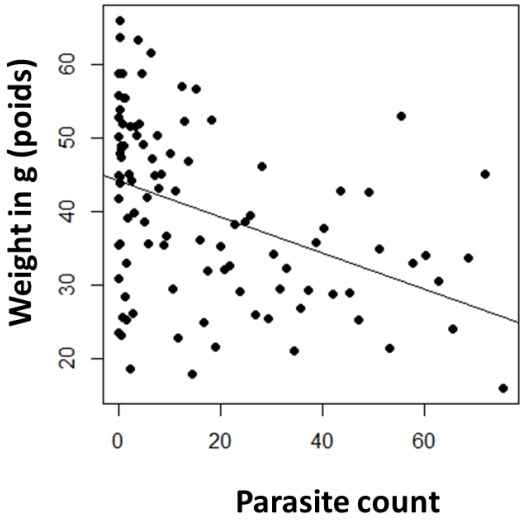

lm(taille~age+sexe+GIparasites, data)

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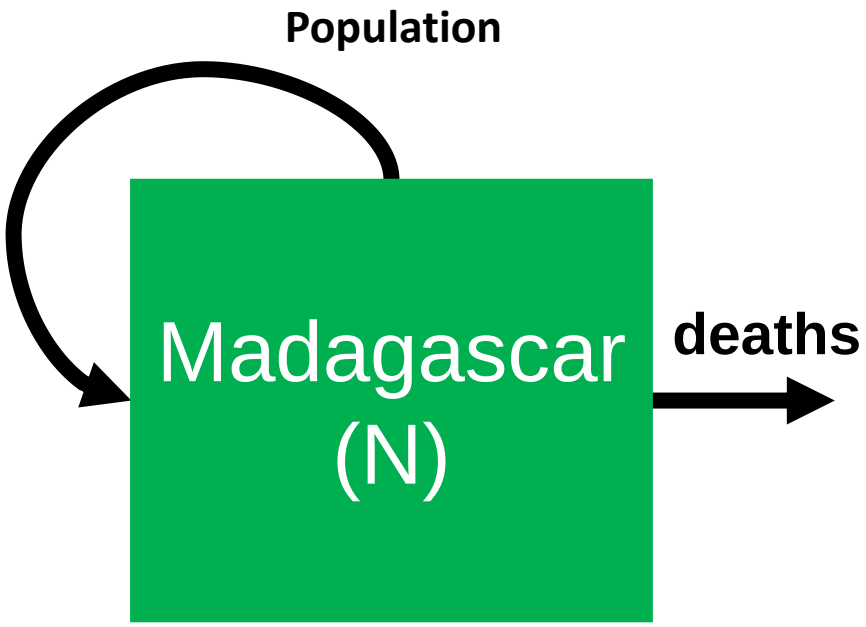
Intro to Compartmental Models
Introduction aux modèles compartimentés



$$N_{t+1}=births*N_t-deaths*N_t$$

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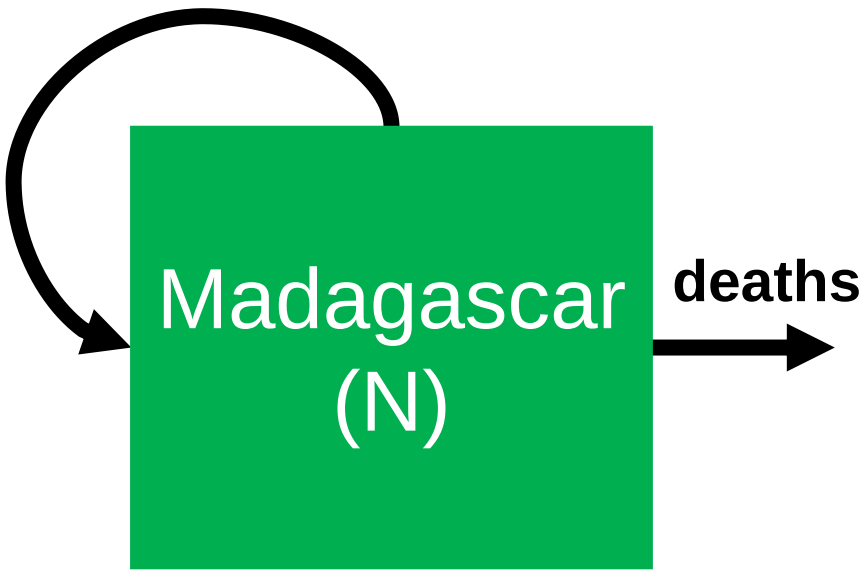
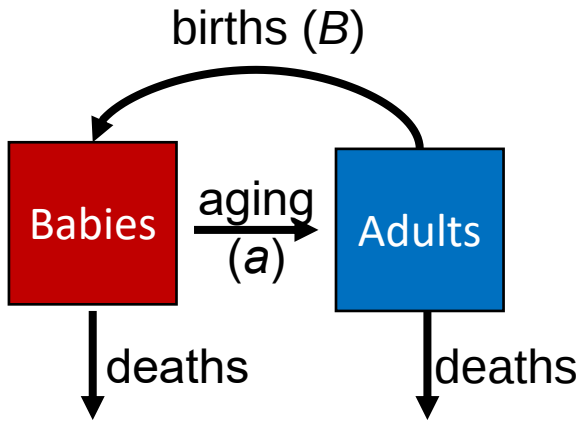
Introduction aux modèles compartimentés

Population



$$N_{t+1}=births*N_t-deaths*N_t$$

Structured Population



$$N_{t+1}=\lambda*N_t$$

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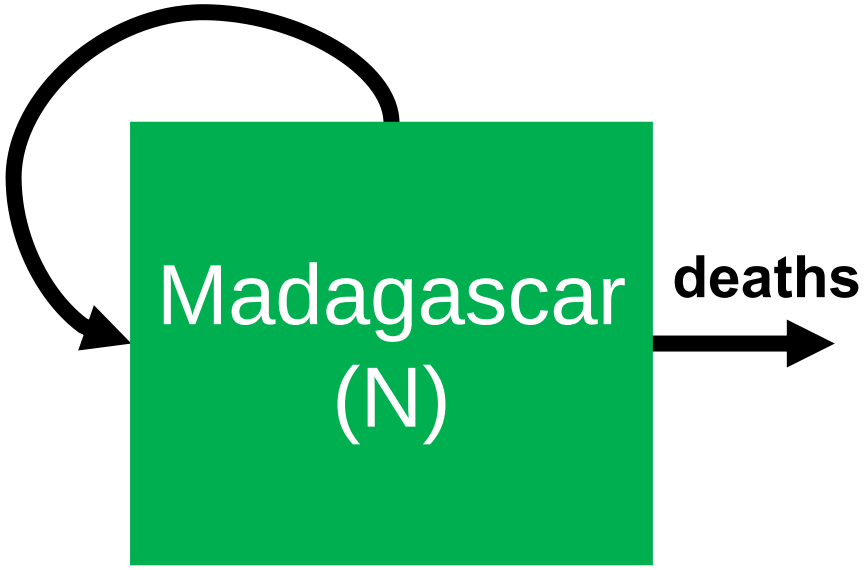

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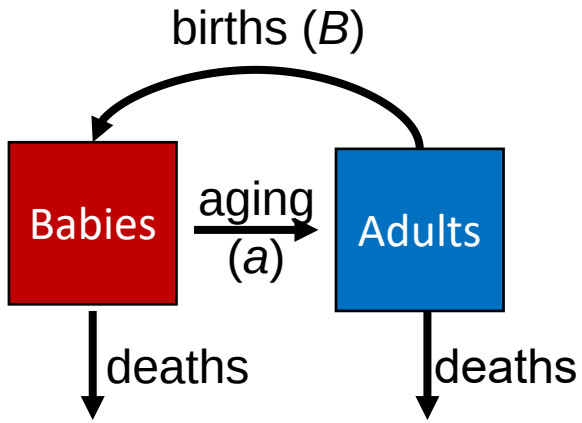
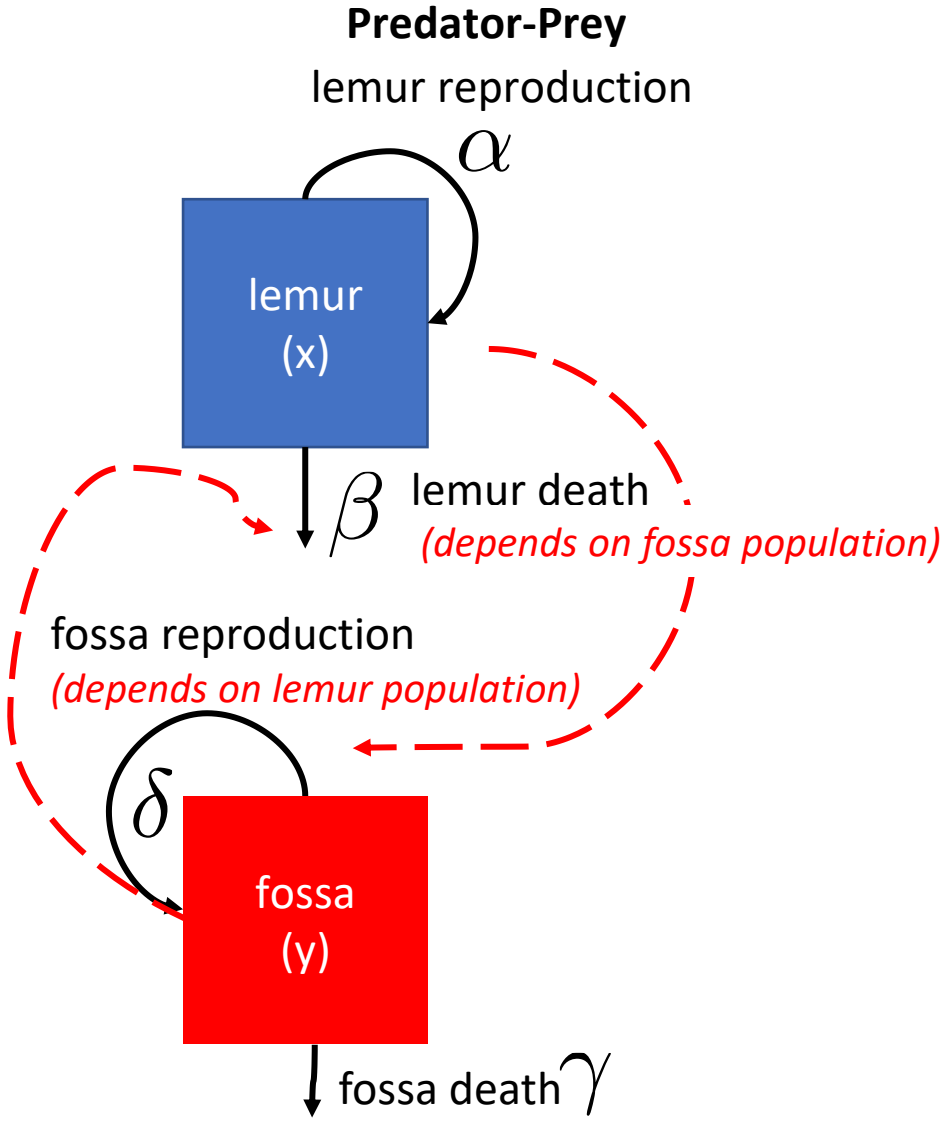


$N_{t+1}=\lambda*N_t$

Predator-Prey



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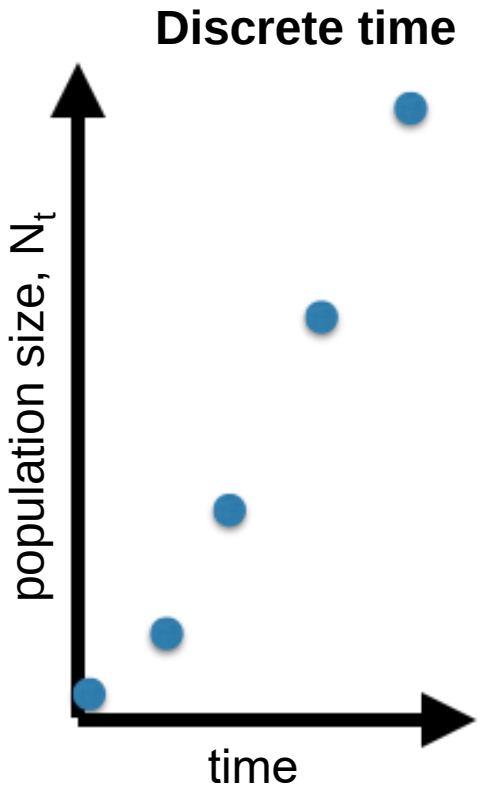

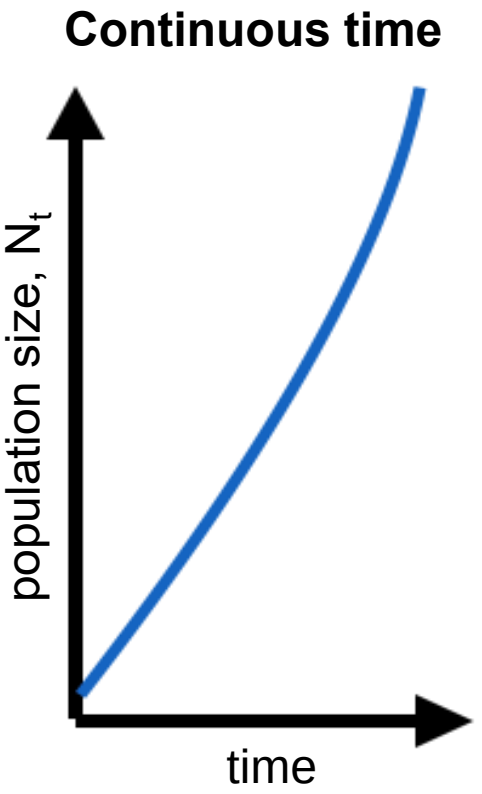

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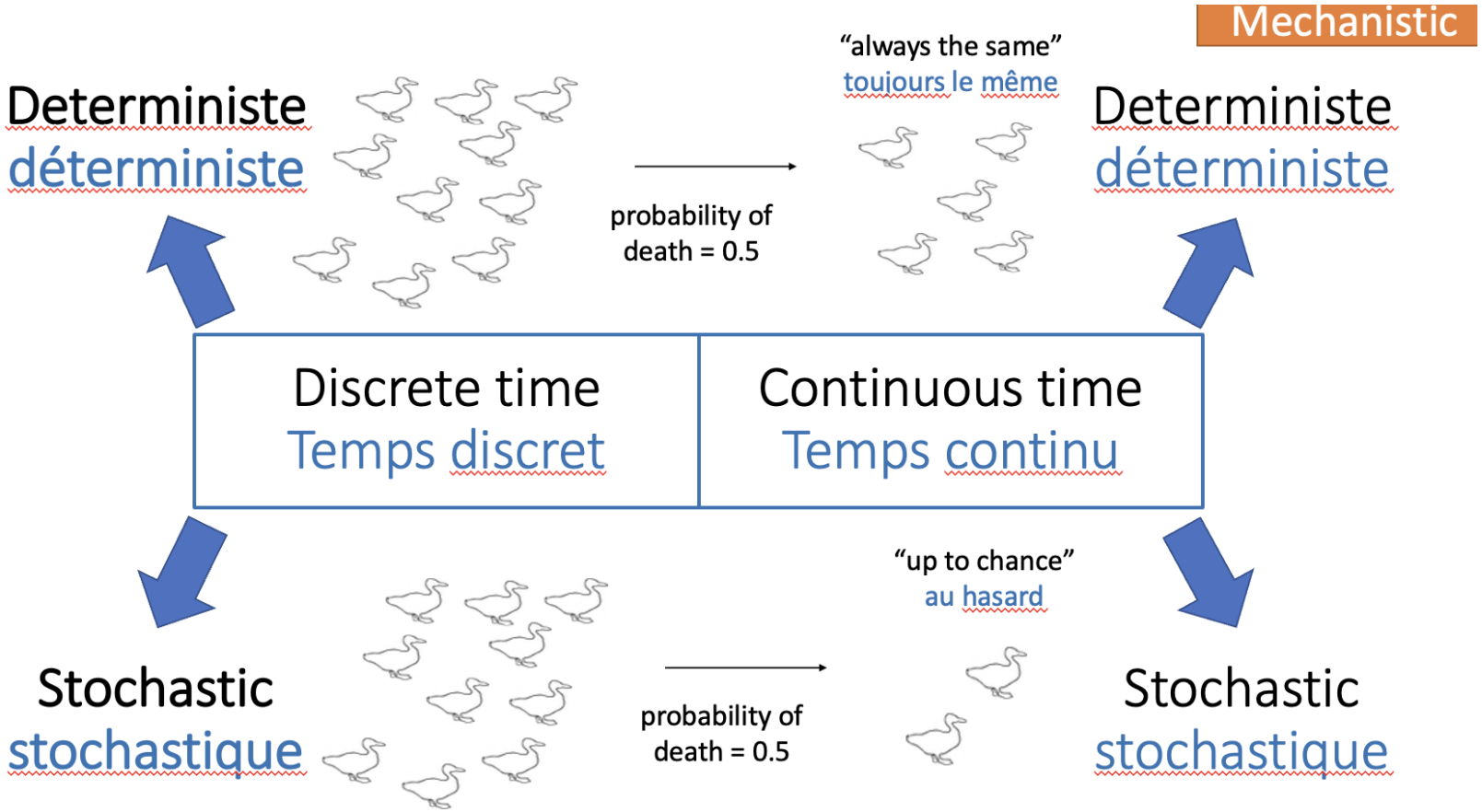

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Refining research questions for modeling
Affiner les questions de recherche pour la modélisation

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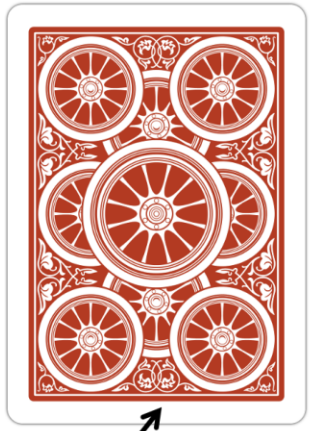
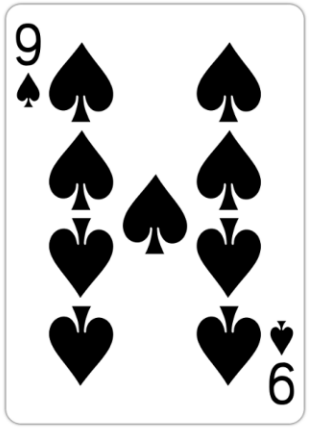
Epidemic Cards
Cartes Épidémie

The Set-Up



The population pile must ALWAYS maintain exactly 26 cards.

What is the equivalent assumption in defining a model world to represent an epidemic?



"current" pile
(EMPTY)

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Reading a Research Paper

Lire un article scientifique

OPEN ACCESS Freely available online

PLoS NEGLECTED TROPICAL DISEASES

An Unexpected Recurrent Transmission of Rift Valley Fever Virus in Cattle in a Temperate and Mountainous Area of Madagascar

Veronique Chevalier[1]*, Toky Rakotondrafara[2], Marion Jourdan[1], Jean Michel Heraud[3], Harena Rasamoelina Andriamanivo[2], Benoit Durand[4], Julie Ravaomanana[2], Pierre E. Rollin[5], René Rakotondravao[2]

1 CIRAD, International Centre of Research in Agronomy for Development (AGIRs Unit), Montpellier, France, **2** FOFIFA-DRZV, BP 04, Antananarivo, Madagascar, **3** Virology Unit, Institut Pasteur de Madagascar, BP 1274, Antananarivo, Madagascar, **4** Agence Nationale de Sécurité Sanitaire (ANSES), Laboratoire de Santé Animale, Maisons-Alfort, France, **5** Viral Special Pathogens Branch, Division of High Consequence Pathogens and Pathology, Center for Disease Control and Prevention, Atlanta, Georgia, United States of America

Table 1. Results of the generalized linear mixed-effect model, with breeder as a random effect.

Variable	Modalities	OR (95%CI)	p-value
Age		3.4[a] (1.8–6.4)	10^{-4}
Minimum distance to water point		0.08[b] (0.01–0.48)	5.10^{-3}
Water point type[c]			
	River	NS[d]	NS
	Paddy field	NS	NS
Minimum distance to the forest		NS	NS
Replacement practices		33 (1–992)	0.04

[a]Change of the odds of seropositivity when the age of animals is increased by 5 years.
[b]Change of the odds of seropositivity when the distance to the nearest water point is increased by 500 m.
[c]Pond as the reference.
[d]Non Significant.
doi:10.1371/journal.pntd.0001423.t001

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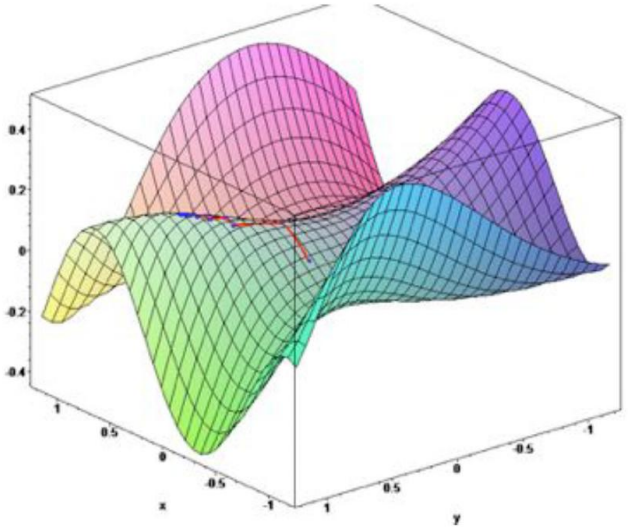
Fitting Models to Data
Adapter les modèles aux données



Model Fitting in Science

1. Define your research question (*Definer votre question de recherche)*
2. Formulate a hypothesis *(Formuler une hypothèse)*
3. Collect Data (*Collection des données)*
4. Construct a model that demonstrates your hypothesis *(Construction d'un modèle qui démontre ton hypothèse)*
5. Assess model fit: assuming our model is true, how likely are we to recover the observed data? (*Evaluation du modèle: si le modèle est vrai, quelle est la probabilité qu'on récupère les données observées?)*
6. Optimize parameters behind the model to result in best model fit (*Optimization des paramètres du modèle pour avoir un modèle bien ajusté)*

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Fitting Models to Data
Adapter les modèles aux données

Statistical models are **data-driven**

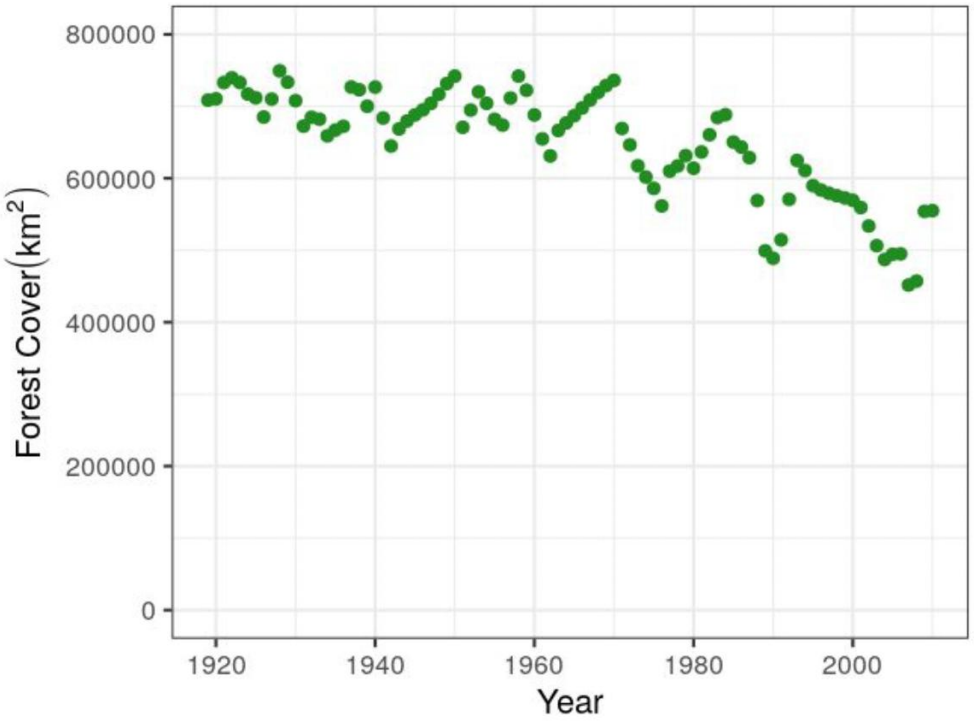
Les modèles statistiques sont basées sur les données

Goal: find patterns and correlations in data

Objectif: révéler des tendances et des corrélations dans les données

What is the trend in Madagascar's forest cover through time?

Quelle est la tendance de la couverture forestière de Madagascar dans le temps?



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Fitting Models to Data
Adapter les modèles aux données

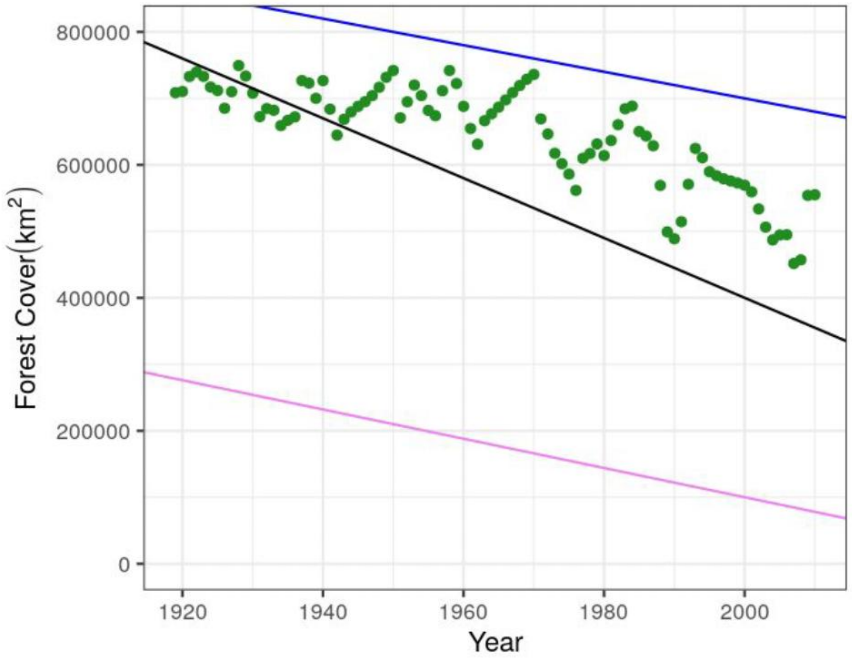
3. Optimize the parameters

Optimisation des paramètres

Optimize slope (m) and intercept (b)

Optimisez le pente (m) and intercept/ ordonnée d'origine (b)

Slope (m)	Intercept (b)
-2200	4.5e6
-4500	9.4e6
-2000	4.7e6



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Fitting Models to Data
Adapter les modèles aux données

Mechanistic modeling is **process-driven**

La modélisation mécanistique est basée sur les processus

We want to understand what happened, when it happened, and why it happened

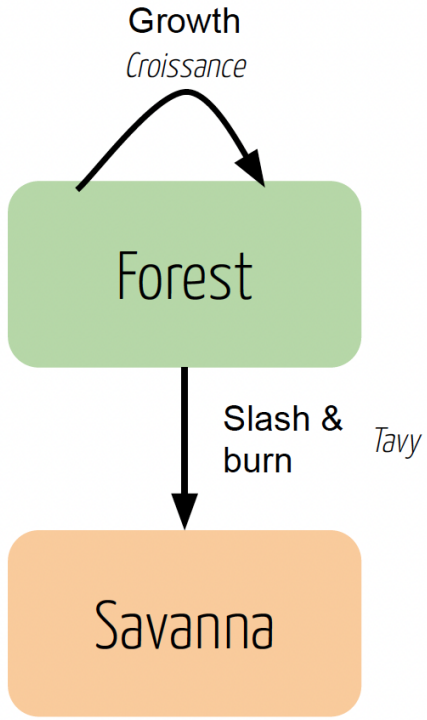
Build a model that uses explicit **processes** to recover the same outcomes ("**populations**") as our data

What are the populations in our data?

Quelles sont les populations dans notre système?

What processes are in our data?

Quels sont les processus?



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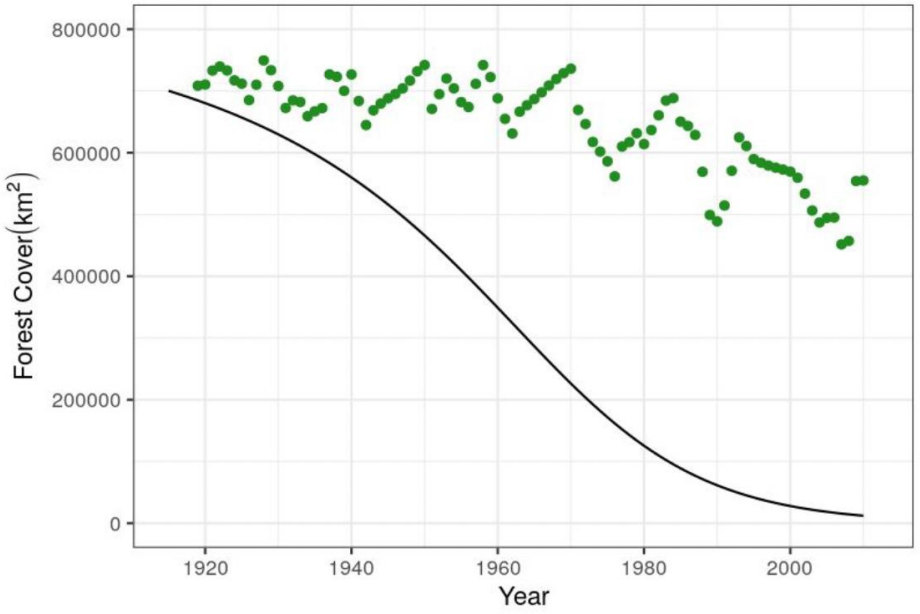
Fitting Models to Data
Adapter les modèles aux données

2. Assess model fit

Évaluation du modèle



Our model predicts forest would decline faster than the data do

Notre modèle prévoit une réduction de la couverture forestière plus rapide que les données

What does this suggest about our guess for the slash and burn rate?

Qu'est-ce que cela suggère à propos de notre estimation du taux du tavy ?

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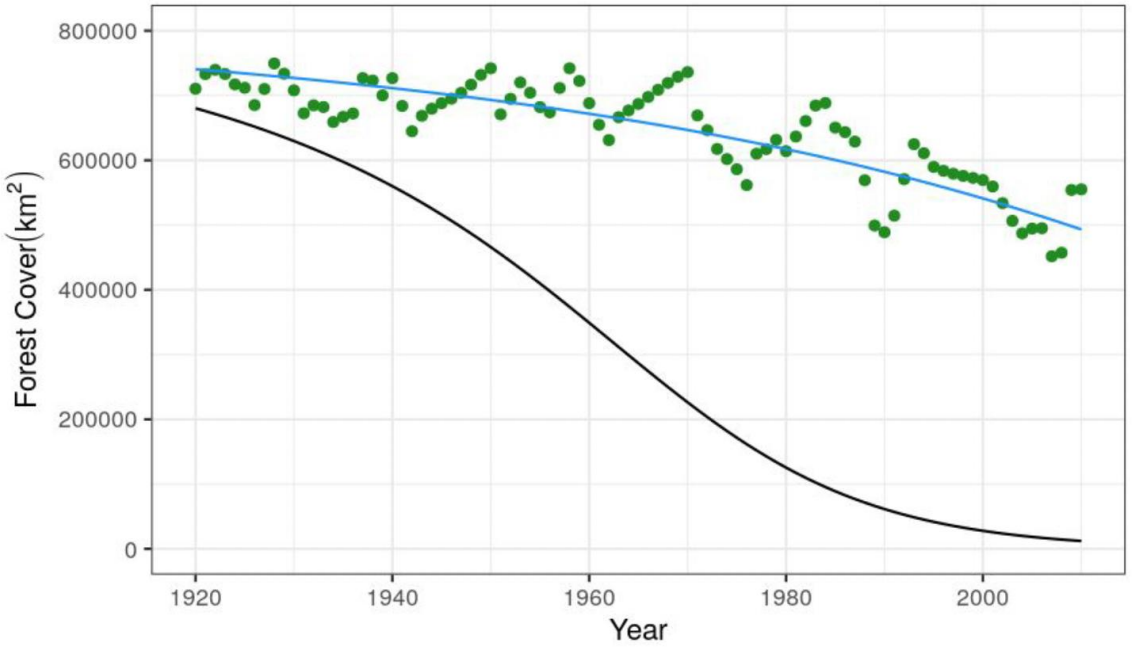
Fitting Models to Data
Adapter les modèles aux données

Does this optimal value result in a model that better matches the data?

Est-ce que cette valeur optimale (en bleu) mieux explique les données?



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Model fitting with epidemic cards

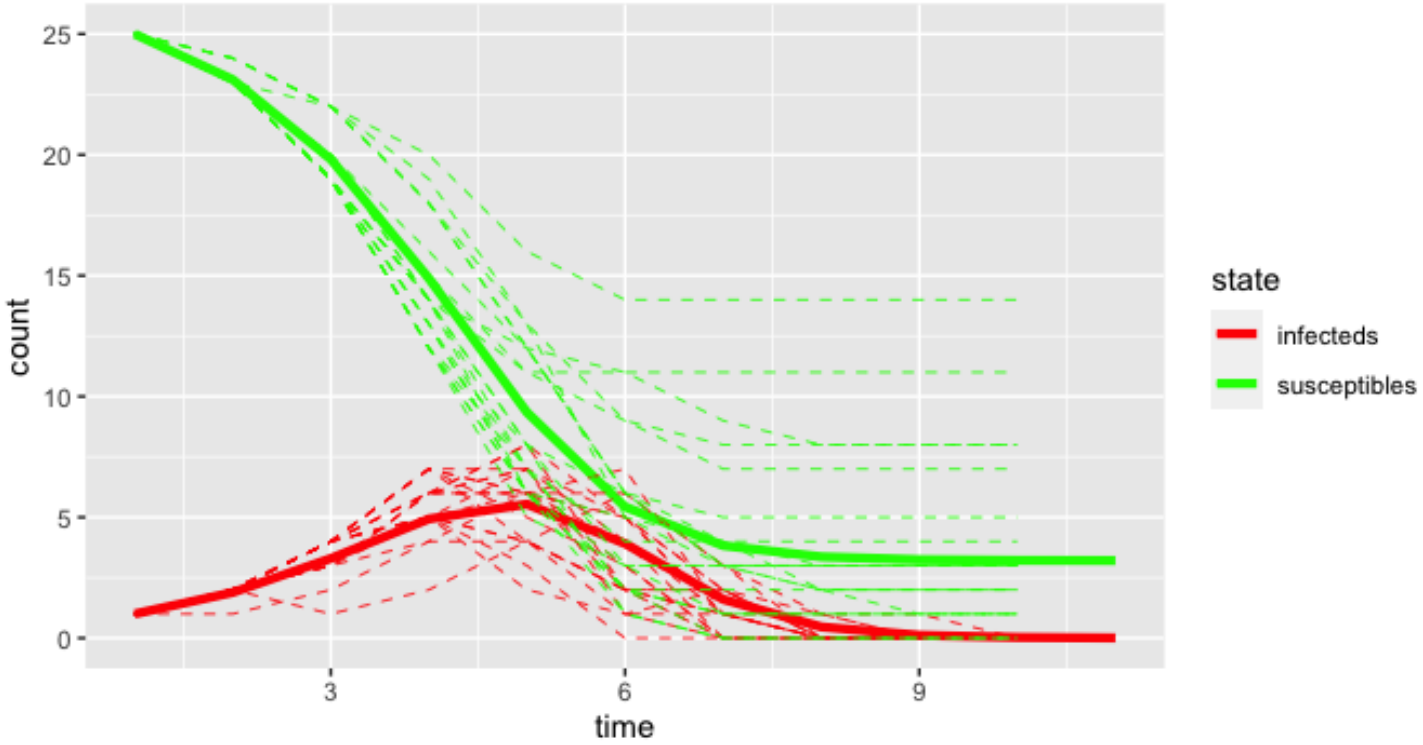
Adjuster les modèles : Cartes d'épidemie

```
## (12) Now, write a for-loop that iterates your discrete time model across the full length of the time series
## Essentially, write the R language that says the following:

##       for (all variables, t, in the length of our time vector){
##              run my discrete time model (hint, use the equations from above, lines 88 and 89)
##             }

## S[t+1] = S[t] - (R0 * S[t]/N)*I[t]
## I[t+1]= (R0 * S[t]/N)*I[t]

for(t in 1:length(time)){
  model.S[t+1] = model.S[t] - (R0 * model.S[t]/N)*model.I[t]
  model.I[t+1]= (R0 * model.S[t]/N)*model.I[t]
}
```



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- Data and Models
- **Formulating Research Questions**
- Simple Mathematics and Statistics
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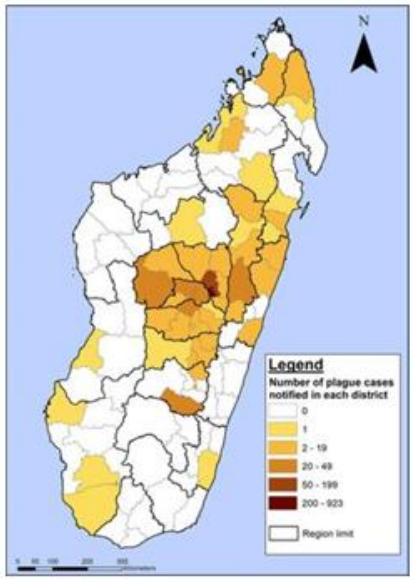
Spatial Analysis and Visualization
L'analyse et la visualization spatiale

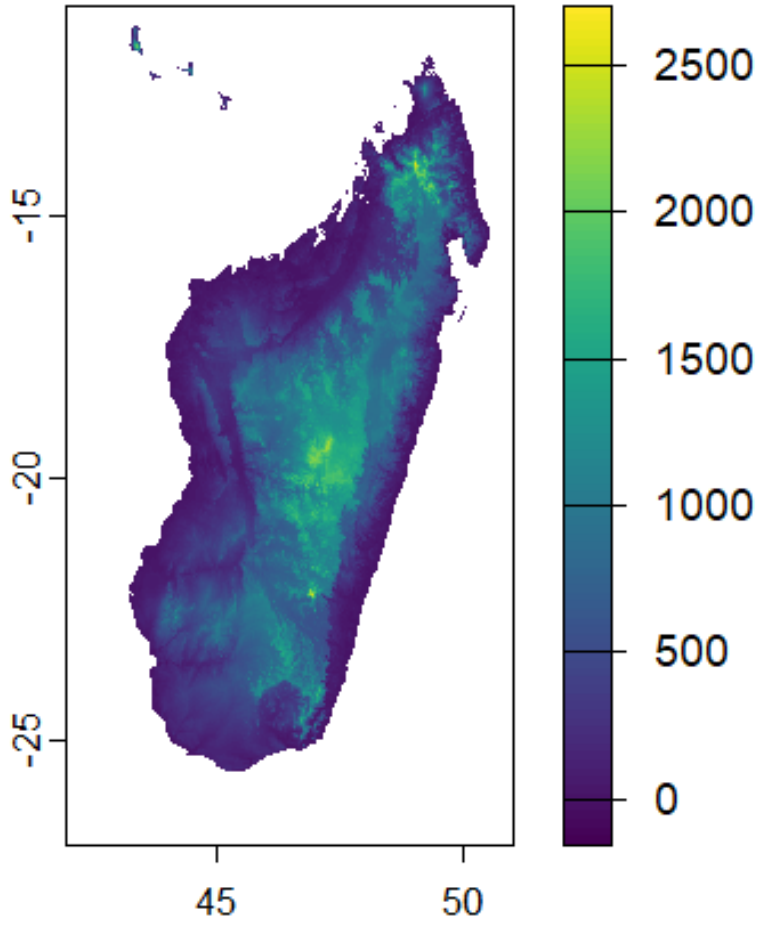
Why do spatial analysis?
Pourquoi faire une analyse spatiale?

Sometimes it matters ***where*** a thing is happening

Parfois, l'endroit ***où*** quelque chose se passe a de l'importance.



Number of Cases Reported in the 2017 Plague Outbreak
Bonds et al., 2018



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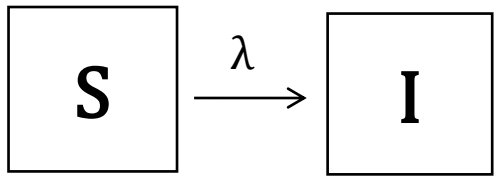
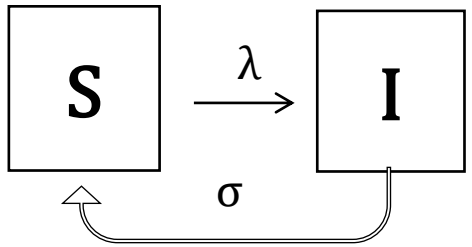
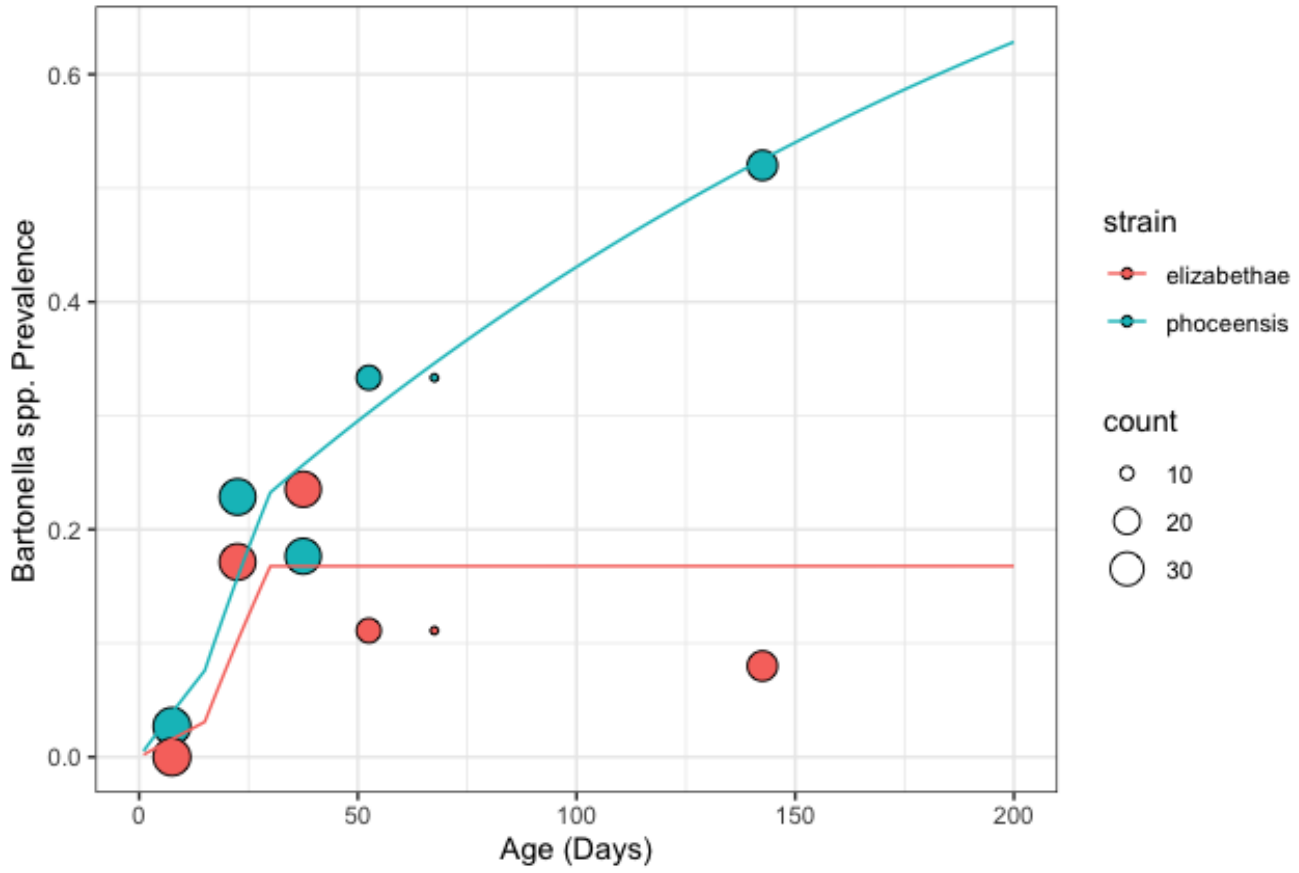
Model Selection and Comparison
Sélection et comparaison de modèles



$$\frac{dI(a)}{da} = I(a)\left(1 - I(a)\right)$$



$$\frac{dI(a)}{da} = I(a)\left(1 - I(a)\right) - sI(a)$$



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- Model Comparison Tutorial
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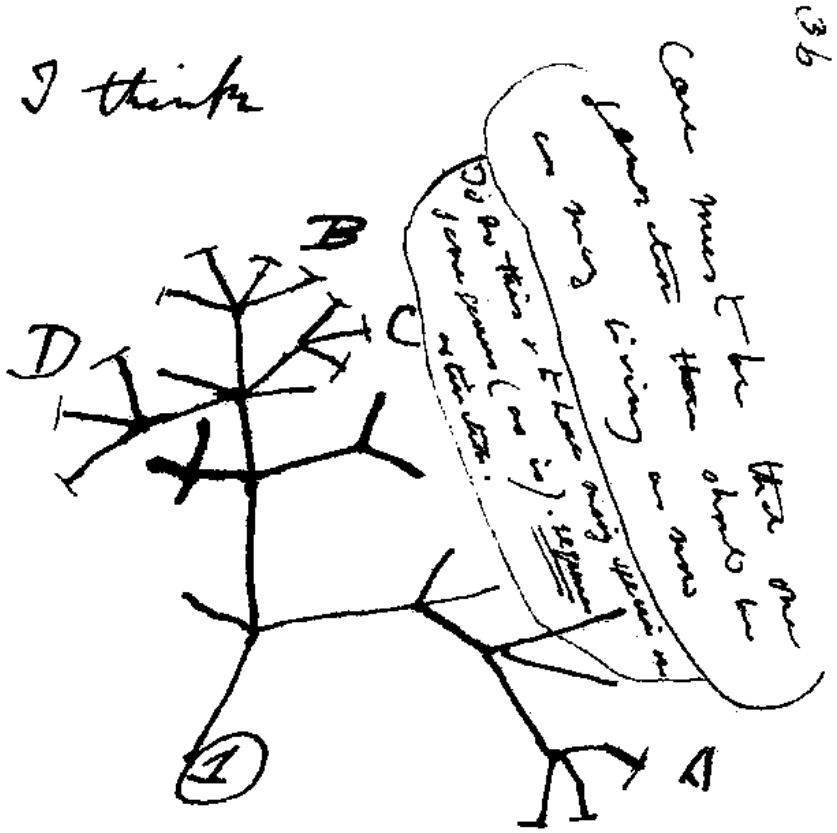
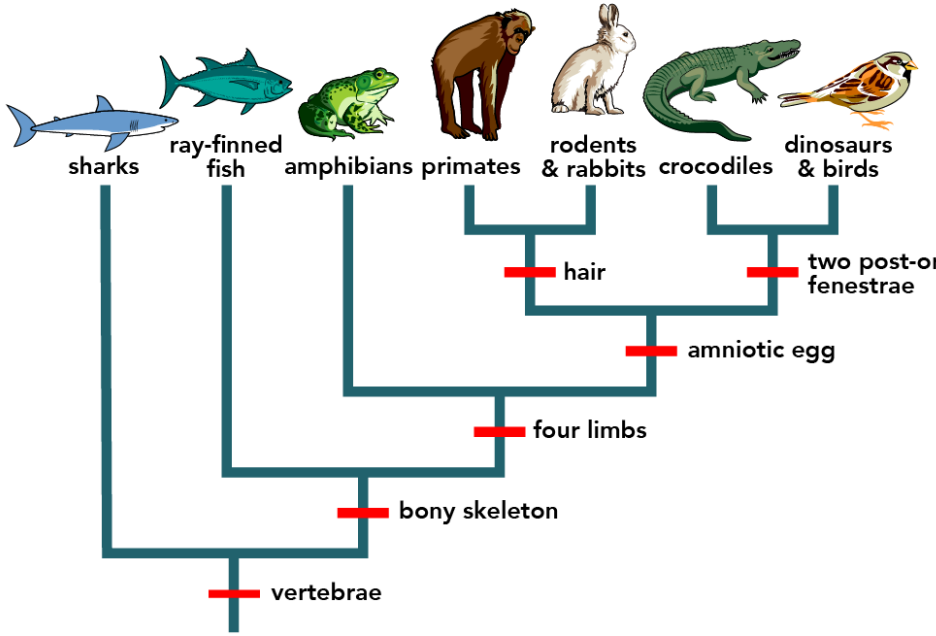
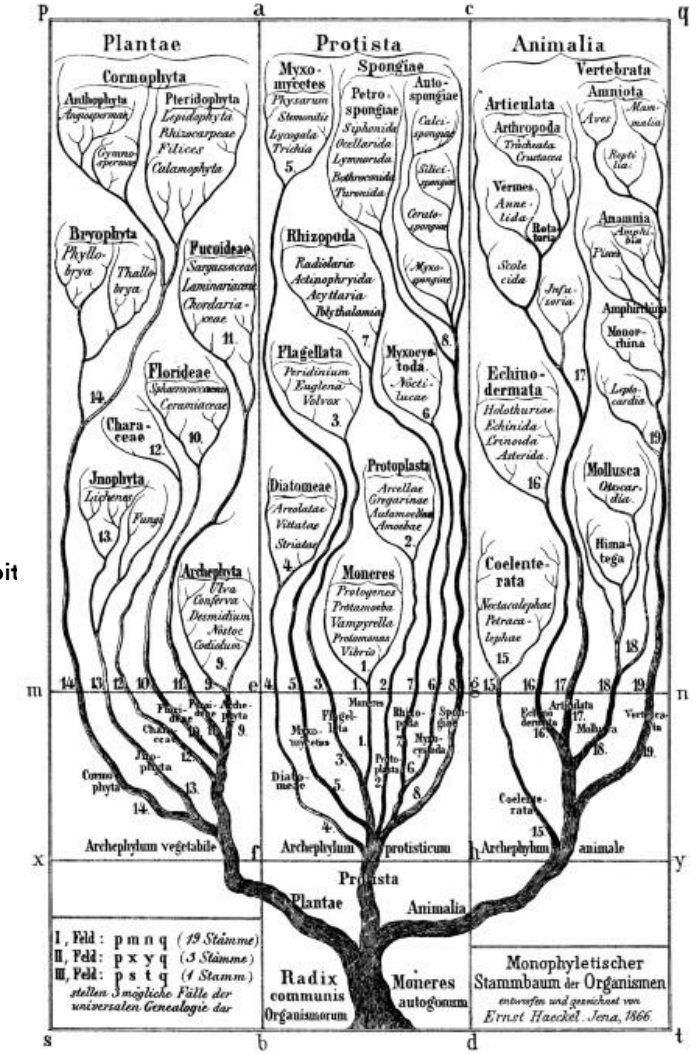
Intro to Phylogenetic Modeling
Introduction à la modélisation phylogénétique







Hossfeld and Levit, Nature, 2016

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Research Seminar

Presentation sur la recherche

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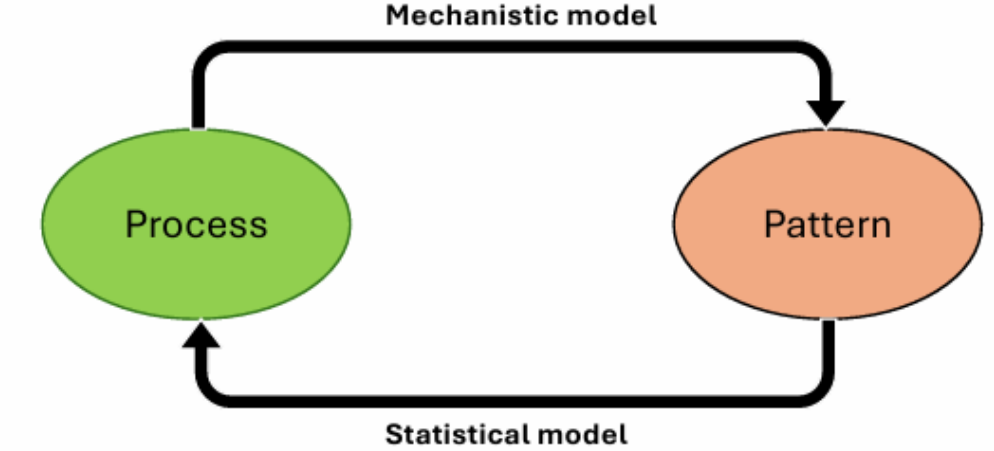
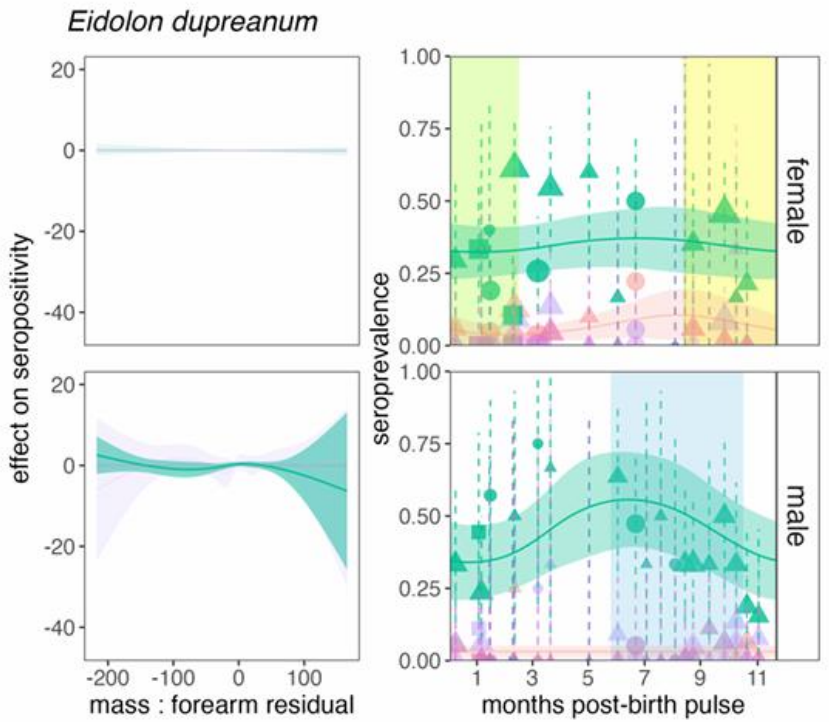
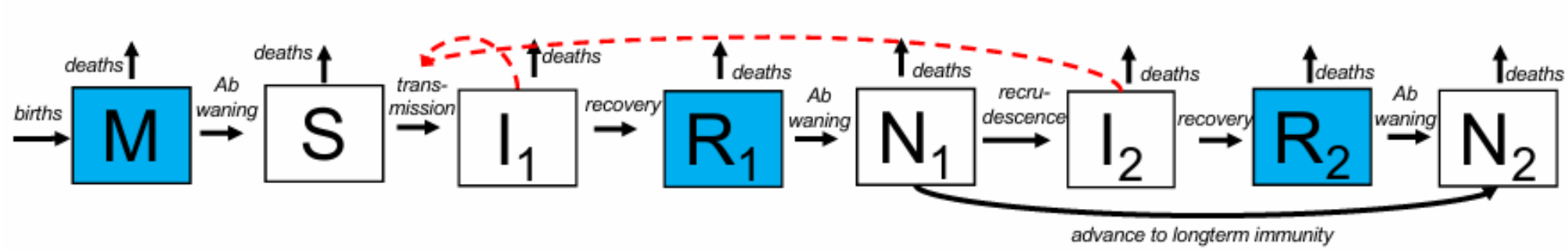
Research Seminar

Presentation sur la recherche







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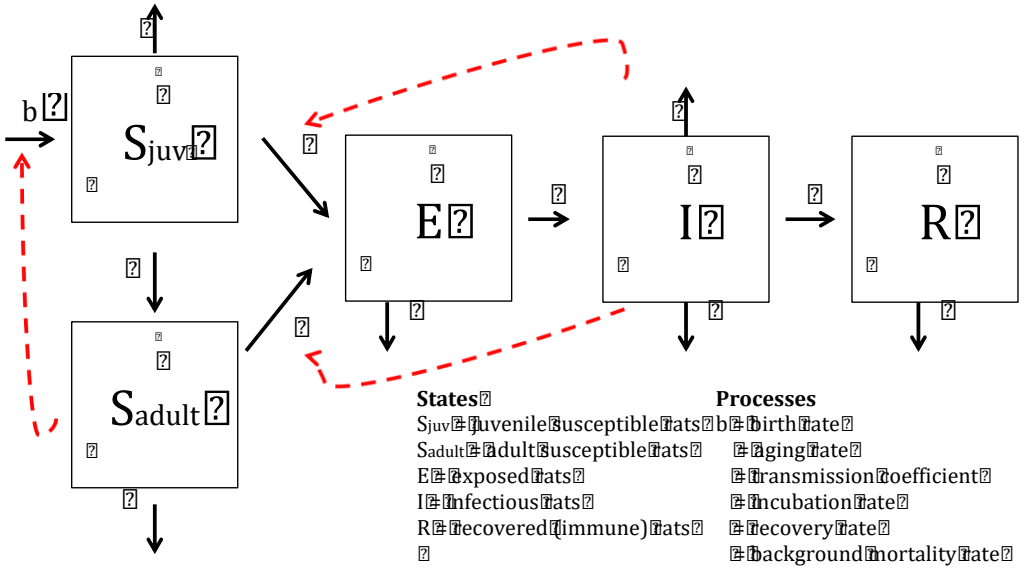
Model Telephone
Modèle de téléphone

Example:

Can the Malagasy black rat (*Rattus rattus)* population independently maintain transmission of the plague bacterium, *Yersinia pestis?*



States

S_{juv} = juvenile susceptible rats
S_{adult} = adult susceptible rats
E = exposed rats
I = infectious rats
R = recovered (immune) rats

Processes

b = birth rate
= aging rate
= transmission coefficient
= incubation rate
= recovery rate
= background mortality rate
= infection-induced mortality rate
= recovery rate

Example Model Description

Can the Malagasy black rat (*Rattus rattus)* population independently maintain transmission of the bacterium, *Yersinia pestis,* responsible for human plague*?*

Susceptible juvenile rats enter the population through birth, at rate *b,* which is influenced by the proportion of uninfected (susceptible) adult rats in the population at a given time. Juvenile rats age into the adult class, on average $1/\omega$ time units after they are born. Both juvenile and adult susceptible rats can be infected by contact with infectious rats of any age, based on a force of infection proportional to the prevalence of infectious rats in the population. Once infected, rats enter the exposed class. The incubation period is $1/\sigma$ time units (on average), after which the animals develop clinical plague, which is equivalent to transitioning from the exposed class to the infectious class. A subset of rats recover from plague to become immune, based on rate γ. All rats in the population experience background mortality with hazard μ, and infectious rats experience an additional disease-induced hazard of mortality, α.

- Programming
- Data
- Models
- Research Development

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Saturday: Travel

Monday: "Sharing Your Work"

- Final student presentations

Any aminareo ny baolina

🇲🇬 E^2M^2

E^2M^2: Ecological & Epidemiological Modeling in Madagascar

Schedule for the rest of the day:

- Please bring your bags to the lobby **before the end of coffee break**
- Bring the key to your room to Sophie during coffee break
- One-on-One meetings will be held according to the schedule
- Please come to lunch promptly at **12pm** so we can have an on-time departure for Tana. We will leave immediately after lunch

Misaotra!