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

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

Centre ValBio

Ranomafana National Park, Madagascar

December 2022

Friday: R Bootcamp

- Intro to R Studio
- Exploring and Visualizing Data in R
- For-loops, Functions, and If-Else Statements

Saturday: Travel

Sunday: "Getting Started with the Basics"

- Data and Models
- Student introductions & presentations
- Linear regression • Tutorial
- Formulating research questions

Monday: "Using Models with Data"

- Model-Guided Study Design
- Study design tutorial
- Intro to Compartmental Models & Differential Equations
- Building mechanistic models in R
- Refining research questions for modeling
- Defining a model world

Tuesday: "Applying Simple Models"

- Dynamical Fever
- Introduction to Mixed Modeling
- Reading a Research Paper

Wednesday: "Refining Your Work"

- Model Fitting in Practice – the Basic Concept
- Epidemic Cards
- Model Fitting with Epidemic Cards
- Model Selection and Comparison
- Model Selection Tutorial
- Model Telephone

Thursday: "Bells and Whistle"

- Introduction to Phylogenetic Modeling • Tutorial
- **Intoduction to Spatial Visualization and Plotting** • Tutorial
- Modeling Insights from the Metapopulation Game • Tutorial
- Introduction to Network Modeling • Tutorial
- Research Snapshots

Friday: "Putting it All in Perspective"

- The Life Cycle of a Modeling Project
- C4C Student Presentations

Saturday: Travel

January: "Sharing Your Work"

- Final student presentations

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

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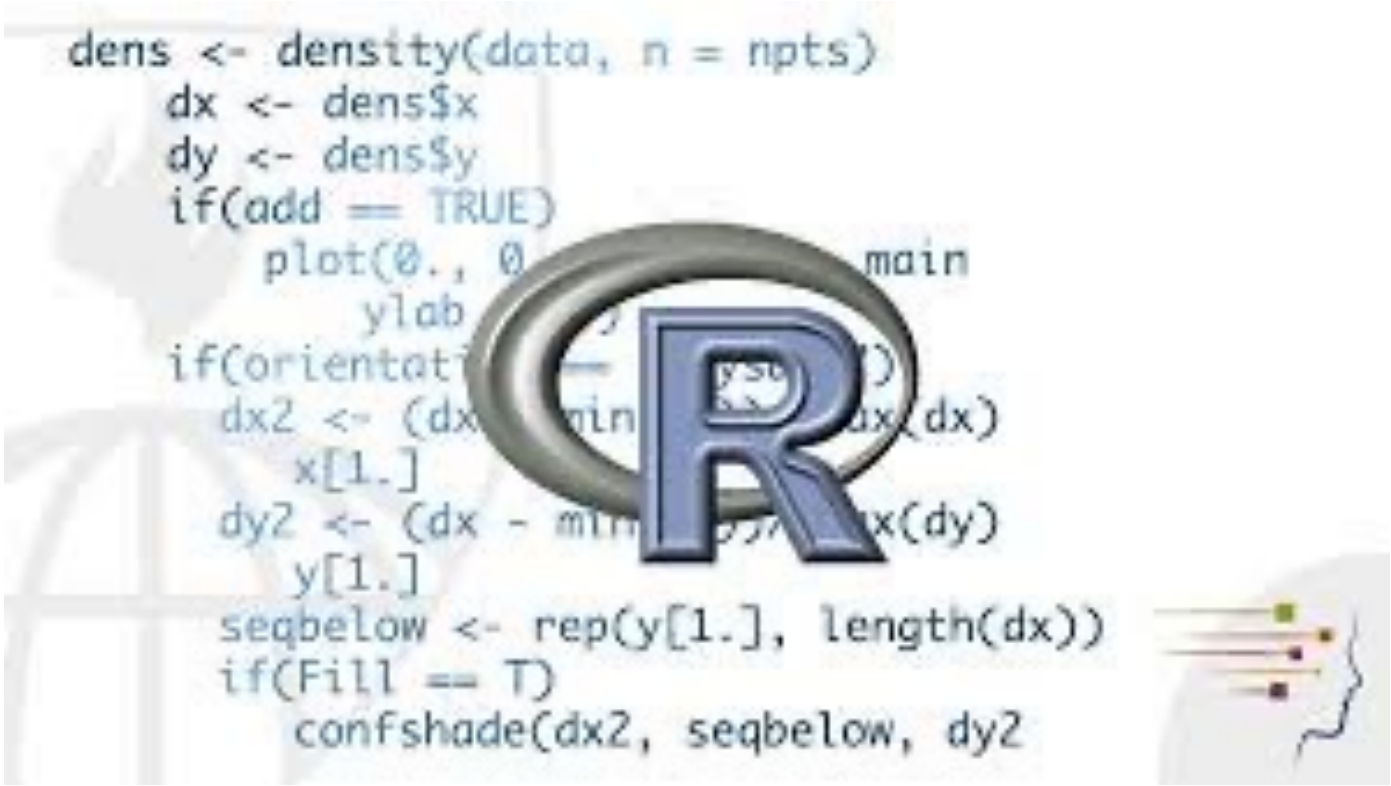

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What is science?

Qu'est ce que la science?

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What is science?
Qu'est ce que 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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Quelles sont les données?

evidence to support a claim

preuves à l'appui d'une réclamation

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What is a model?

Qu'est-ce qu'un modèle?

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an abstract representation of a phenomenon

une représentation abstraite d'un phénomène

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Statistical Statistique	Mechanistic Mécaniste

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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:

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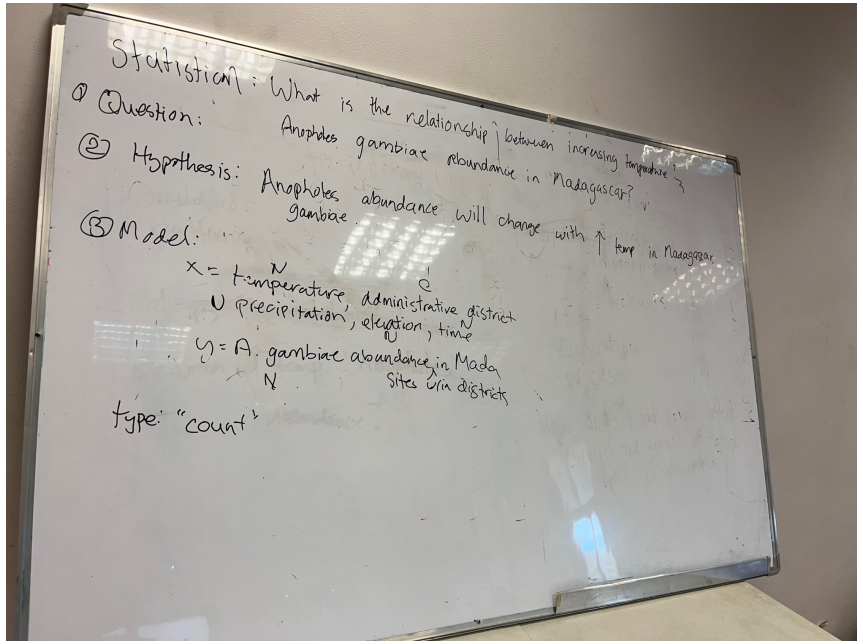
Statistical: What is the relationship between increasing temperature and *A. gambiae* occurrence in Madagascar?

Statistique : Quelle est la relation entre l'augmentation de la température et la présence d'A. gambiae à Madagascar ?



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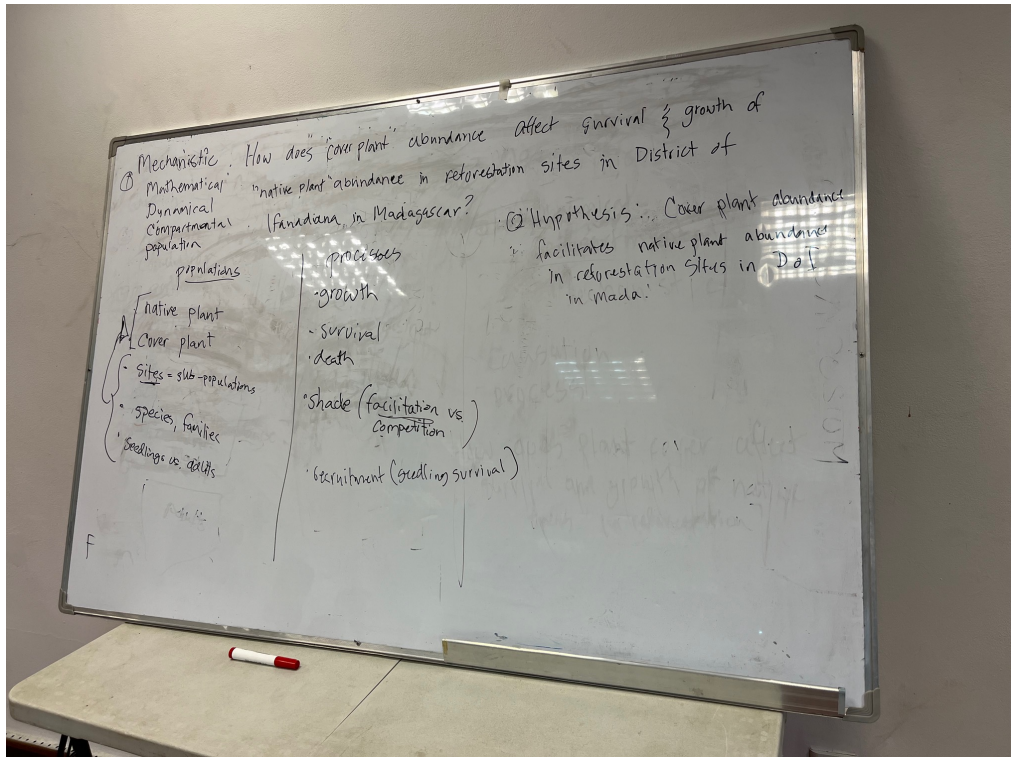
Mechanistic:



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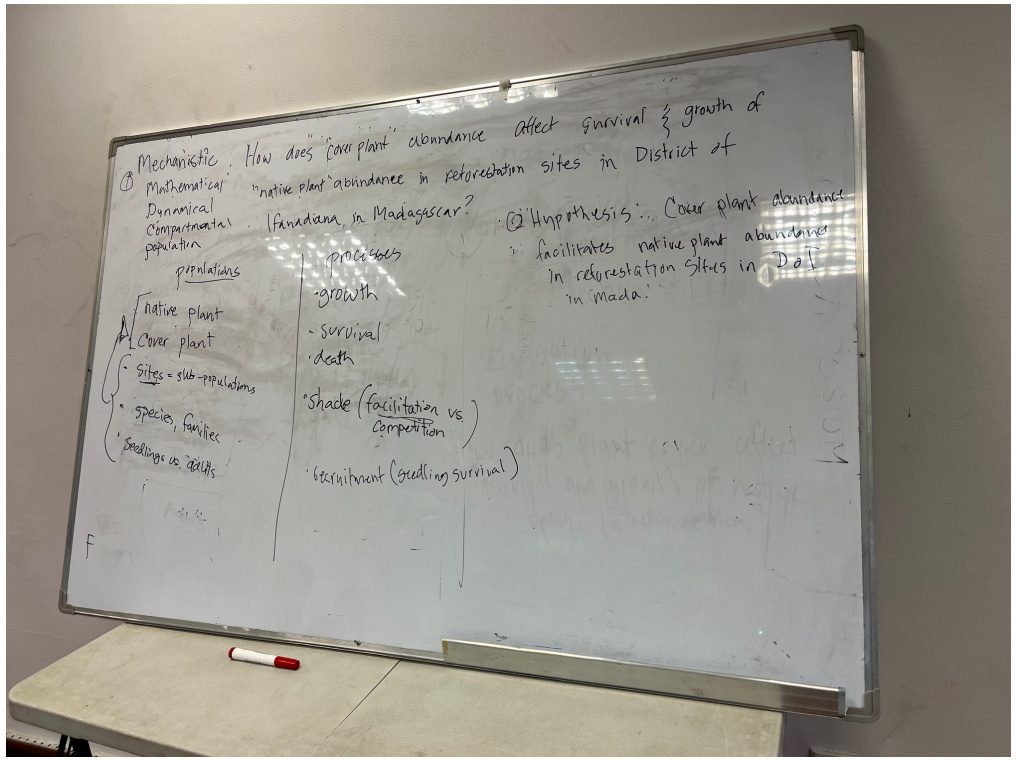
Mechanistic: How does cover plant abundance affect survival and growth of native plants in reforestation sites in the District of Ifanadiana?

Mécaniste : comment l'abondance des plantes de couverture affecte-t-elle la survie et la croissance des plantes indigènes dans les sites de reboisement du district d'Ifanadiana ?



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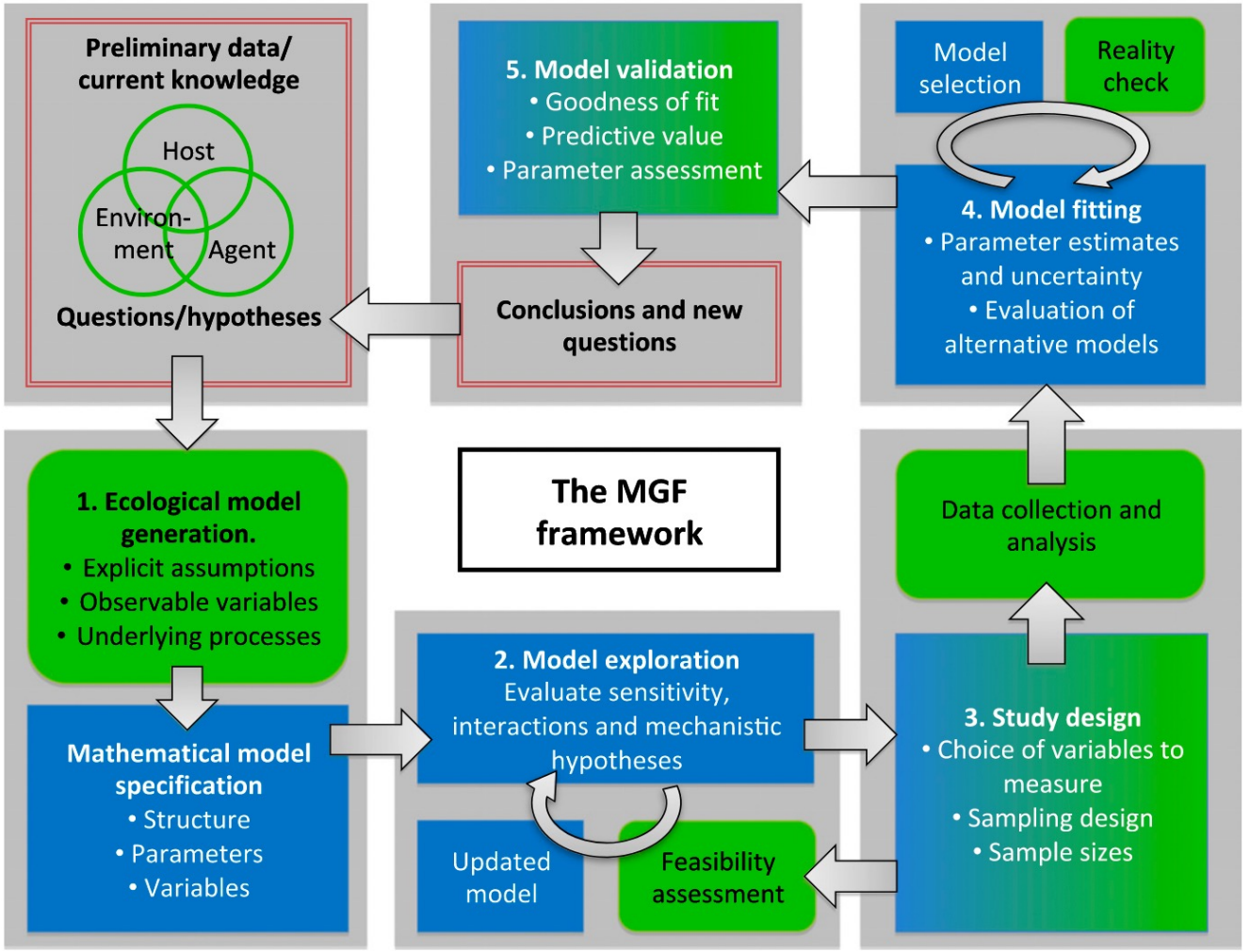
Model-Guided Study Design
Conception d'étude guidée par modèle



Restif et al. 2012 *Ecology Letters*

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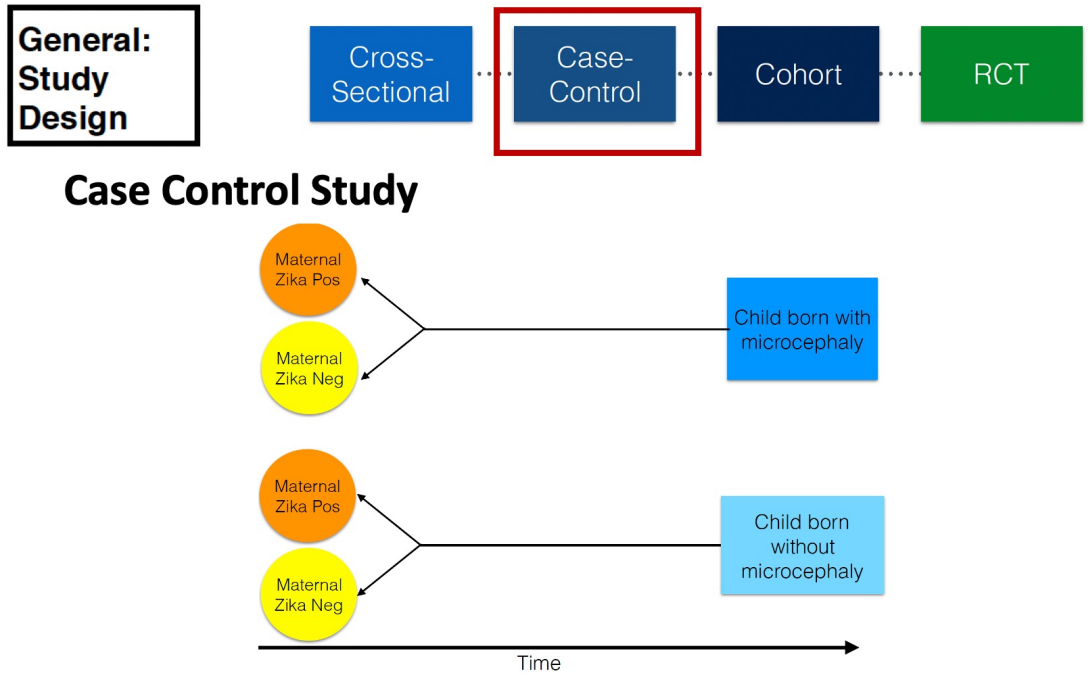


```
> # independent t-test
> pwr2t <- pwr.t2n.test(d=0.2,
+                       n1=175,
+                       power = .8,
+                       sig.level=0.05,
+                       alternative="greater")
> # inspect
> pwr2t

     t test power calculation

             n1 = 175
             n2 = 1333.83
              d = 0.2
      sig.level = 0.05
          power = 0.8
    alternative = greater
```

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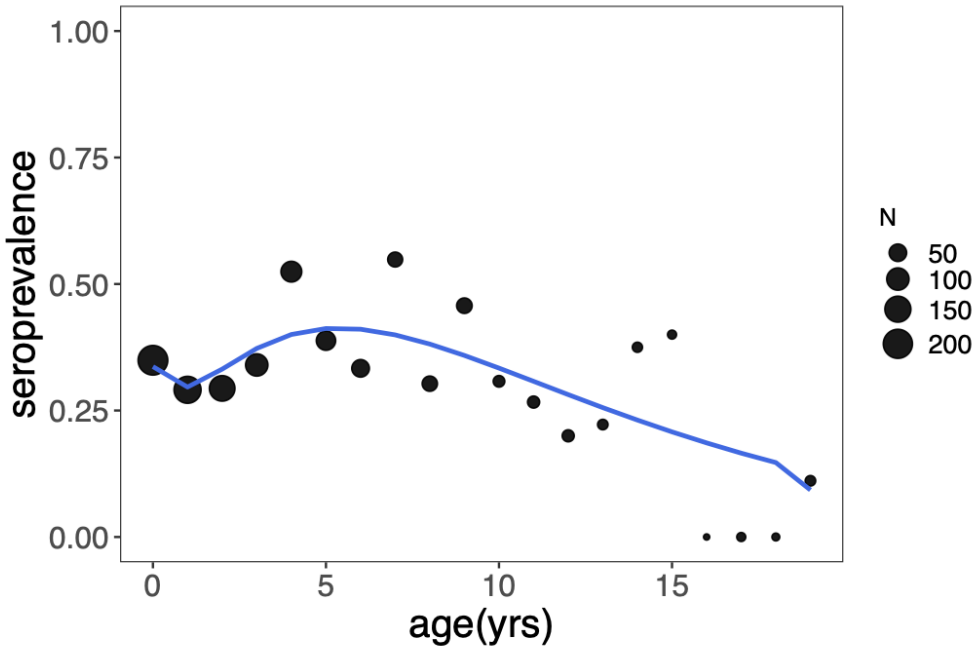
Simulation and evaluation for mechanistic models



AIC = 1277

Restif et al. 2012 *Ecology Letters*

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Intro to Compartmental Models
Introduction aux modèles compartimentés

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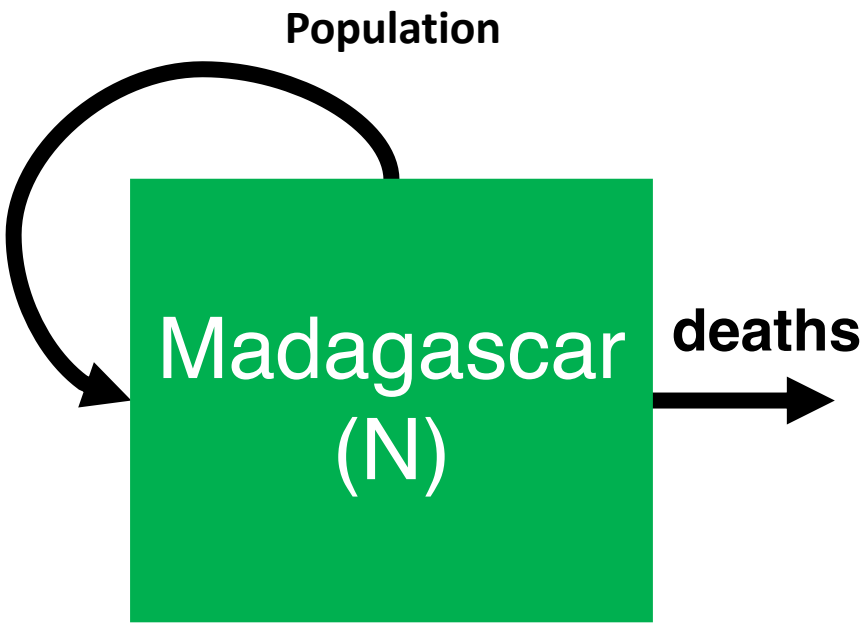

$$N_{t+1} = births * N_t - deaths * N_t$$

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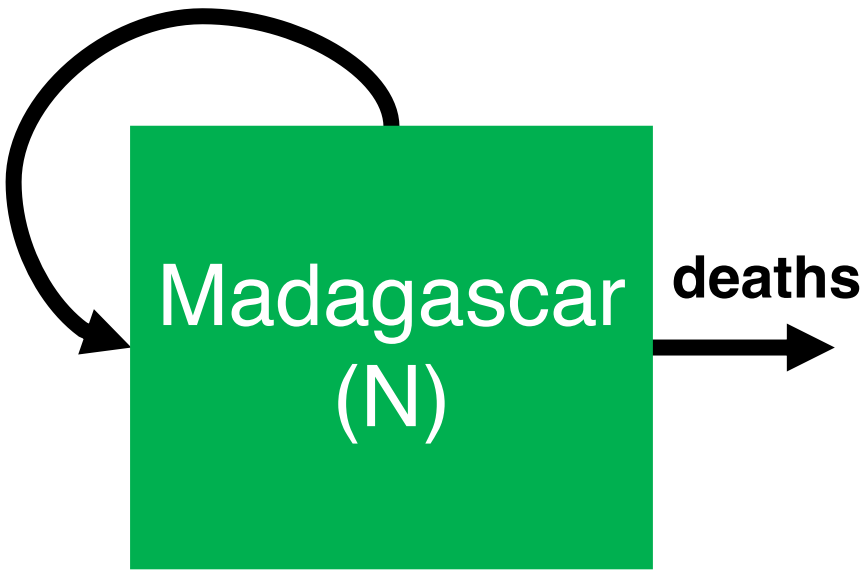
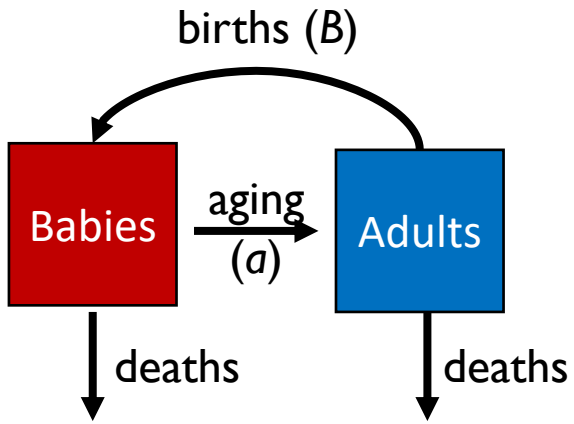
Population



Structured Population



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

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

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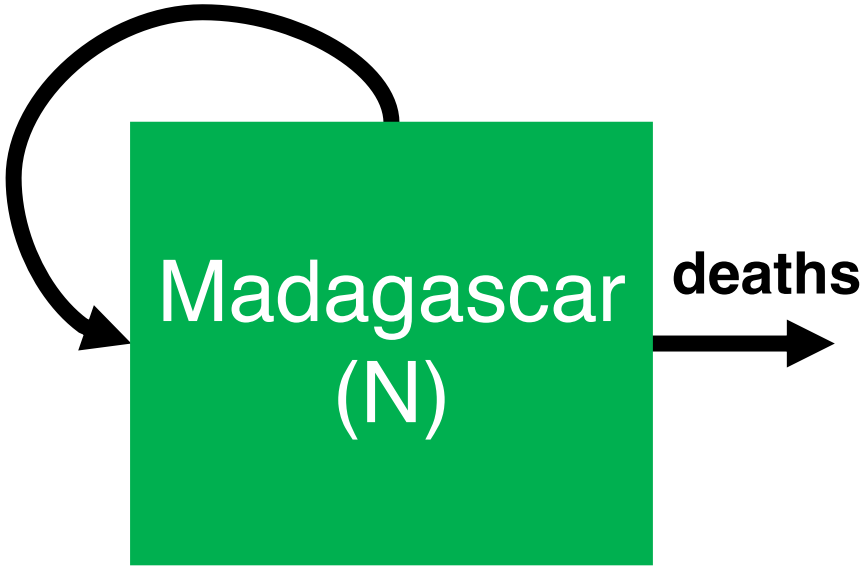

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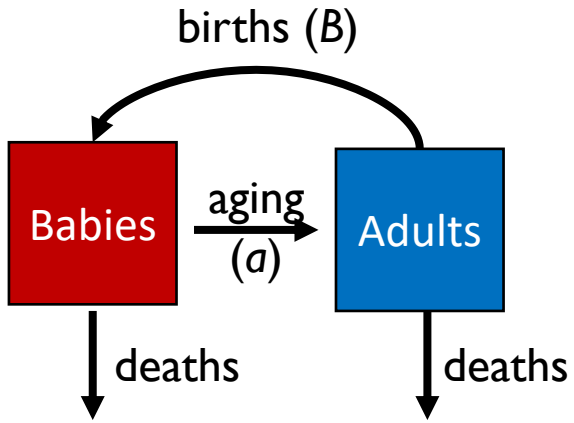

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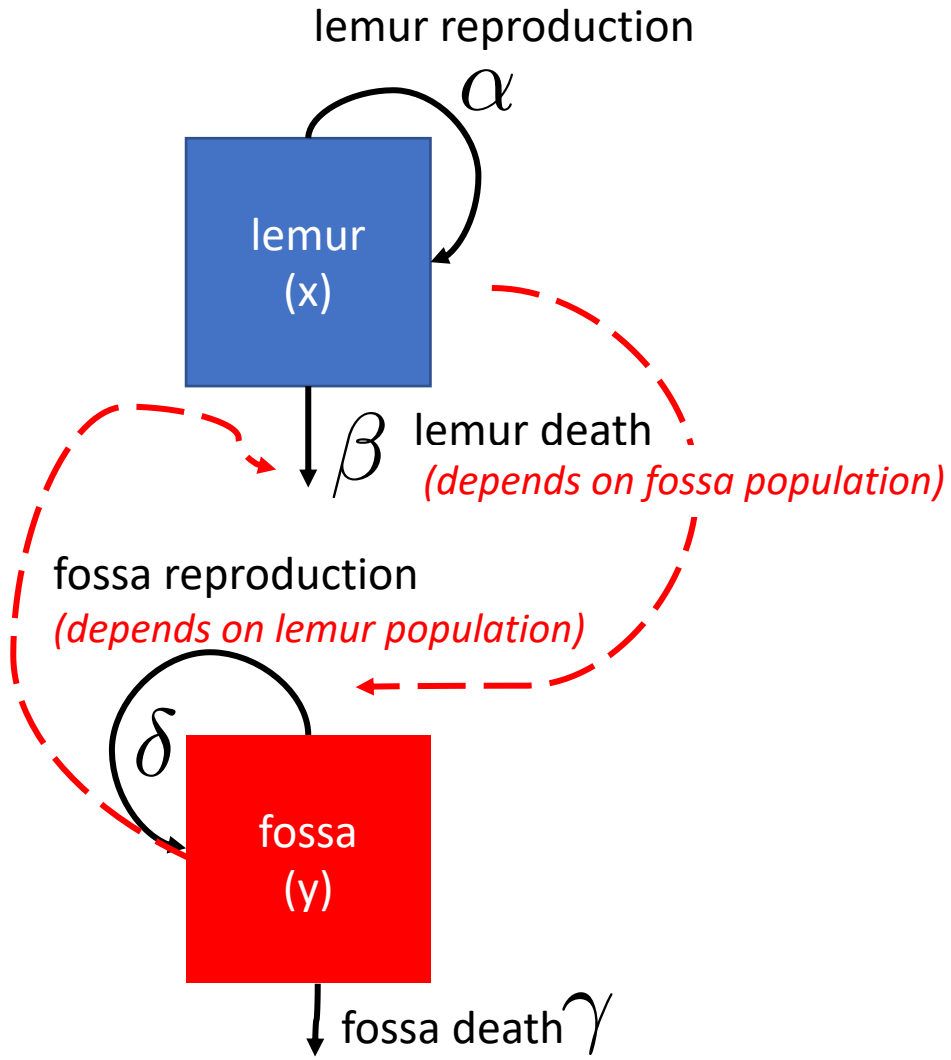
Predator-Prey



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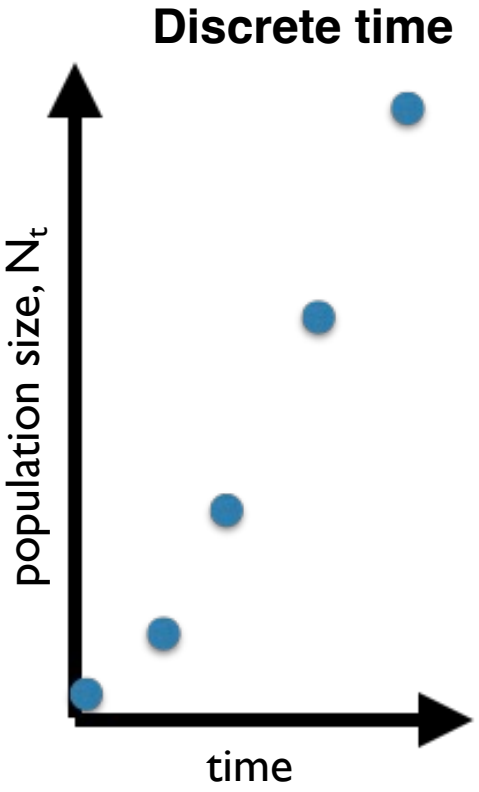

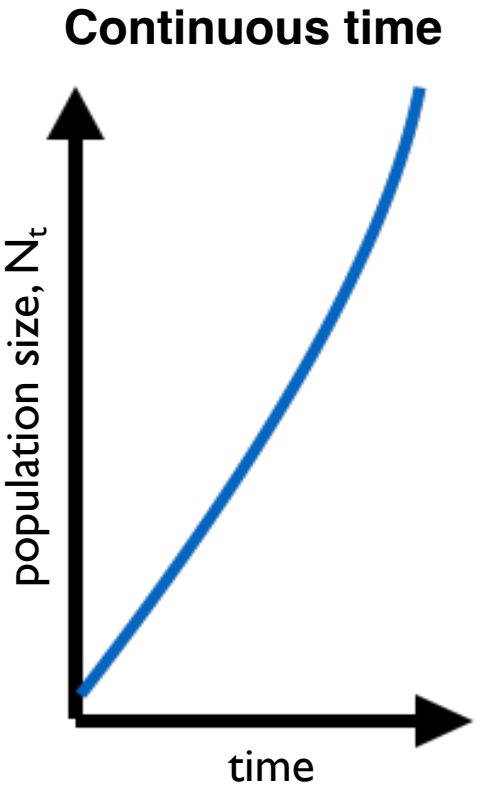

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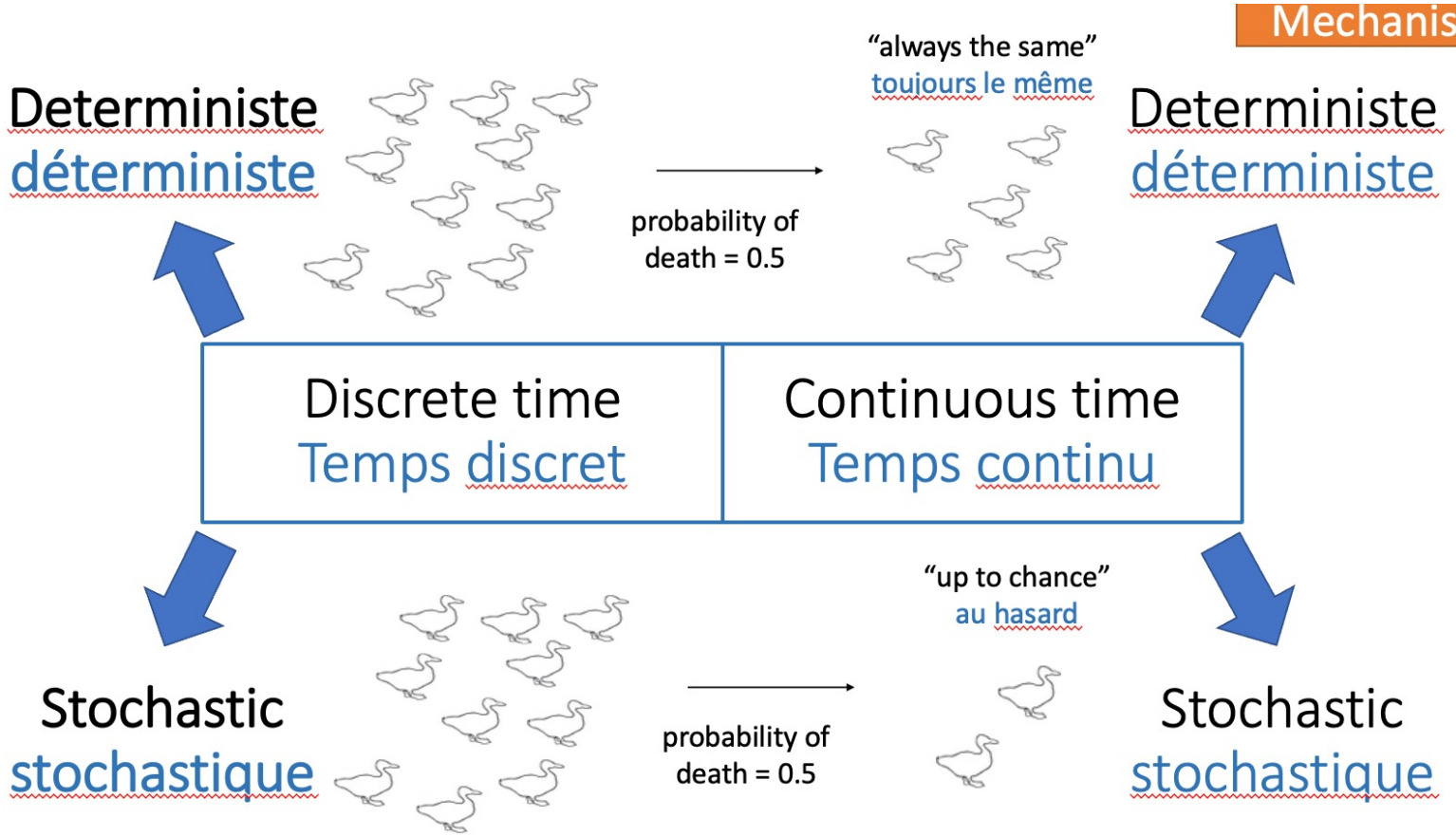

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Refining research questions for modeling

Affiner les questions de recherche pour la modélisation

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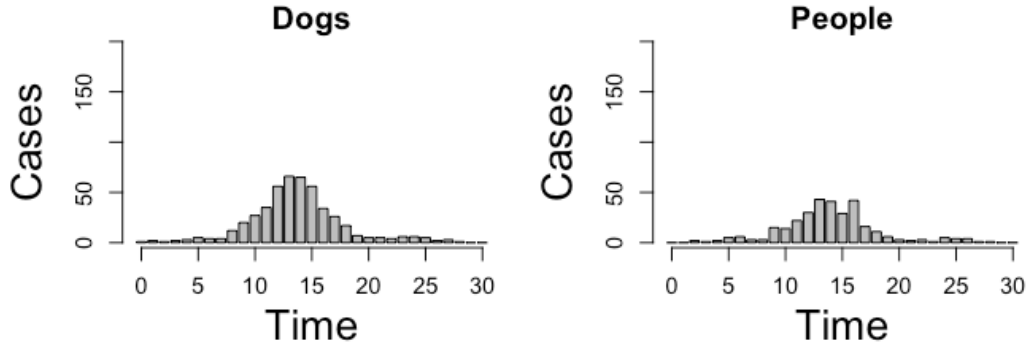
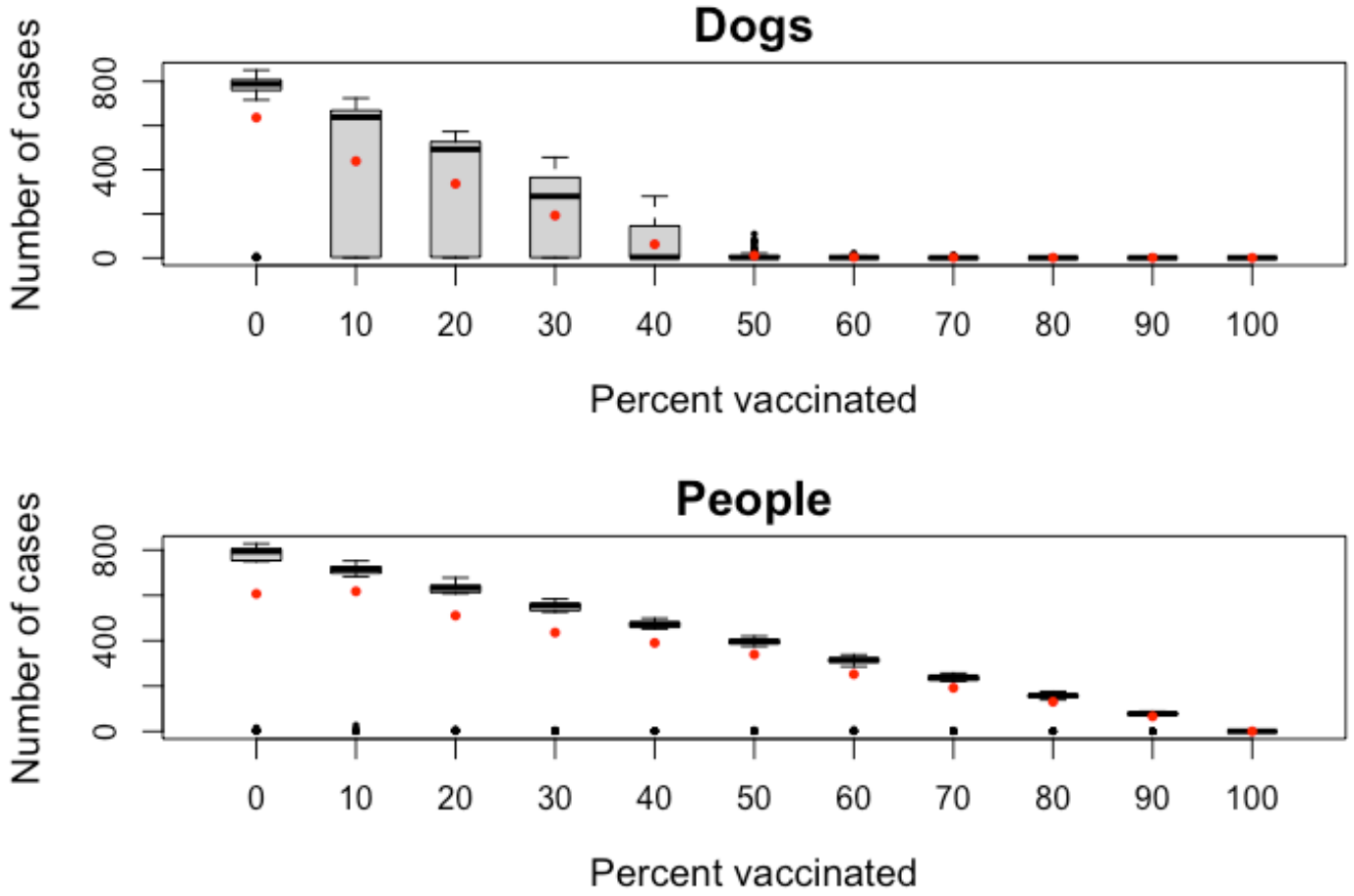
Dynamical Fever
Fièvre dynamique





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

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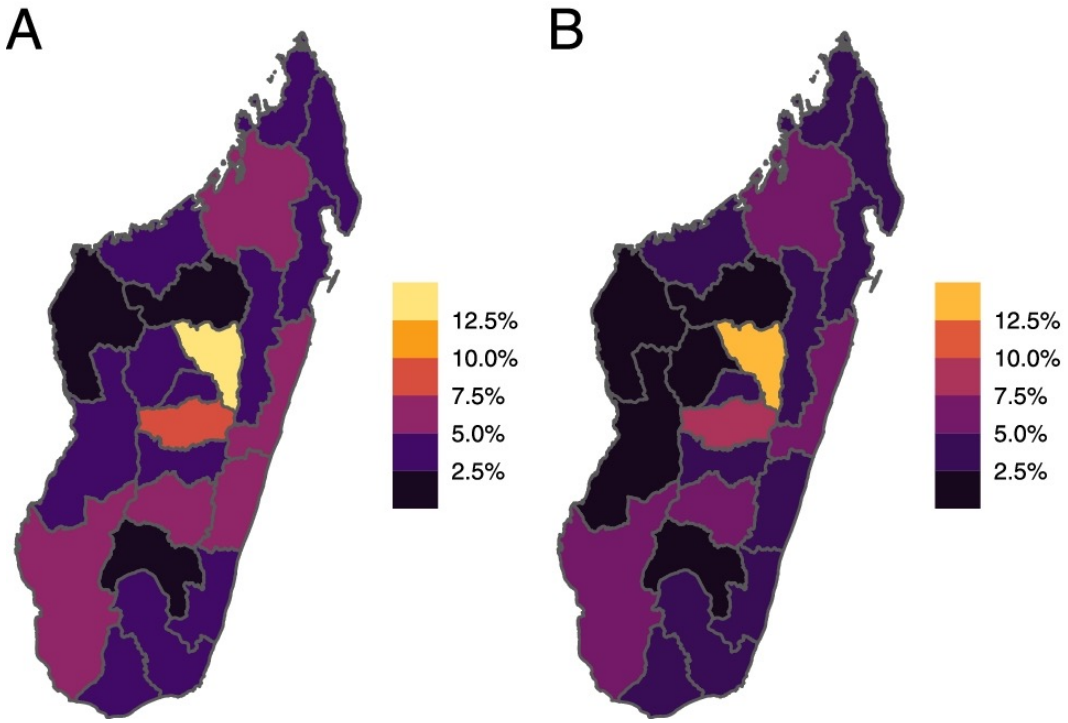
Reading a Research Paper
Lire un article scientifique



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Prioritizing COVID-19 vaccination efforts and dose allocation within Madagascar

Fidisoa Rasambainarivo, Tanjona Ramiadantsoa, Antso Raherinandrasana, Santatra Randrianarisoa, Benjamin L. Rice, Michelle V. Evans, Benjamin Roche, Fidiniaina Mamy Randriatsarafara, Amy Wesolowski & Jessica C. Metcalf

BMC Public Health **22**, Article number: 724 (2022) | Cite this article

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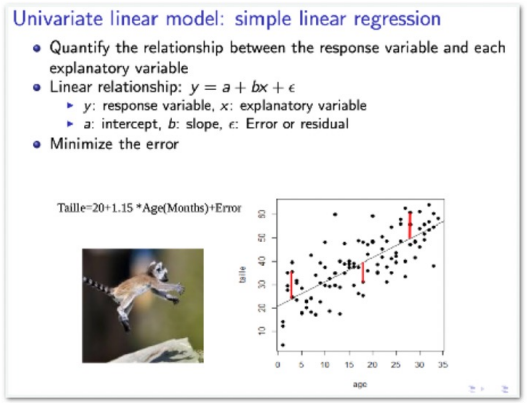
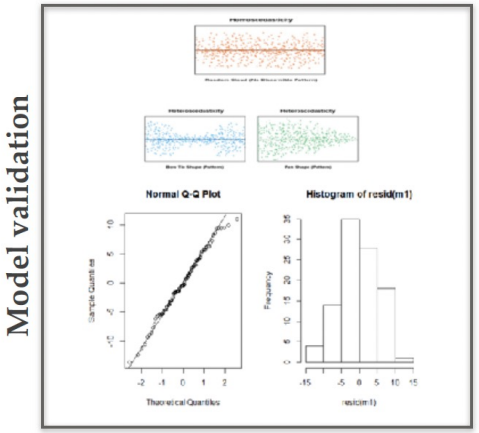
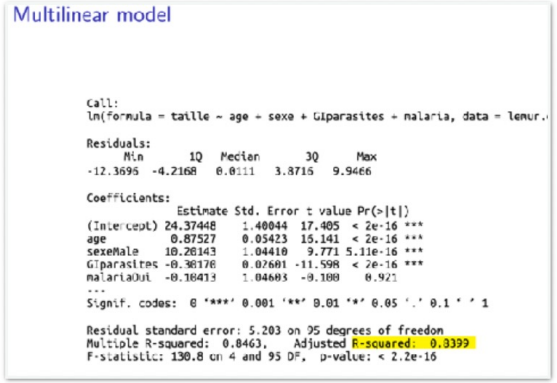
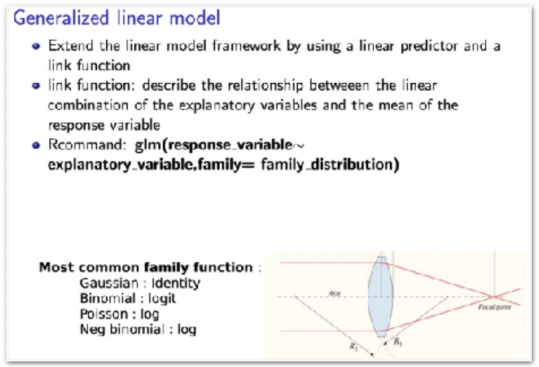
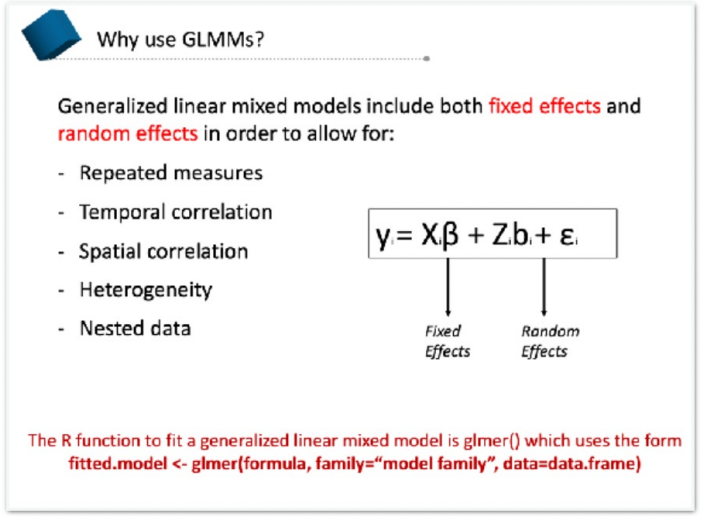
Generalized linear mixed effect models
modèles linéaires généralisés à effets mixtes

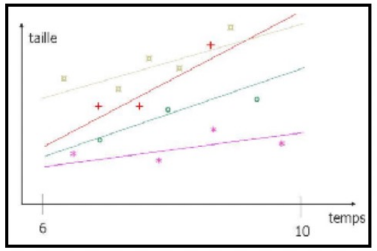


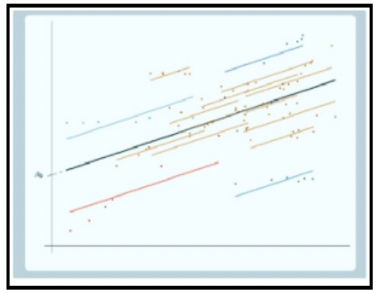


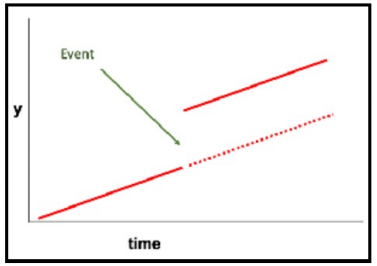


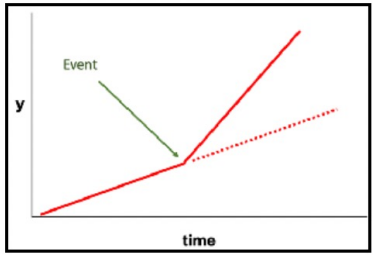


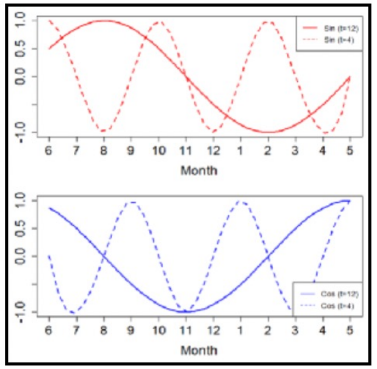












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Generalized linear mixed effect models
modèles linéaires généralisés à effets mixtes

	linear	generalized
fixed	linear regression régression linéaire normal distribution lm()	generalized linear regression régression linéaire généralisée non-normal distribution glm()
mixed	linear mixed model modèle mixte linéaire normal distribution random effects effets aléatoires lmer()	generalized linear mixed model modèle mixte linéaire généralisé non-normal distribution random effects effets aléatoires glmer()

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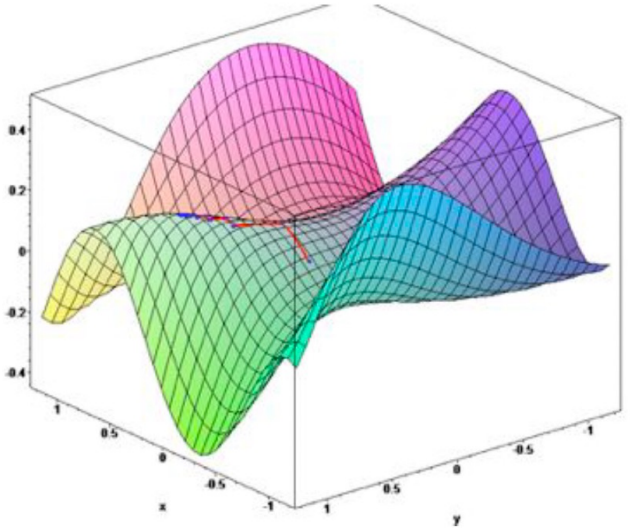
Fitting Models to Data
Adapter les modèles aux données



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**

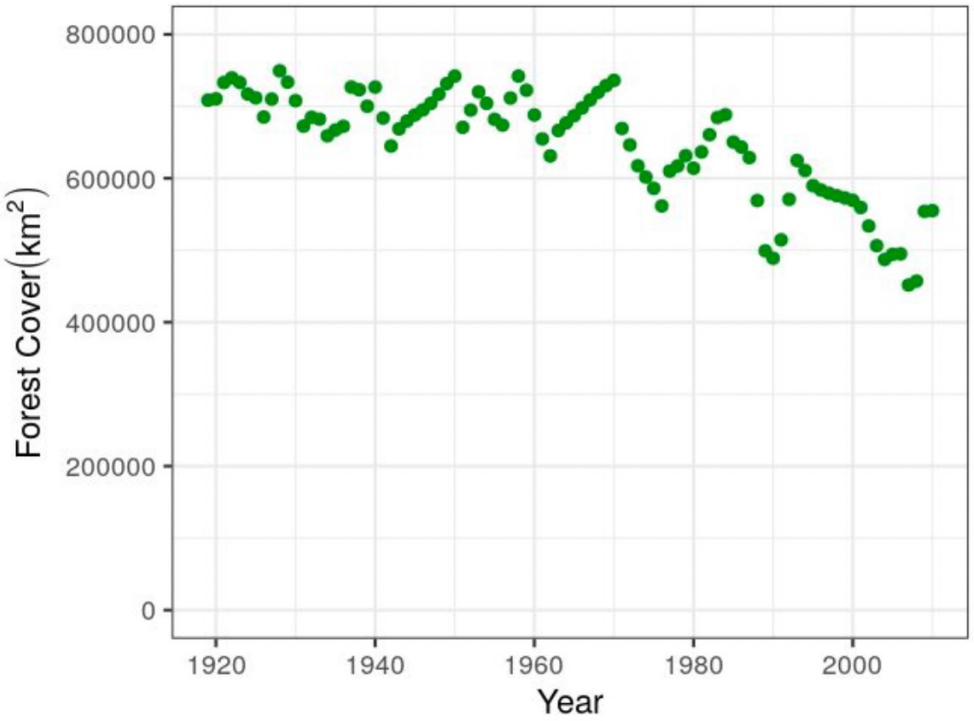
Les modèles statistiques sont basées sur les données

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?



Wednesday: "Fitting Models to Data"

- Model Fitting in Practice – the Basic Concept
- Epidemic Cards
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Fitting Models to Data
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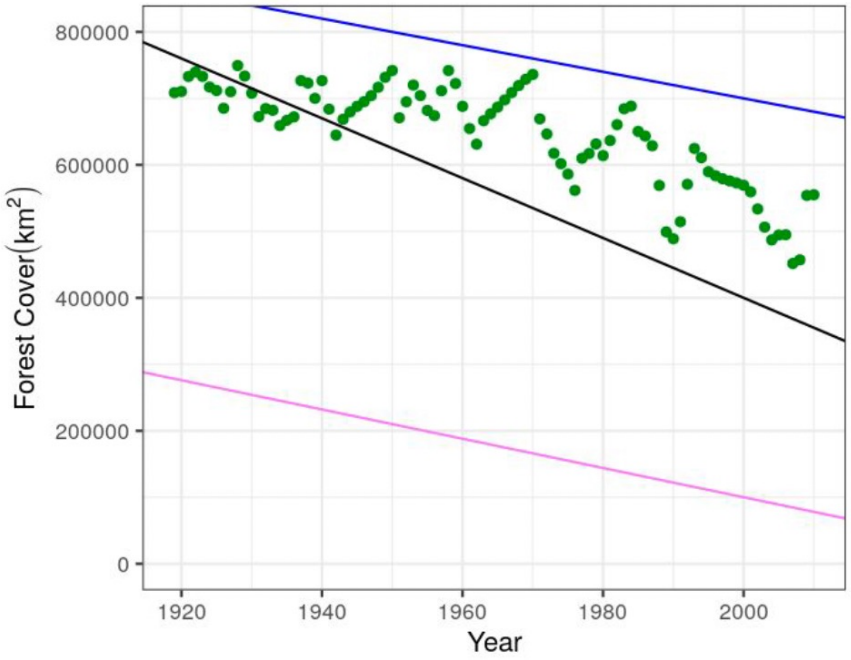
3. Optimize the parameters

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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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

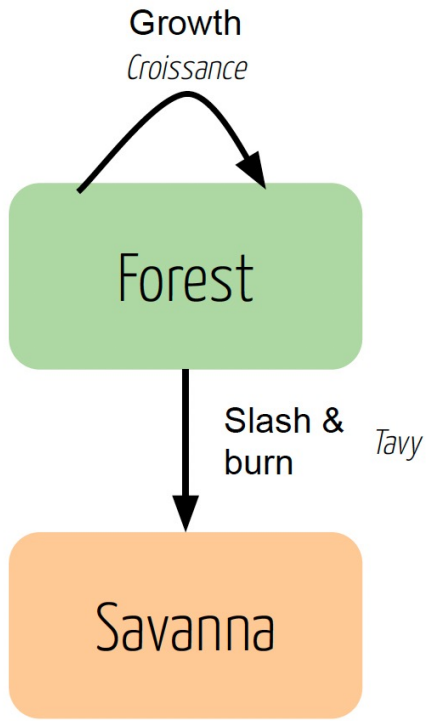
Build a model that uses explicit **processes** to recover the same outcomes ("**populations**") as our data

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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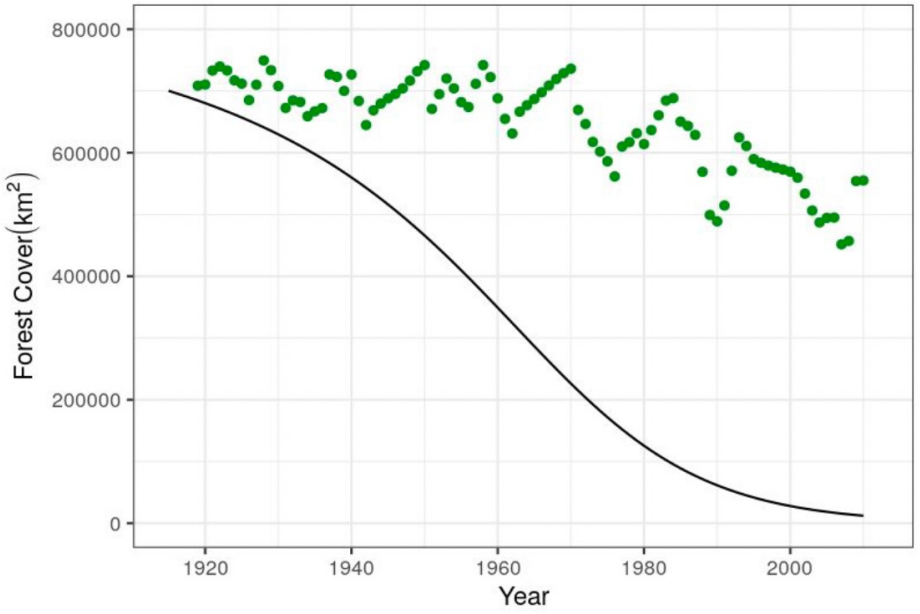
2. Assess model fit

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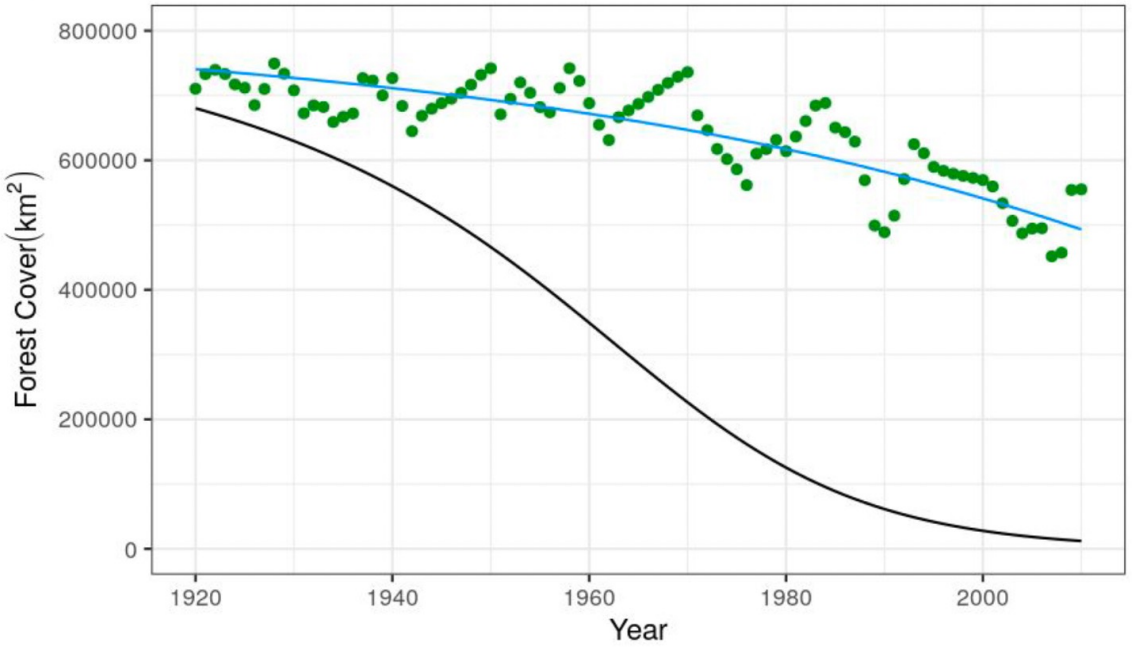
Does this optimal value result in a model that better matches the data?

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



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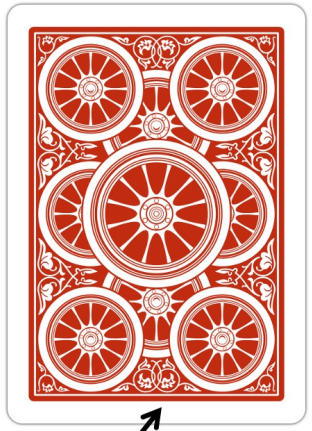
Epidemic Cards
Cartes Épidémie

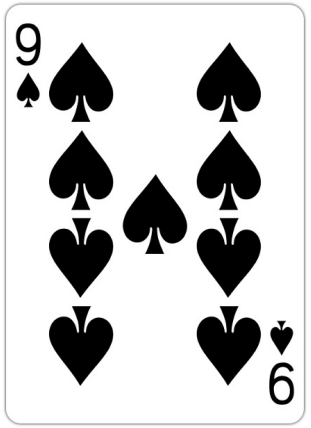
The Set-Up



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)



Round One

Timestep	Infecteds	Susceptibles	Trial	R0
1	1	25	1	2
2			1	2
3			1	2
4			1	2
5			1	2
6			1	2
7			1	2
8			1	2
9			1	2
10			1	2

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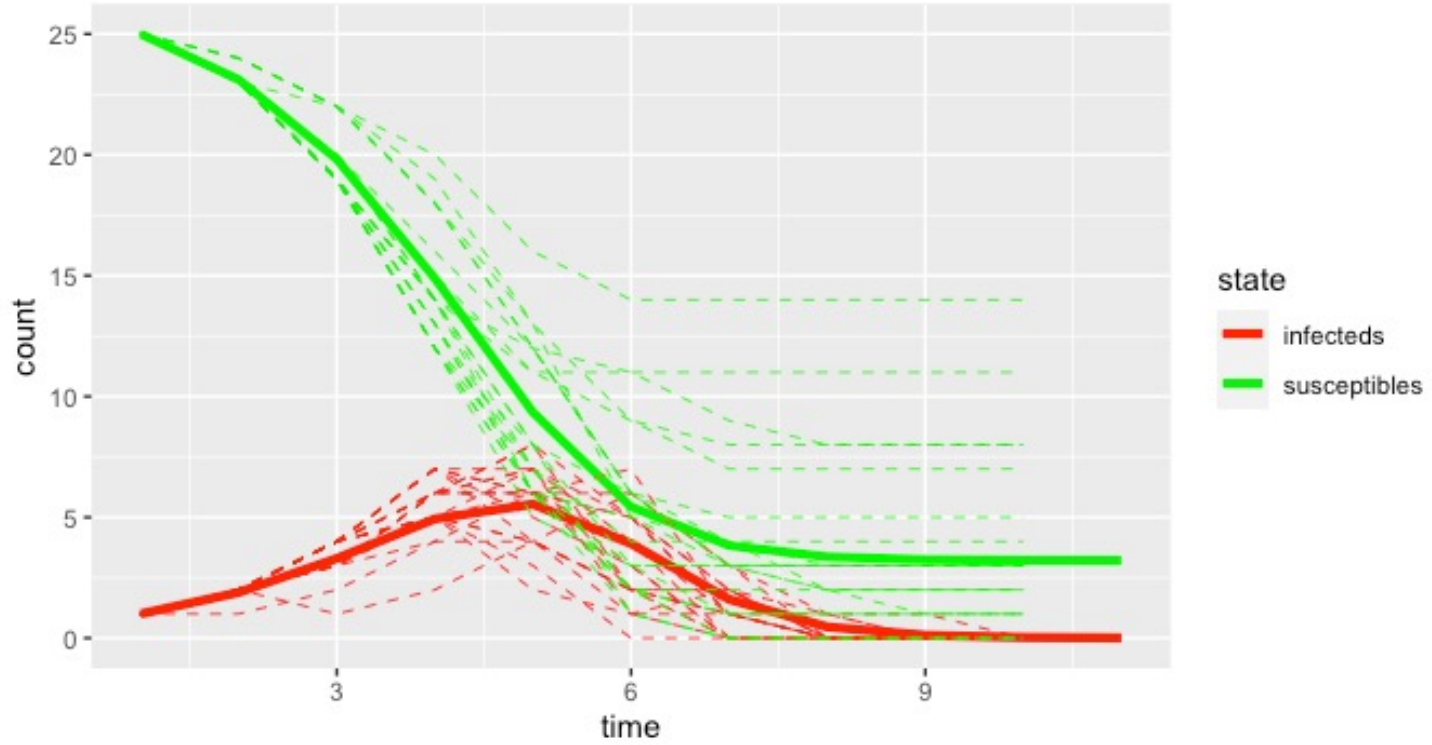
Epidemic Cards
Cartes Épidémie

```
## (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]
}
```



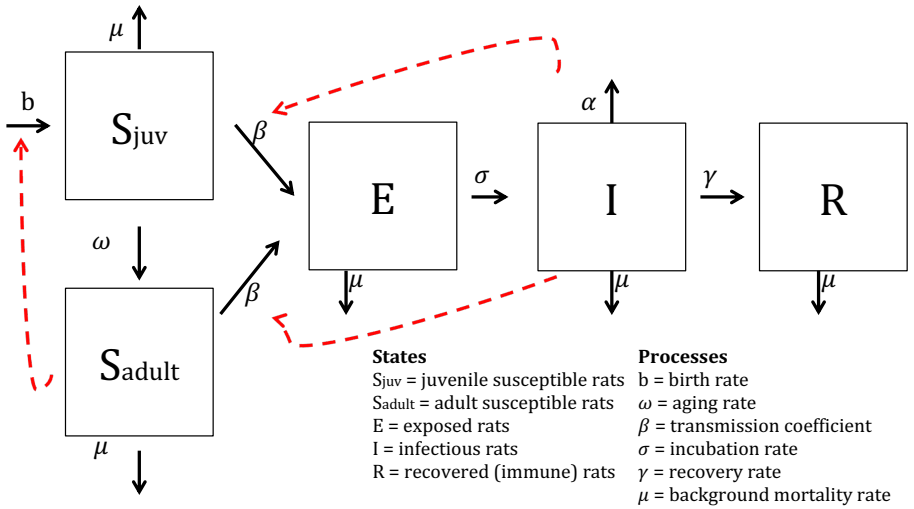
Thursday: "Refining Your Work + Bells and Whistle"

- Model Telephone
- Model Selection and Comparison ● Tutorial
- Introduction to Phylogenetic Modeling ● Tutorial
- Introduction to Network Modeling ● Tutorial
- Research Snapshots

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
ω = aging rate
β = transmission coefficient
σ = incubation rate
γ = recovery rate
μ = background mortality rate
α = infection-induced mortality rate
γ = 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.

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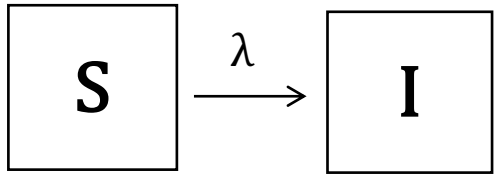
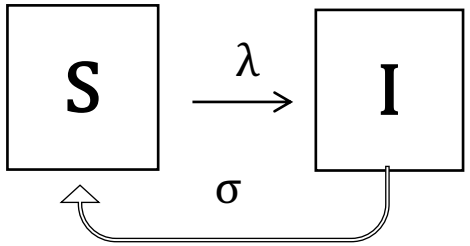
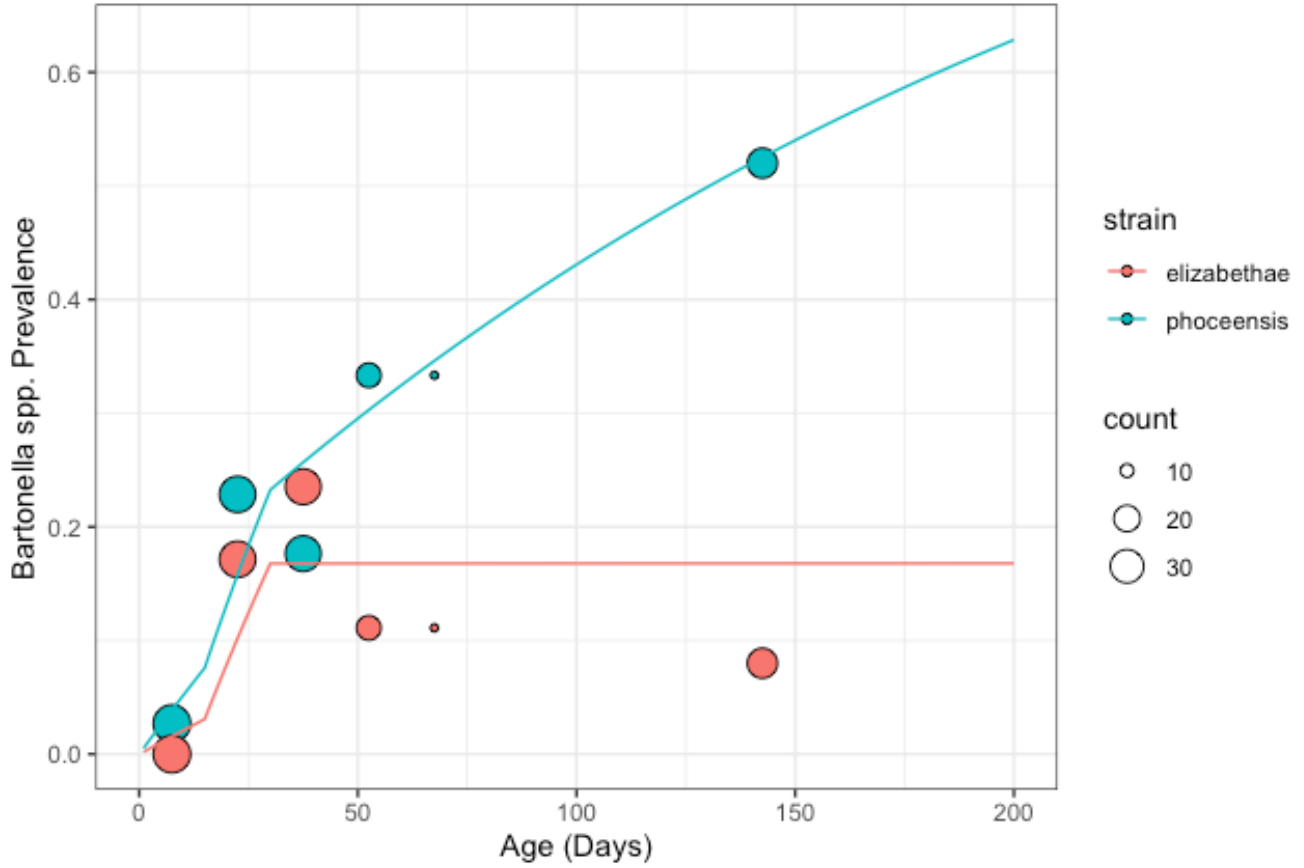
Model Selection and Comparison
Sélection et comparaison de modèles



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



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



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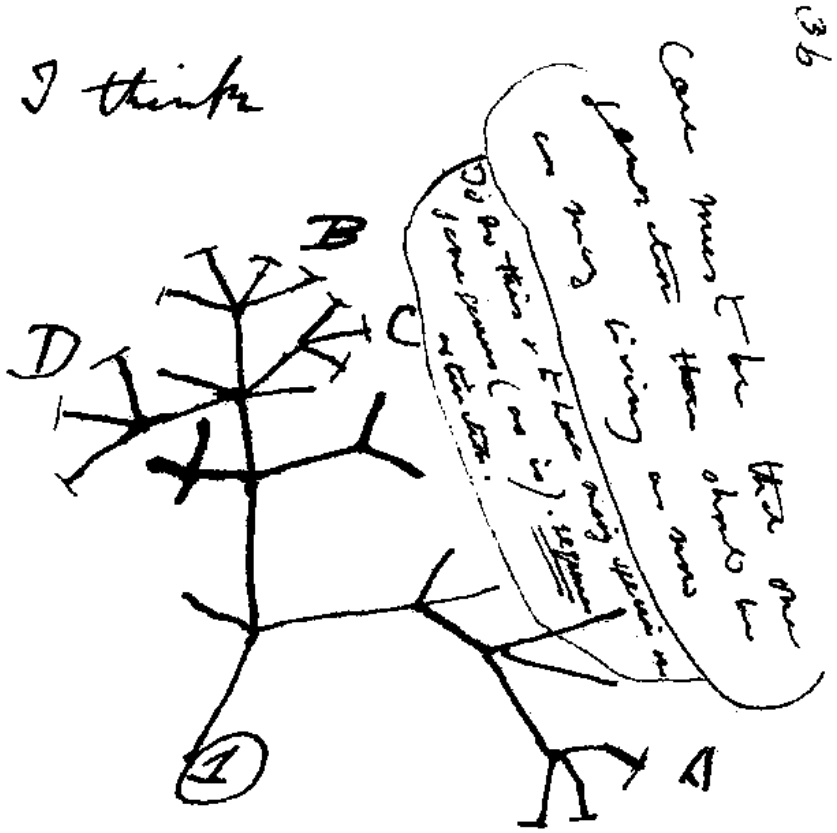
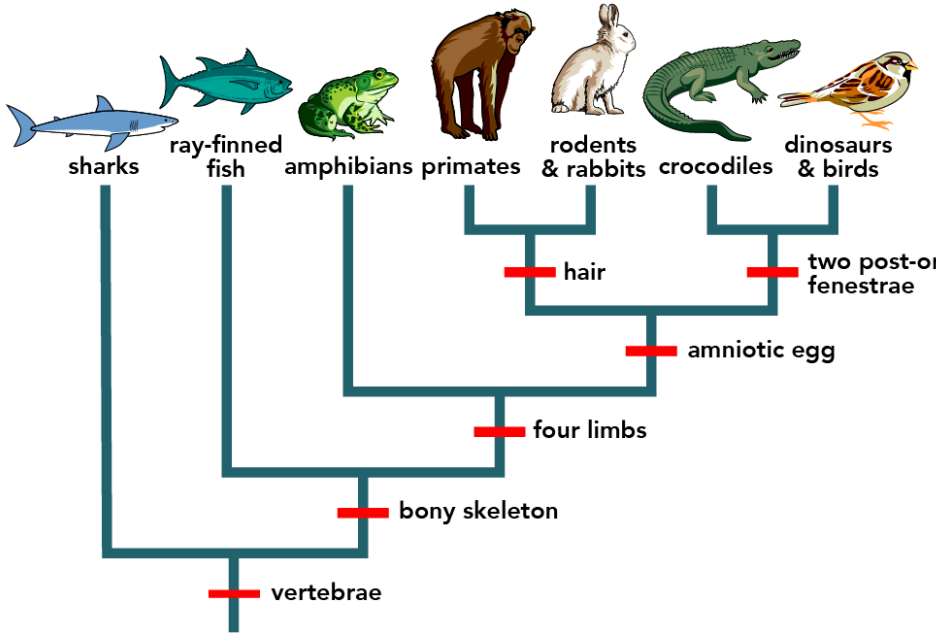
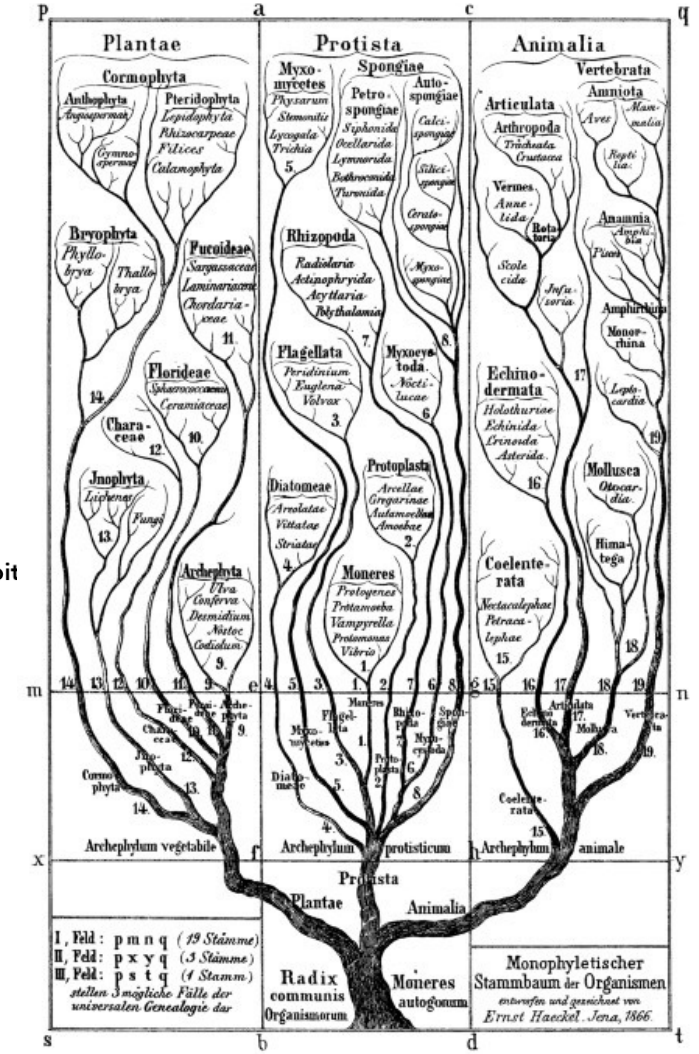
Intro to Phylogenetic Modeling
Introduction à la modélisation phylogénétique







Hossfeld and Levit, Nature, 2016

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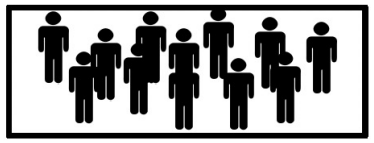
Intro to Network Modeling
Introduction à la modélisation de réseau

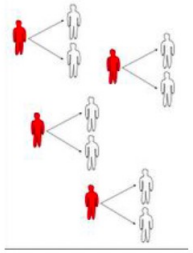
Why do we use networks in epidemiology?

Pourquoi utiliser les réseaux dans epidemiologie?

Classic epidemiological models assume full mixing (everyone can contact everyone)

Les modèles épidémiologiques classiques supposent un mélange complet (tout le monde peut contacter tout le monde)

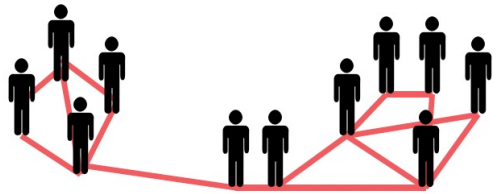


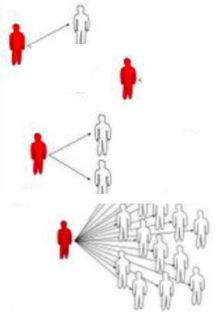


$R_0 = 2$

Reality is better represented by a network

La réalité est mieux représenté par un réseau





Average $R_0 = 2$,

But more realistic heterogeneity

Friday: R Bootcamp

- Intro to R Studio
- Exploring and Visualizing Data in R
- For-loops, Functions, and If-Else Statements

Saturday: Travel

Sunday: "Getting Started with the Basics"

- Data and Models
- Student introductions & presentations
- Linear regression • Tutorial
- Formulating research questions

Monday: "Using Models with Data"

- Model-Guided Study Design
- Study design tutorial
- Intro to Compartmental Models & Differential Equations
- Building mechanistic models in R
- Refining research questions for modeling
- Defining a model world

Tuesday: "Applying Simple Models"

- Dynamical Fever
- Introduction to Mixed Modeling
- Reading a Research Paper

Wednesday: "Refining Your Work"

- Model Fitting in Practice – the Basic Concept
- Epidemic Cards
- Model Fitting with Epidemic Cards
- Model Selection and Comparison
- Model Selection Tutorial
- Model Telephone

Thursday: "Bells and Whistle"

- Introduction to Phylogenetic Modeling • Tutorial
- **Intoduction to Spatial Visualization and Plotting** • Tutorial
- Modeling Insights from the Metapopulation Game • Tutorial
- Introduction to Network Modeling • Tutorial
- Research Snapshots

Friday: "Putting it All in Perspective"

- The Life Cycle of a Modeling Project
- C4C Student Presentations

Saturday: Travel

January: "Sharing Your Work"

- Final student presentations

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

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