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

# Data and Models

Centre ValBio

Ranomafana National Park, Madagascar

13 – 20 January, 2019

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Lecture contributions from:

Tanjona Ramiadantso

Steve Bellan

International Clinics on Infectious Disease, Dynamics, & Data

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**MMED:** ***Clinic on the Meaningful Modeling of Epidemiological Data***

May-June 2019, Cape Town, South Africa

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**South African Center for Epidemiological Modeling and Analysis (SACEMA), Director**

Dr. Juliet Pulliam

*University of Stellenbosch*

**ICI3D, Program Director**

Dr. Steve Bellan

*University of Georgia*

International Clinics on Infectious Disease, Dynamics, & Data

www.ici3d.org

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- To explain what we’re doing here

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- To introduce the “E” in $E^2M^2$
  - Ecology
  - Epidemiology

All course materials are available at:

https://carabrook.github.io/E2M2/E2M2_2019.html

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

**Sunday: Travel**

**Monday: "Dealing with Data"**
- Data and Models
- Student introductions & presentations
- Linear regression & simple stats
- Basic statistical modeling in R
- Formulating research questions

**Tuesday: "Deeper Thinking About Data"**
- Dynamical Fever
- Intro to Mixed Modeling
- Mixed modeling in R
- Study Design and Data Collection
- Refining research questions for modeling

**Wednesday: "Thinking About Mechanism"**
- Intro to Compartmental Models & Differential Equations
- Building mechanistic models in R
- Defining a model world
- Refining research questions for modeling
- Discussion of a scientific paper
- Mentor research presentations

**Thursday: "Fitting Models to Data"**
- Model Fitting in Practice – the Basic Concept
- Introduction to Occupancy Modeling
- Intro to Spatial Modeling
- Occupancy modeling in R
- Epidemic Cards
- Model Fitting with Epidemic Cards
- Model Telephone

**Friday: "Refining Your Work"**
- Intro to Network Modeling
- Model Selection and Comparison
- Modeling Vector-Borne Disease
- Final research plans

**Saturday: "Putting it All in Perspective"**
- Modeling in Practice: The Lifecycle of a Modeling Project
- Research snapshots

**Sunday: Travel**

**Monday: "Sharing Your Work"**
- Final student presentations

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

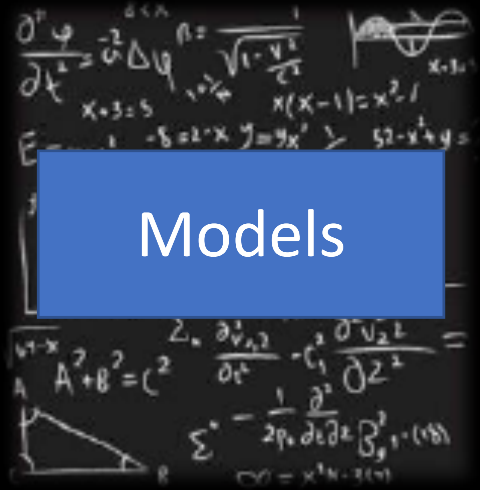
# What is science?

the systematic observation of natural events and conditions in order to discover facts about them and to formulate laws and principles based on these facts.

– *Academic Press Dictionary of Science & Technology*

# Observations and Laws and Principles

# Data and Models

# Data and Models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  - Backbone of science

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# Data vs. Models


- What is data?
  - Backbone of science
  - Evidence to support a claim

# Data or not data?


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# Data or not data?


- 19
- 19  = total number of fingers and toes
- 19 = total number of fingers and toes of Andry Rajoelina
- This is a fact. It becomes data when we use it to support a claim.

*There is a negative correlation between the number of years someone has served as president of Madagascar and their total number of fingers and toes.*

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- 5, 11, 27

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*Tenrecs have high fecundity rates.*

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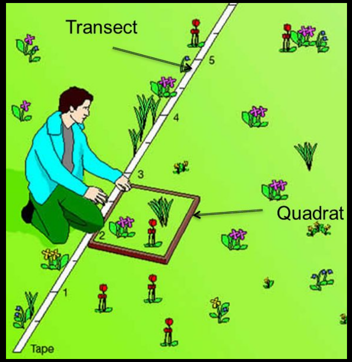
# What is data?

- Backbone of science
- Evidence to support a claim
- A relationship between at least two variables
    - x: explanatory, control, driver, independent variable(s)
    - y: response, dependent variable(s)
- x and y should be clearly defined
    - with respect to the **question!**

# Data: Sources of x and y

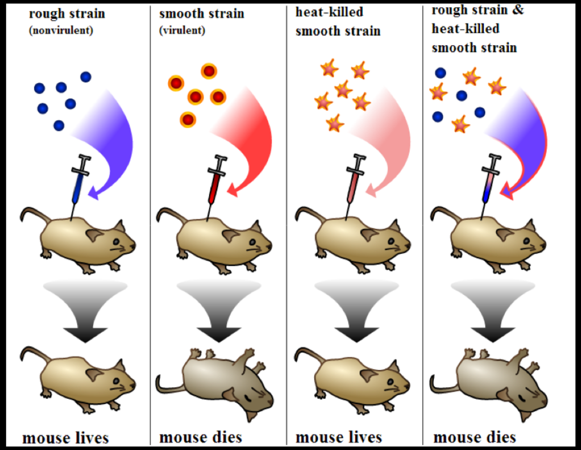

**Observational**

- Just measure x and y



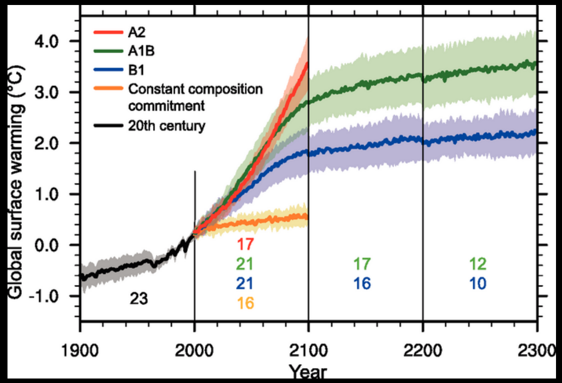

**Experimental**

- Interfere with x or the relationship between x and y




**Simulated**

- Create a relationship between x and y




**Empirical data**

# Data: Types


**Numerical**

**Categorical**

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- Examples?

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- Examples:
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**Categorical**

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- Examples:
- Colors, (blood) types, species name


# Data: Things to consider

- Data acquisition


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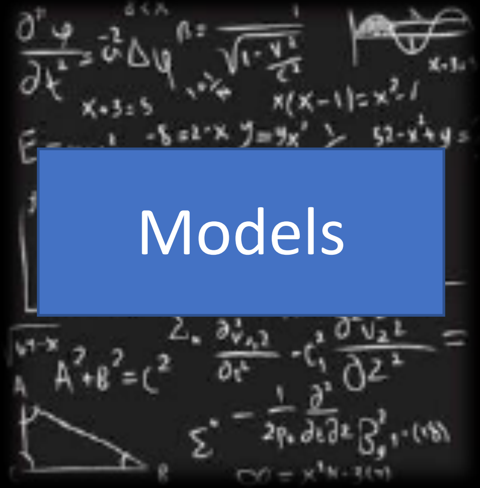
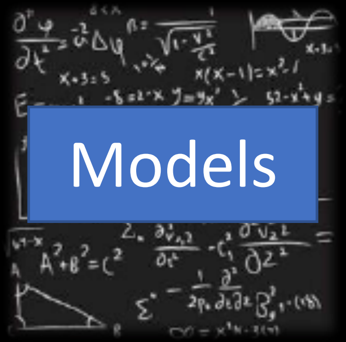
# Data and Models

# Data vs. Models

- What is a model?



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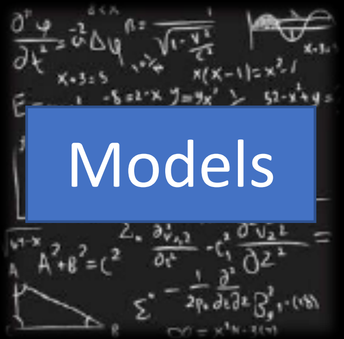
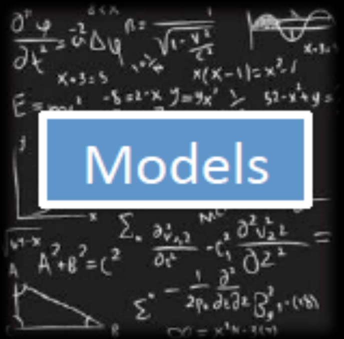
# Laws and Principles




- A theory = a declaration to explain a phenomenon
  - Logical and falsifiable
- A model = an abstract representation of a phenomenon
- A hypothesis = a testable declaration that is derived from a theory

# Theory, Models, Hypotheses




Theory — General

Model

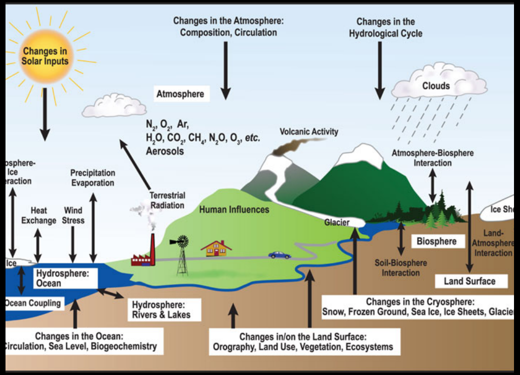
Hypothesis — Specific

# Models: many types

Human

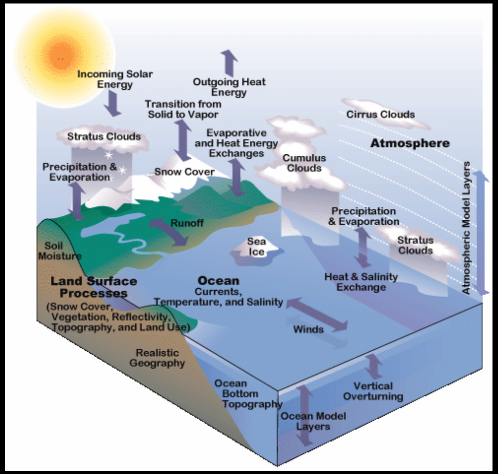
Car

Ecosystem

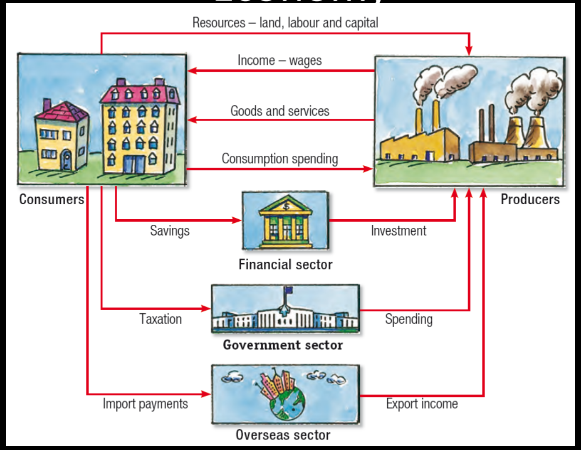


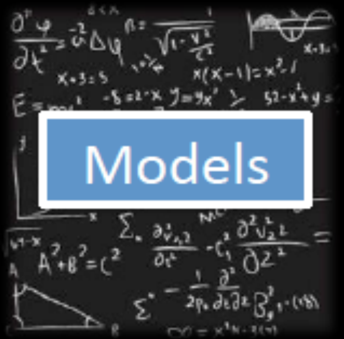

Ecology & Evolution

Climate




Economy






- When you make a model,

  you include the

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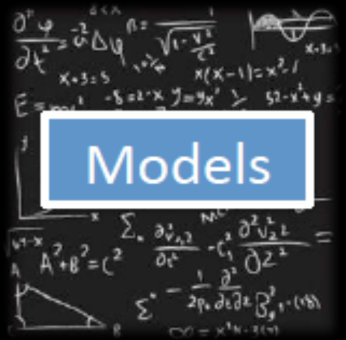
  to explain a phenomenon.

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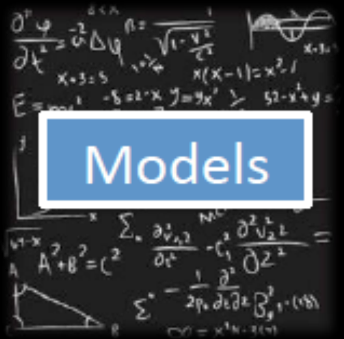


- When you make a model,

  you include the

  elements that you feel are most important to explain a phenomenon.
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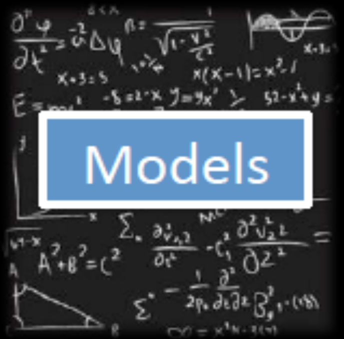
  that can reproduce real-world data
- In $E^2M^2$, we distinguish between statistical and mechanistic models

# Statistical vs. Mathematical Model




The choice depends on the research question!

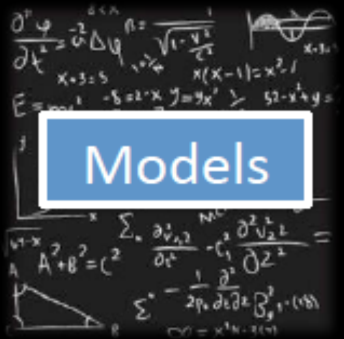
# Statistical Models

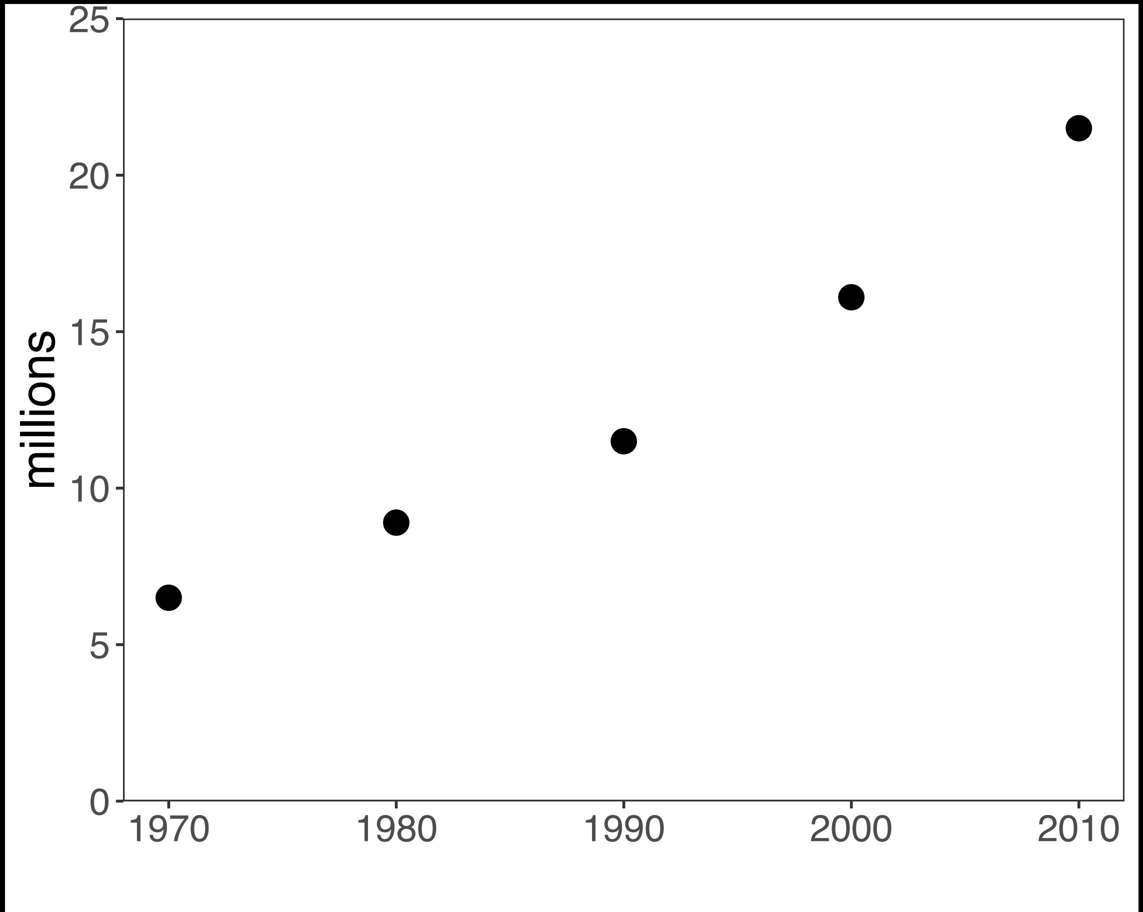

- Goal: To rigorously assess the strength of relationship between x and y
  - Find a significant relationship using a p-value as a measure of relationship strength
  - Statistical models can demonstrate correlations.

# Statistical Models


- Goal: To rigorously assess the strength of relationship between x and y (describe patterns)
  - Find a significant relationship using a p-value as a measure of relationship strength
  - Statistical models can demonstrate correlations.
- Steps:
  1. Formulate a research question
  2. Formulate a hypothesis
  3. Develop a model to demonstrate your hypothesis.
  4. Collect **data (required!!!)**
  5. Evaluate hypothesis with appropriate statistical tools
     - t-test, Chi-square, ANOVA
     - Ordination (PCA)
     - Regression (LM, GLM, GLMM, GAM)

# 1. Example Question: What is the trajectory Malagasy population size through time?

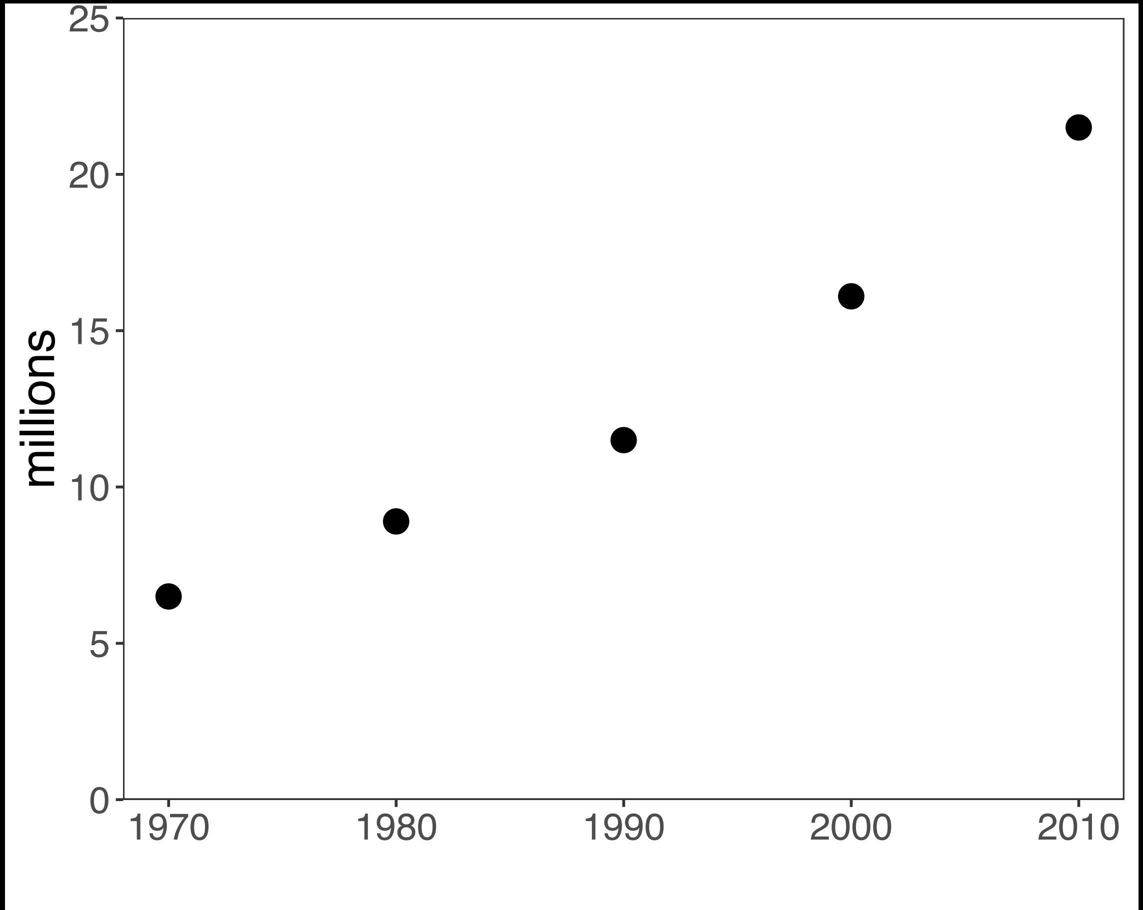



Source: World Bank

# 1. Example Question: What is the trajectory of Malagasy population size through time?


2. Hypothesis: Malagasy population size increases with time

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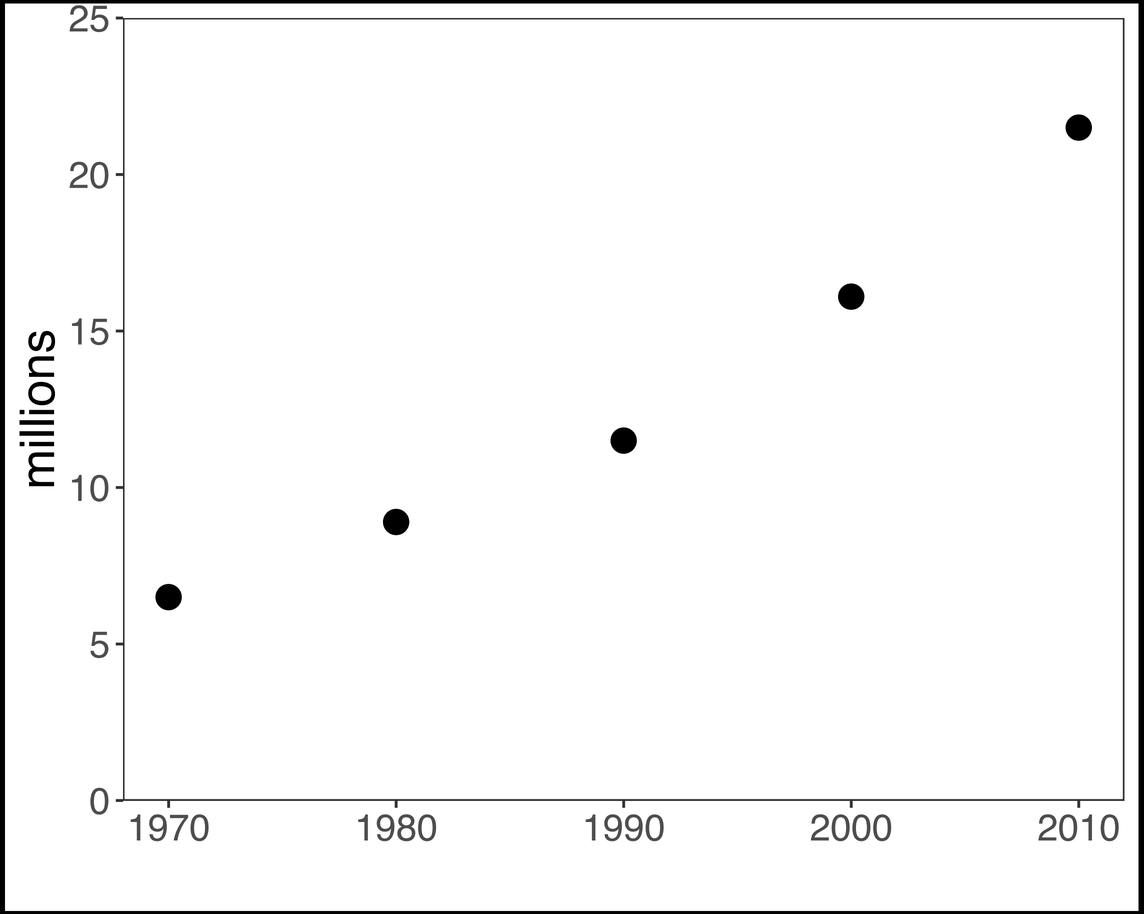
3. Statistical Model:

$$y = mx + b$$

Linear Regression

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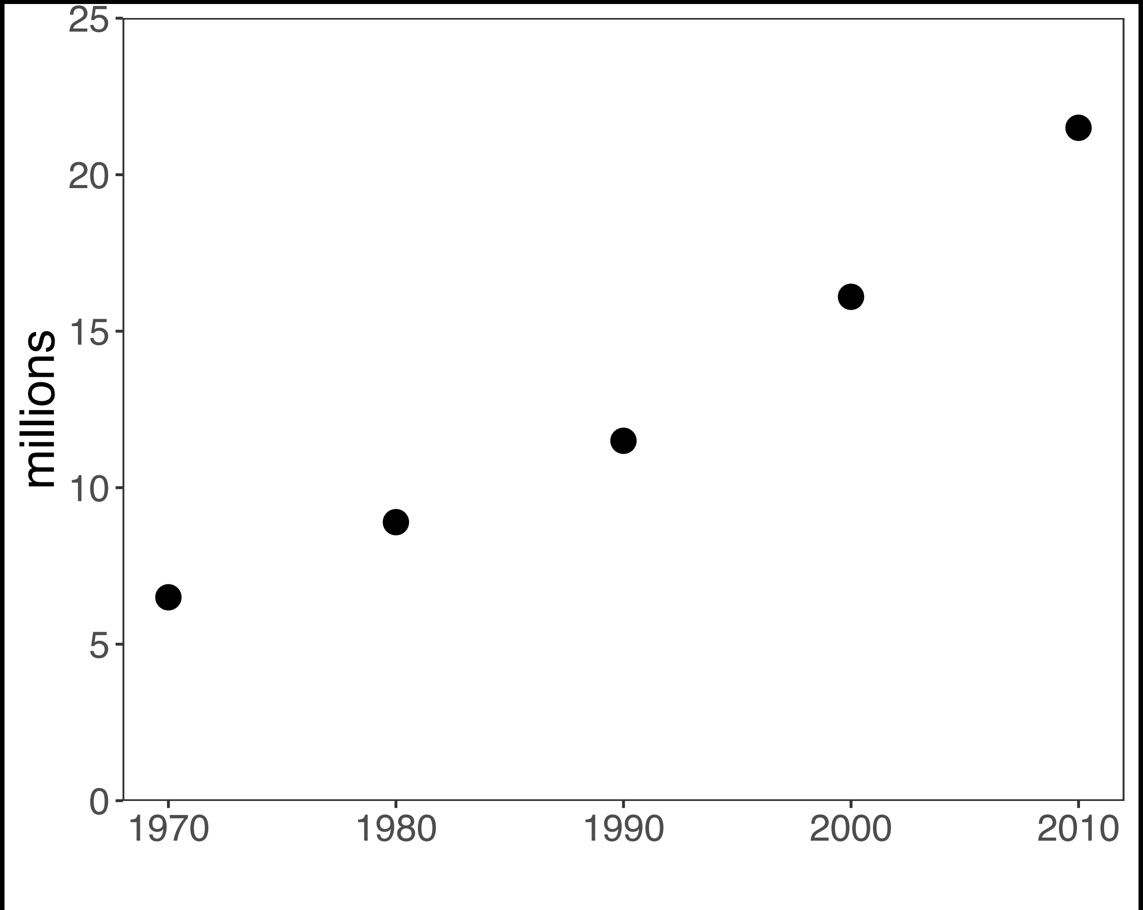


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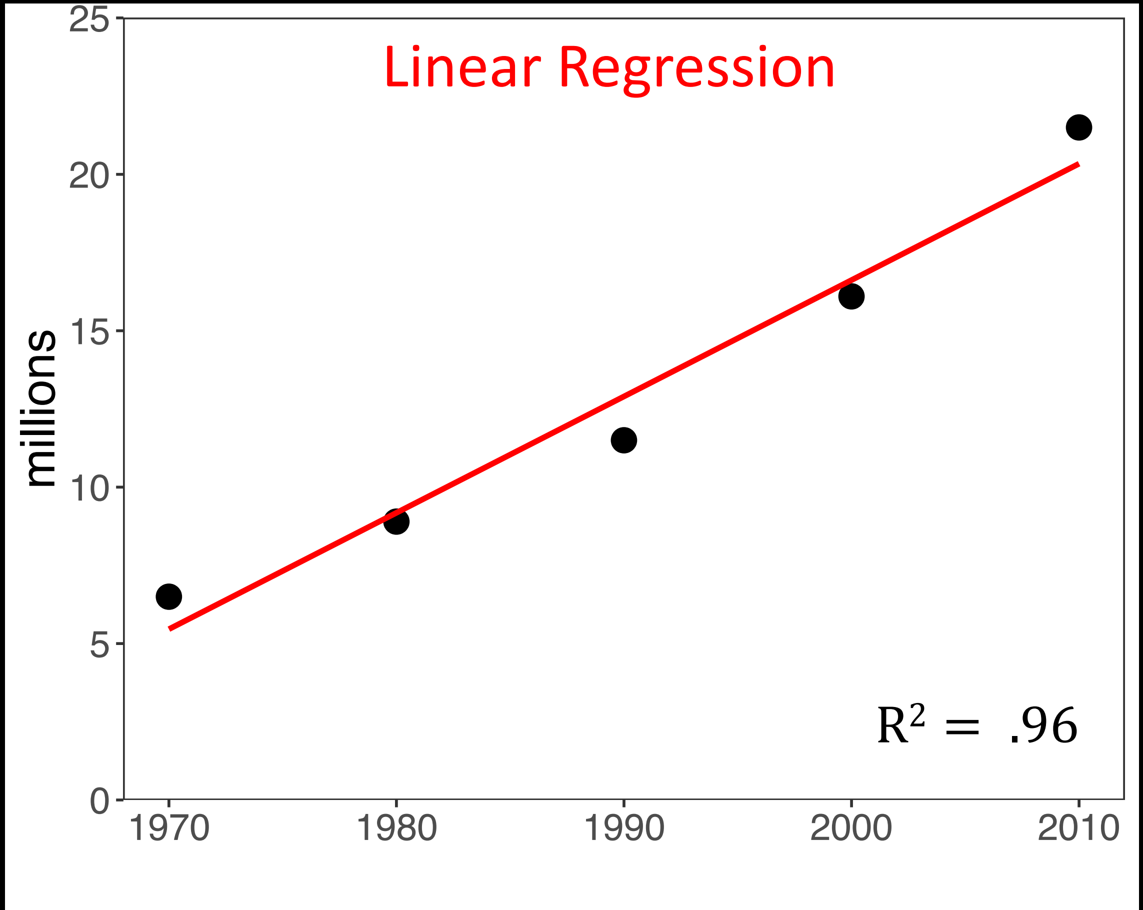


5. Evaluation

$$m = .372 \text{ million}$$

$$p = .003$$

What can we conclude from this fitted model?

Source: World Bank

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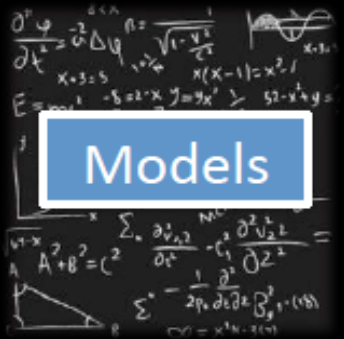


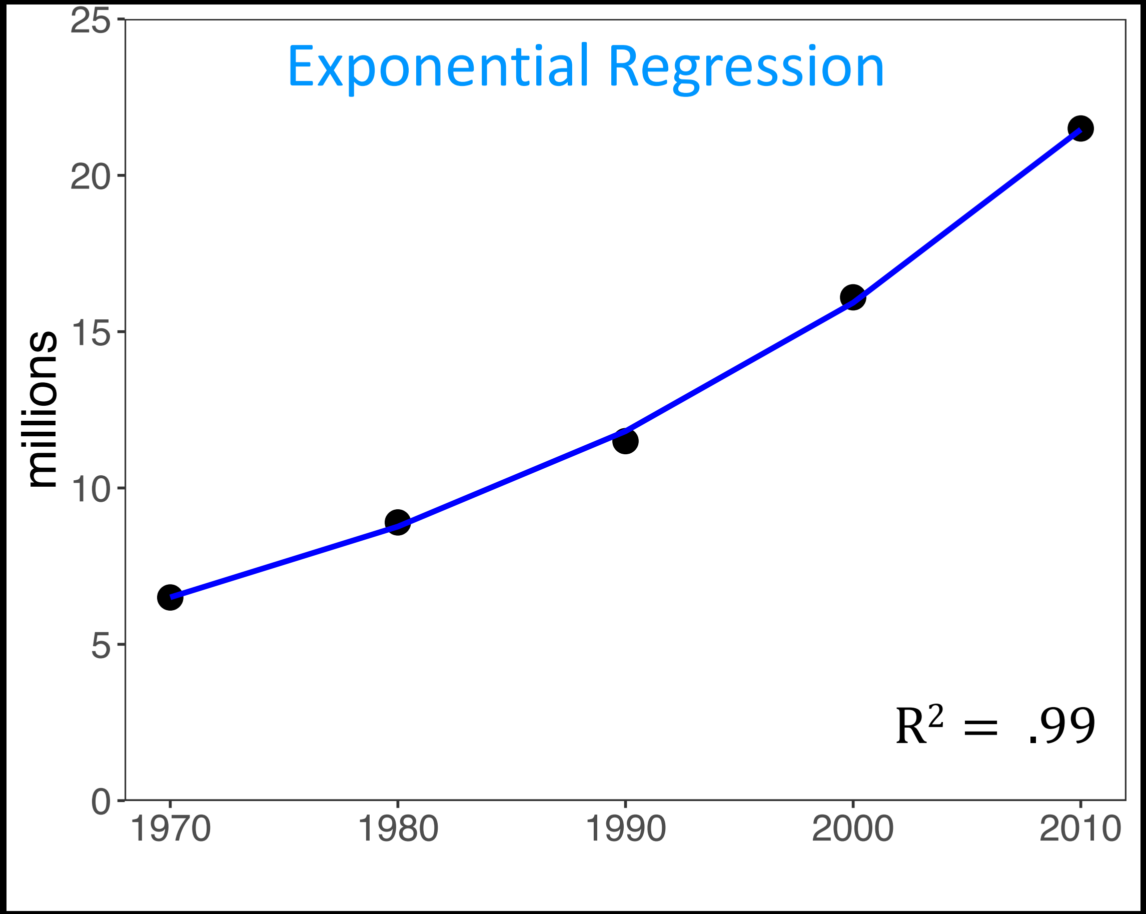

7. Adapt your model and re-evaluate:

$$y = e^{mx+b}$$

Exponential Regression

$m = 0.029$ mil.

$p < .001$

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# Statistical Models: Beware!


- Statistical models and tests are based on specific assumptions
  - data normally distributed
  - y and y independent
  - etc.

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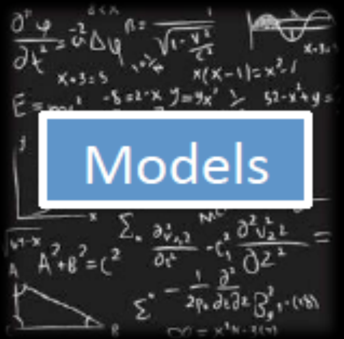


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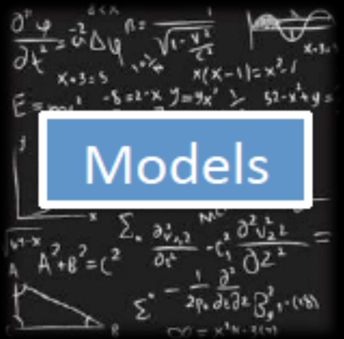
- Statistical models and tests are based on specific assumptions
    - data normally distributed
    - y and y independent
    - etc.
- Assessing a model means you need to make sure the assumptions are not violated.
- There are so many statistical models…

# Statistical vs. Mathematical Model

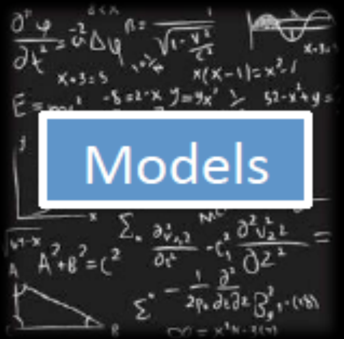

**The choice depends on the research question!**

# Mechanistic Models




- Goal: To demonstrate the processes that underlie a relationship between x and y
  - Find a significant relationship using a p-value as a measure of relationship strength
  - Mechanistic models can demonstrate causation.
- Steps:
  1. Formulate a research question
  2. Formulate a hypothesis
  3. Develop a model to demonstrate your hypothesis.
  4. Collect **data** (for certain questions)
  5. Evaluate the extent to which your model-simulated data matches that from the real world.

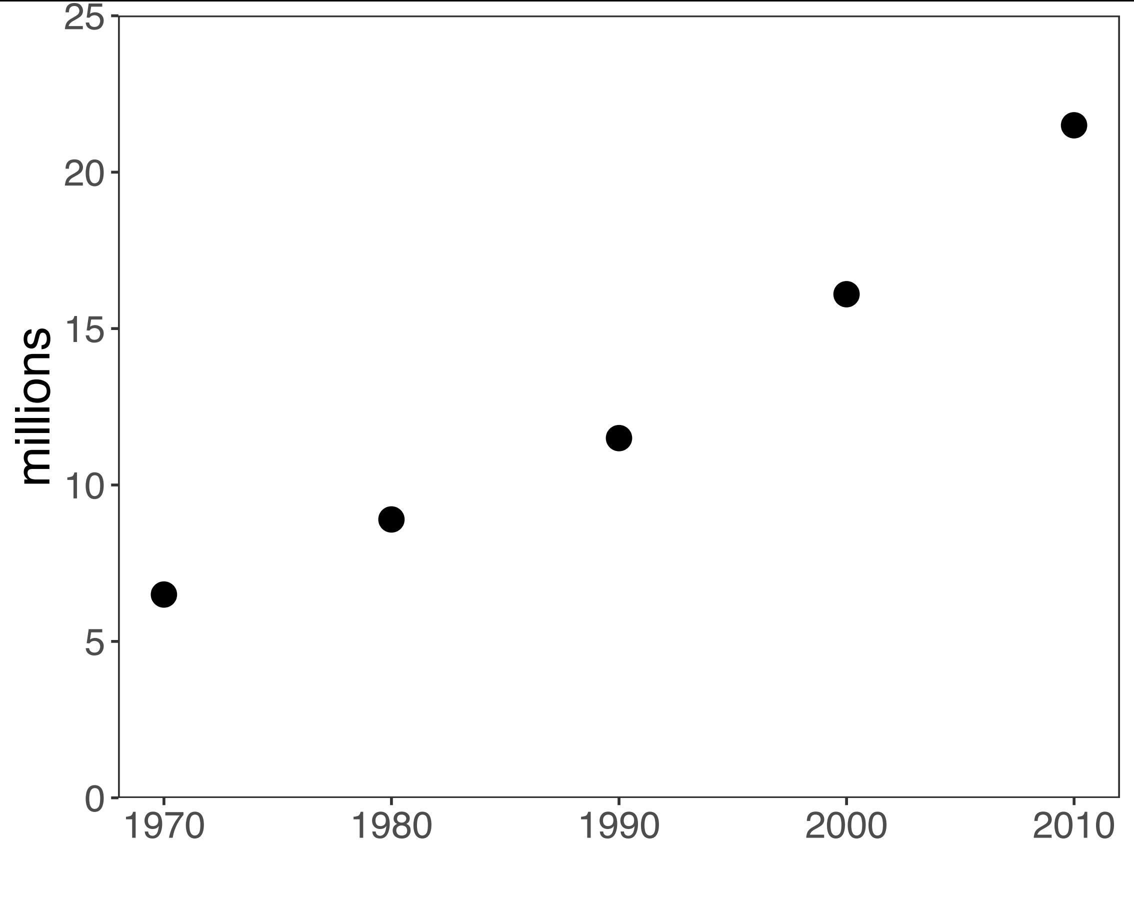
# 1. Example Question: How does Malagasy population size change with time?




2. Hypothesis: Malagasy population size increases because people are having children.

*Can you think of an alternative hypothesis?*

4. Data:

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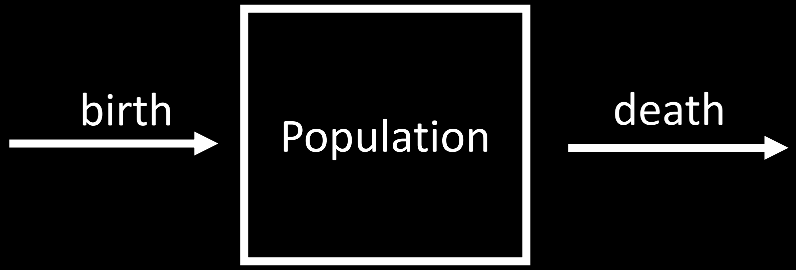
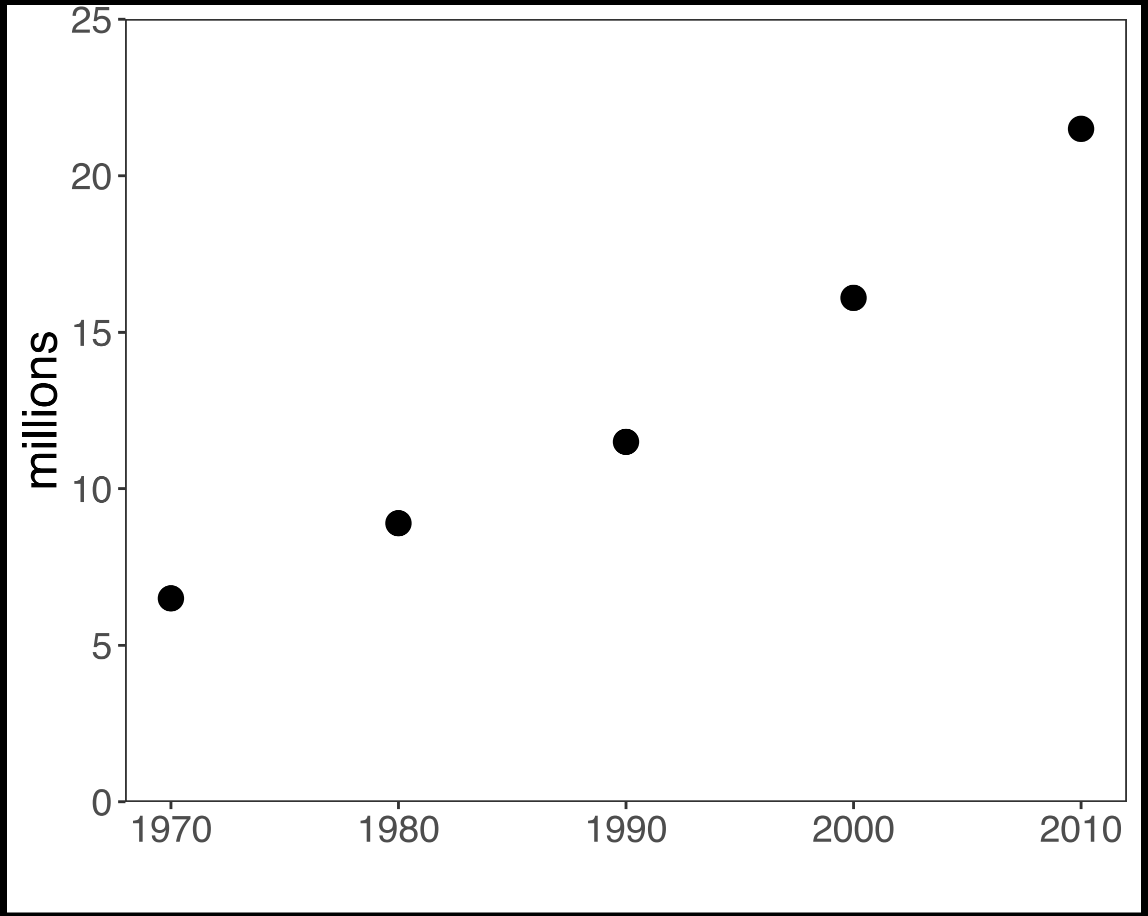



$$P_{t+1} = P_t + b * P_t - d * P_t$$

$$P_{t+1} = P_t + r * P_t$$

4. Data:

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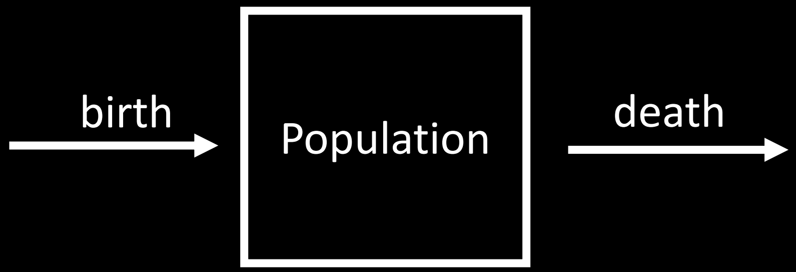


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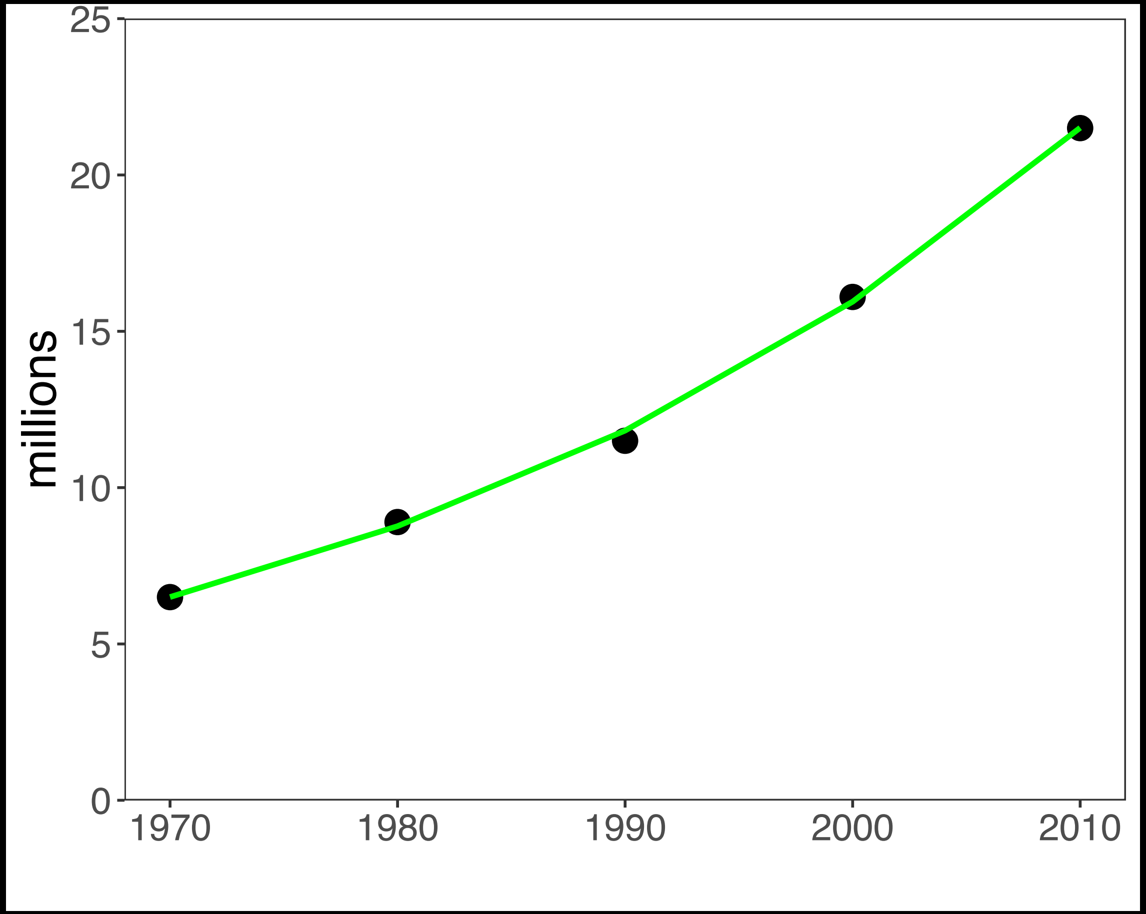
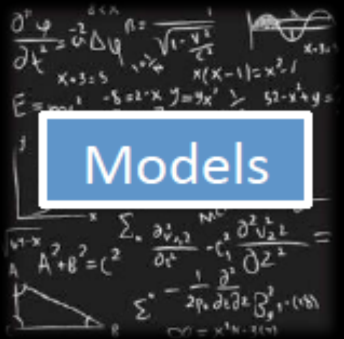



5. Evaluation:

$r = $ .349/person/yr

What can we conclude from this fitted model?

# Mechanistic Models: Beware!

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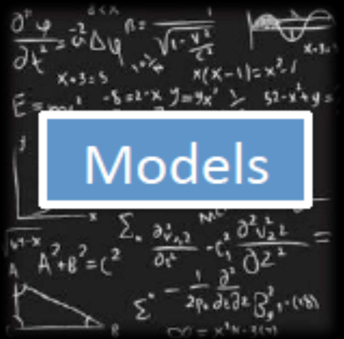
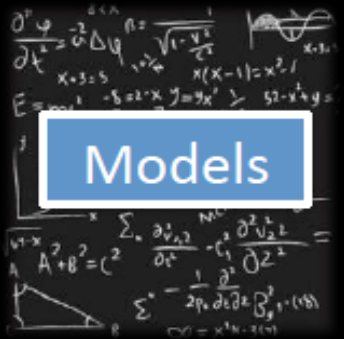



- Parameters used in the mechanistic models sometimes are not measurable!
- Simulations can be computationally intensive
- Advances in computational power often inspire development of more complex models which are not necessarily better

# Mechanistic Models: Beware!

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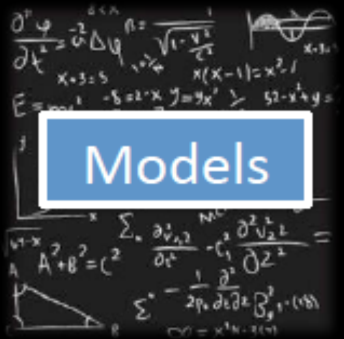
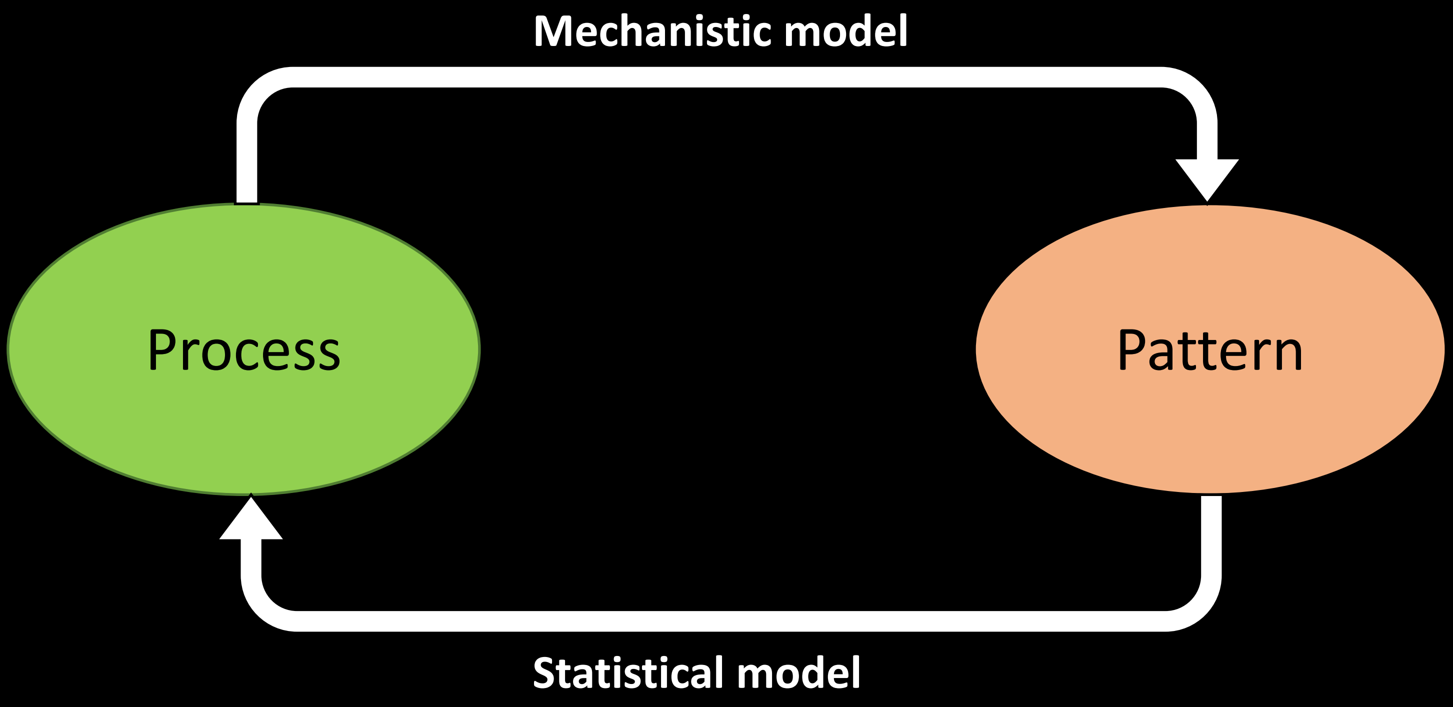
We use models to both predict and explain.

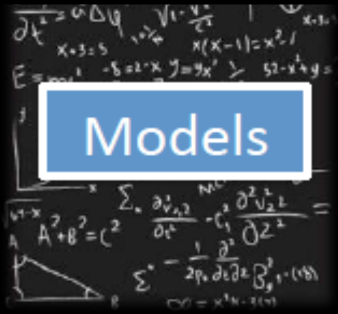
# It is ideal when statistical and mechanistic models meet:



# A Tool for $E^2M^2$

- Computer power keeps increasing
- Language/software
  - Fortran, C, C++
  - Julia, Java, Python
  - Matlab, Maple, Mathematica,
  - SAS, SPSS, Stata
- Specific programs
  - Vortex, RAMAS, NetLogo for IBM
  - NicheMapper for physiology, iLand for forest dynamics
  - MaxEnt for species distribution modeling
  - Zonation for reserve selection etc…
- The compromise: R---very powerful for
  - Visualization
  - Data formatting and sorting
  - Statistical analyses
  - Simulation (mechanistic model)

# Goals for this lecture

- To explain what we're doing here
- To define ”science”
- To define ”data”
- To define “models”
- To introduce many different types of models
  - Statistical
  - Mathematical
- To introduce the “E” in $E^2M^2$
  - Ecology
  - Epidemiology

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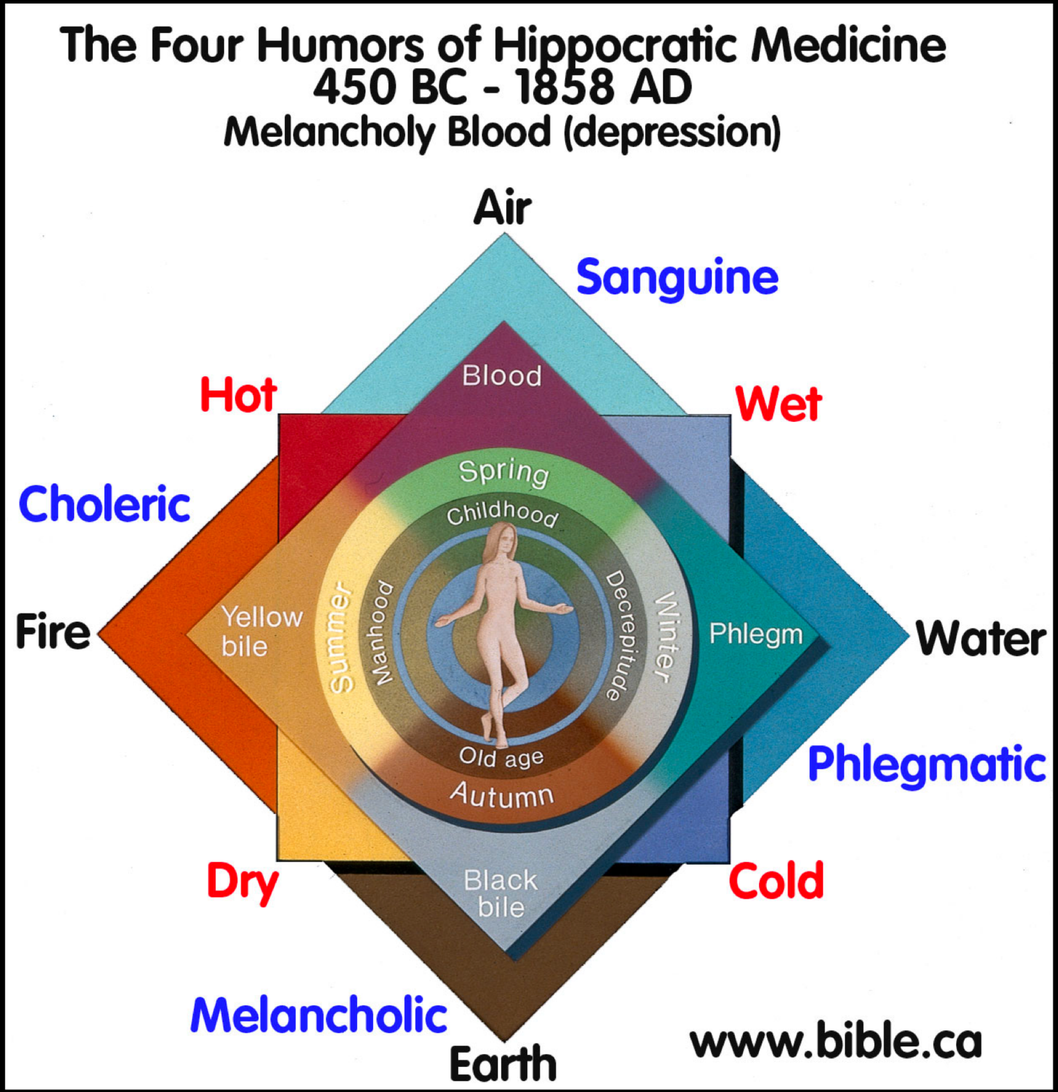

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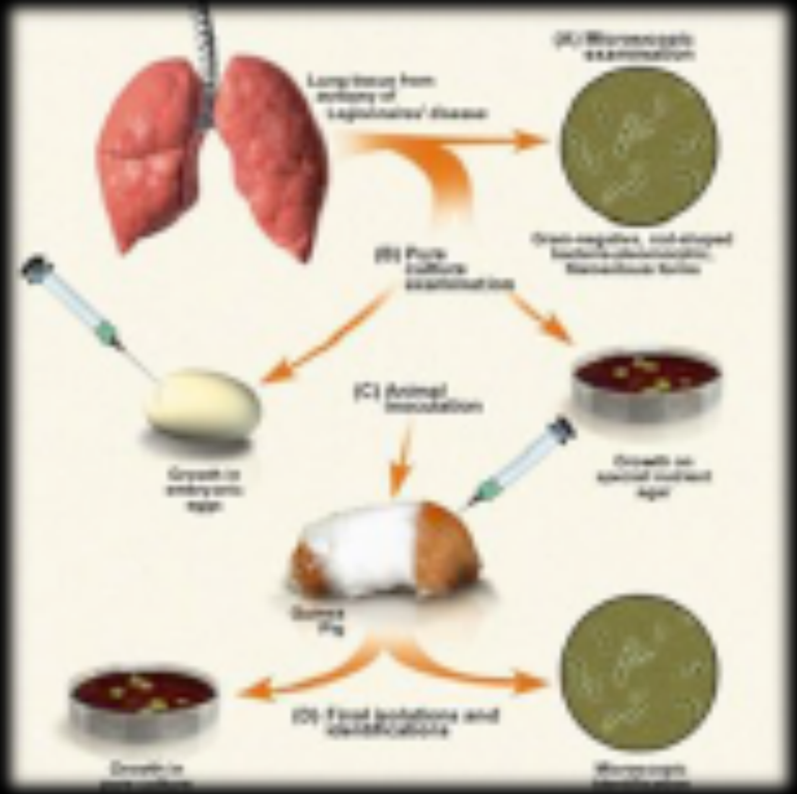

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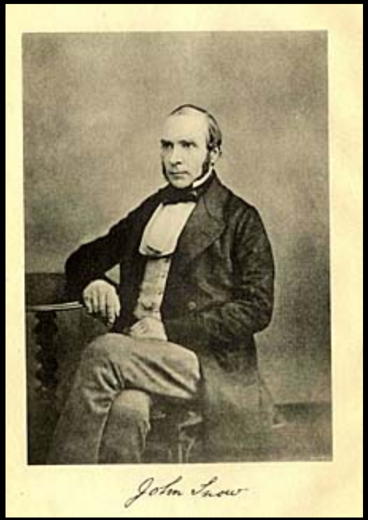

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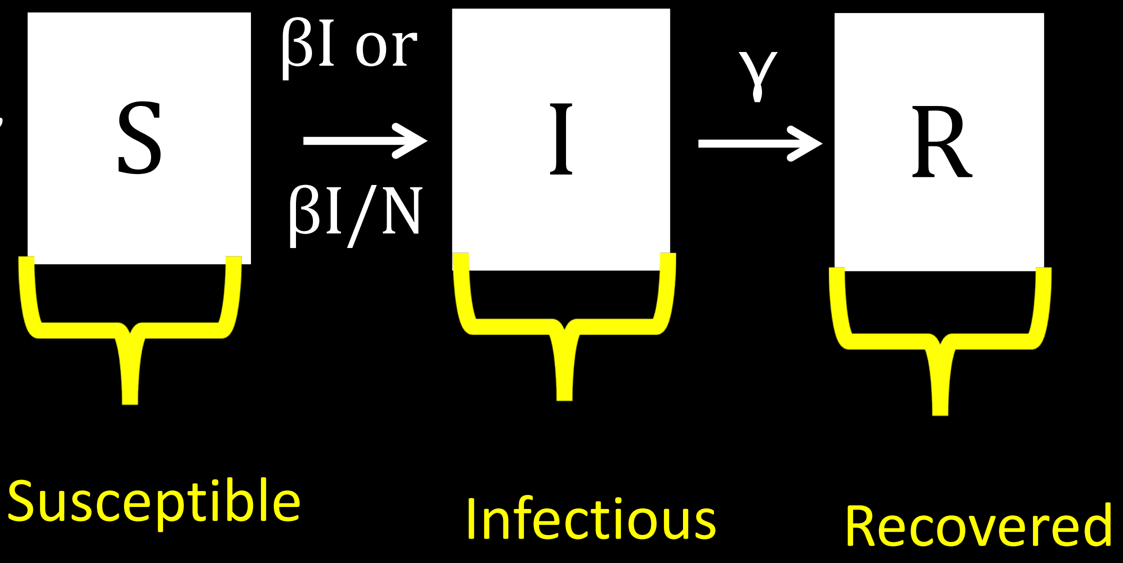

# What is Ecology?

- The study of the interactions of organisms and their environment
  - Coined in 1866 by German scientist Ernst Haeckel
  - Nile crocodiles opening mouths for sandpipers (Herodotus)
- Emphasis on explaining dynamical processes in nature

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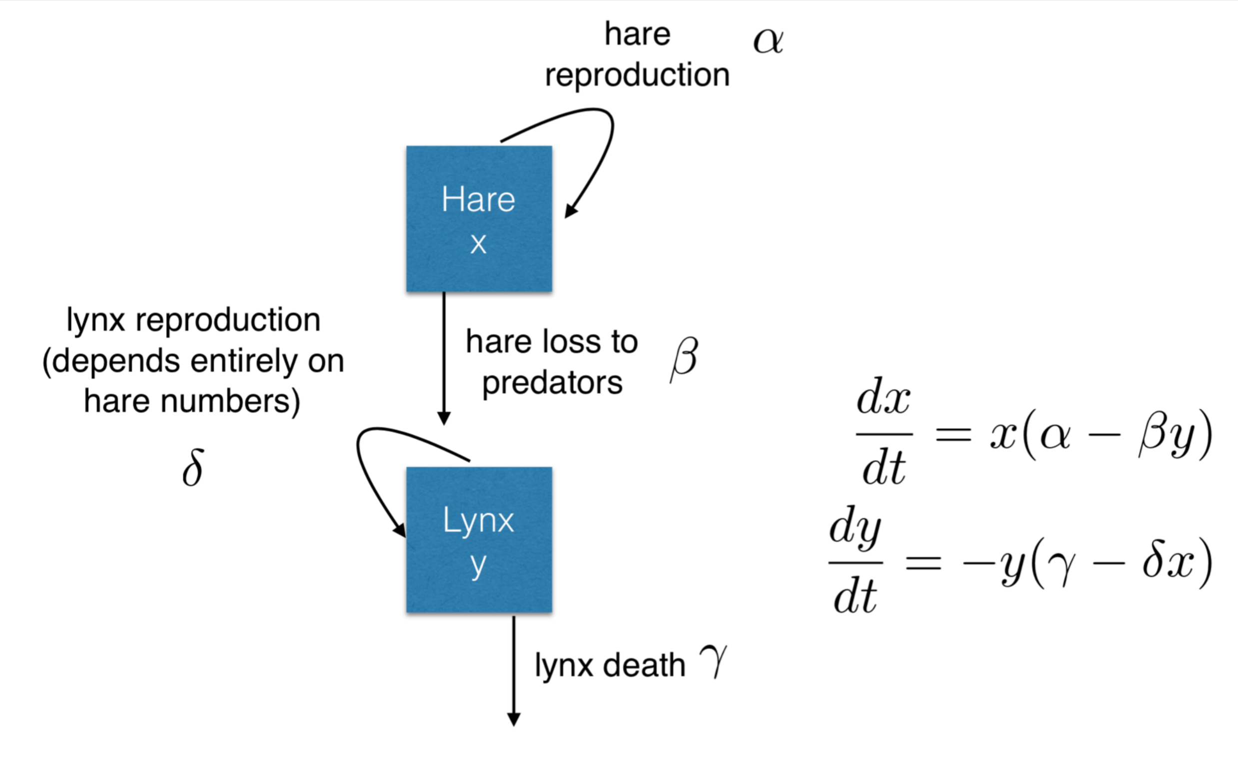

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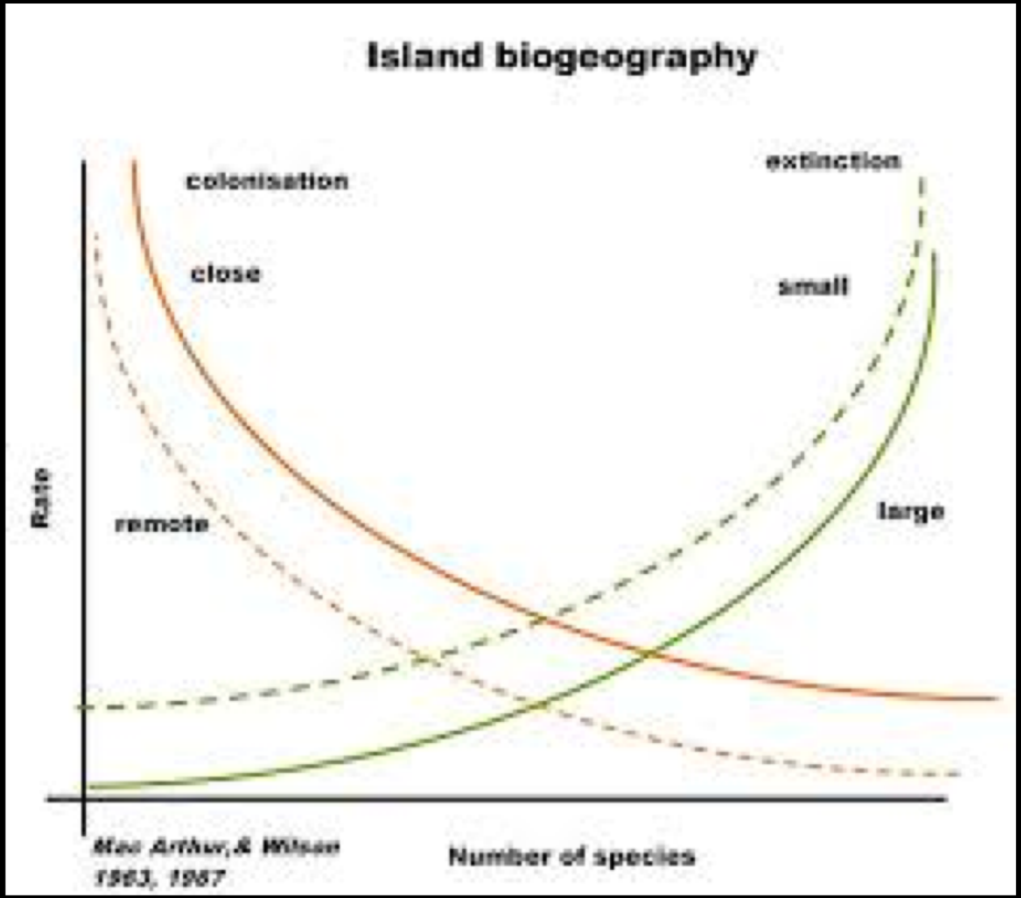

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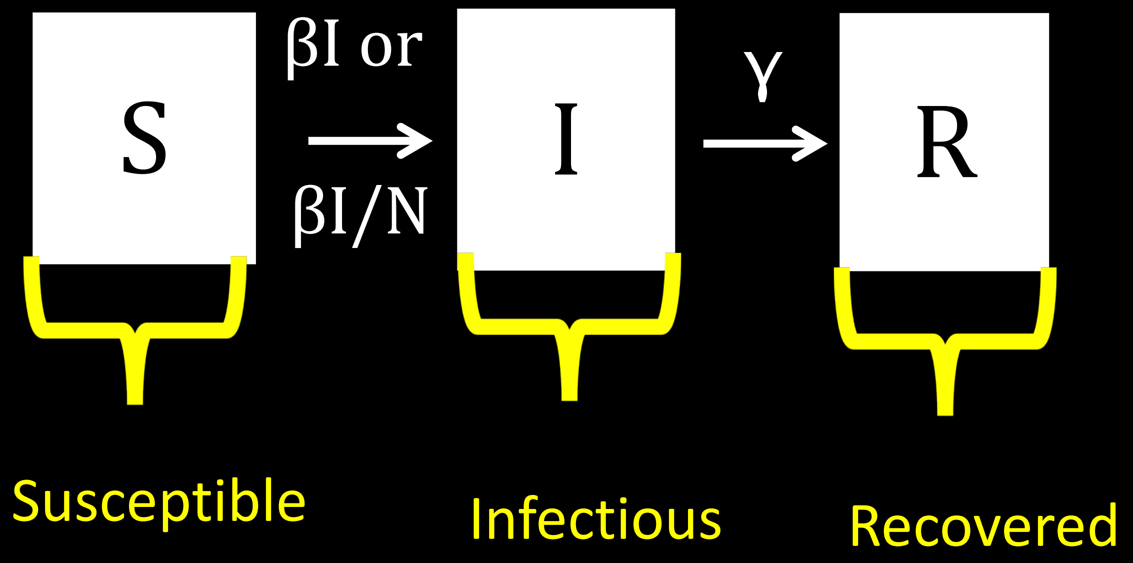

# Misaotra!