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

Data and Models

Centre ValBio

Ranomafana National Park, Madagascar

March 2024

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CENTRE VALBIO

PIVOT

MADAGASCAR BIODIVERSITY CENTER

Mahaliana

IT ALWAYS STARTS WITH A QUESTION

Lecture contributions from:

Tanjona Ramiadantsoa

Steve Bellan

Goals for this lecture

- To explain what we’re doing here

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- To define “science”

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

E2M2.org

What is science?

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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*

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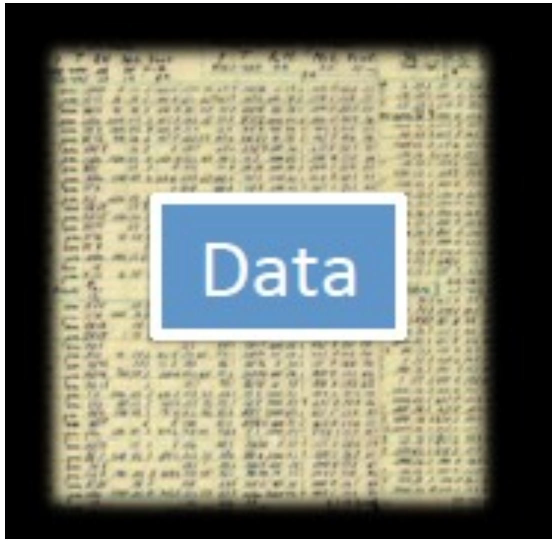
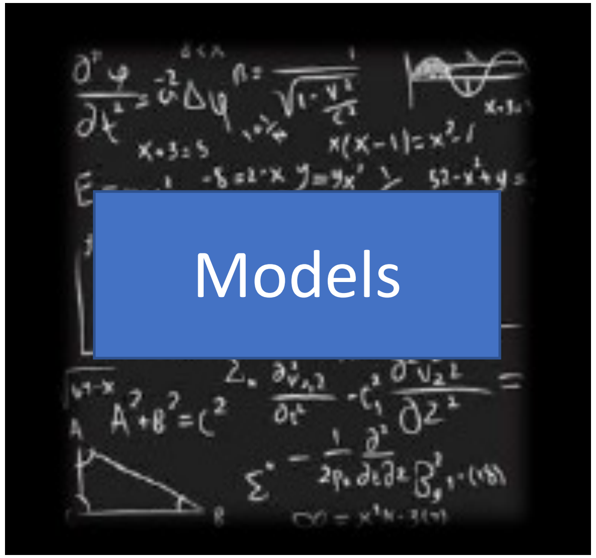
Observations and Laws and Principles

Data and Models





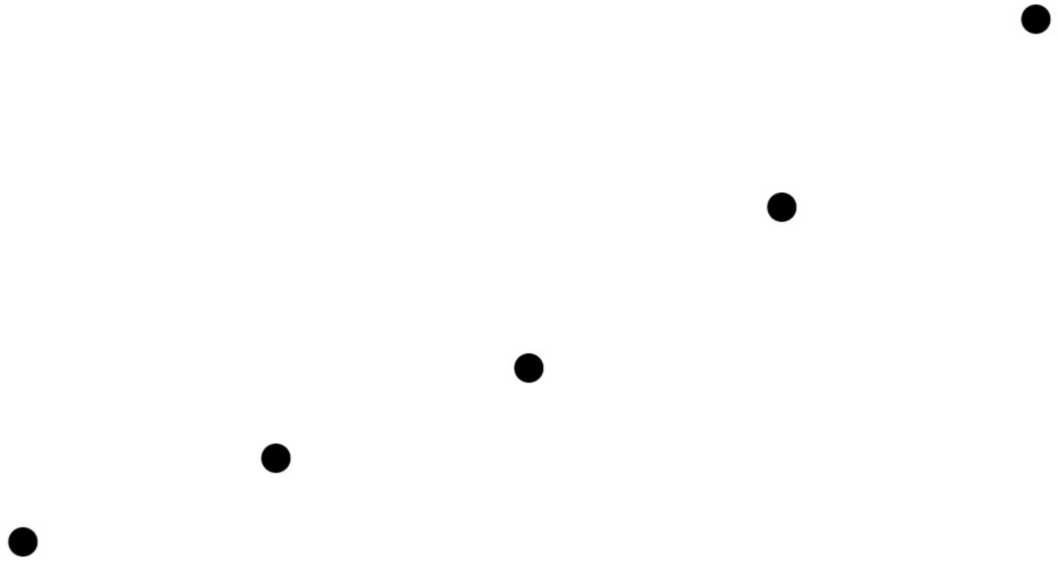
Data and Models

- What are data?

Data and Models

- What are data?
  - Evidence to support a claim

Are these data?



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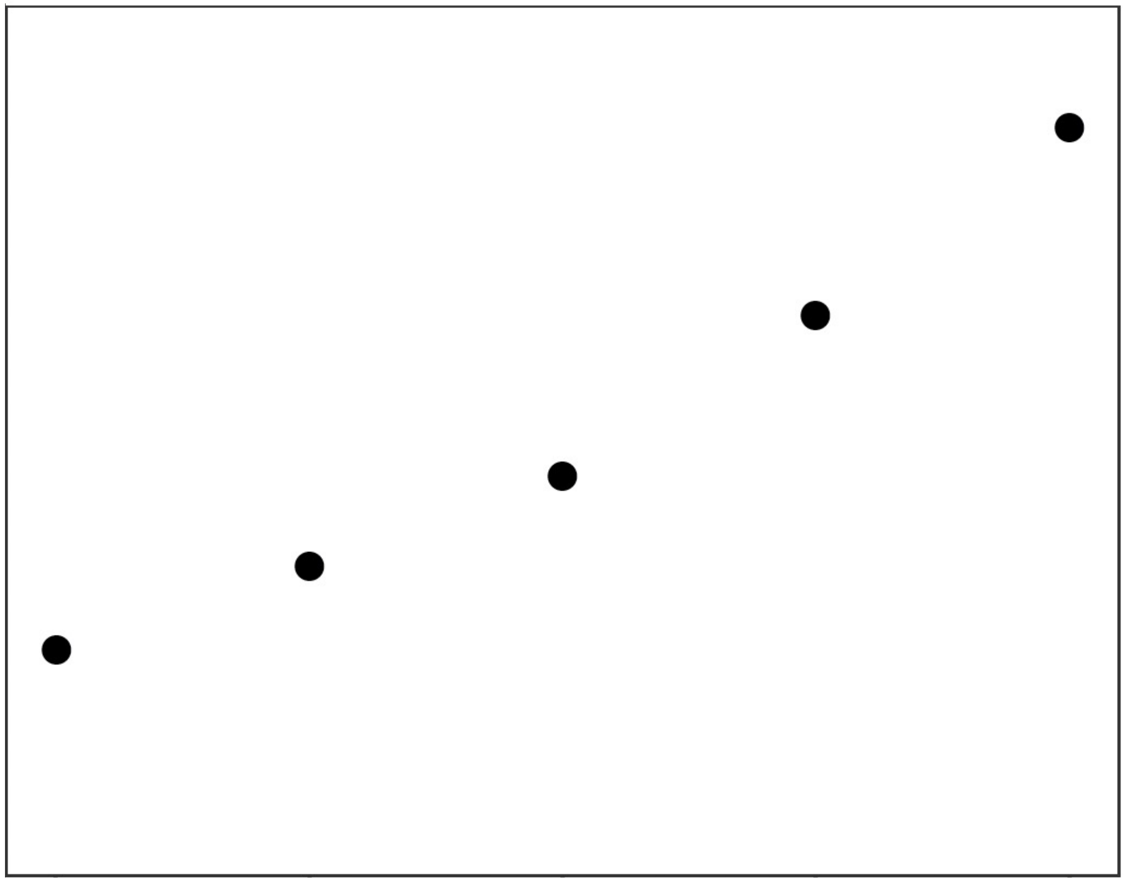
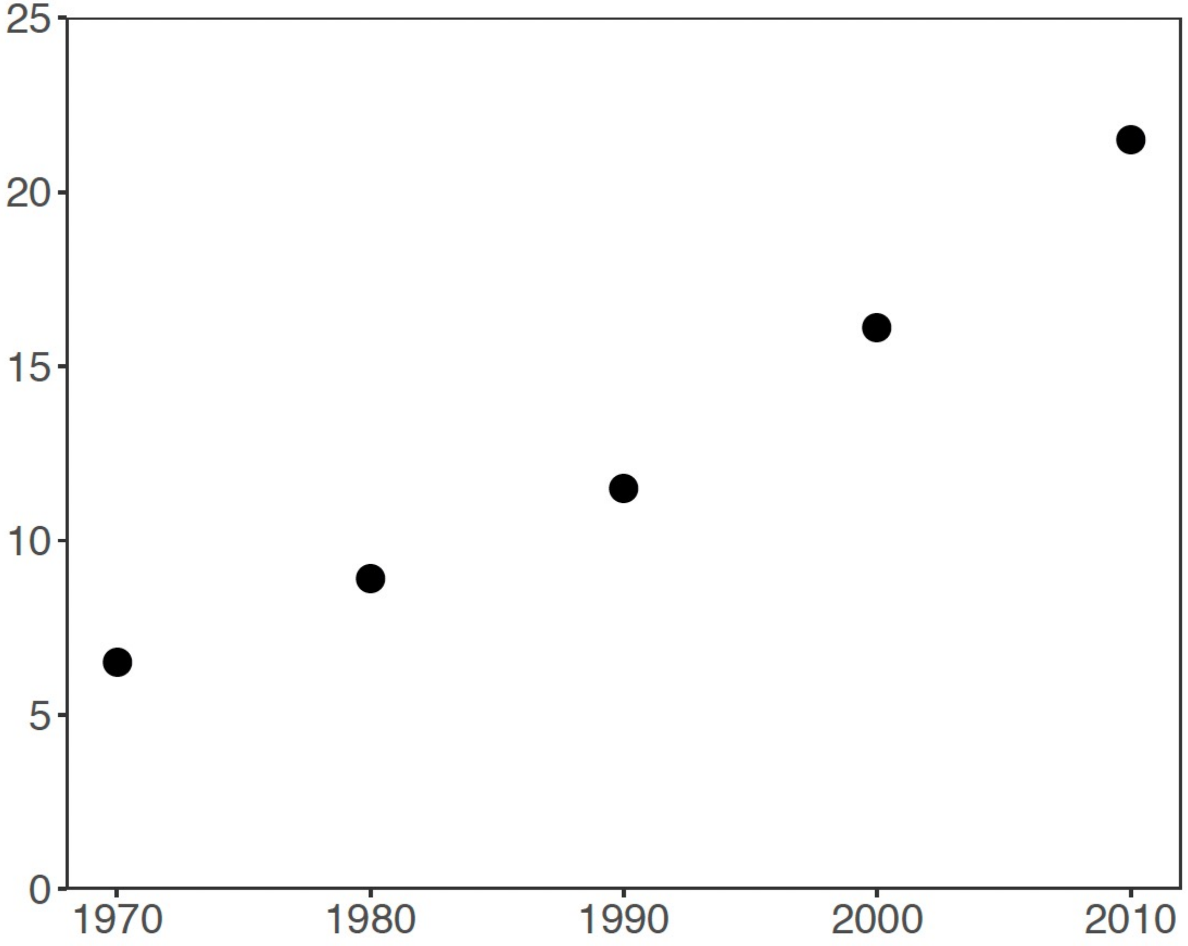


What do we need to make these data?

Are these data?



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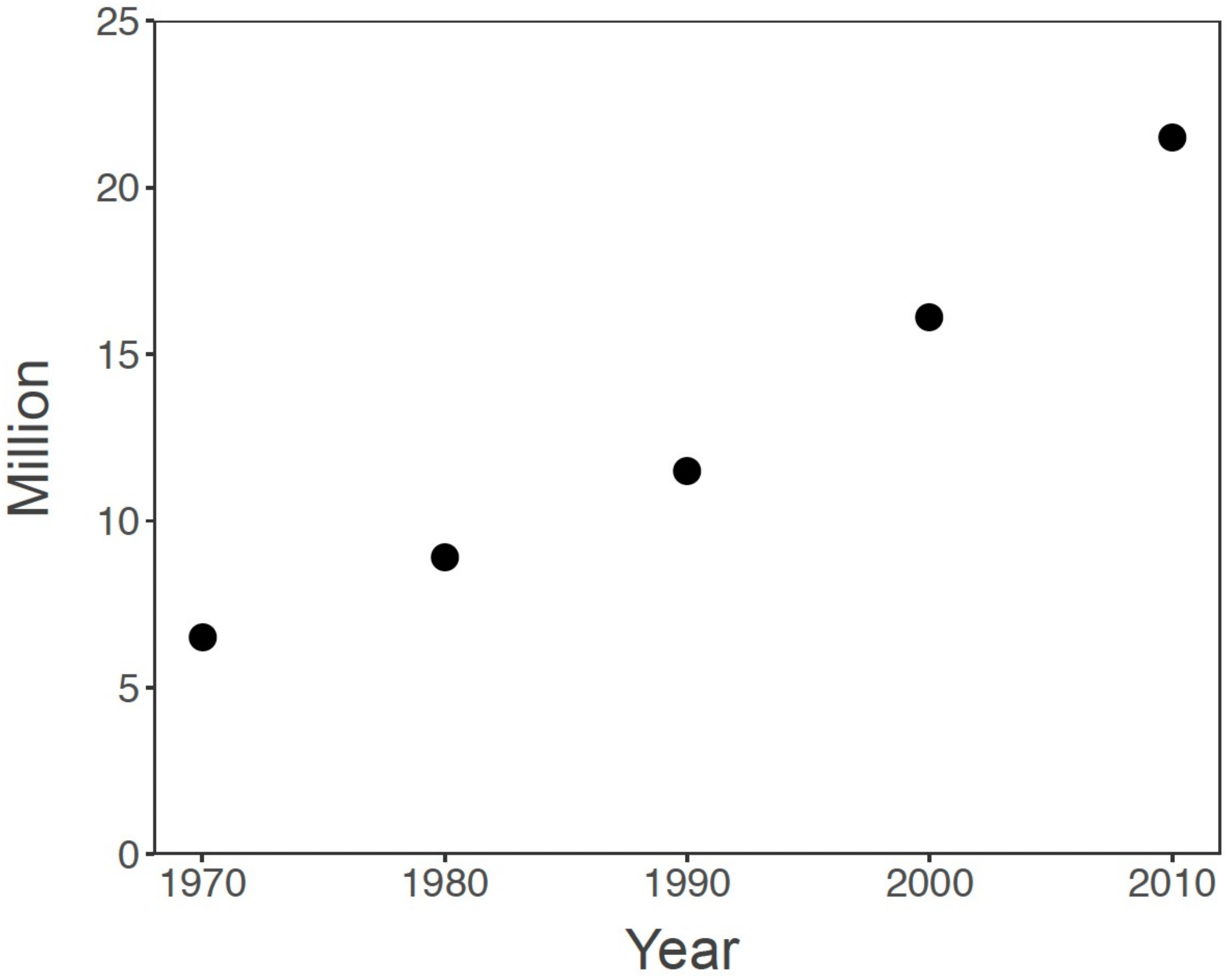
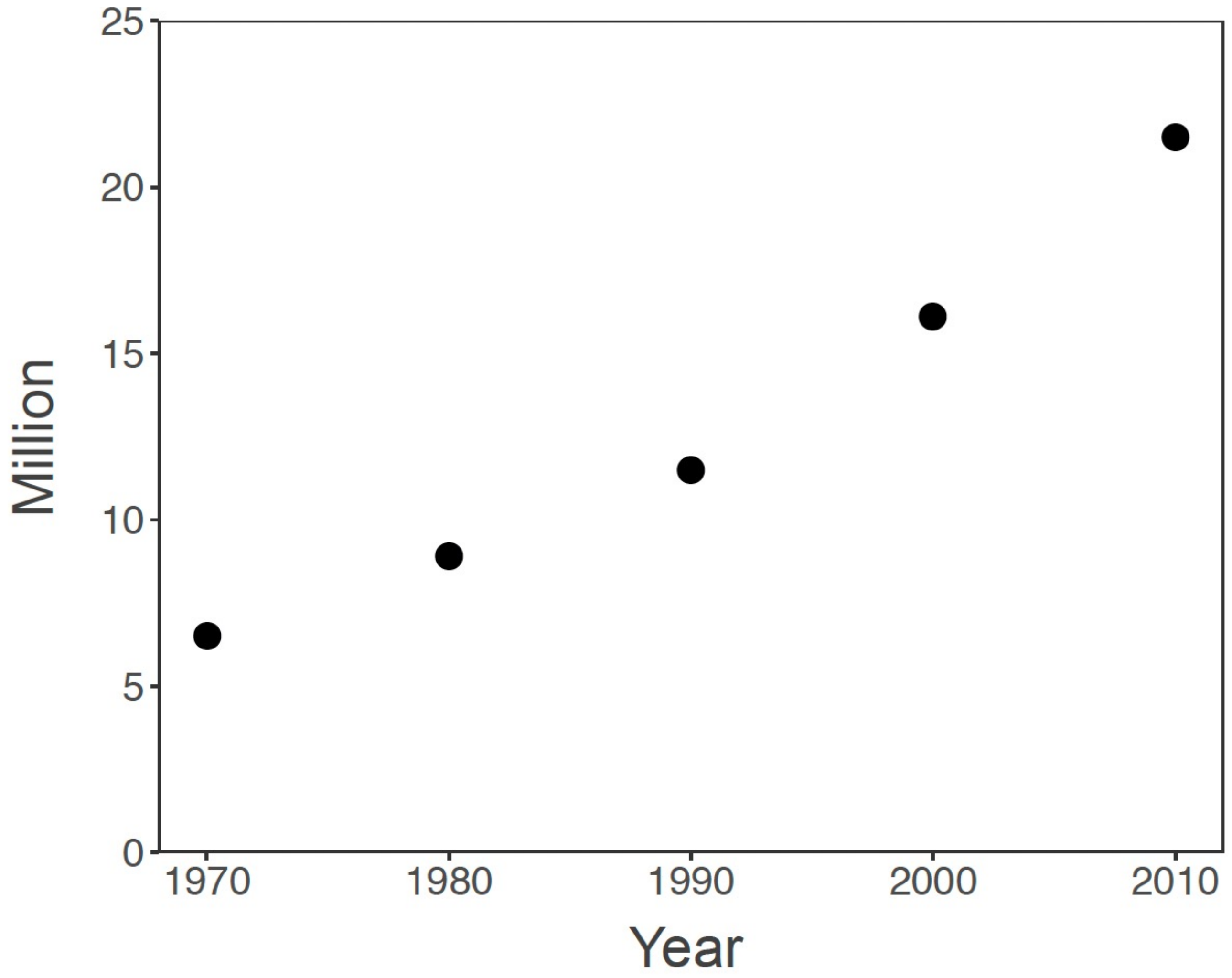


Are these data?

Number of views for Justin Bieber's "Baby" video on Youtube



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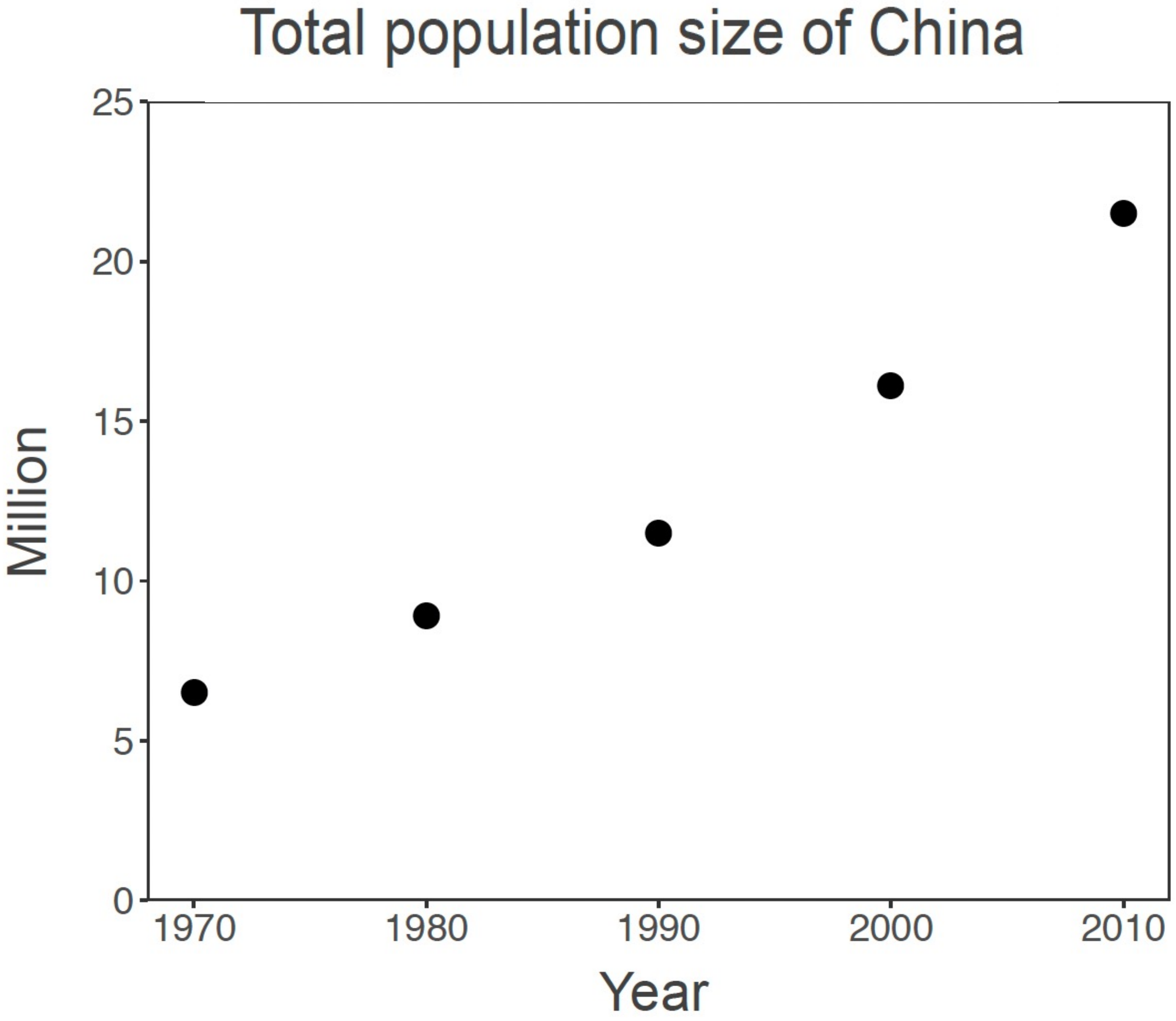

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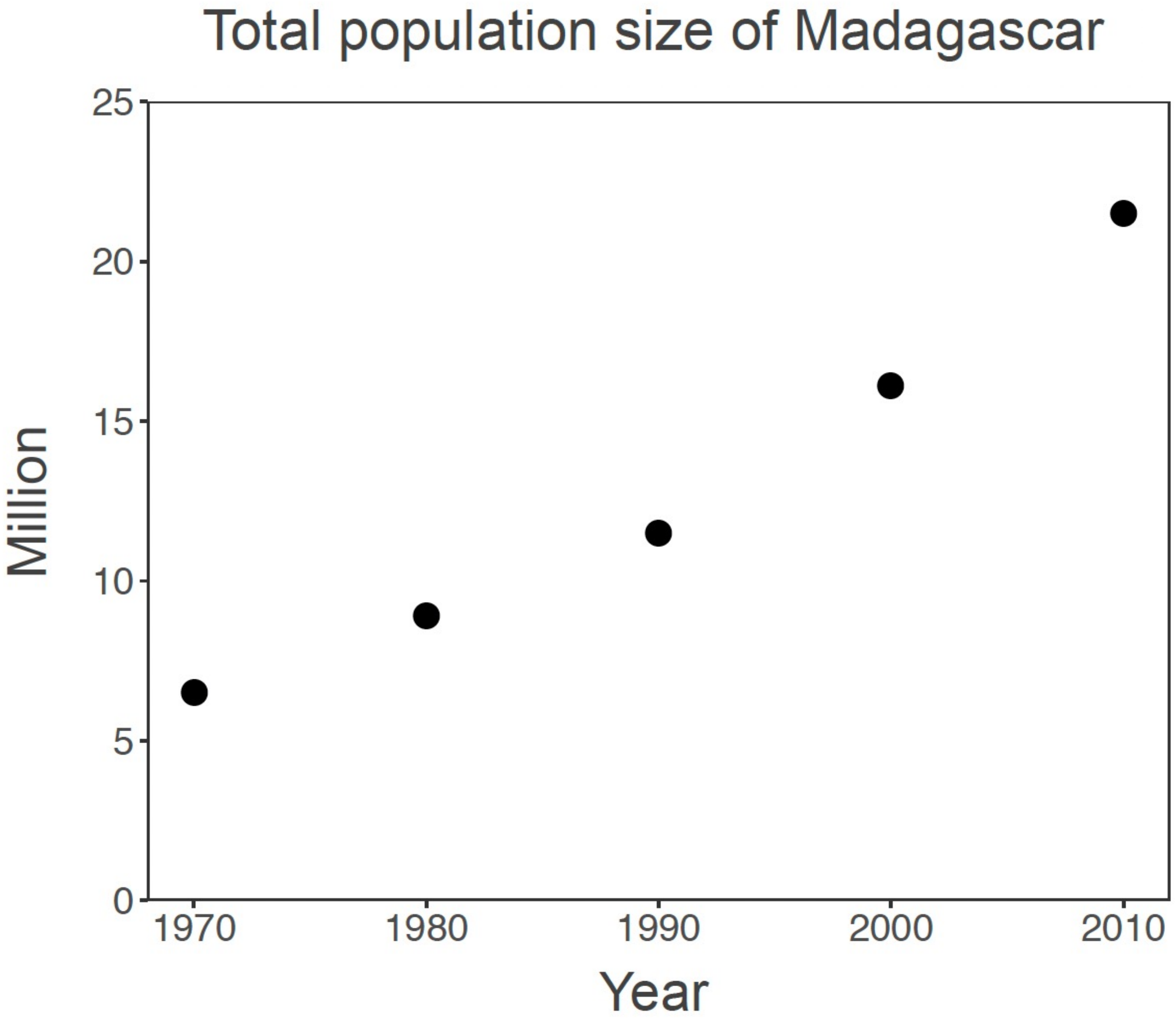

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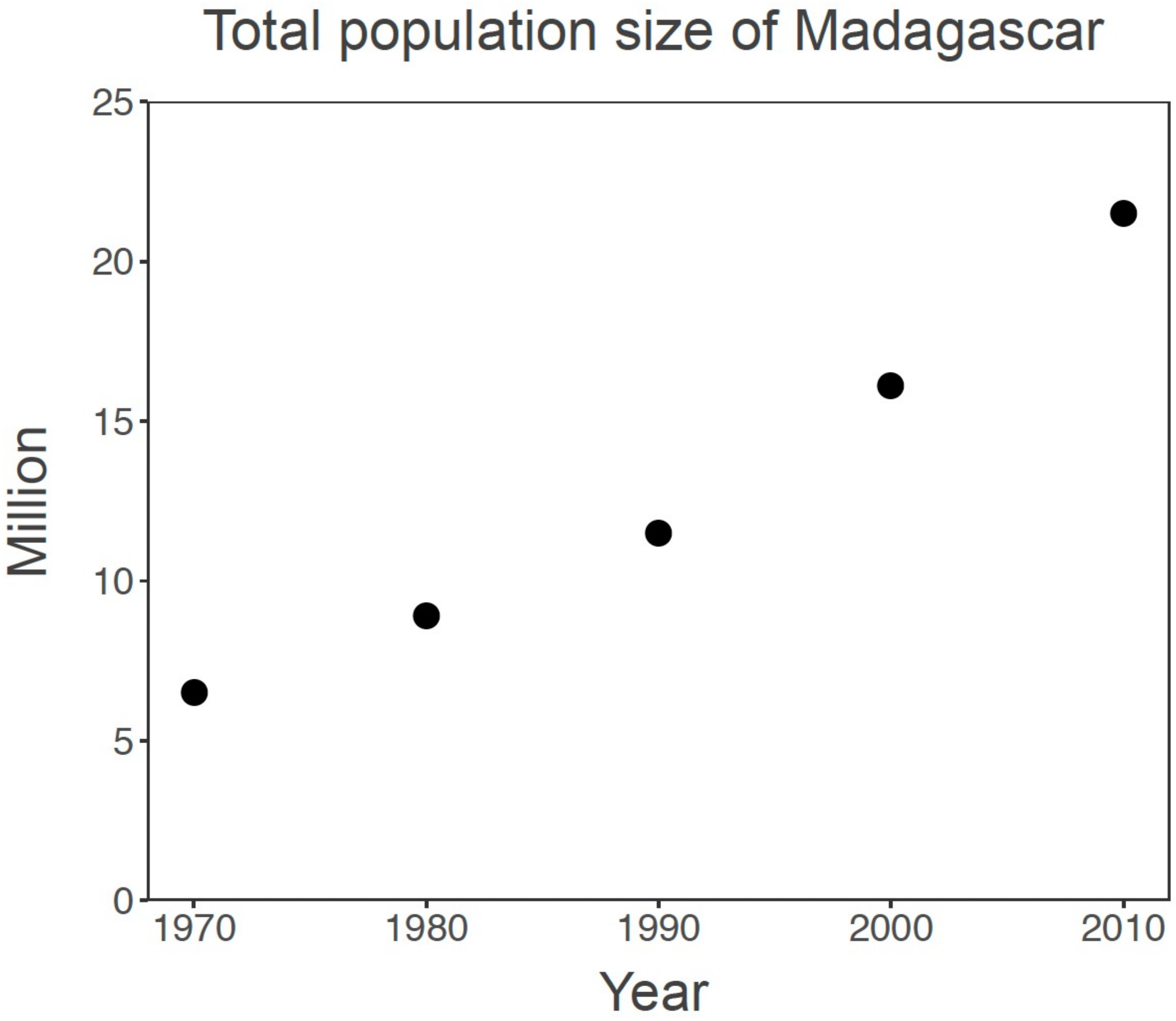

Source: World Bank (accessed 2017)

What are data?

- A relationship between at least two variables
  - x: explanatory, control, driver, independent variable(s)
  - y: response, dependent variable(s)

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- x and y should be clearly defined
  - with respect to the **question!**

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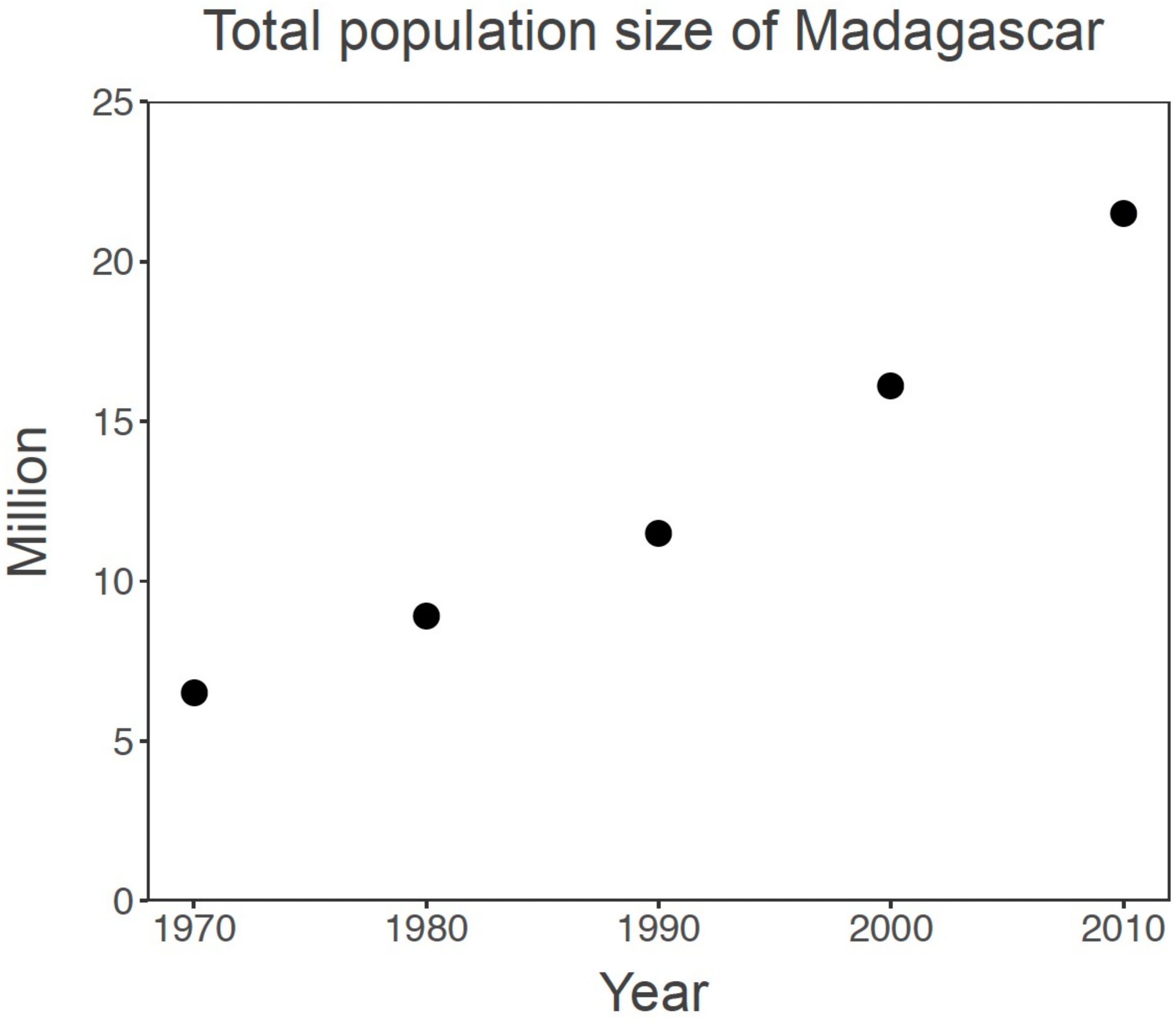
  - with respect to the **question!**
- **Evidence** to support a **claim**

Data provide evidence to support a claim.

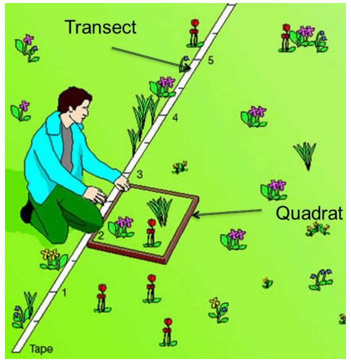


CLAIM: The population size of Madagascar has increased throughout the past 50 years

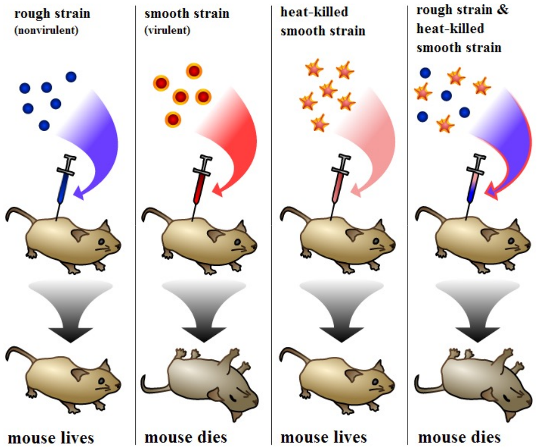
Source: World Bank (accessed 2017)

Data: Sources of x and y

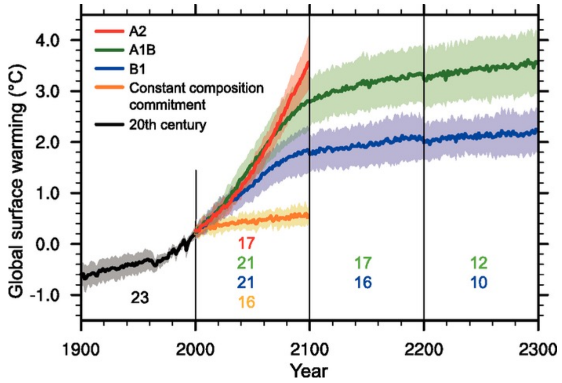
Observational



Experimental



Simulated



Empirical data

Data: Types

Numerical

Categorical

Data: Types

Numerical

- A variable is numerical when you can transform it with mathematical operation
- Examples?

Categorical

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- A variable is categorical when it is not numerical but a categorical can be numerical?
- Examples?

Data: Types

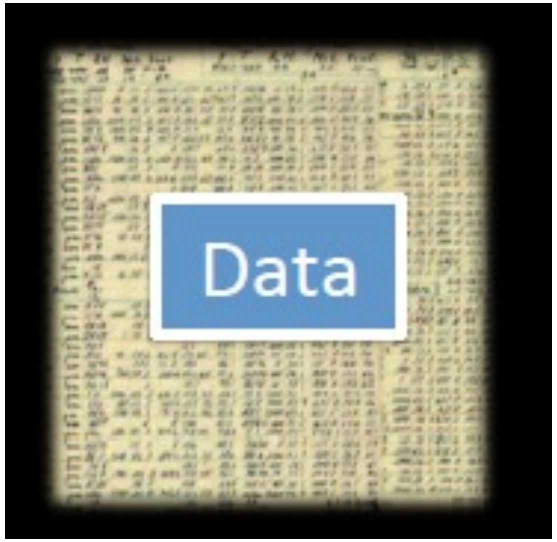
Numerical

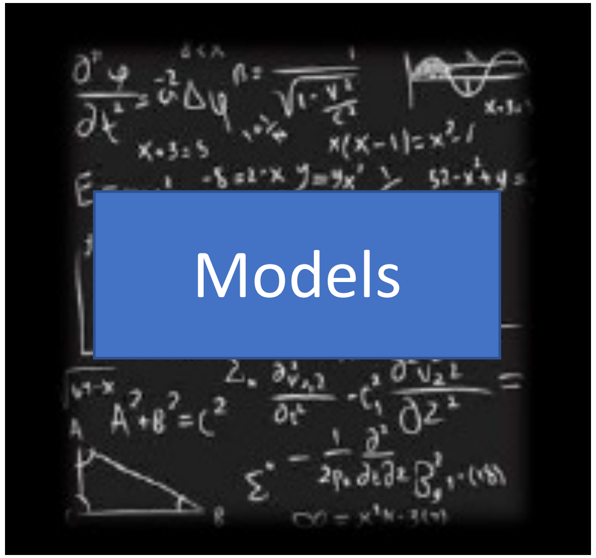
- A variable is numerical when you can transform it with mathematical operation
- Examples:
- Integer, real number, multi-dimensional number

Categorical

- A variable is categorical when it is not numerical but a categorical can be numerical?
- Examples:
- Colors, (blood) types, species name

Data and Models





Data and Models

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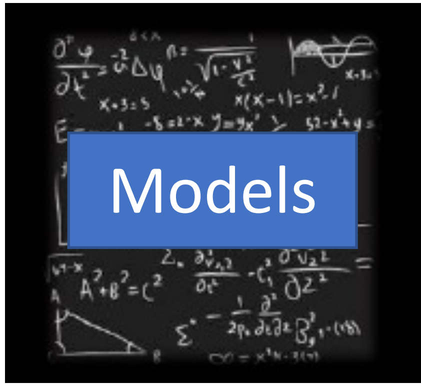

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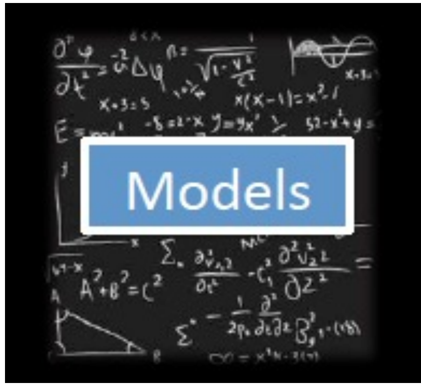
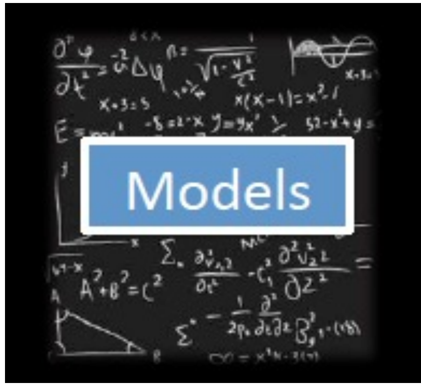
Laws and Principles



Theory — General

Model

Hypothesis — Specific



Laws and Principles

Theory

a declaration to explain a phenomenon

Model

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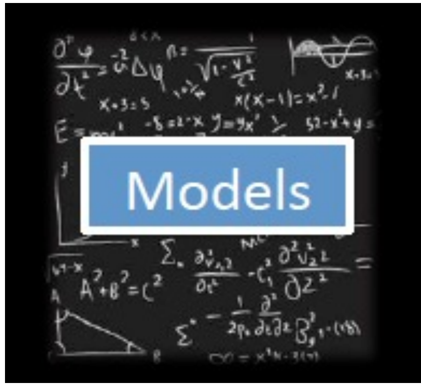
Specific

Laws and Principles



Theory

a declaration to explain a phenomenon

Model

an abstract representation of a phenomenon

Hypothesis

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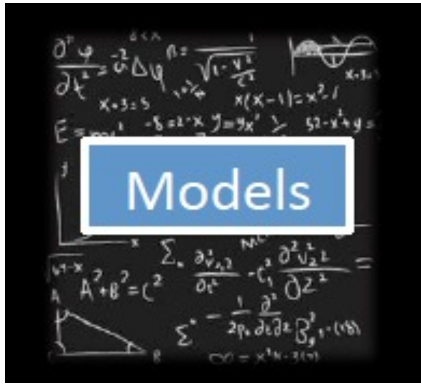
Laws and Principles



Theory

a declaration to explain a phenomenon

Model

an abstract representation of a phenomenon

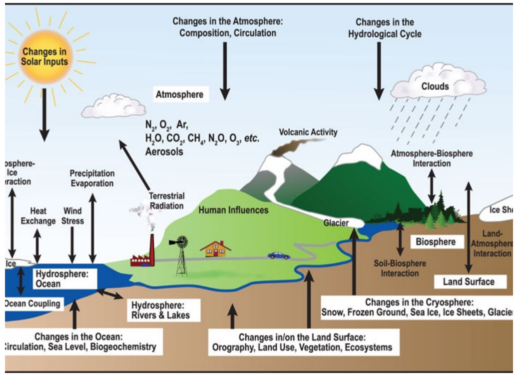
Hypothesis

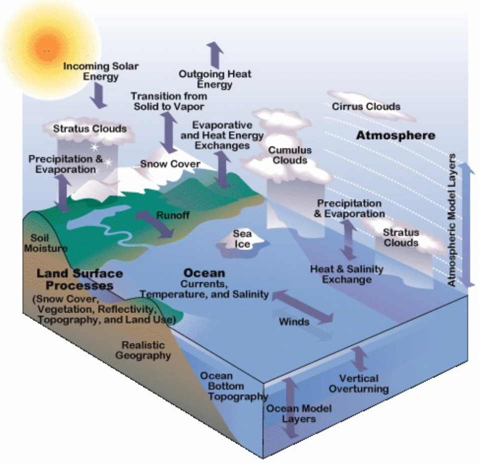
a testable declaration that is derived from a theory

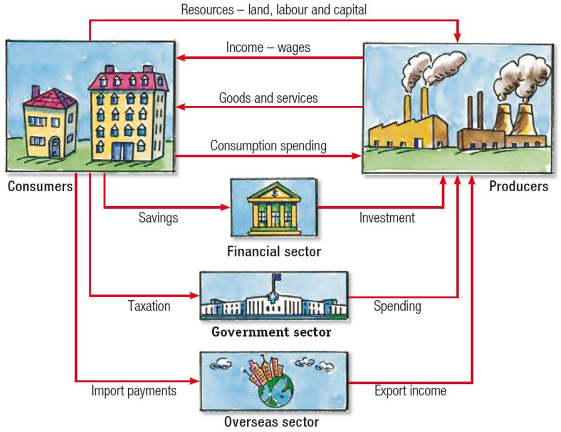
General

Specific

Models


Changes in Solar Inputs
Changes in the Atmosphere: Composition, Circulation
Changes in the Hydrological Cycle
Atmosphere
Clouds
Volcanic Activity
Atmosphere-Biosphere Interaction
Precipitation Evaporation
Terrestrial Radiation
Human Influences
Heat Exchange
Wind Stress
Glacier
Biosphere
Hydrosphere: Ocean
Soil-Biosphere Interaction
Land Surface
Ocean Coupling
Hydrosphere: Rivers & Lakes
Changes in the Cryosphere:
Changes in the Ocean:
Changes in/on the Land Surface: Orography, Land Use, Vegetation, Ecosystems

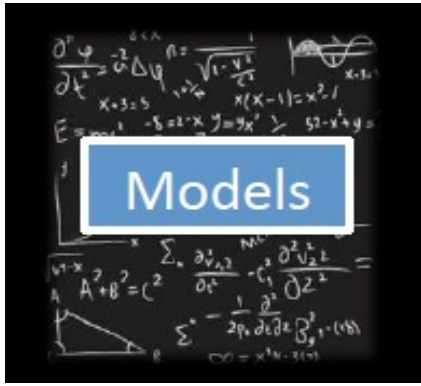

Incoming Solar Energy
Outgoing Heat Energy
Transition from Solid to Vapor
Cirrus Clouds
Stratus Clouds
Evaporative and Heat Energy Exchanges
Atmosphere
Precipitation & Evaporation
Snow Cover
Cumulus Clouds
Atmospheric Model Layers
Runoff
Precipitation & Evaporation
Soil Moisture
Sea Ice
Stratus Clouds
Land Surface Processes
(Snow Cover, Vegetation, Reflectivity, Topography, and Land Use)
Ocean Currents, Temperature, and Salinity
Heat & Salinity Exchange
Winds
Realistic Geography
Ocean Bottom Topography
Vertical Overturning
Ocean Model Layers

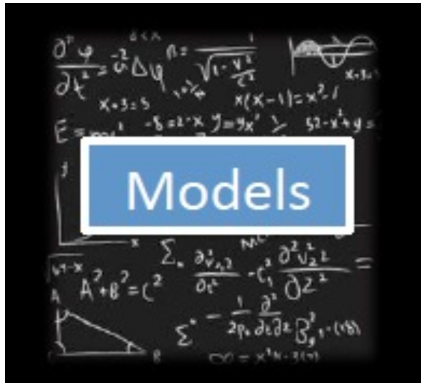

Resources – land, labour and capital
Income – wages
Goods and services
Consumption spending
Consumers
Producers
Savings
Investment
Financial sector
Taxation
Spending
Government sector
Import payments
Export income
Overseas sector

- When you make a model,

  you include the

  elements that you feel are most important
  to explain a phenomenon.





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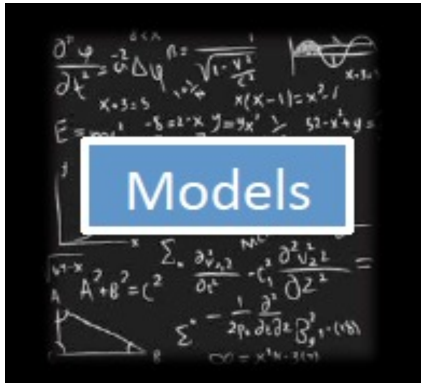

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- Generally, we try to make models
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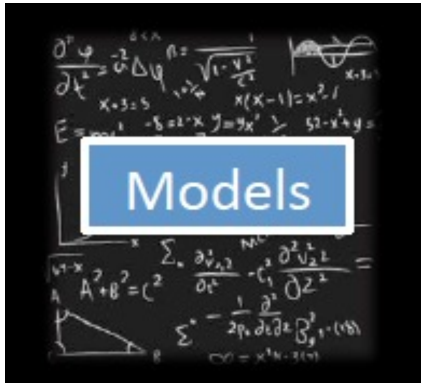
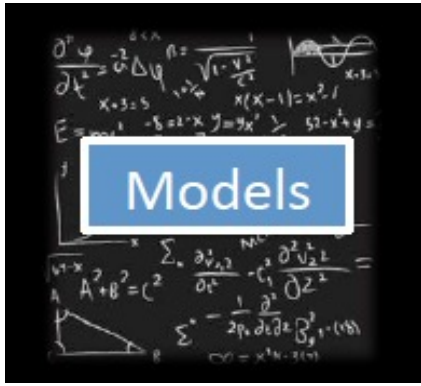
- In E^2M^2, we distinguish between
  statistical and mechanistic models

Statistical vs. Mathematical Model



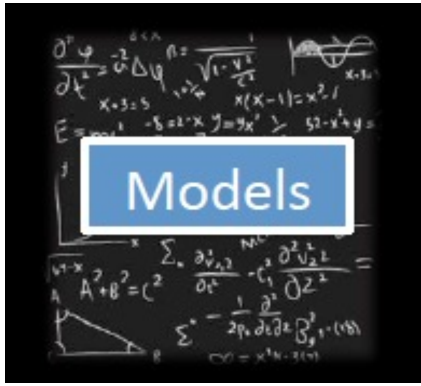
The choice depends on the research question!

Statistical Models



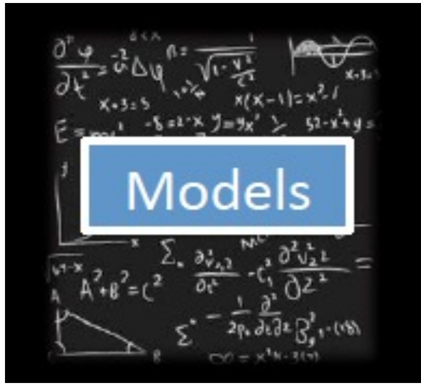
- Goal: To rigorously **assess** the strength of relationship between x and y

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



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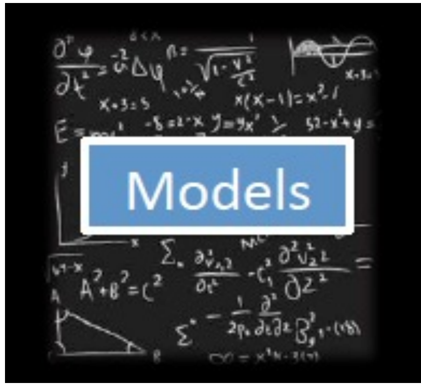
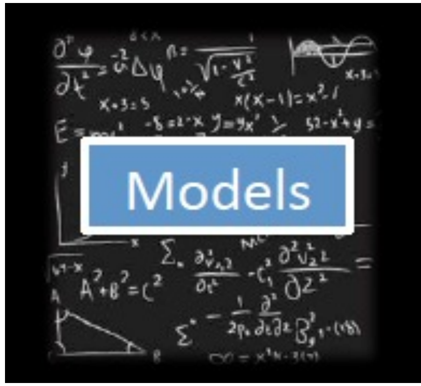
  - **Statistical models can demonstrate correlations.**

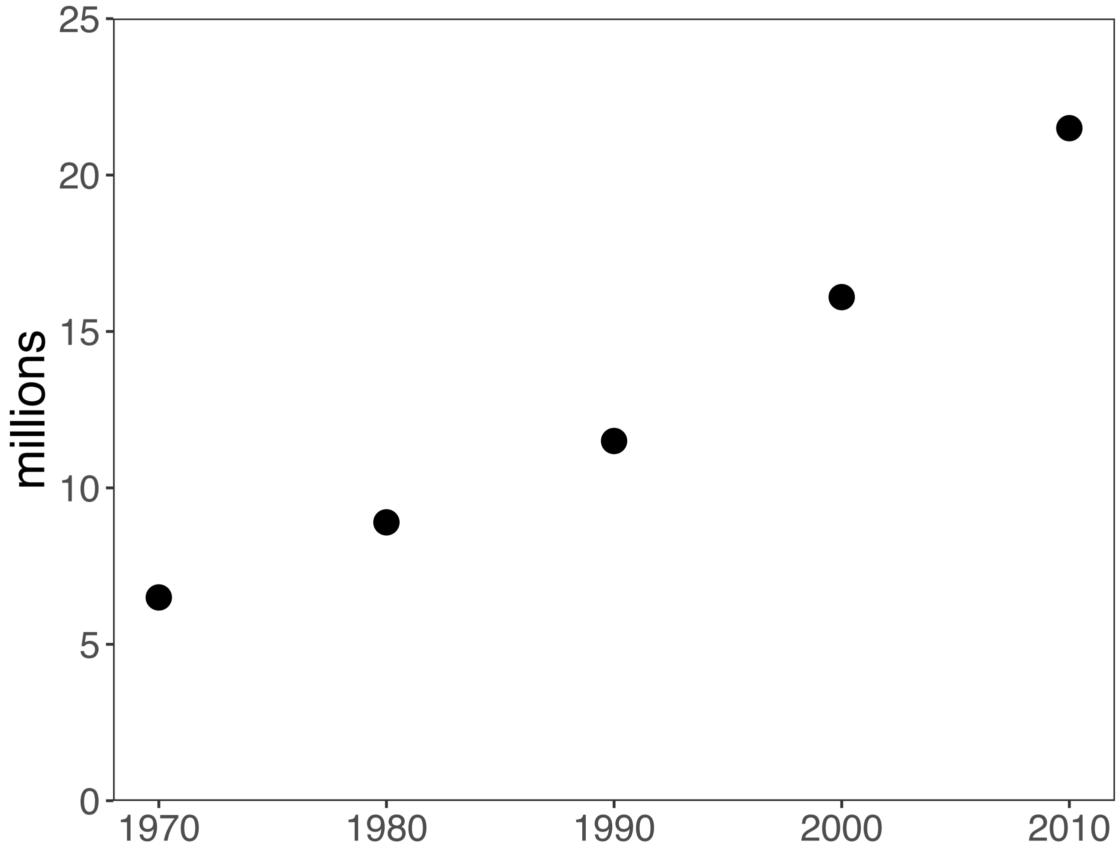
Statistical Models



- 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

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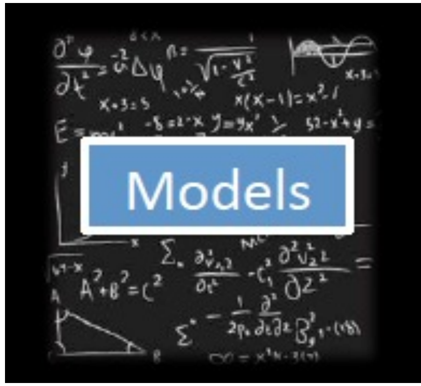

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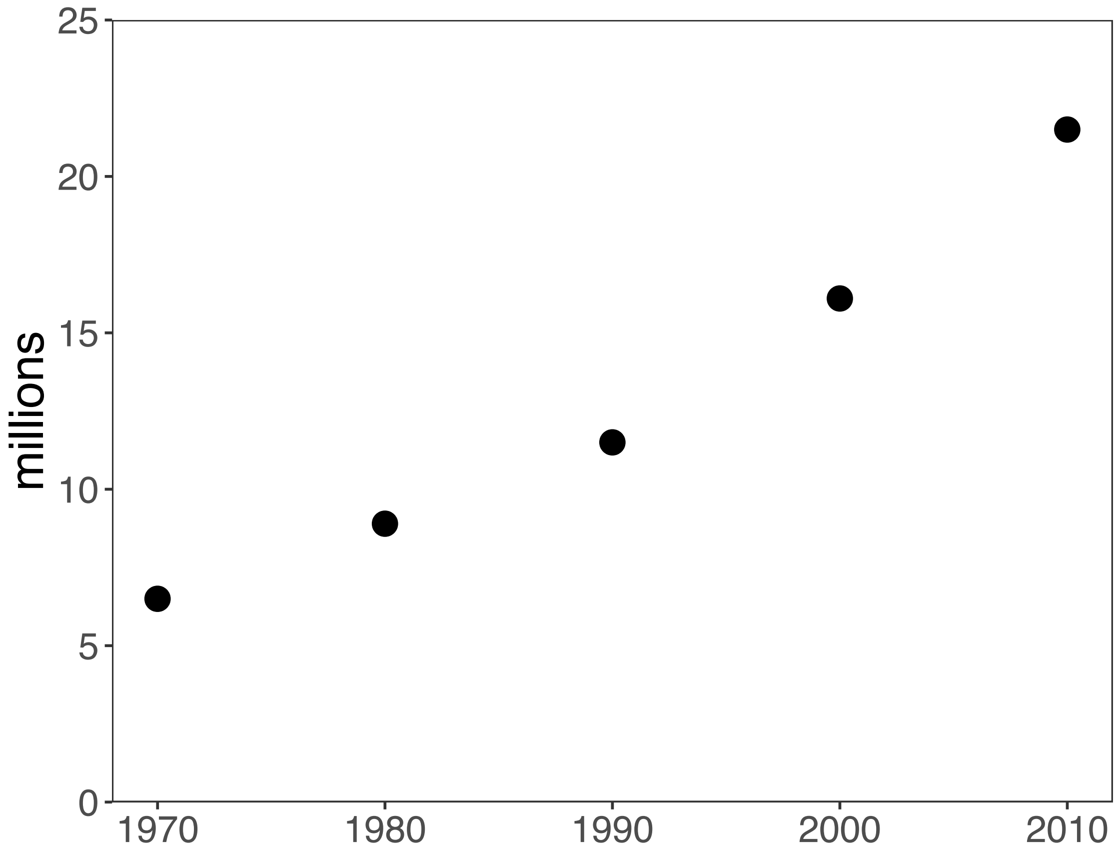

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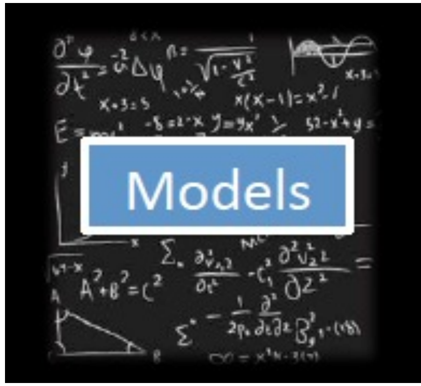

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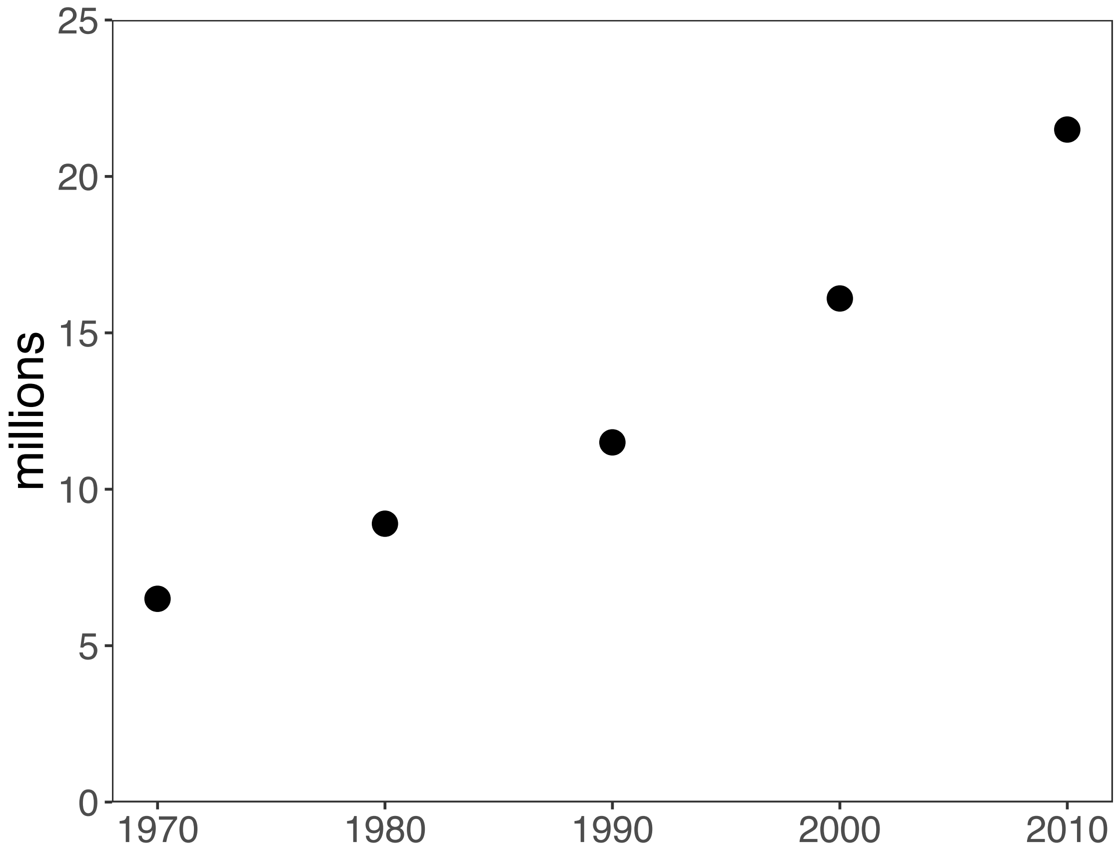
3. Statistical Model:

$$y = mx + b$$

Linear Regression



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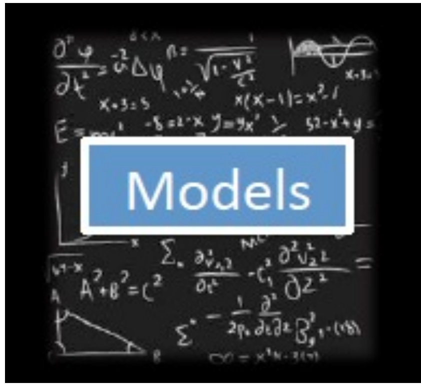

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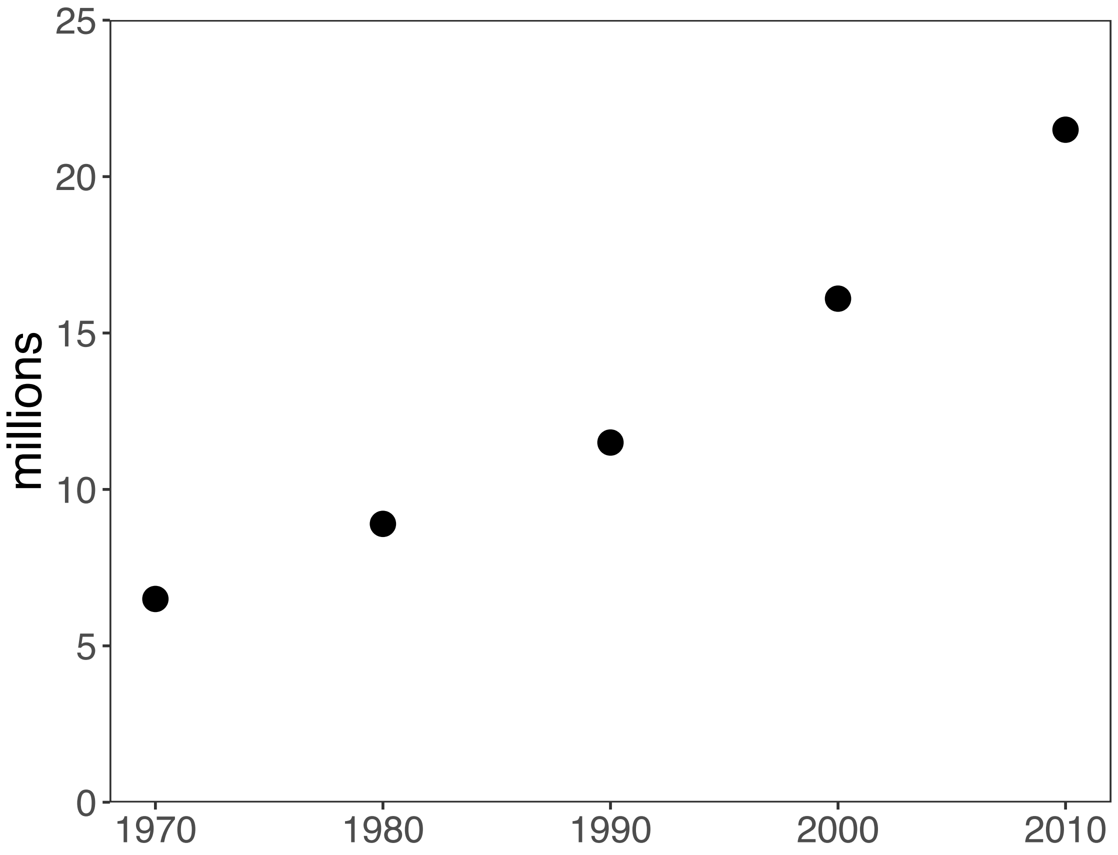

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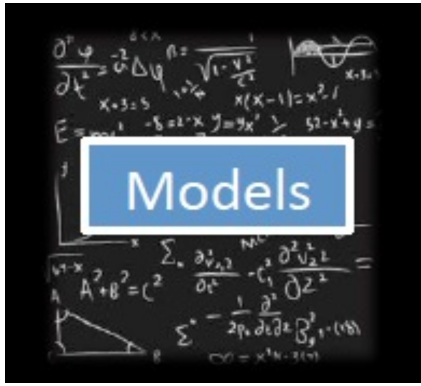

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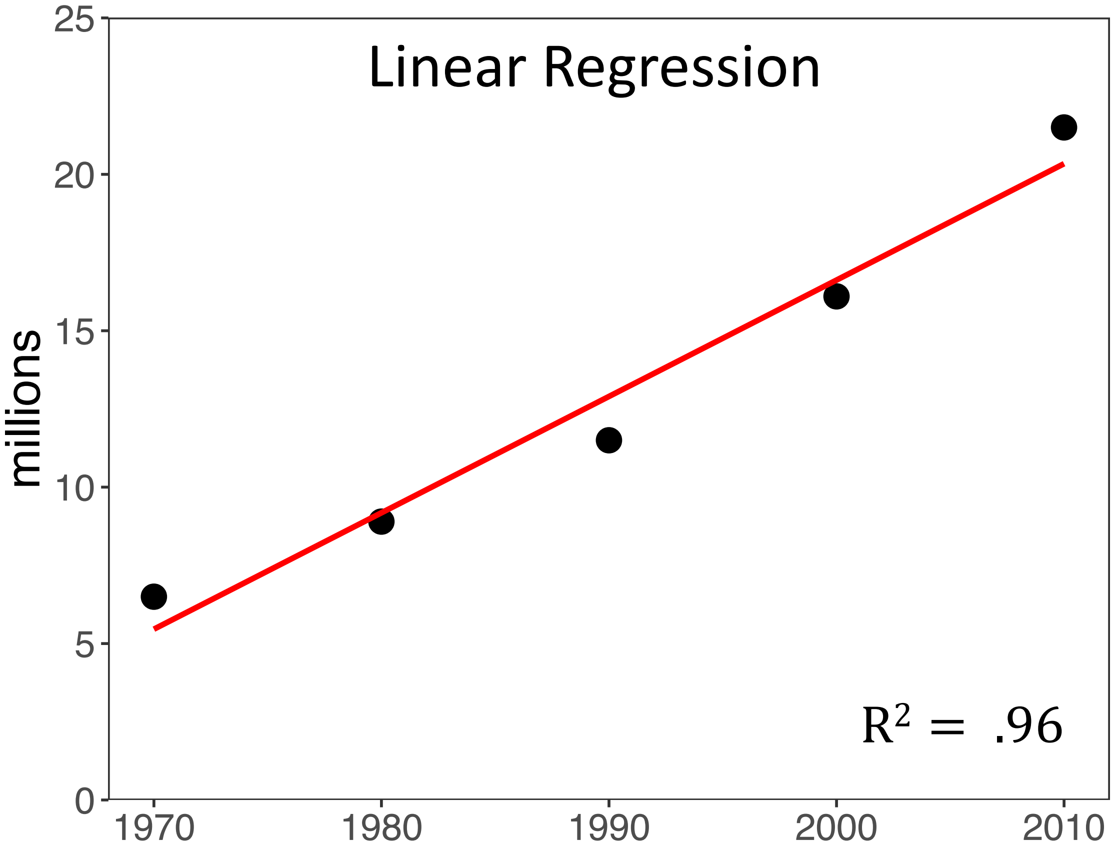

5. Evaluation

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

$$p = \ .003$$

What can we conclude from this fitted model?

Source: World Bank

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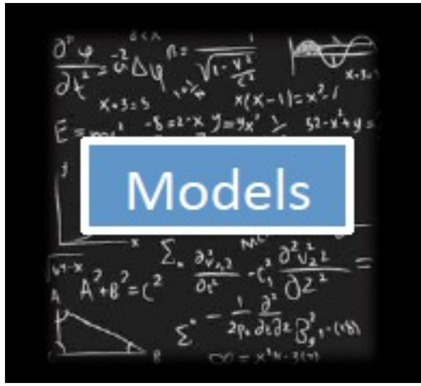


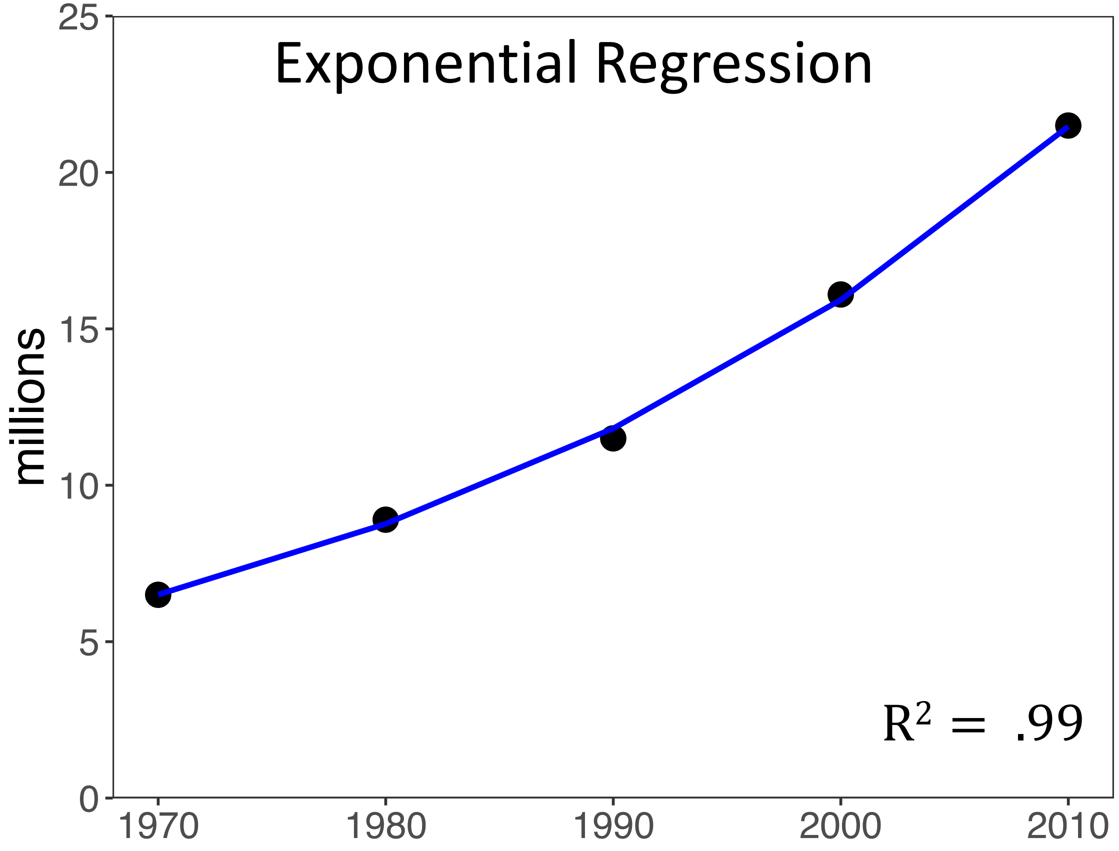
6. Adapt your model and re-evaluate:

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

Exponential Regression

$m = 0.029$ mil.

$p < .001$



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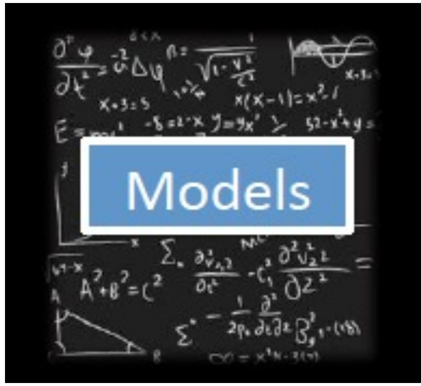
Statistical Models: Beware!



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  - data normally distributed
  - x and y independent

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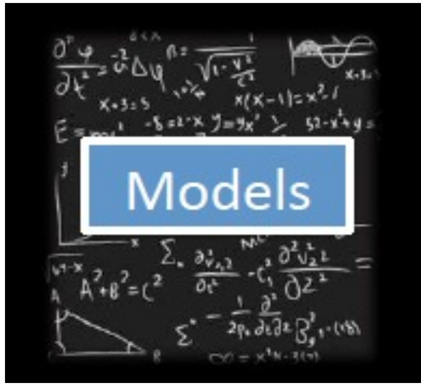

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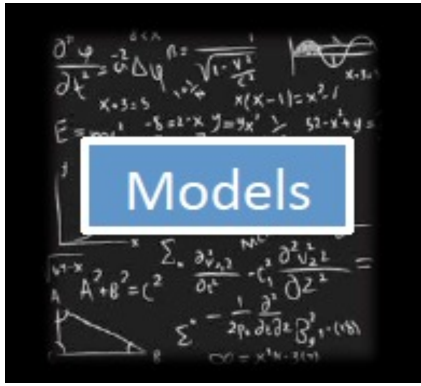
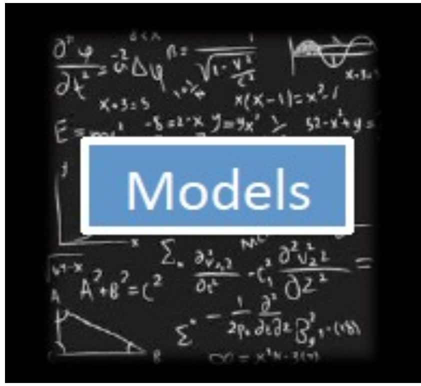


- Statistical models and tests are based on specific assumptions
  - data normally distributed
  - x and y independent
- Assessing a model means you need to make sure the assumptions are not violated.
- There are so many statistical models…

Statistical vs. Mathematical Model



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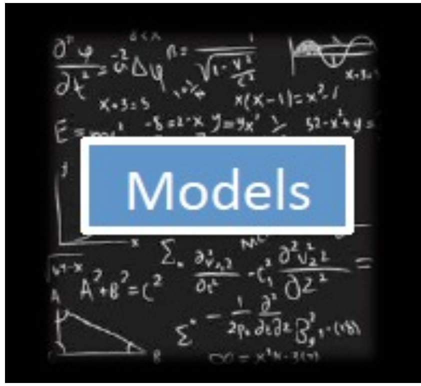
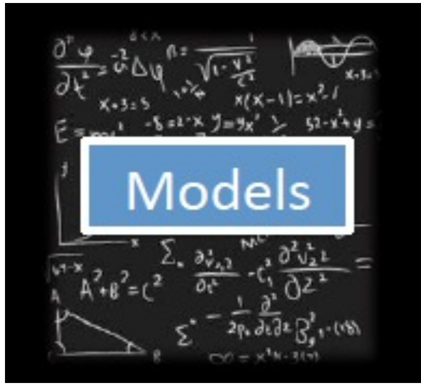
Mechanistic Models



- Goal: To **demonstrate the processes** that underlie a relationship between x and y

Mechanistic Models



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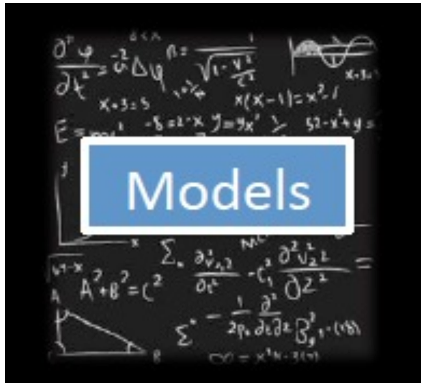
Mechanistic Models



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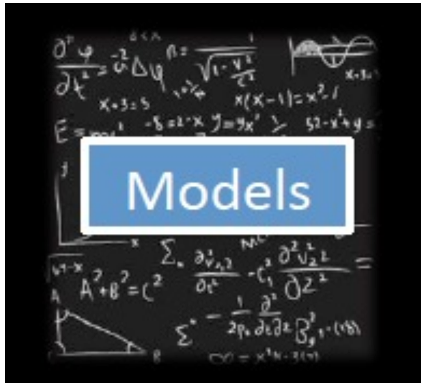
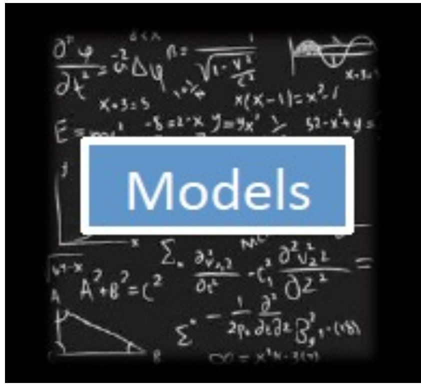


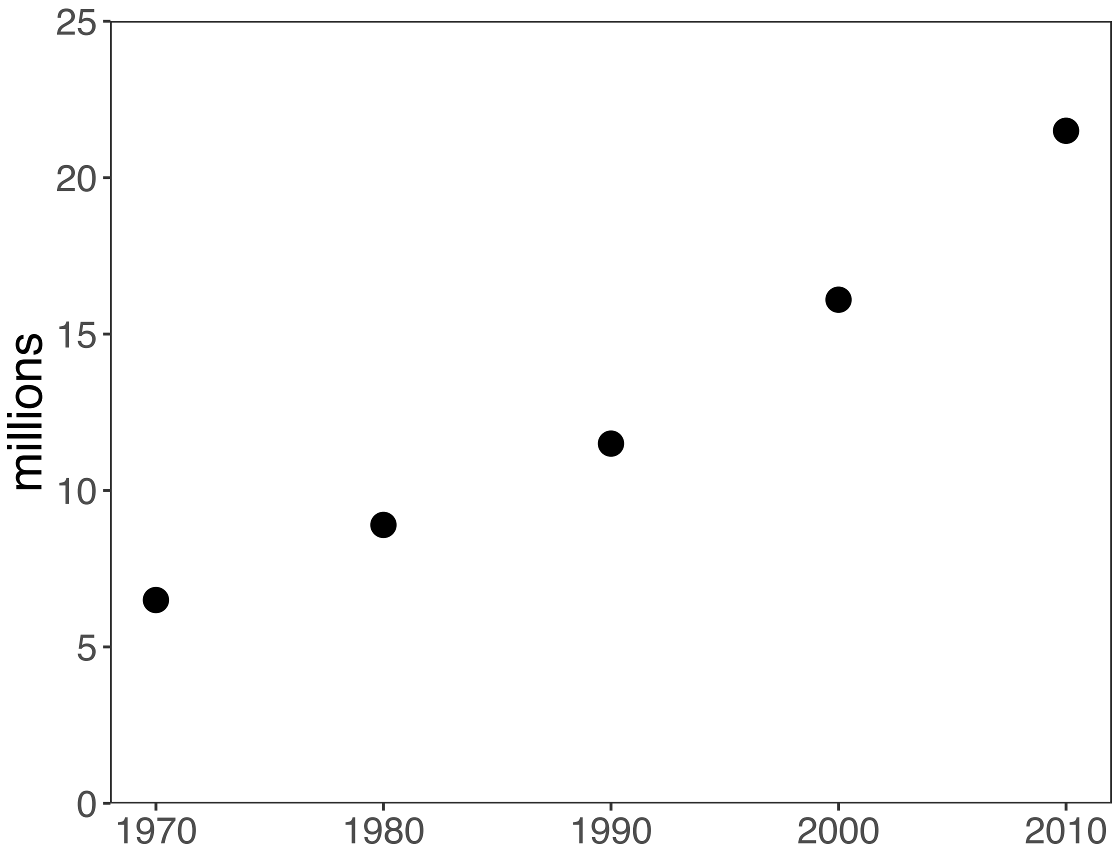
- Goal: To **demonstrate the processes** that underlie a relationship between x and y
  - Find a significant relationship using a p-value as a measure of relationship strength
  - **Mechanistic models can demonstrate causation.**
- Steps:
  1. Formulate a research question
  2. Formulate a hypothesis
  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?



Source: World Bank

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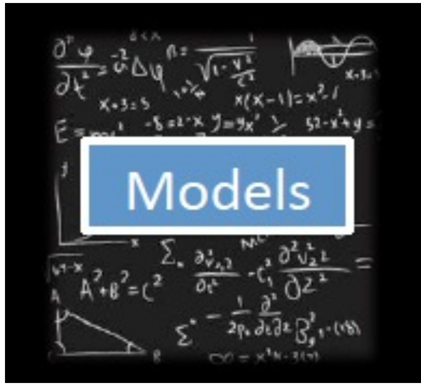

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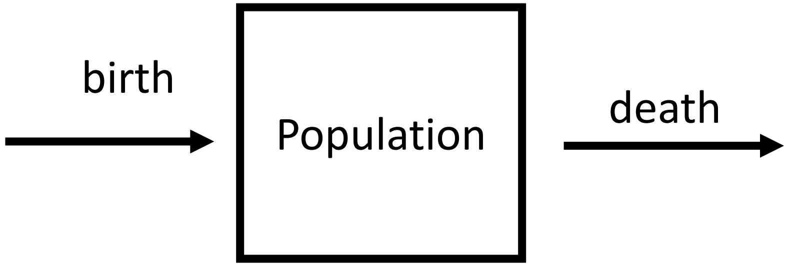
3. Mechanistic Model:



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

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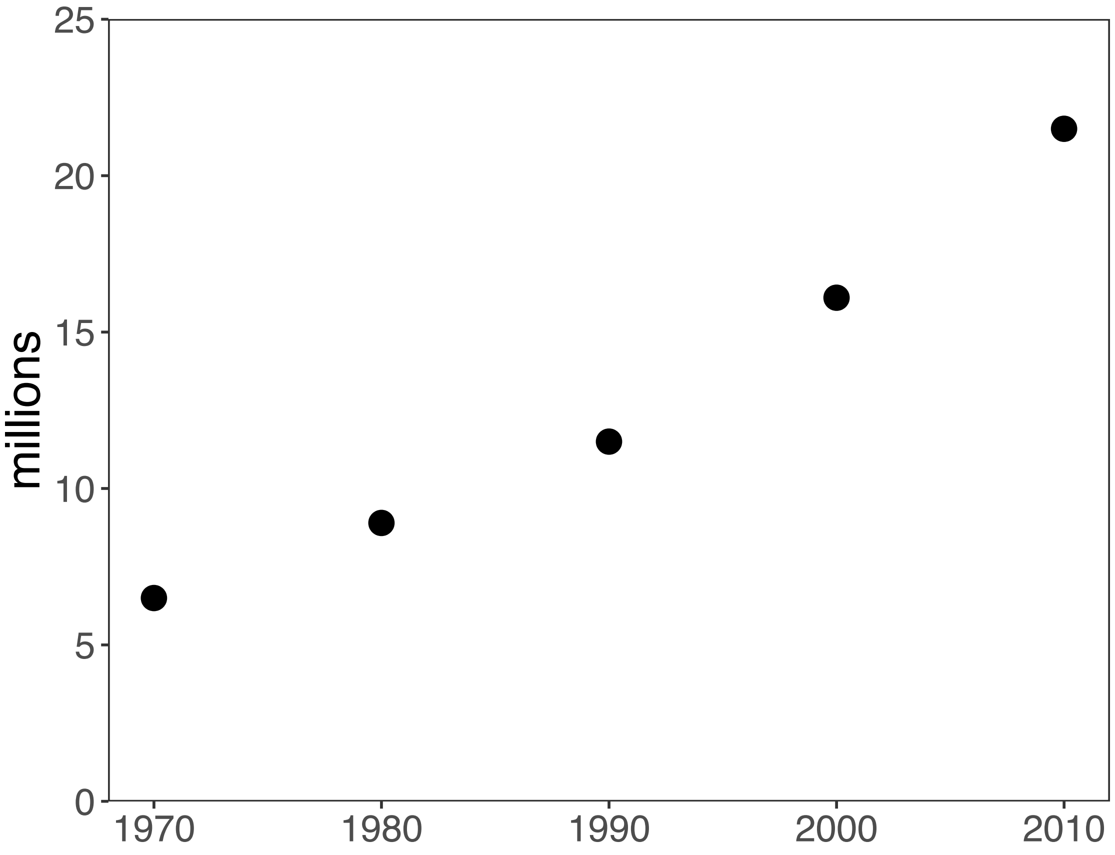

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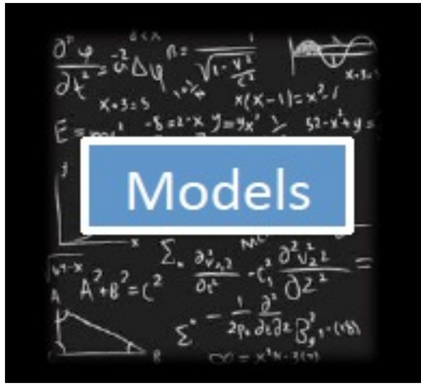

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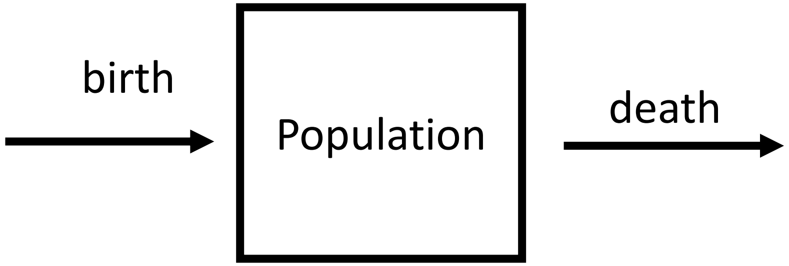

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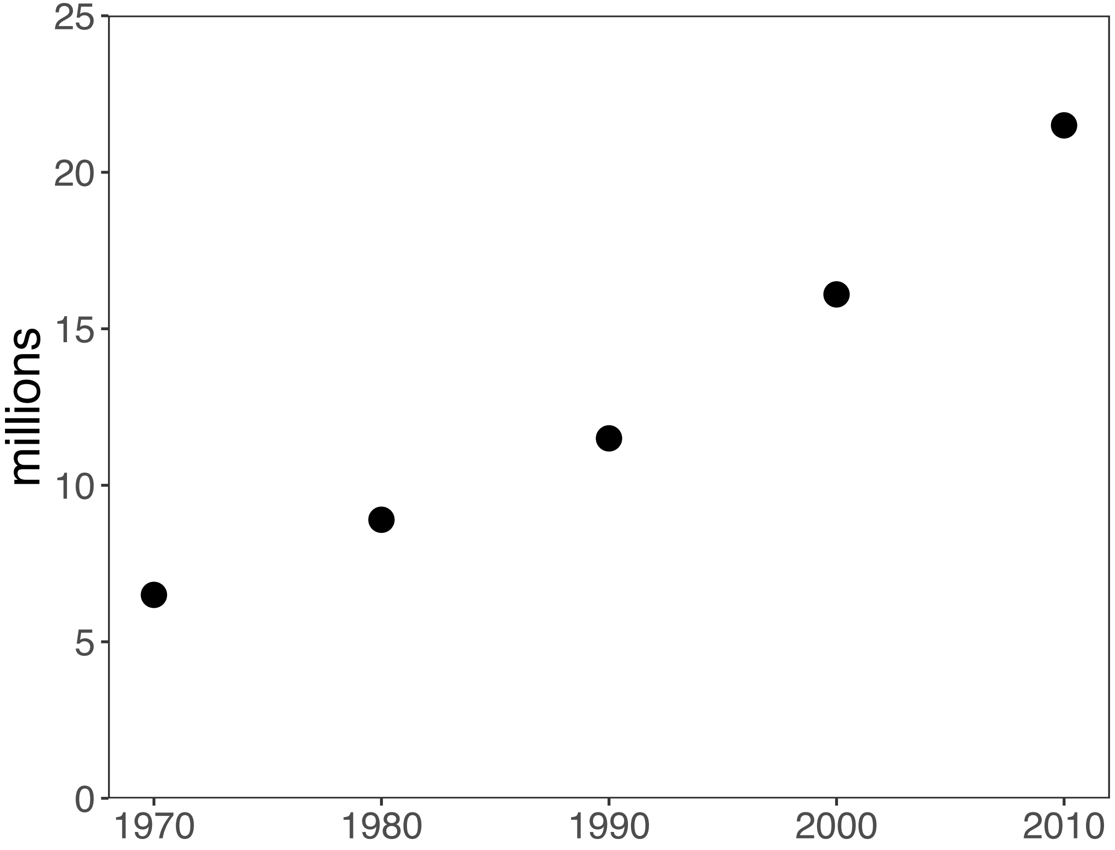

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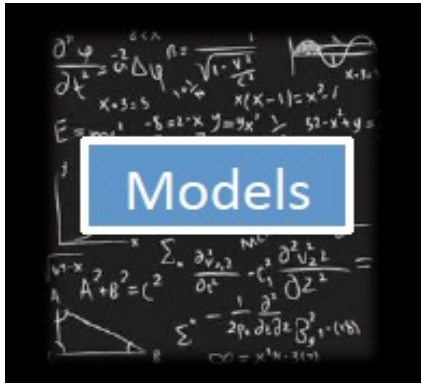

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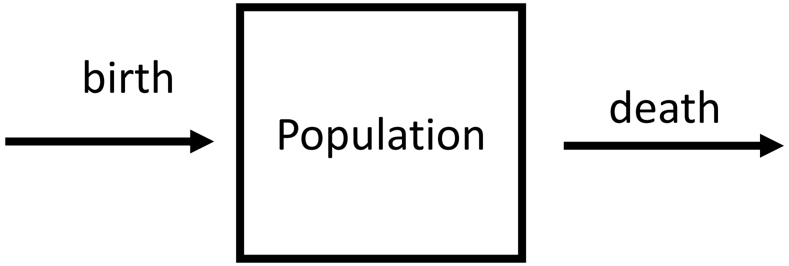

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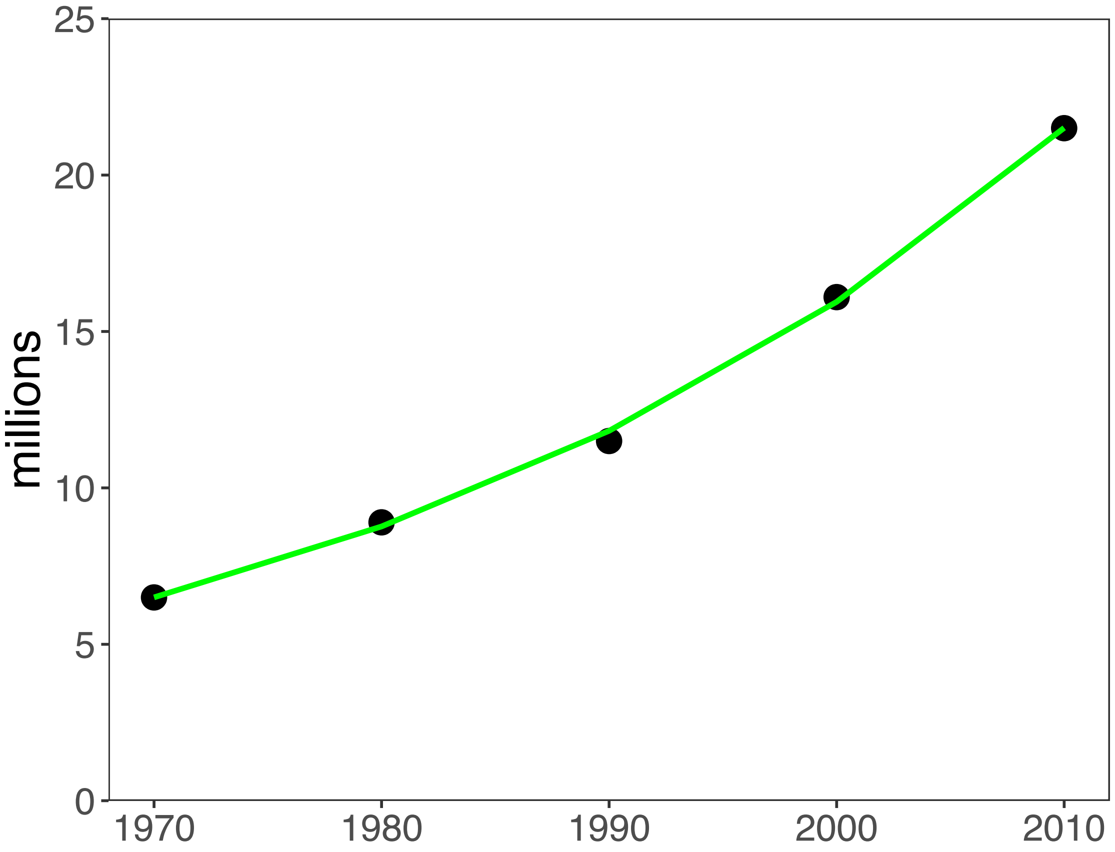
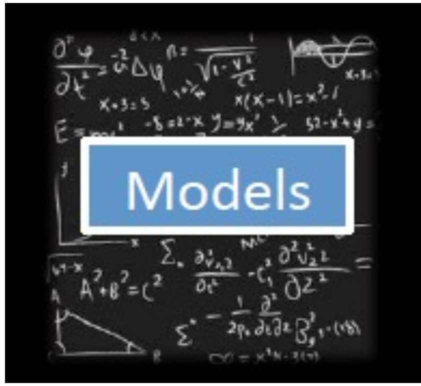


5. Evaluation:

$r = .349$/person/yr

What can we conclude from this fitted model?

Mechanistic Models: Beware!



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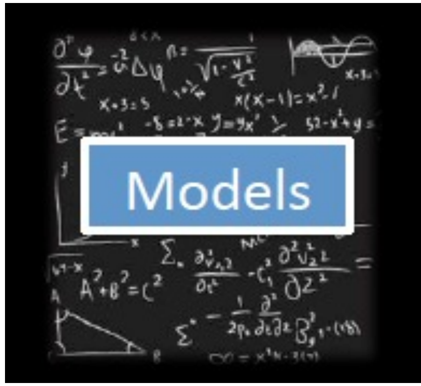

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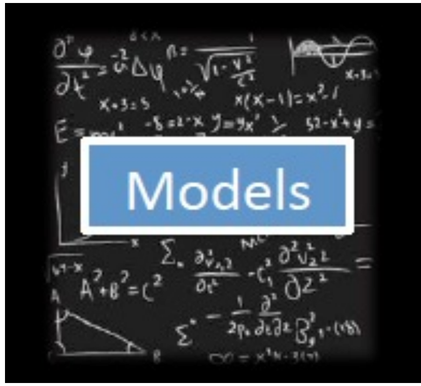

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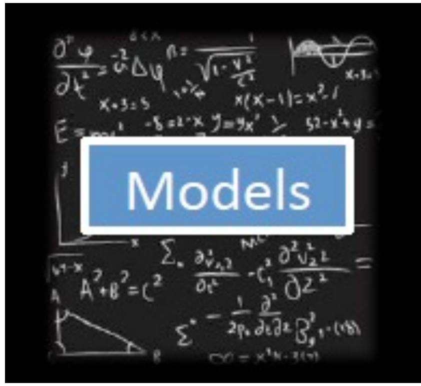

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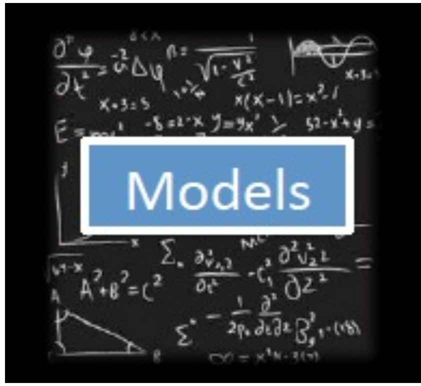

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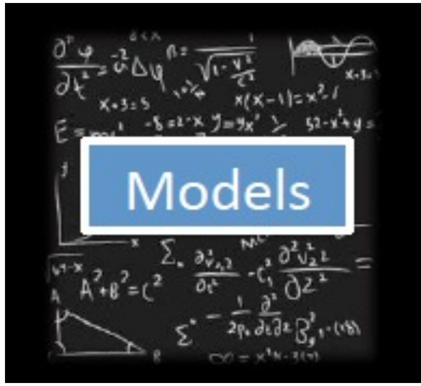
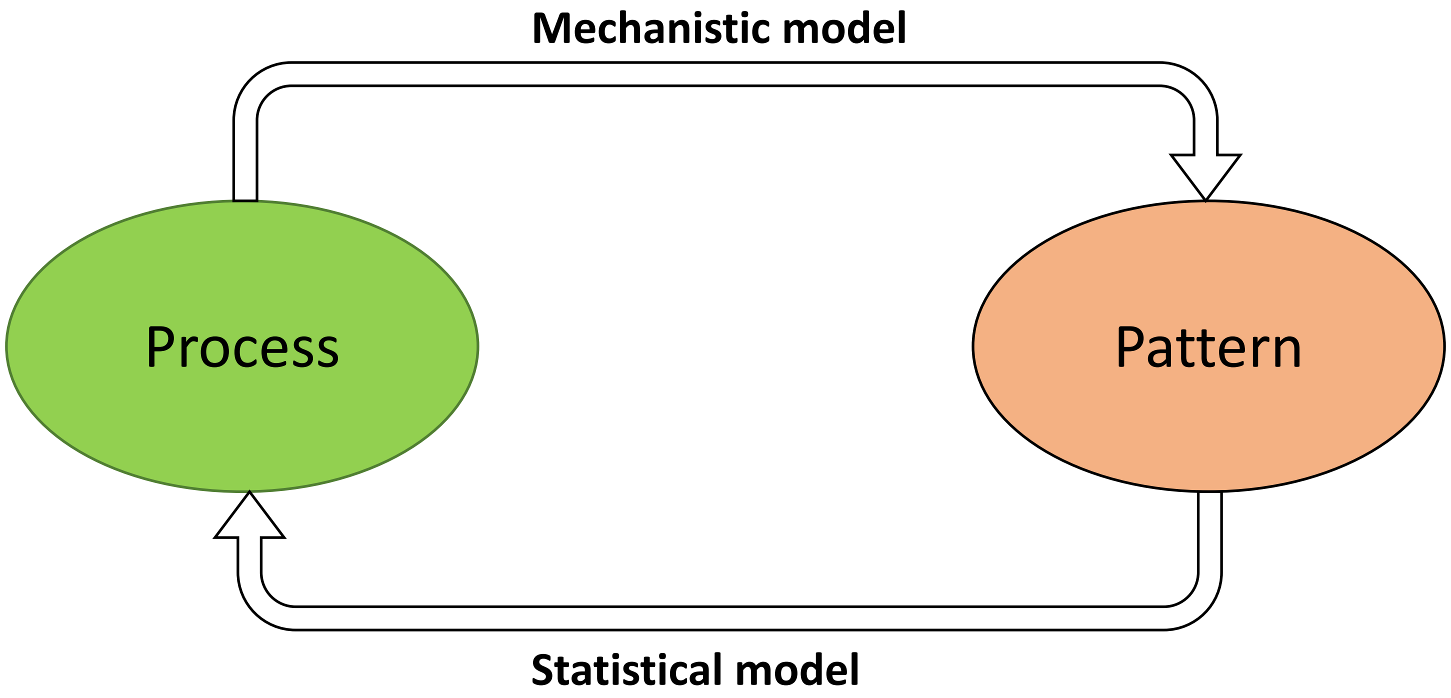
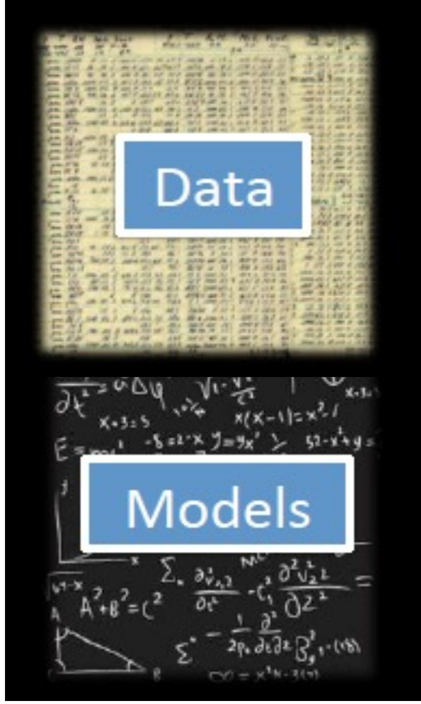
We use models to both **predict** and **explain**.

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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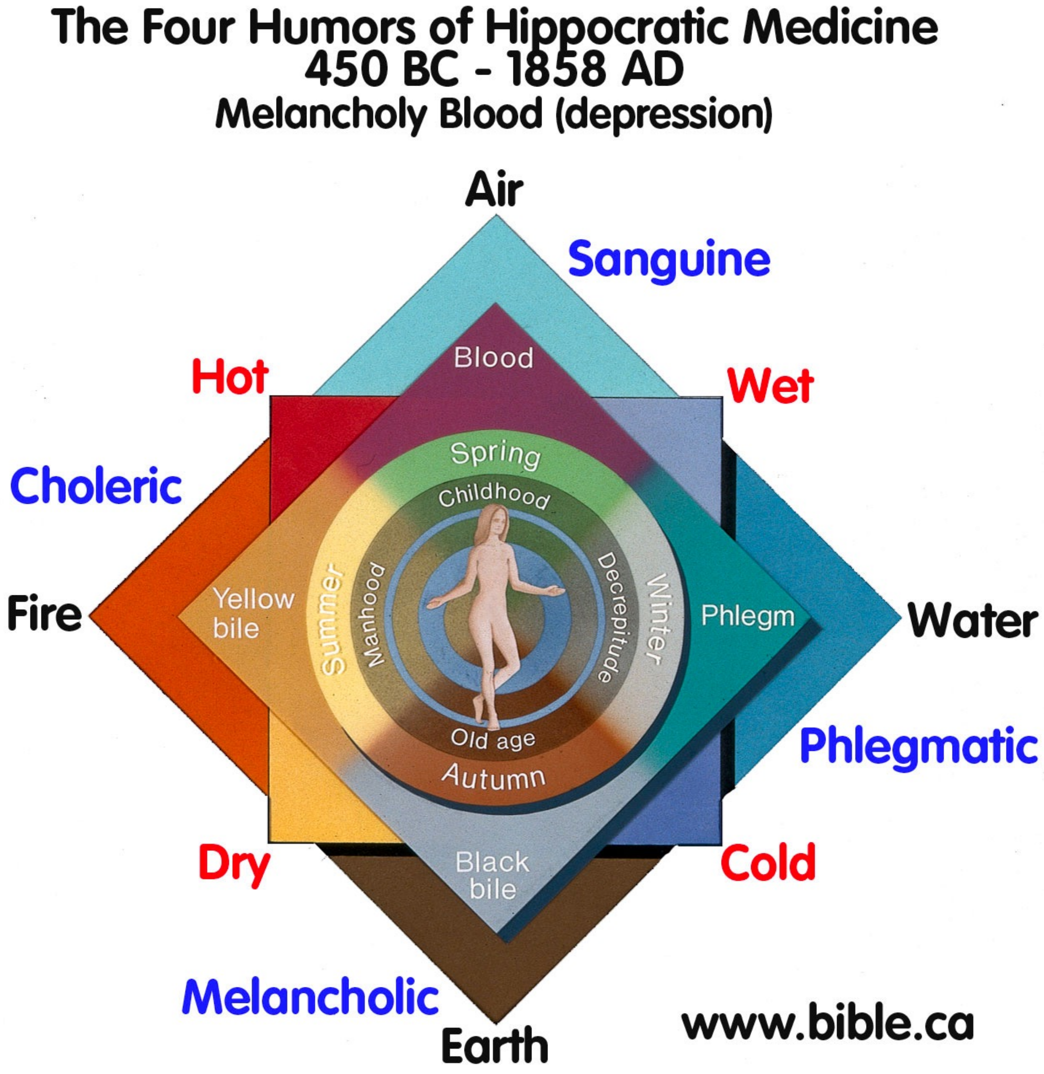
  - Epidemiology

What is Epidemiology?

- “the study of **what** is on the people”
  - coined in 1802 to describe diseases in the Spanish population
- Emphasis on the study and analysis of the distribution and determinants of health and disease (“risk factors”)

Models in Epidemiology

1. Sickness caused by an imbalance in the four humors (Hippocrates)



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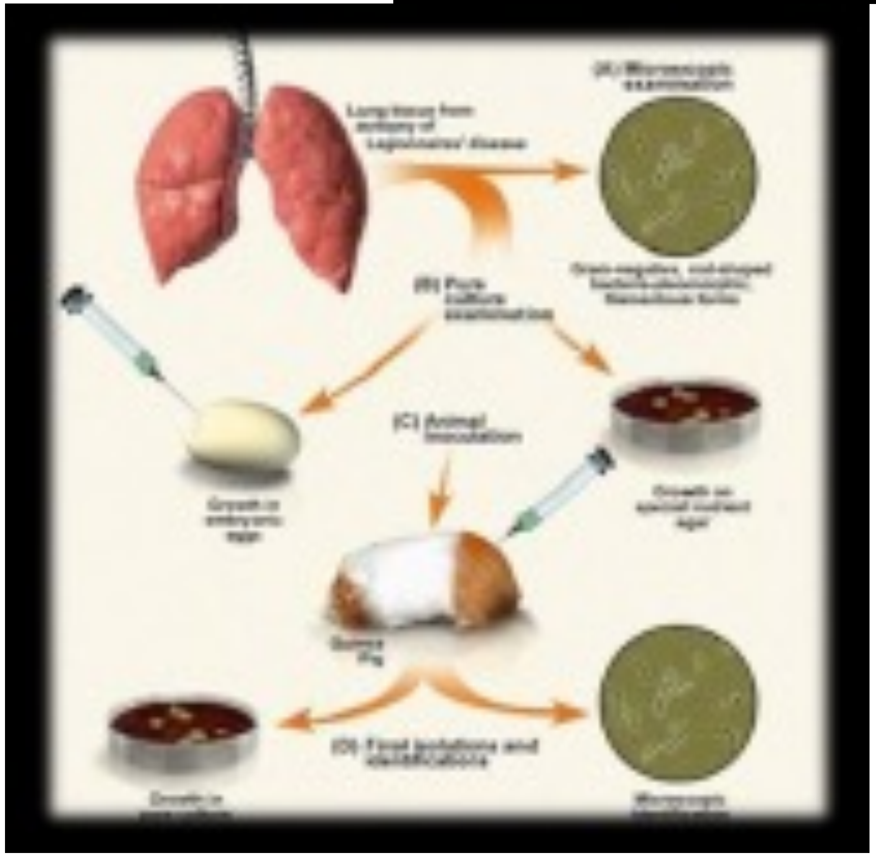

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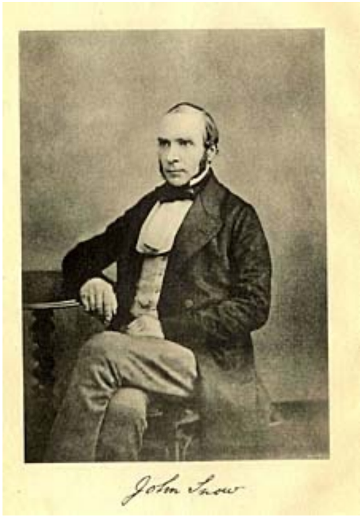

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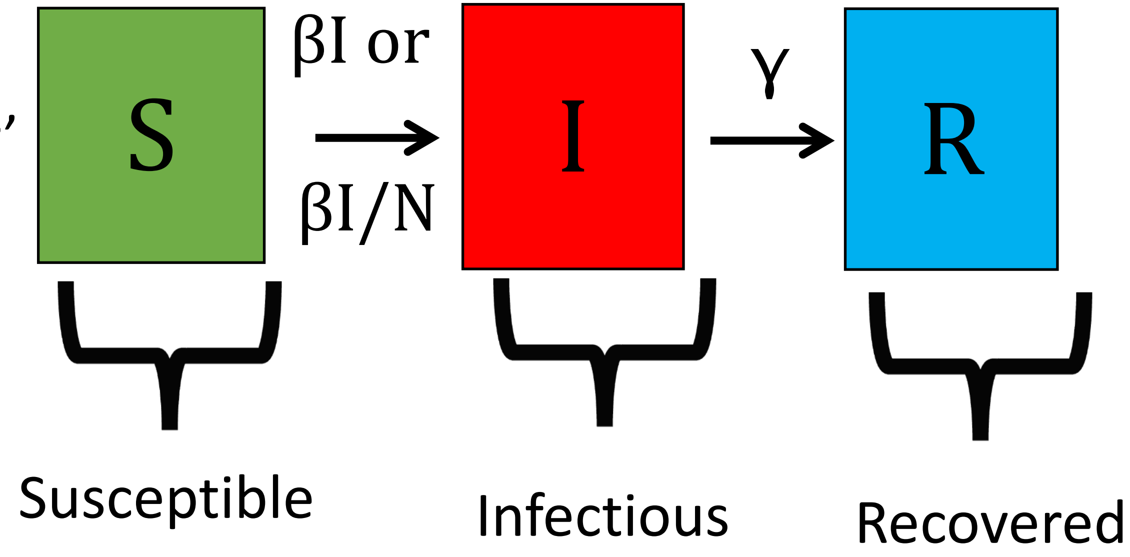

What is Ecology?

- 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

Models in Ecology

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    - Clements and Gleason (1910s-20s)

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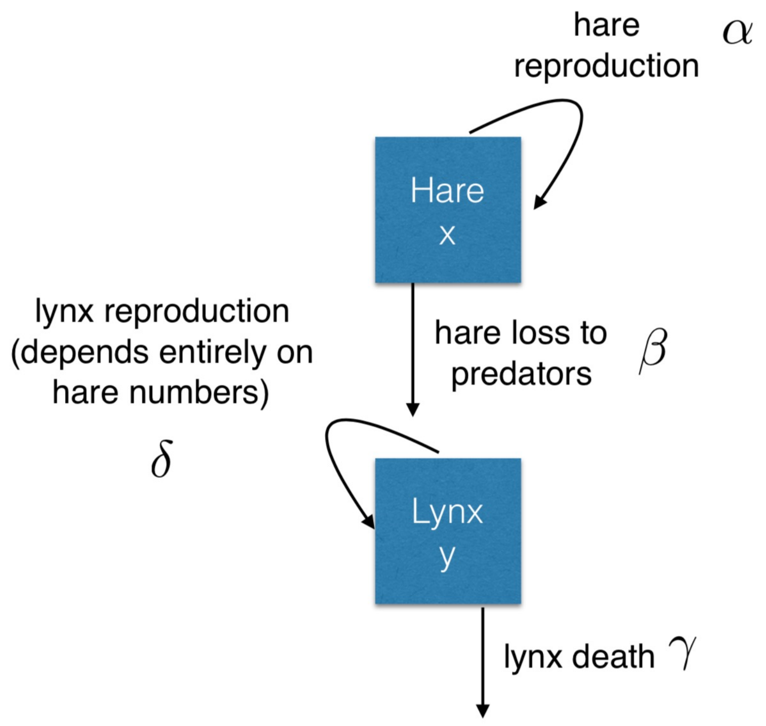

$$\frac{dx}{dt} = x(\alpha - \beta y)$$
$$\frac{dy}{dt} = -y(\gamma - \delta x)$$

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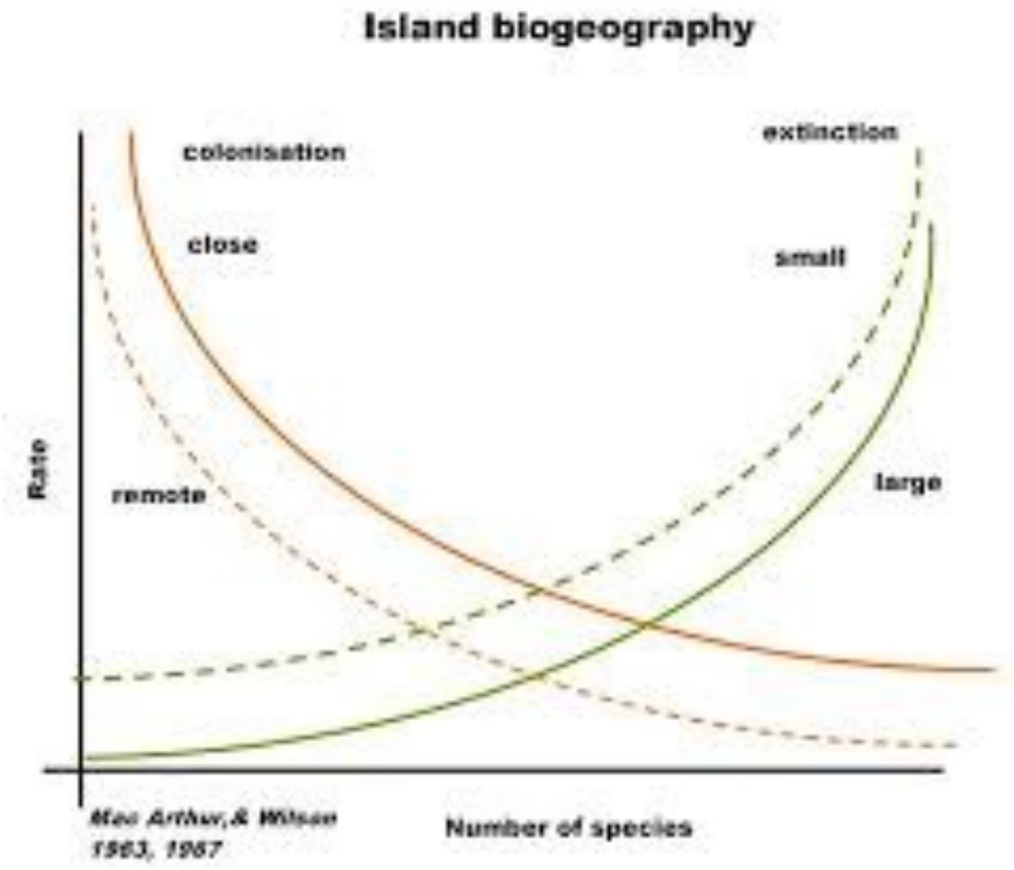

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5. Disease Ecology
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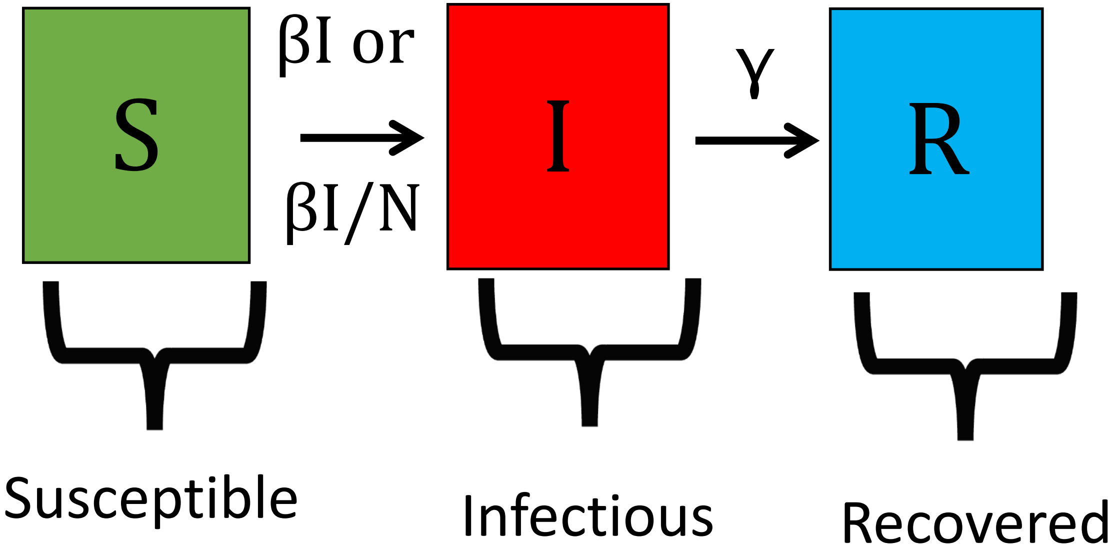

Misaotra!