Introduction to Environmental Sciences

EES 102

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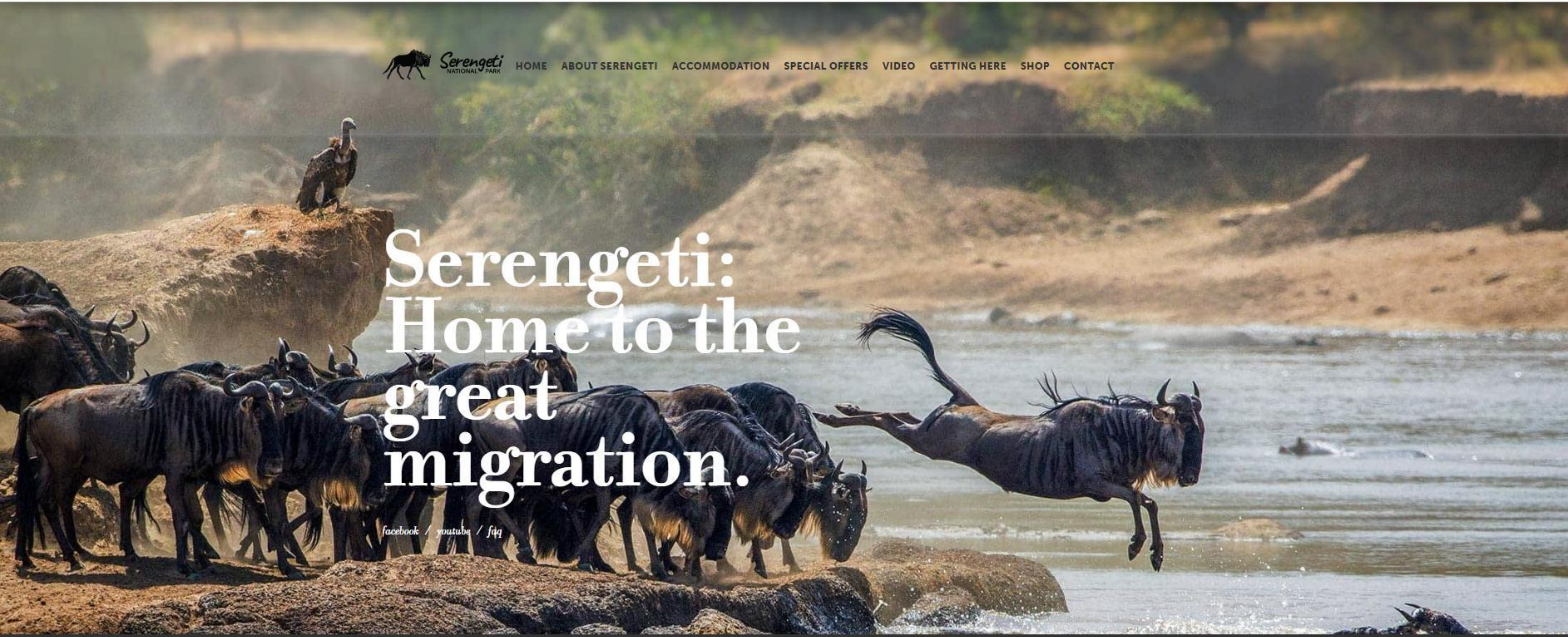
Principles of Science and Systems

serengeti.com/index.php



Snapshot Serengeti

Despite 40 years of studies, though, much remains unknown about basic dynamics and interactions among species. The ecosystem is vast, and collecting data is difficult. How do predator and prey species shift over time? How are they affected by droughts, or by poachers? Where do animals go, and what do they do at night, when it's difficult and dangerous for biologists to be out on the plains?

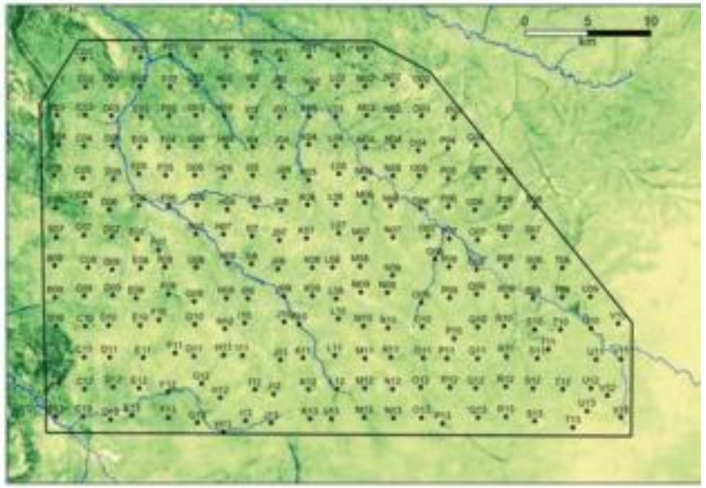


FIGURE 2.1 The grid of camera traps in the Snapshot Serengeti project.

Source: Dr. Craig Packer, Department of Ecology, Evolution and Behavior, University of Minnesota, Saint Paul, MN 55108, USA.

This rich data source also supports graduate student research, and other projects now mine the data set as they form new research questions on wildlife distributions, species interactions, and animal behavior.

Their work makes it possible to understand more of the ecological structure of the system, test hypotheses of community ecology, and inform management decisions.

https://www.youtube.com/watch?v=aGNn9vOz-Vo

https://www.zooniverse.org/about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What is Science?

- **Science** is a process for producing knowledge methodically and logically
  - Are wildlife populations surviving in the Serengeti?
  - How are they affected by human presence?
- Science rests on the assumption that the world is knowable and that we can learn about the world by careful observation.
- By testing our ideas with observable evidence, we can evaluate whether our explanations are reasonable.

Table 2.1 Basic Principles of Science

1.	*Empiricism:* We can learn about the world by careful observation of empirical (real, observable) phenomena; we can expect to understand fundamental processes and natural laws by observation.
2.	*Uniformitarianism:* Basic patterns and processes are uniform across time and space; the forces at work today are the same as those that shaped the world in the past, and they will continue to do so in the future.
3.	*Parsimony:* When two plausible explanations are reasonable, the simpler (more parsimonious) one is preferable. This rule is also known as Ockham's razor, after the English philosopher who proposed it.
4.	*Uncertainty:* Knowledge changes as new evidence appears, and explanations (theories) change with new evidence. Theories based on current evidence should be tested on additional evidence, with the understanding that new data may disprove the best theories.
5.	*Repeatability:* Tests and experiments should be repeatable; if the same results cannot be reproduced, then the conclusions are probably incorrect.
6.	*Proof is elusive:* We rarely expect science to provide absolute proof that a theory is correct, because new evidence may always undermine our current understanding.
7.	*Testable questions:* To find out whether a theory is correct, it must be tested; we formulate testable statements (hypotheses) to test theories.

Science depends on skepticism and accuracy

- Ideally, scientists are skeptical
- There is always a possibility that some additional evidence may appear to disprove the existing explanations
- Scientists also aim to be methodical and unbiased
- The peer review process helps in maintaining good standards in study design, data collection, interpretation of results, etc.
- Scientists demand **reproducibility** because they are cautious about accepting conclusions
- Science also relies on accuracy (closeness to true value) and precision (repeatable)
- Inaccurate data can produce sloppy and misleading conclusions
- Precision means repeatability of results and level of detail

Deductive and inductive reasoning are both useful

- Logical reasoning from general to specific is known as **deductive reasoning.** We know about gravity, so apples if released from the tree, will fall on the ground.

- Reasoning from many observations to produce a general rule is **inductive reasoning.** Birds appear and disappear as a year goes by. Through repeated observations in different places, we can infer that the birds move from place to place.

- We often rely on inductive reasoning to understand the world because we have few immutable laws.

Testable hypotheses and theories are essential tools

Observe that your flashlight doesn't light; also, there are three main components of the lighting system (batteries, bulb, and switch).

Propose a ***hypothesis***, a testable explanation: "The flashlight doesn't work because the batteries are dead."

Develop a *test* of the hypothesis and *predict* the result that would indicate your hypothesis was correct: "I will replace the batteries; the light should then turn on."

Gather *data* from your test: After you replaced the batteries, did the light turn on?

Interpret your results: If the light works now, then your hypothesis was right; if not, then you should formulate a new hypothesis, perhaps that the bulb is faulty, and develop a new test for that hypothesis.

Science follows a structured process, often referred to as the **scientific method**

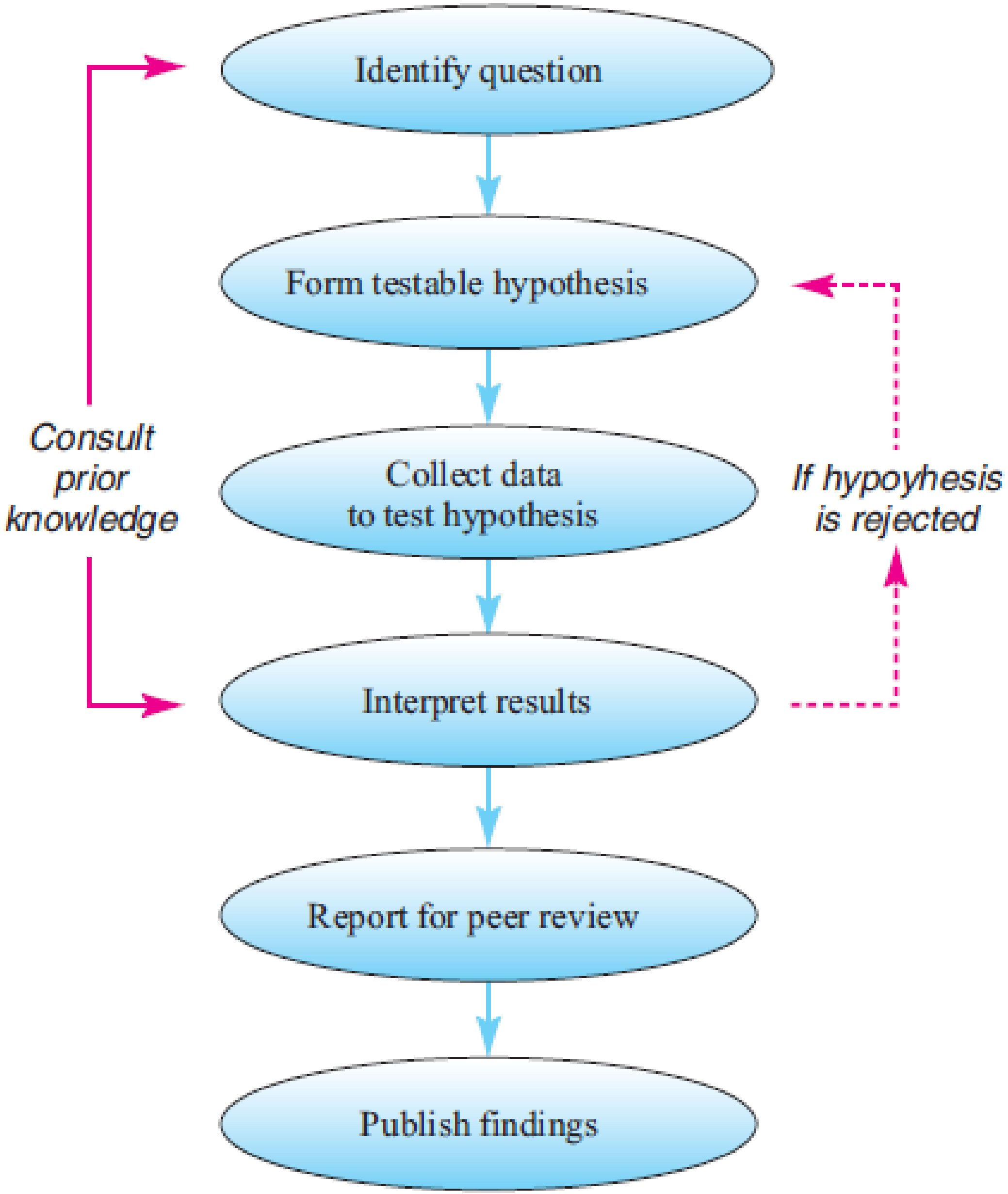


FIGURE 2.3 Ideally, scientific investigation follows a series of logical, orderly steps to formulate and test hypotheses.

Testable hypotheses and theories are essential tools

- It is almost always easier to prove a hypothesis wrong than to prove it unquestionably true.
- When many tests have supported an explanation, and when many experts have reached a consensus that it is a reliable description or explanation, we call it a scientific theory.
- One strategy to improve confidence in the face of uncertainty is to focus on probability.
- Probability does not tell you what will happen, but it tells you what is likely to happen.

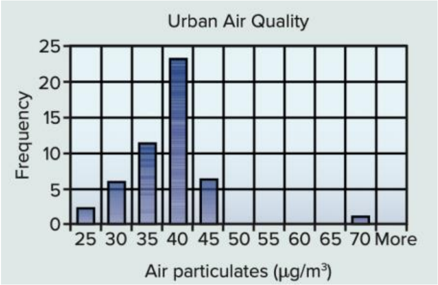
Understanding probability helps reduce uncertainty

- If you hear on the news that you have a 20 percent chance of catching a cold this winter, it means that 20 of every 100 people are likely to catch a cold.
- Sometimes probability is weighted by circumstances: The probability that you will catch a cold this winter depends partly on whether you encounter someone who is sick (largely random chance) and whether you take steps to stay healthy (get enough rest, wash your hands frequently, eat a healthy diet, and so on)
- Scientists often increase their confidence in a study by comparing results to a random sample or a larger group.

Why Do Scientists Answer Questions with a Number?

- Statistics are numbers that let you evaluate and compare things.
- Suppose you found a mean particulate level of 30 micrograms per cubic meter ($\mu g/m^3$) of air. Is this level high or low?
- In 1997, the EPA set a standard of 50 $\mu g/m^3$ as a limit for allowable levels of coarse particulates (2.5–10 micrometers in diameter). Higher levels tend to be associated with elevated rates of asthma and other respiratory diseases. Now you know that your town, with an annual average of 30 $\mu g/m^3$, has relatively safe air, after all.
- How does the air quality of your area compare with the rest of the cities in the country?
- You could compare your town's air quality with a "sample" or subset of cities.
- A large, random sample of cities should represent the general "population" of cities reasonably well.
- Suppose you get average annual particulate levels from 50 randomly selected cities.

You can draw a frequency distribution, or histogram, to display your results.



- The mean value of this group is 36.8 $\mu g/m^3$, so by comparison, your town (at 30 $\mu g/m^3$) is relatively clean.

Why Do Scientists Answer Questions with a Number?

- How do you know that the 50 cities you sampled really represent all the cities in the country?
- The confidence limit refers to the range of values within which a parameter, such as air quality mean, is expected to lie with a certain level of confidence.
- Using statistical software, we can calculate that, for our 50 cities, the mean is 36.8 µg/m3, and the confidence interval is 35.0 to 38.6. This suggests that, if you take 1,000 samples from the entire population of cities, 95 percent of those samples ought to be within 2 µg/m3 of your mean.
- Is your group unusual? You can compare mean air quality levels for the two groups. Then you can calculate confidence intervals for the difference between the means, to see if the difference is meaningful.
- Are respiratory diseases correlated with air pollution?

- Statistics need to be interpreted in terms of who produced them, when, and why. Awareness of some of the standard assumptions behind statistics, such as sampling, confidence, and probability, will help us interpret statistics that we see and hear.

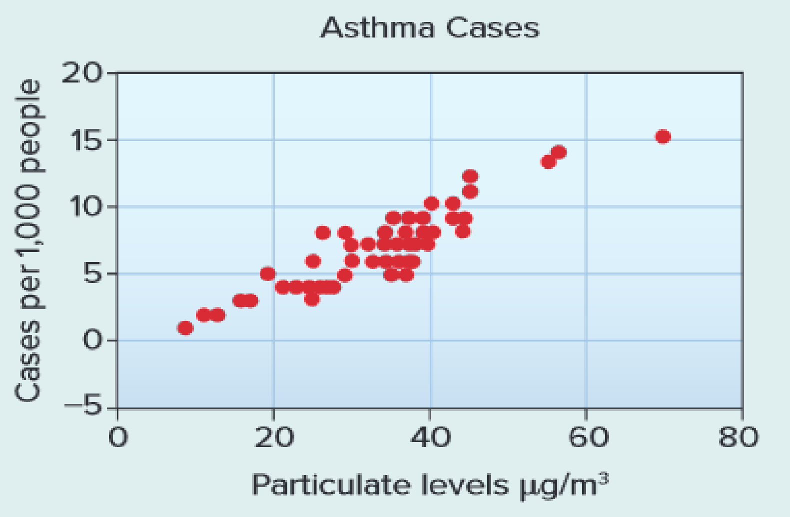


FIGURE 3 A scatter plot shows relationships between variables.

Experimental design can reduce bias

- **Observational experiment or natural experiment** – in large-scale natural systems, you observe the systems, collect a large data set, and then make inferences on questions such as species abundances and distributions, daily activity patterns, seasonal movements, etc.
- **Manipulative experiments**: A researcher wants to study how quickly species colonize small islands, depending on the distance to the mainland.
- Wilson and MacArthur fumigated several tiny islands in the Florida Keys, killing all resident insects, spiders, and other invertebrates. They then monitored the islands to test a theory that populations would reestablish faster on large islands and those near the mainland, compared to small or remote islands.
- This approach could be difficult, costly, and potentially ecologically damaging.

Experimental design can reduce bias

Controlled study: Most manipulative experiments are done in the laboratory, where conditions can be carefully controlled.

Let's say a researcher wants to study whether lawn chemicals contribute to deformities in tadpoles

Keep two groups of tadpoles in fish tanks and expose one to chemicals.

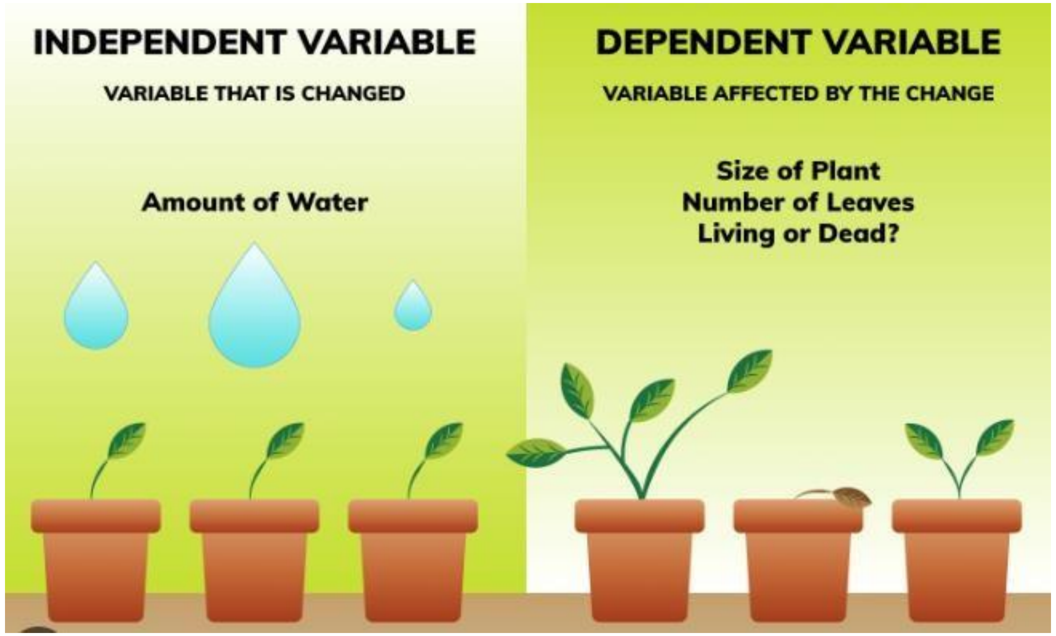
Ensure both tanks have identical temperatures, light, food, and oxygen.
Compare a treatment (exposed) group and a control (unexposed) group

Experimental design can reduce bias

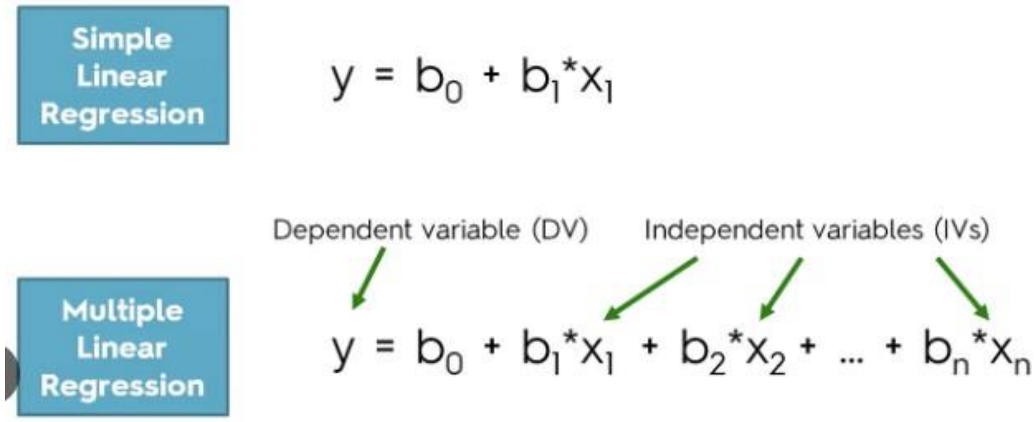
- Experimenter bias: a tadpole with a small nub that looks like it might become an extra leg. Whether the researcher will call this nub a deformity might depend on whether he/she knows that the tadpole is in the treatment group or in the control group
- Blind experiments are often used - the researcher doesn't know which group is treated until after the data have been analyzed.
- Double-blind experiments are also used, for instance, in health studies. Neither the subject (who receives a drug or a placebo) nor the researcher knows who is in the treatment group and who is in the control group.

Experimental design can reduce bias

- Dependent variable or response variable
- Independent variables or explanatory variables – they explain the differences in the dependent variable.



https://sciencenotes.org/independent-and-dependent-variables-examples/



https://medium.com/@manjabogicevic/multiple-linear-regression-using-python-b99754591ac0

Models

FIGURE 2.7 A model uses just the essential elements to represent a complex system.
DNY59/Getty Images

A model is a simple representation of something.

It is another way to gather information about environmental systems.

NASA wind tunnel with the scale model of an airplane (MD-11 in this picture)

- Scientific models vary greatly in complexity, depending on their purposes.
- Engineers test new cars and airplanes in wind tunnels to see how they perform
- Biologists often test theories about evolution and genetics using “model organisms” such as fruit flies or rats as a surrogate for humans.

Models are an important experimental strategy

- A model could be a mathematical equation, such as a simplistic representation of population change $N_t = r^*N_{(t-1)}$

- More complicated models for climate change study – simulation models

Energy balance model: $$C\frac{dT}{dt} = S(1-\alpha) - \epsilon\sigma T^4$$

- A climatologist can raise CO2 levels and see how quickly temperatures respond.
- One model might show temperature rising quickly in response to CO2; another might show temperature rising more slowly, depending on how evaporation, cloud cover, and other variables are considered.

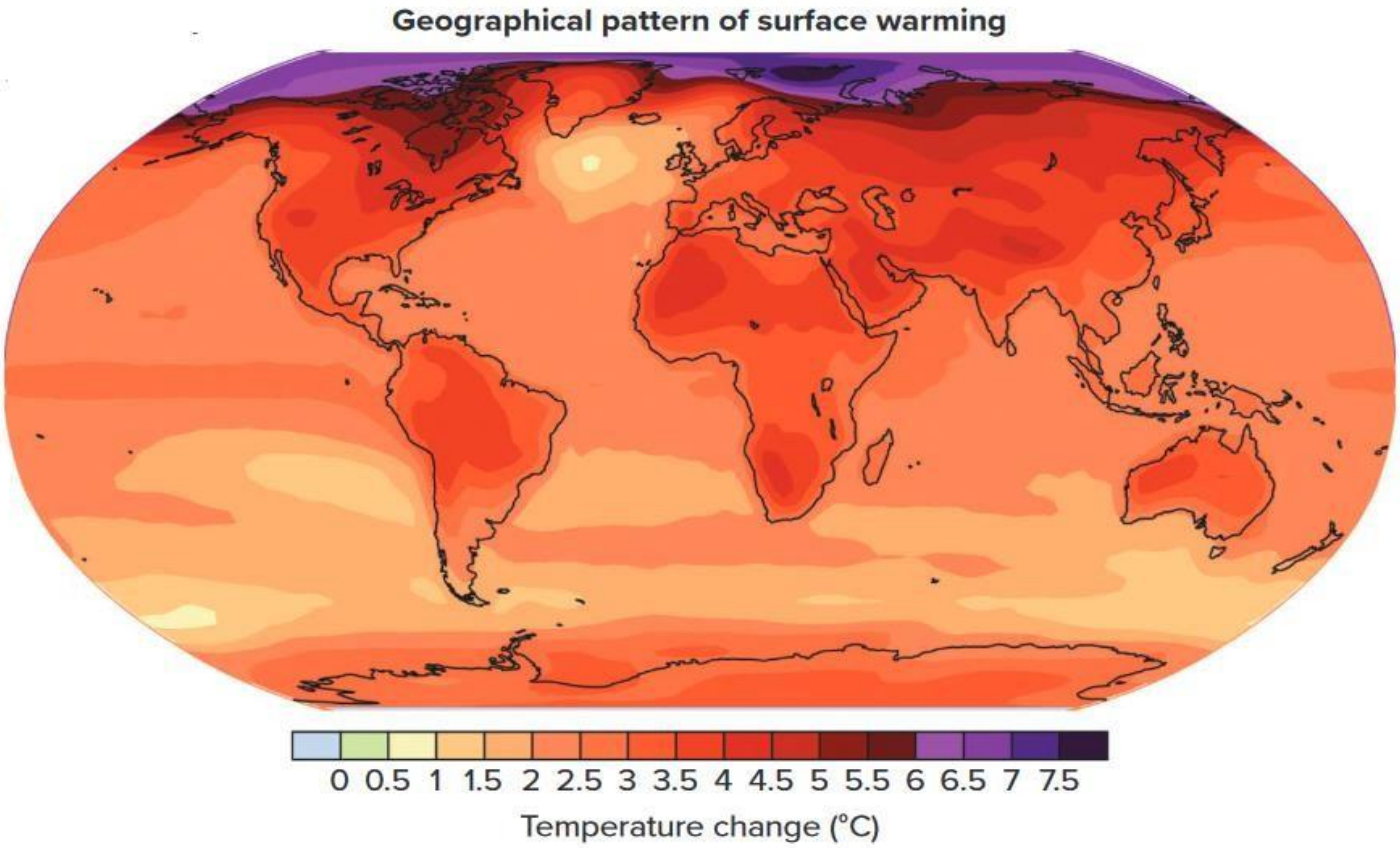


FIGURE 2.8 Numerical models, calculated from observed data, can project future scenarios. Here, temperature changes in 2090–2099 are modeled, relative to 1980–1999 temperatures.

Figure SPM.6 from Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K. and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland. Used with permission.

- These models are also very useful in laying out and testing our ideas about how a system works.

- They allow the researcher to manipulate variables quickly and easily, without actually destroying anything.