BIO3SS3: Population Ecology
UNIT 1: Introduction

1 Course overview

1.1 Course structure

Communication

- Lecture notes for each section will be available the afternoon before you need them
  - Check Avenue frequently for announcements and new information
  - All info will also be on the course resource page
    - `http://bio3ss.github.io/`
- The professor is Jonathan Dushoff
  - `dushoff@mcmaster.ca`
  - Office hours will be announced
  - Or ask questions electronically
    - We need a forum!

Expectations of professor

- Start and end on time
- Focus on conceptual understanding
- Make clear what terminology and facts must be learned
- Open to questions – both in class (within reason) and at office hours
- Responsive to questions on class forums (to be decided)

Expectations of students

- Start and end on time
- Don't talk while other students are talking, or while I am responding to student questions
- If you must talk at other times, be unobtrusive
- Don't use the internet for non-class activities
- Attend the lecture, and the mandatory tutorials

Texts

- The primary text for this course is the lecture notes
- You will be given readings, which will be posted to Avenue

Structure of presentation

- Required material will be clearly outlined in the notes
  - **Answer:** This is an answer: it was omitted from the notes for discussion purposes, you should probably write it in
  - *Comment:* This is a comment: I omitted from the notes because I thought it wasn't necessary for you to study. If you write it in, make a note to yourself that it's a comment.
- Required terminology will be presented in **bold**
- General ideas and approaches presented in class may also be required; you should take notes on these in your own words

Taking notes

- You will do best if you take notes
  - You should know by now what works for you
  - Or else that you need to keep working on it
- If a new concept is making sense to you right now, write something that will help you remember
- If there's something specific I think you all need to write down, I will write it for you (or mark it as an answer)

Polling

- You can obtain extra credit by responding to in-class polls
  - Text from your cell phone, or answer on the web
- Poll: Why are you taking this class?

1.2 People

Li

- Ex-TA
- Post-doc
- Studies evolution and spread of infectious diseases
  - Rabies, ebola, influenza, ...
  - Statistics, math, theoretical biology, computations, ...
  - Mechanisms and disease control

Dushoff

- Loves math
- Lived in four countries
- Studies evolution and spread of infectious diseases
  - HIV, rabies, ebola, influenza, ...
  - `http://lalashan.mcmaster.ca/theobio/DushoffLab/`
  - `https://twitter.com/jd_mathbio`

TAs

- Steve Cygu
- Zachery Dickson
- Danielle Montocchio

Students

- Poll: What year are you in?
- Poll: What kind of career are you aiming for?

2 Course content

2.1 Learning goals

- Ecology and population ecology
- Quantitative thinking
- Dynamical modeling

Ecology

- Poll: What is ecology?
- My answer
  - **Answer:** The study of how organisms interact with each other and with the environment
  - **Answer:** Ecology is not environmentalism

Population ecology

- Poll: What is population ecology?
- My answer
  - **Answer:** The study of how organisms interact with each other and with the environment at the population scale
  - **Answer:** Larger spatial scale, longer temporal scale
  - **Answer:** We use *dynamical models* to link from the individual level to the population level

Dynamical modeling

- Investigates the links between local, short-term processes, and large-scale, long-term outcomes
- Allows us to explore what assumptions we're making, and how assumptions affect the link

Math

- Population ecology uses math
  - Math is a critical tool for linking processes to outcomes
  - Math will play a central role in the course
- We will keep it *simple*
  - But we understand that simple does not always mean easy
- Review the math supplement

Humans and abstract thought

- People are evolved to be concrete thinkers, not conceptual thinkers
- A goal of this course is to build conceptual thinking skills

2.2 Examples

Malaria

- A nasty, mosquito-borne disease
- In some places (e.g., the southeastern US), it has been eradicated almost by accident
  - Mosquitoes are still present
- In other places it persists at high levels despite concerted efforts at elimination
- *What factors determine when and where malaria spreads?*

Red squirrels

- Red squirrels are rapidly disappearing from England
  - Loss of suitable habitat?
  - Competition from gray squirrels introduced from North America?
  - Diseases carried by gray squirrels?
- `http://en.wikipedia.org/wiki/Eastern_grey_squirrels_in_Europe`

Cod fisheries

- Is the ocean too big for people to affect?
- What happened to the cod?
- `http://en.wikipedia.org/wiki/Collapse_of_the_Atlantic_northwest_cod_fishery`

Populations

- Poll: What population of organisms interests you?

Dandelions

- Start with one dandelion; it produces 100 seeds, of which only 4% survive to reproduce the next year.
  - How many dandelions after 3 years?
    - **Answer:** 64?
    - **Answer:** 125?

3 Example populations

3.1 Dandelions

- Start with one dandelion; it produces 100 seeds, of which only 4% survive to reproduce the next year.
- How many dandelions after 3 years?
  - **Answer:** 64?
  - **Answer:** 125?
  - See spreadsheet on resource page
- The spreadsheet is an implementation of a dynamical model!

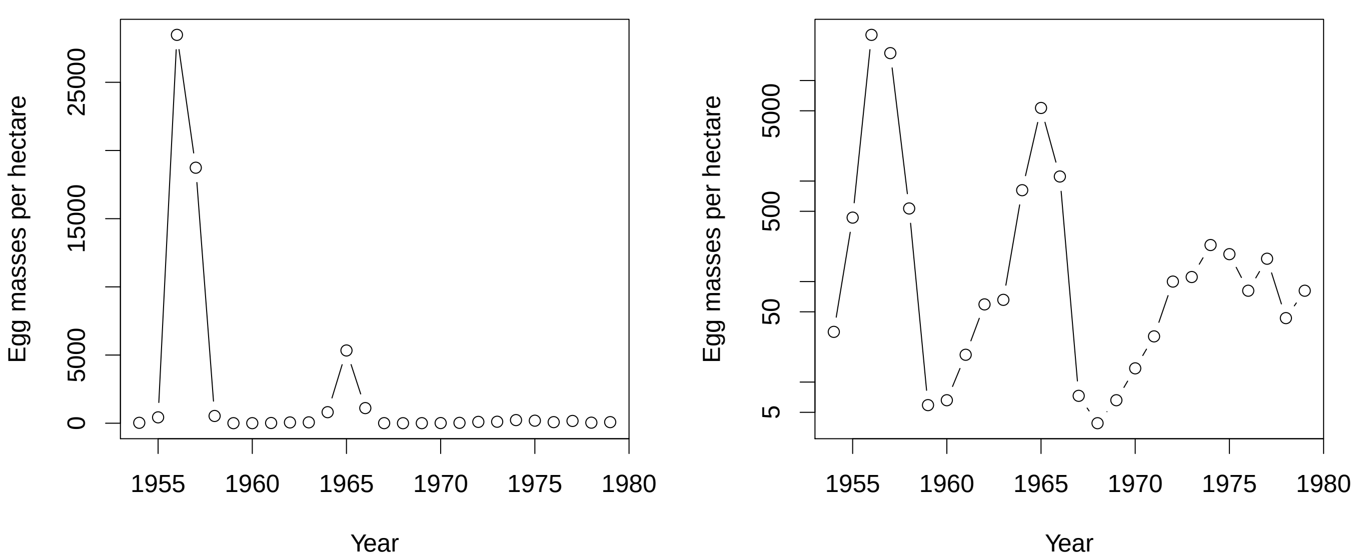
Dynamical models

- Make rules about how things change on a small scale
- Assumptions should be clear enough to allow you to calculate or simulate population-level results
- Challenging and clarifying assumptions is a key advantage of models

3.2 Gypsy moths

- A pest species that feeds on deciduous trees
- Introduced to N. America from Europe 150 years ago
- Capable of wide-scale defoliation

Gypsy moth populations



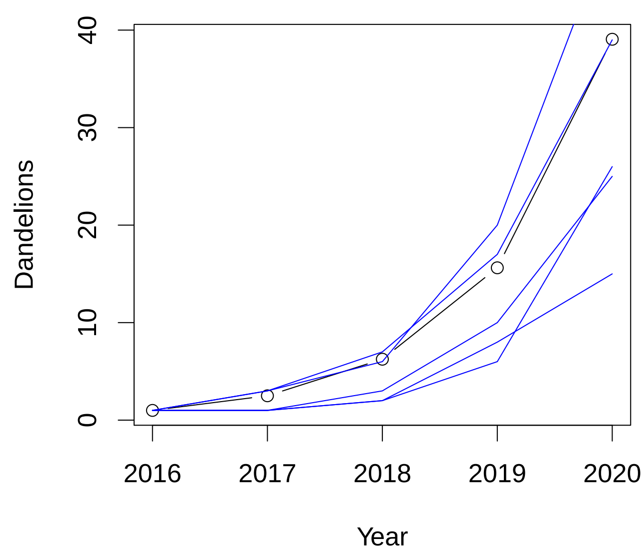
Moth calculation

- Researchers studying a gypsy moth population make the following estimates:
  - The average reproductive female lays 600 eggs
  - 10% of eggs hatch into larvae
  - 10% of larvae mature into pupae
  - 50% of pupae mature into adults
  - 50% of adults survive to reproduce
  - All adults die after reproduction
- What happens if we start with 10 moths?
  - **Answer:** If 5 are female, we end up with an average of 7.5 moths

Stochastic version

- Obviously, we will not get *exactly* 7.5 moths.
- If we consider moths as individuals, we need a **stochastic** model
- What do we mean by stochastic?
  - **Answer:** The model has randomness, to reflect details that we can't measure in advance, or can't predict

Stochastic model



- A stochastic model has randomness in the model.

- If we run it again with the same parameters and starting conditions, we get a different answer

3.3 Bacteria

- Imagine we have some bacteria growing in a big tank, constantly dividing and dying:
  - They divide (forming two bacteria from one) at a rate of 0.04/ hr
  - They wash out of the tank at a rate of 0.02/ hr
  - They die at a rate of 0.01/ hr
- Rates are **per capita** (i.e., per individual) and **instaneous** (they describe what is happening at each moment of time)
- We start with 10 bacteria/ml
  - How many do we have after 1 hr?
  - What about after 1 day?

Bacteria, rescaled

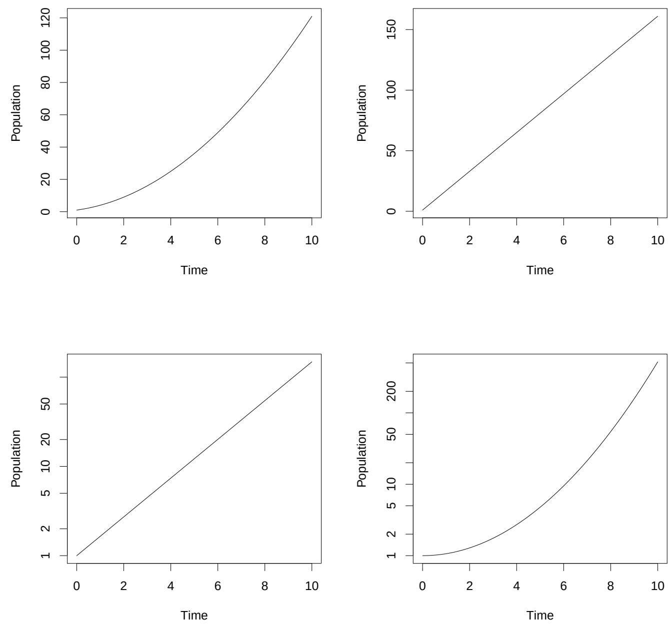
- Imagine we have some bacteria growing in a big tank:
  - They divide (forming two bacteria from one) at a rate of 0.96/day
  - They wash out of the tank at a rate of 0.48/day
  - They die at a rate of 0.24/day
- If we start with 10 bacteria/ml, how many do we have after 1 day?

Units

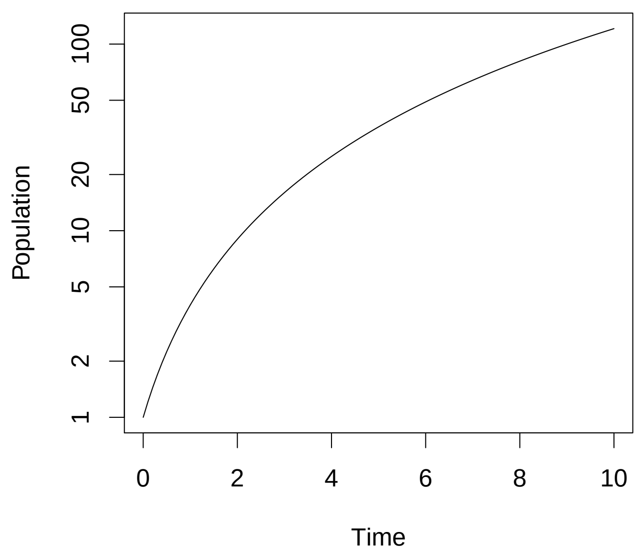
- When we attach units to a quantity, the meaning is concrete
  - 0.24/day *must* mean exactly the same thing as 0.01/hr
  - The two questions above *must* have the same answer

4 Exponential growth

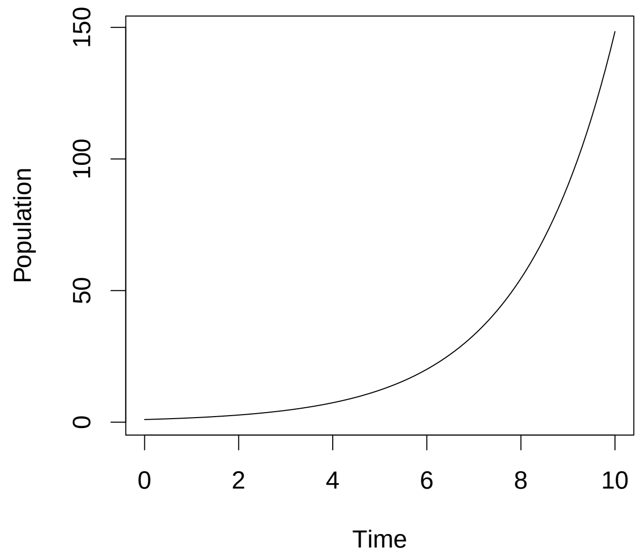
- What is exponential growth?
- Which of these is an example?



Answer slide: *A on the log scale*



Answer slide: *C on the linear scale*



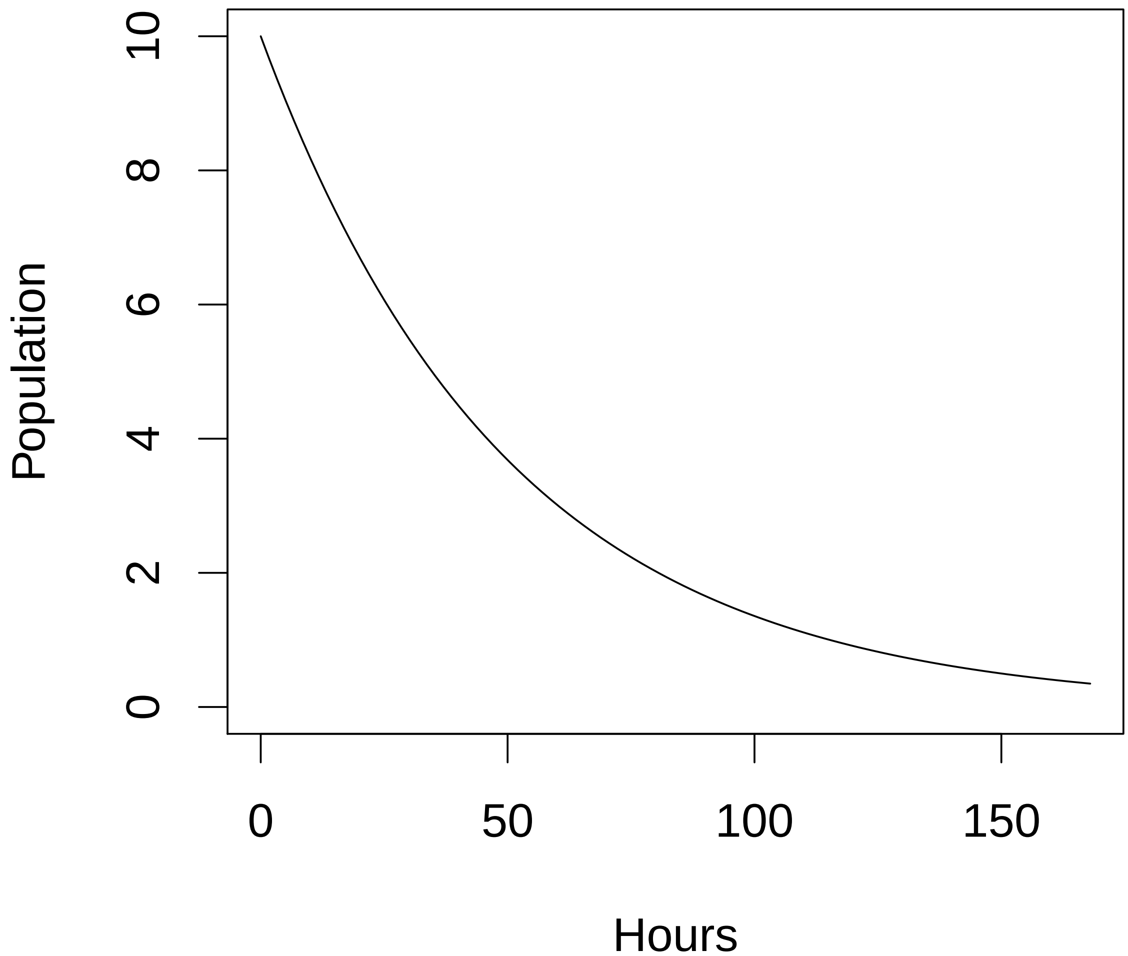
Types of growth

- arithmetic/linear:
  - **Answer:** *Add* a fixed amount in a given time interval
  - **Answer:** Total growth rate is constant
- geometric/exponential:
  - **Answer:** *Multiply* by a fixed amount in a given time interval
  - **Answer:** Per-capita growth is constant
  - **Answer:** Only C is exponential, mathematically speaking.
- other:
  - Many possibilities, we may discuss some later

Exponential decline?

- Poll: What is exponential decline?
  - **Answer:** Decline is proportional to size
  - **Answer:** Declines more and more *slowly* (on linear scale)

<u>Answer slide</u>: *Exponential decline*



- Decline is proportional to size
- Declines more and more *slowly* (on linear scale)

Terminology

- Sometimes people distinguish
  - **arithmetic** from **linear** growth, or
  - **geometric** from **exponential** growth

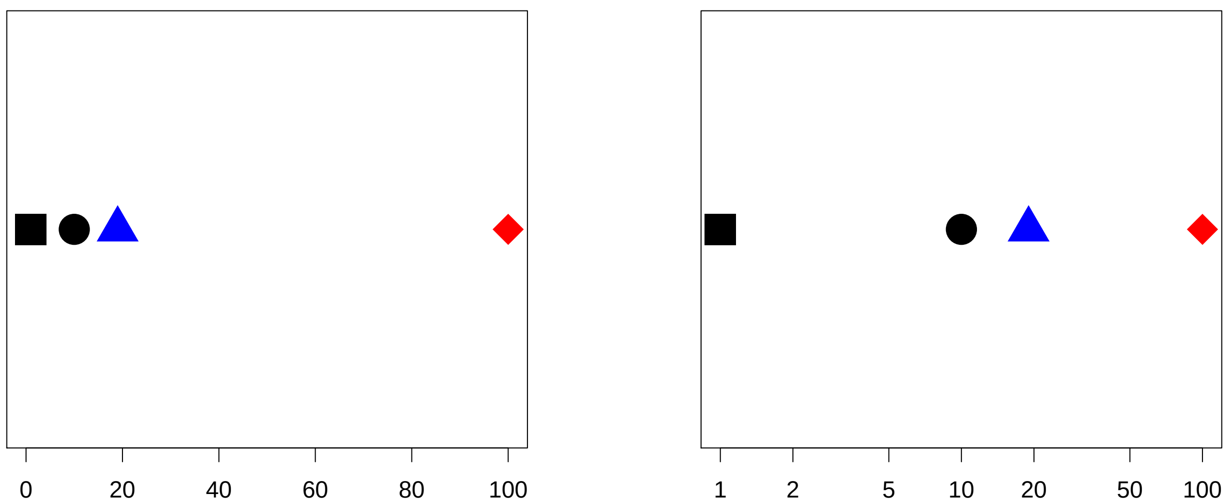
- Based on:
  - **<u>Answer</u>: discrete** vs. **continuous** time
- We won't worry much about this.

4.1 Log and linear scales

Scales of comparison

- Poll: 1 is to 10 as 10 is to what?
  - **<u>Answer</u>:** If you said 100, you are thinking multiplicatively
  - **<u>Answer</u>:** If you said 19, you are thinking additively

Scales of display

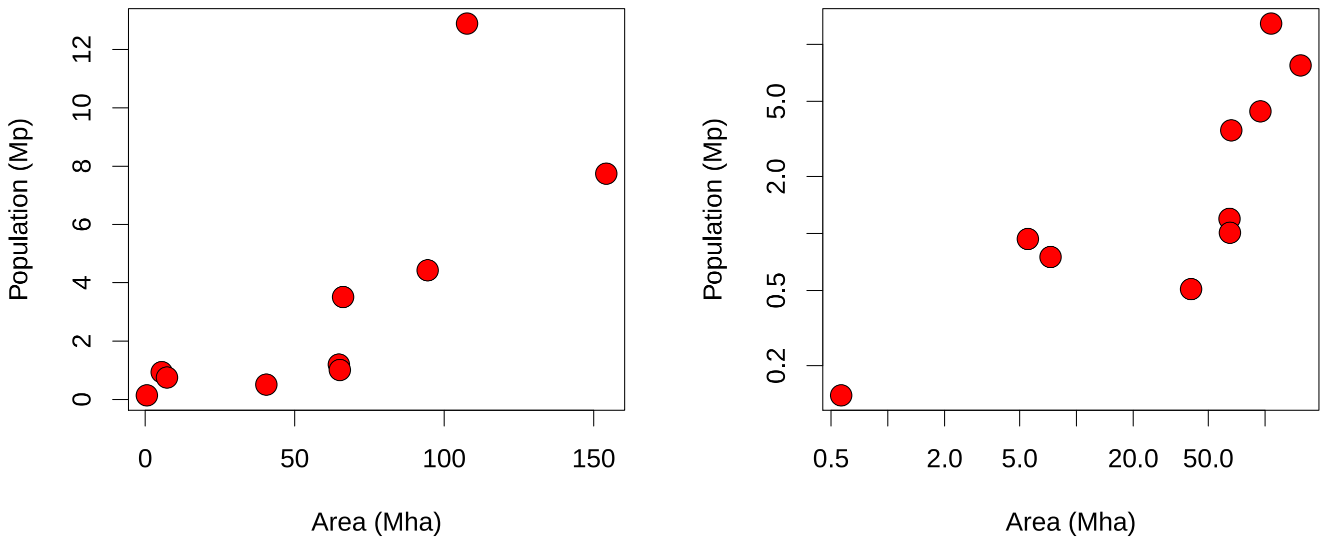


There is only one log scale; it doesn't matter which base you use!

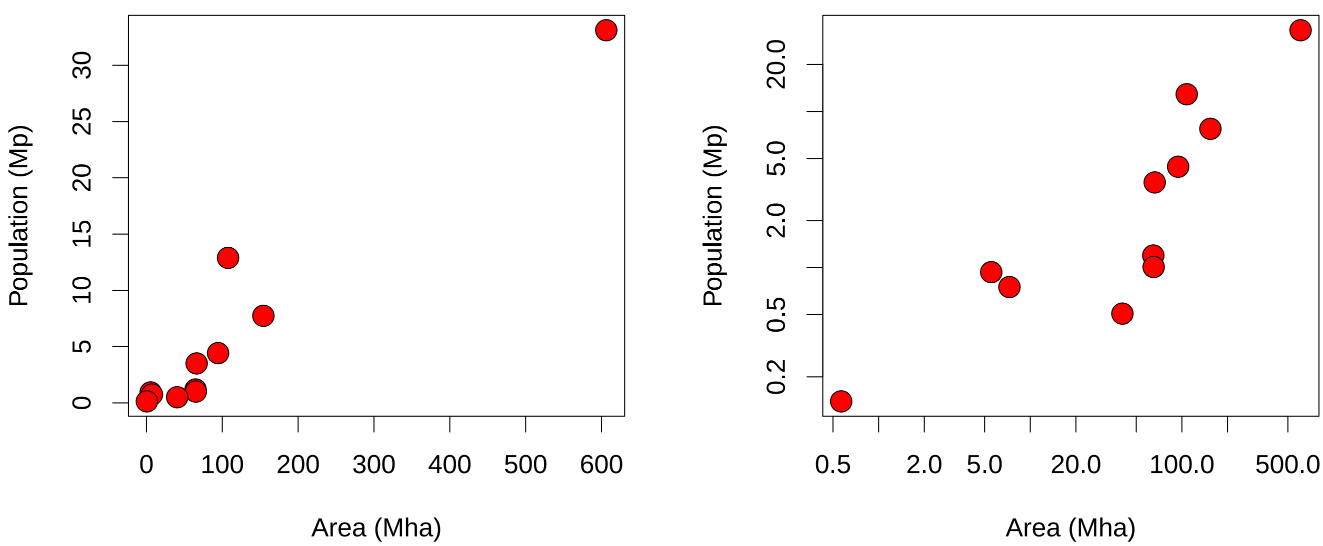
Canadian provinces

- How many people know the Canadian provinces song?
- Poll: Which Canadian province is the most unusual in terms of area?
- Poll: Which Canadian province is the most unusual in terms of population?

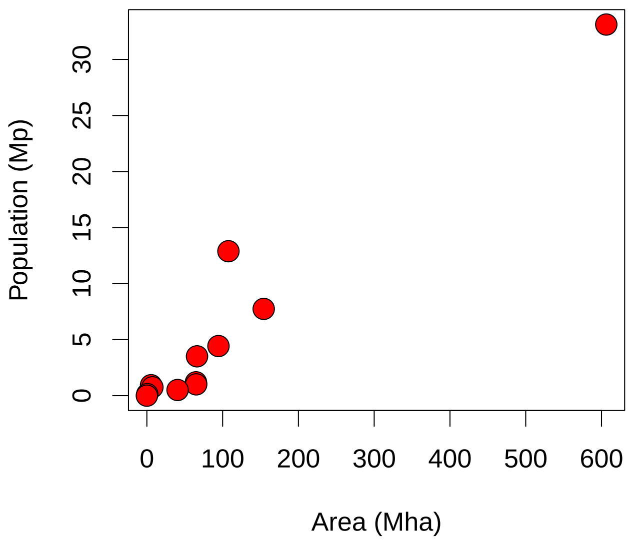
Canadian provinces

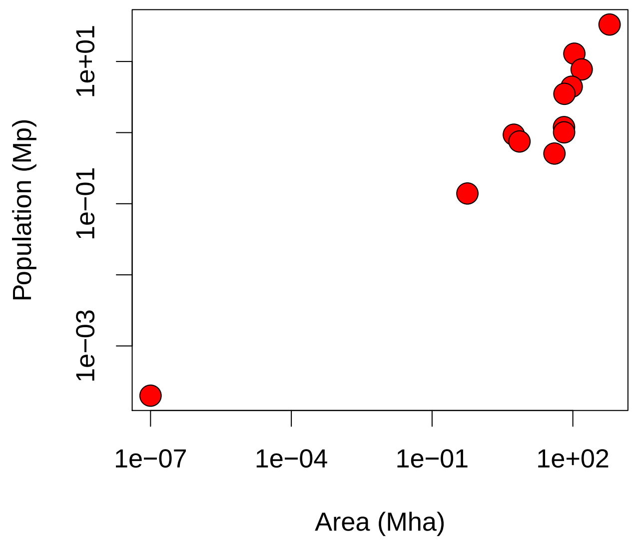


<u>**Answer slide**</u>**:** *Canadian provinces plus Canada*



<u>**Answer slide**</u>**:** *Canada plus room Room 1105*





Predation comparison

- A 300 lb lion is attacking a 600 lb buffalo!
- Poll: This is analogous to a 15 lb red fox attacking: a beaver, an elk
  - A 30 lb beaver (twice as heavy)?
  - A 315 lb elk (300 lbs heavier)?

Different scales

- The log scale and linear scale provide different ways of looking at the same data
- Equally valid
- What are some advantages of each?

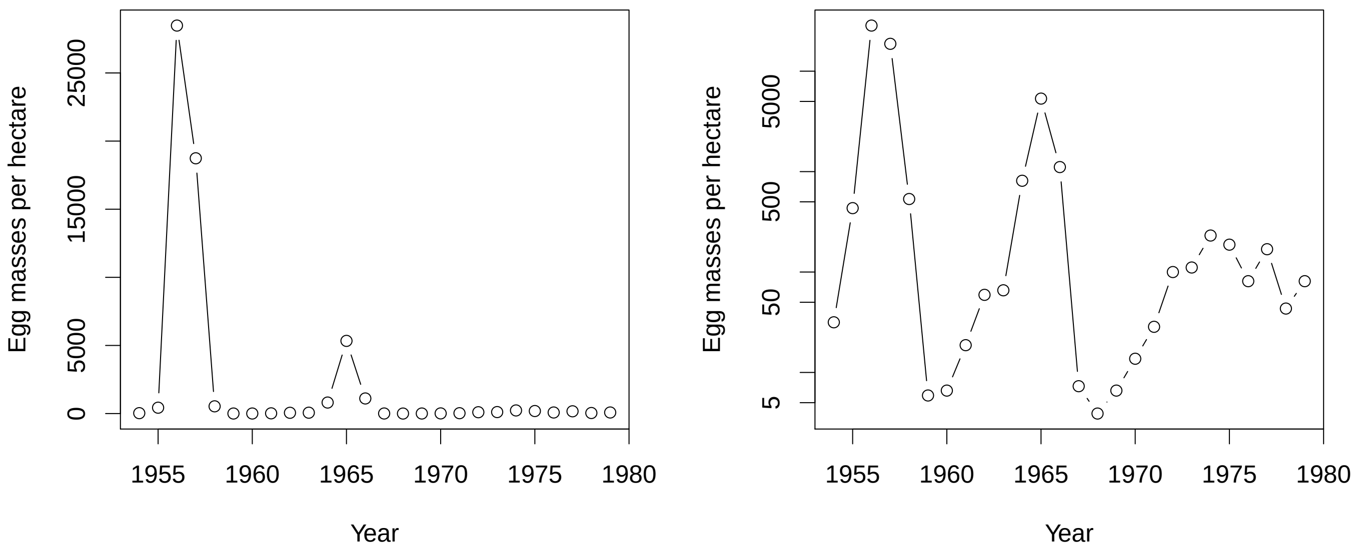
Advantages of arithmetic view

- **Answer:** When there is no natural zero (or the natural zero is irrelevant)
  - **Answer:** Often the case for time or geography
- **Answer:** When zeroes (or negative numbers) can occur
- **Answer:** When we are interested in adding things up

Advantages of geometric view

- **Answer:** When comparing physical quantities, or quantities with natural units
- **Answer:** When comparing proportionally

Gypsy-moth example



Scales in population biology

- The linear scale looks at differences at the population scale
- The log scale looks at differences at the individual scale (per capita)

4.2 Time scales

<u>Comment slide</u>: *Speeding in Taiwan*

- A life experience
- Some clarifications
  - I was reading the sign wrong
  - I didn't actually know how to say speed
  - The whole thing never happened

<u>Comment slide</u>: *Speeding in Taiwan*

- Moral:
  - Units (km is *not* a speed)
  - Exponential decay
- Imagine now that I follow the signs exactly and unrealistically.
- Poll: Do I ever arrive in the (ideal) town of Speed?

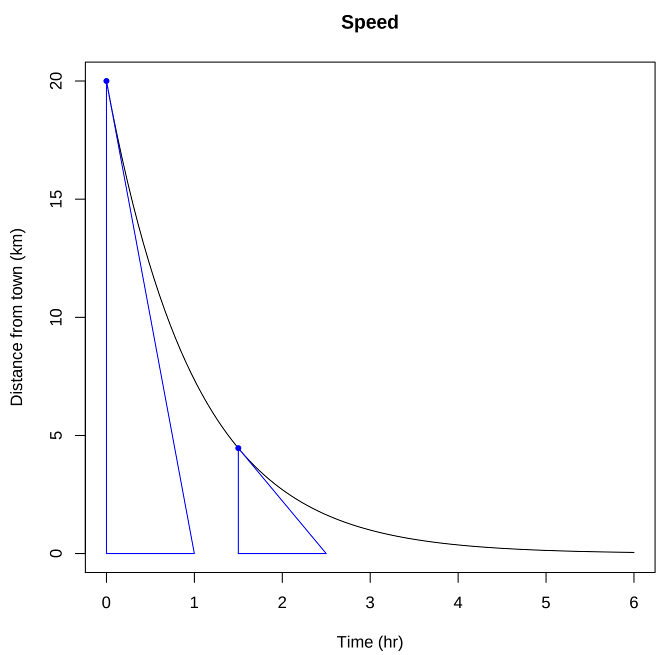
- **Answer:** No. I am always an hour away!
- **Answer:** But I do get extremely close (after several hours)

- Does anyone remember Zeno's paradox?
  - **Answer:** Don't worry about it, then

Characteristic times

- If something is declining exponentially, the rate of change (units [widgets/time]) is always proportional to the size of the thing ([widgets]).
- The constant ratio between the rate of change and the thing that is changing is:
  - the **characteristic time** (something/change), or
  - the **rate of exponential decline** (change/something)
- *Comment:* I'm always 1 hour away from the town of Speed

Answer slide: *Characteristic times*



Bacteriostasis

- What if we add an agent to the tank that makes the birth and death rates nearly zero?
- Now the bacteria are merely washing out at the rate of 0.02/hr
- If we start with 10 bacteria/ml, how many do we have after:
  - Poll: 1 hr?
  - Poll: 1 wk?

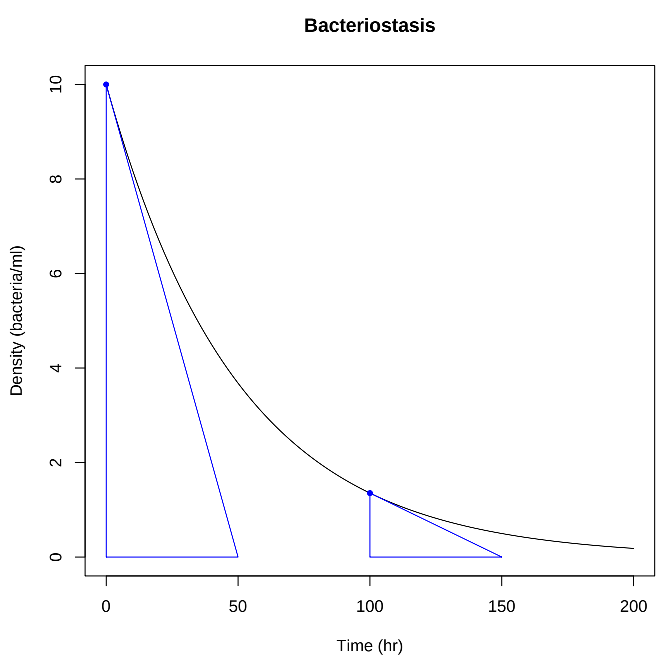
Bacteriostasis answers

- Bacteria wash out at the rate of 0.02/hr
  - **Answer:** This can only make sense with concrete units if we think of it as an instantaneous rate – more soon
  - **Answer:** $N = N_0 exp(-rt)$
- Start with 10 bacteria/ml:
  - **Answer:** After one hour, 9.802 bacteria/ml
  - **Answer:** After one week, 0.347 bacteria/ml

Bacteriostasis analysis

- Rate of exponential decline is $r = 0.02/\,\mathrm{hr}$
- Characteristic time is $T_c = 1/r = 50\,\mathrm{hr}$
- If experiment time $t \ll T_c$, then proportional decline $\approx t/T_c$
- The answer makes sense for short times and for long times
- *Comment:* We will come back to this

Answer slide: *Characteristic times*



Euler's e

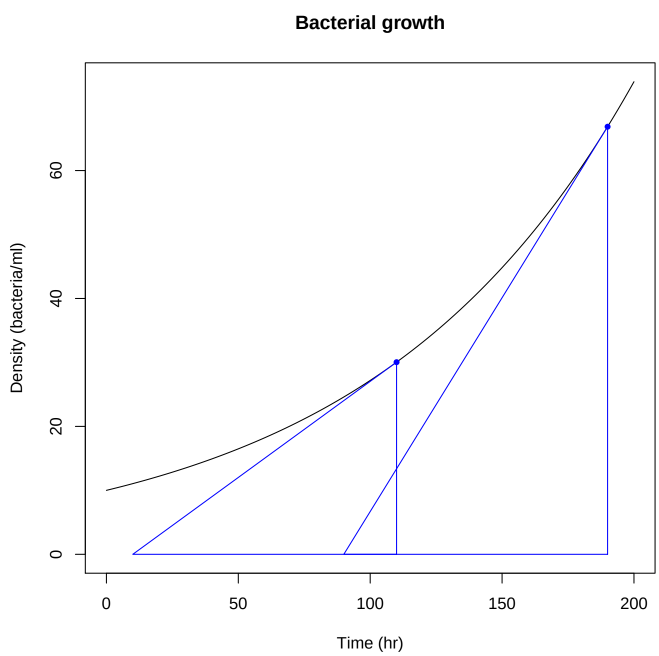
- The reason mathematicians like e is that it makes this link between instantaneous change and long-term behaviour
- If I drive for an hour, how much closer do I get to the ideal town of Speed?
  - **Answer:** e times closer

- e or $1/e$ is the approximate answer to a lot of questions like this one
  - If I compound 1%/year interest for 100 years, how much does my money grow?
  - If two people go deal out two decks of cards simultaneously, what is the probability they will never match cards?
  - If everyone picks up a backpack at random after a test, what's the probability nobody gets the right backpack?

Exponential growth

- We can think about exponential growth the same way as exponential decline:
  - Things are always changing at a rate that would take a fixed amount of time to get (back) to zero
  - This is the characteristic time
  - Exponential growth follows $N = N_0 \exp(rt) = N_0 \exp(t/T_c)$

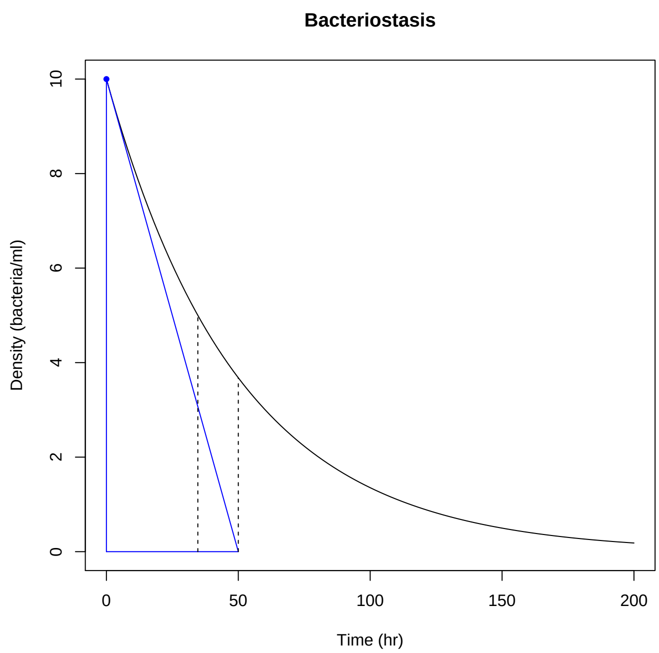
Answer slide: *Characteristic times*



Half life

- Some people prefer to think about half lives.
- Half life is similar to characteristic time, but doesn't have the direct link to the instantaneous change.
  - It takes T_c time to decrease by a factor of e
  - It takes $\log_e(2)T_c \approx 0.69T_c$ to decrease by a factor of 2
  - We can write $T_h = \log_e(2)T_c$
- You should be able to do this calculation
  - $\exp(-rT_h) = 1/2$
  - $-rT_h = log_e(1/2) = -\log_e(2)$
  - $T_h = \log_e(2)/r$
  - $T_h = \log_e(2)T_c$

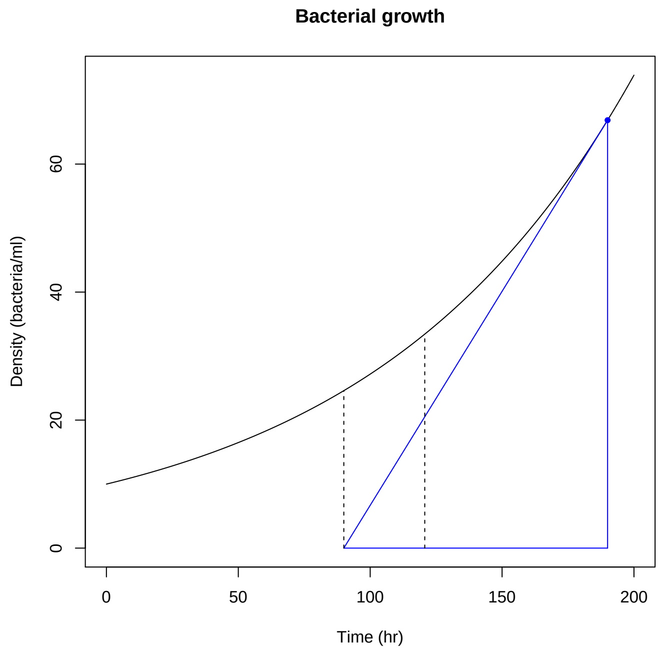
Answer slide: *Characteristic time and half life*



Doubling time

- The doubling time plays the same role for exponential growth as the half life does for exponential decline:
  - $T_h = \log_e(2)T_c$
  - It takes T_c time for a declining population to decrease by a factor of e
  - It takes $\log_e(2)T_c \approx 0.69T_c$ to decrease by a factor of 2
  - We can write $T_h = \log_e(2)T_c$

<u>**Answer slide**</u>**:** *Characteristic time and doubling time*



Summary

- Exponential growth is a specific thing
  - At least in math and science
- Often tied to a specific mechanism
  - <u>**Answer**</u>**:** Individuals growing or declining
  - <u>**Answer**</u>**:** Population behaves in proportion to number of individuals
- Units can help us think clearly
  - or notice our mistakes