

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
- The professor is Jonathan Dushoff
 - Contact via forum on Avenue
 - or email dushoff@mcmaster.ca

Expectations of professor

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

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
- Additional resources will be shared through 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

- Why are you taking this class?

1.2 People

Dushoff

- Loves math
- Lived in four countries
- Studies evolution and spread of infectious diseases
 - HIV, rabies, ebola, influenza, ...
 - <https://mac-theobio.github.io/dushoff.html>
 - https://twitter.com/jd_mathbio

2 Course content

2.1 Learning goals

- Ecology and population ecology
- Quantitative thinking
- Dynamical modeling

Ecology

- What is ecology?
- My answer
 - **Answer:** The study of how organisms interact with each other and with the environment
 - **Answer:** Studying ecology is not the same as protecting the environment
 - * **Answer:** But it can help if you want to protect the environment

Population ecology

- 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

Dynamical modeling

- We use *dynamical models* to link from the individual level to the population level
- 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: <https://bio3ss.github.io/materials/math.handouts.pdf>

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

- 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?
 - Dandelion spreadsheet: <http://tinyurl.com/DandelionModel2026>
- The spreadsheet is an implementation of a dynamical model!

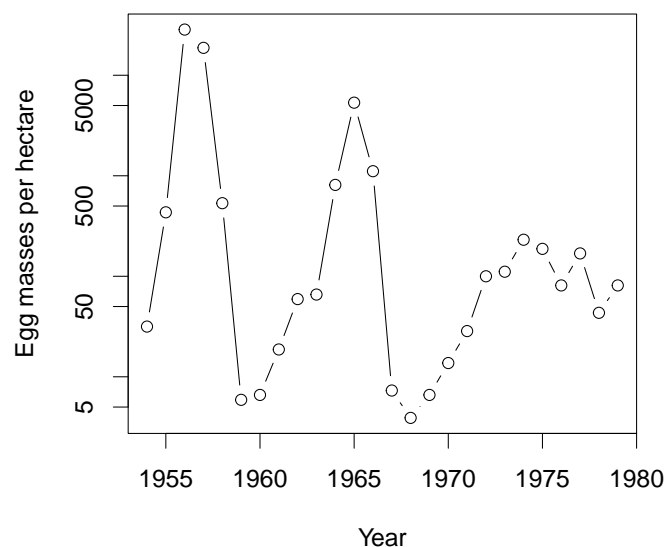
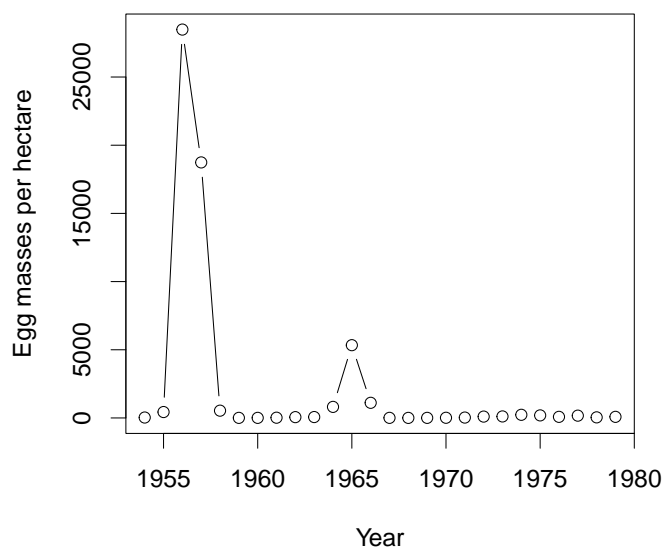
Dynamical models

- 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 6000 years ago
 - **Where did that come from? Right answer is 150 years**
- Capable of wide-scale defoliation

Gypsy moth populations



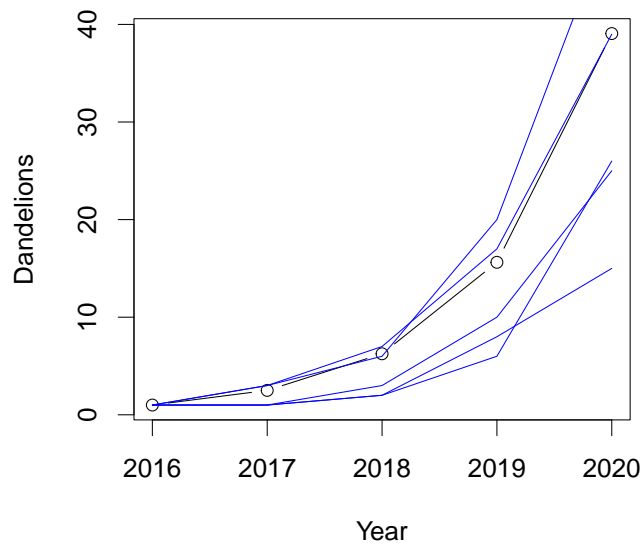
Moth calculation

- 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
 - **Answer:** On average

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
- *Comment:* $N_0 = 1$; $\lambda = 2.5$

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 **instantaneous** (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

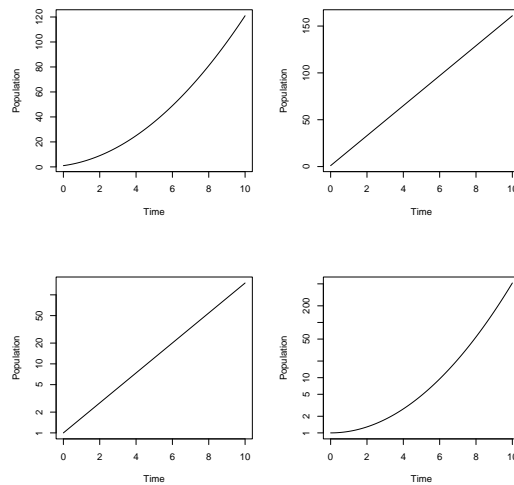
- Imagine we have some bacteria growing in a big tank:
 - They divide (forming two bacteria from one) at a rate of 0.96/day
 - They wash out of the tank at a rate of 0.48/day
 - They die at a rate of 0.24/day
- If we start with 10 bacteria/ml, how many do we have after 1 day?

Units

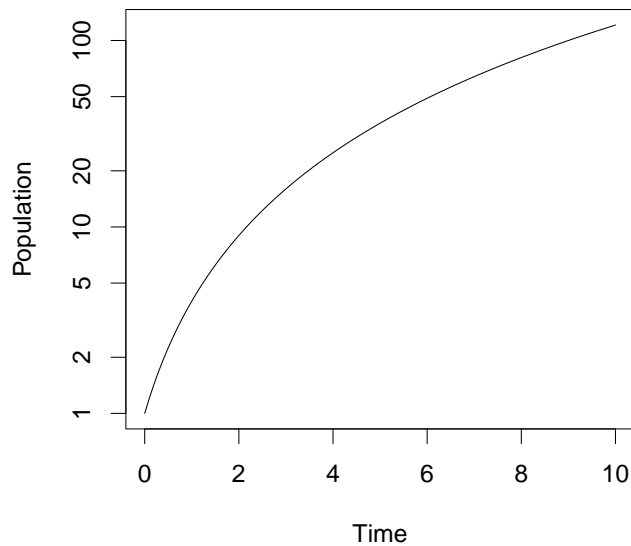
- When we attach units to a quantity, the meaning is concrete
 - 0.24/day *must* mean exactly the same thing as 0.01/hr
 - The two questions above *must* have the same answer

4 Exponential growth

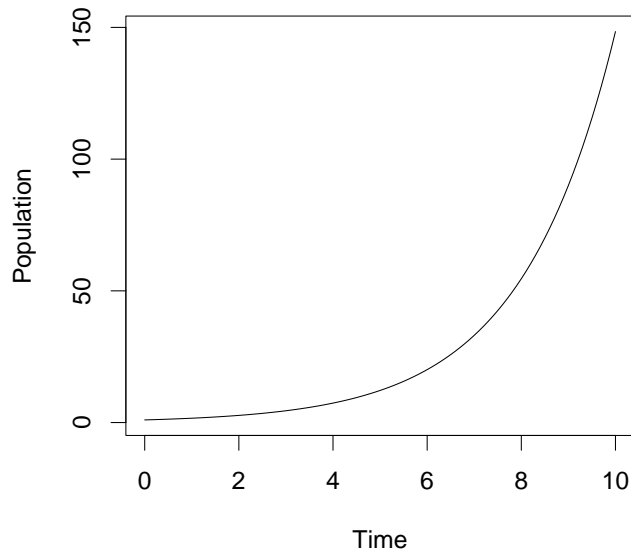
- What is exponential growth?
- Which of these is an example?



Answer slide: *A on the log scale*



Answer slide: *C on the linear scale*



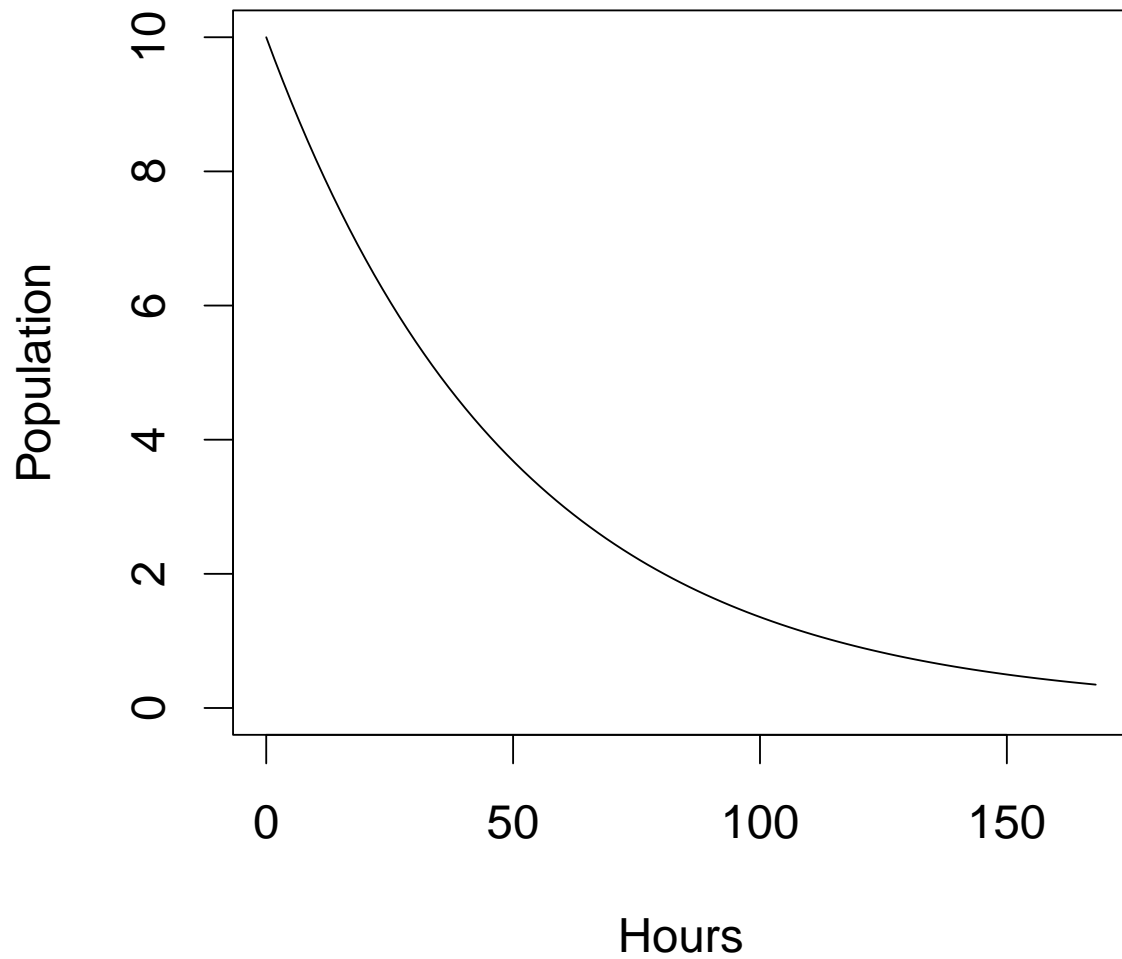
Types of growth

- 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?

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

Answer slide: *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

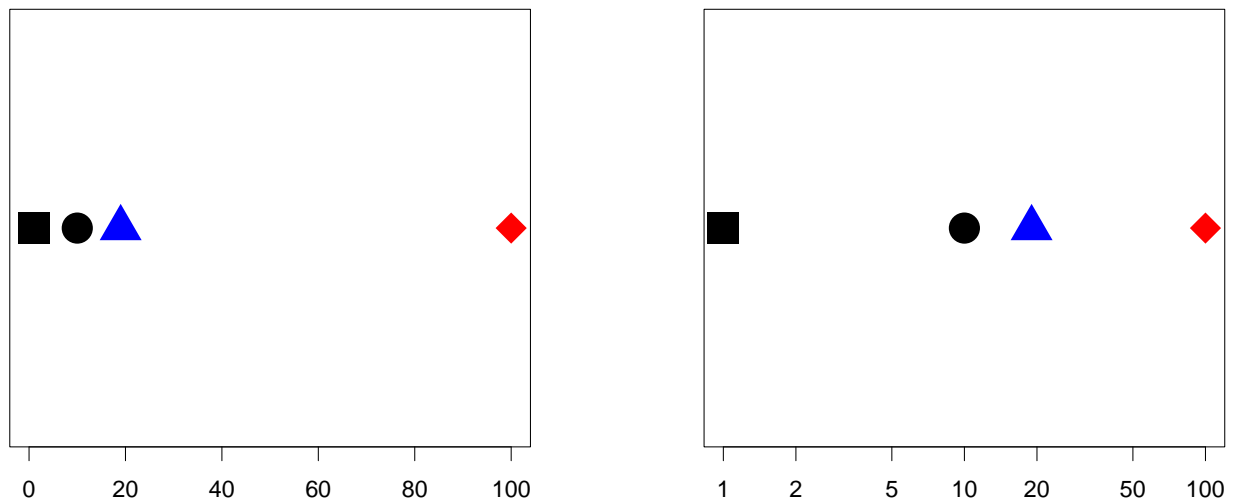
- Based on:
 - Answer: discrete vs. continuous time
- We won't worry much about this.

4.1 Log and linear scales

Scales of comparison

- 1 is to 10 as 10 is to what?
 - Answer: If you said 100, you are thinking multiplicatively
 - Answer: If you said 19, you are thinking additively

Scales of display

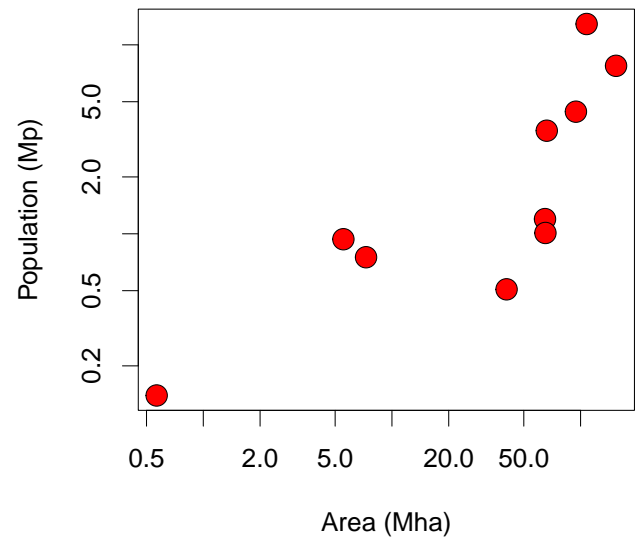
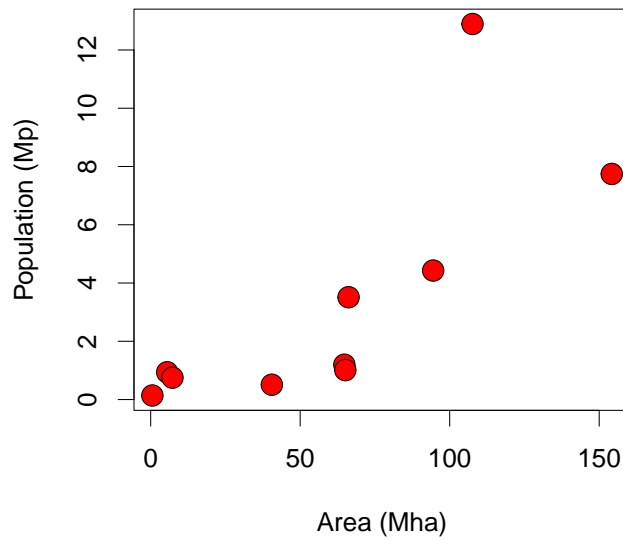


There is only one log scale; it doesn't matter which base you use!

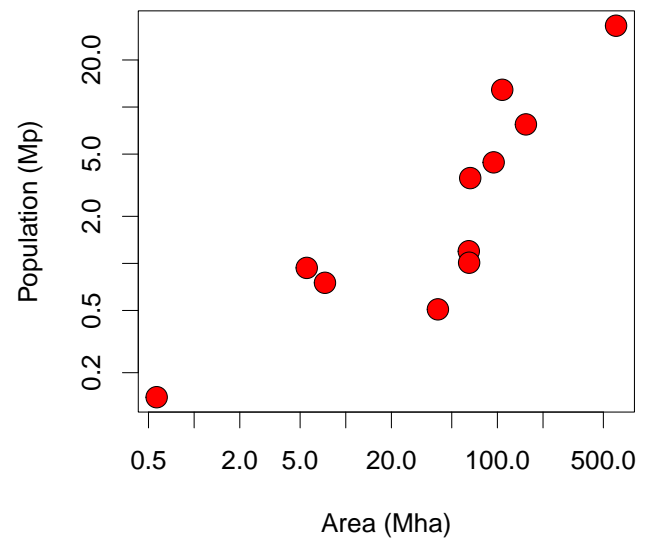
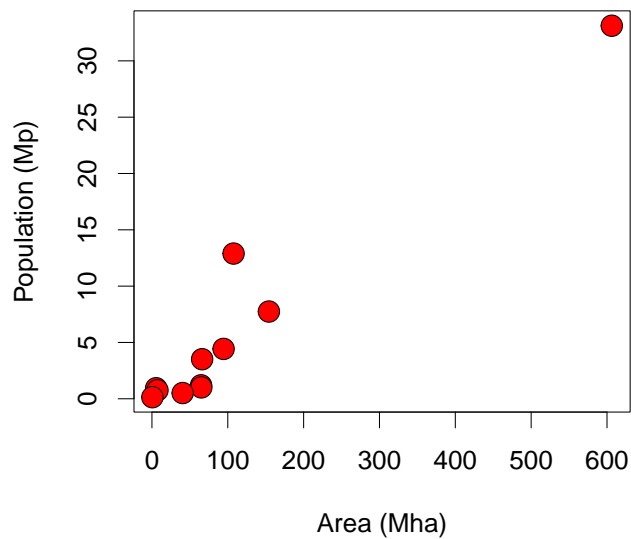
Canadian provinces

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

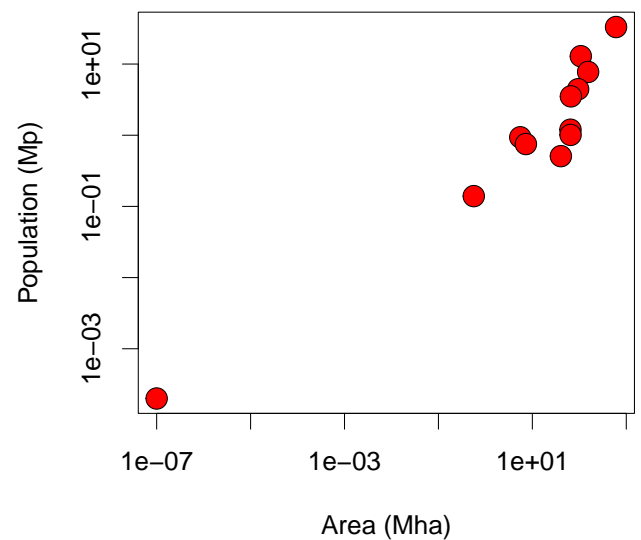
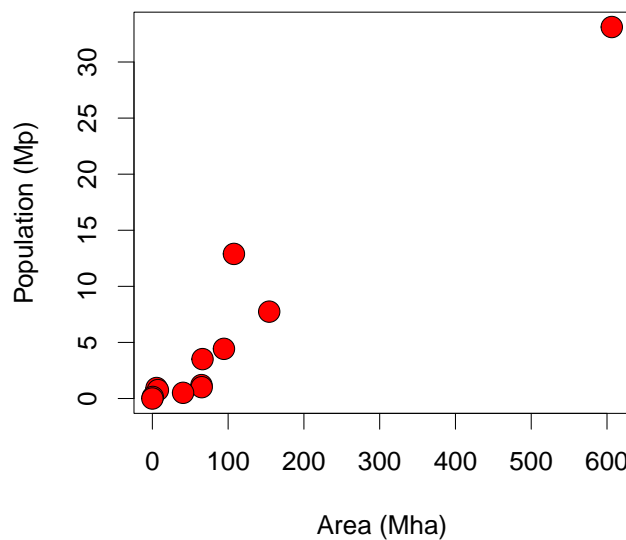
Canadian provinces



Answer slide: *Canadian provinces plus Canada*



Answer slide: *Canada plus this classroom*



Predation comparison

- A 300 lb lion is attacking a 600 lb buffalo!
- 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?

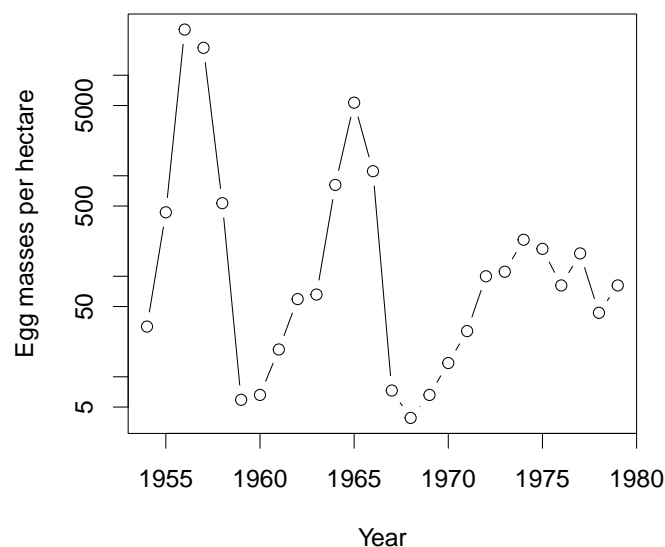
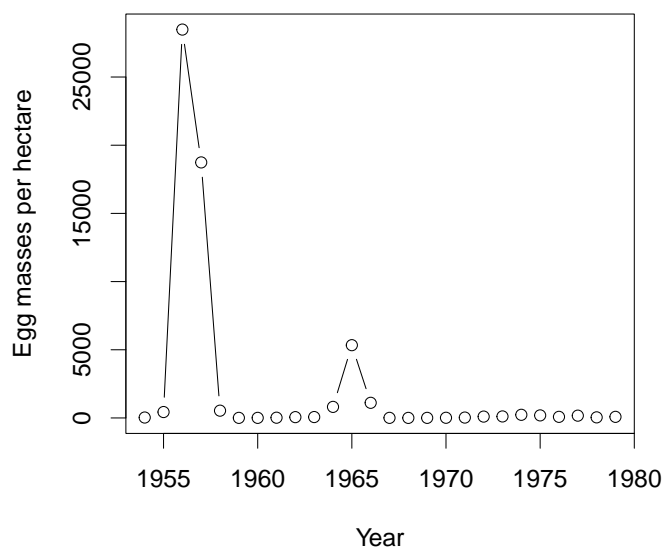
Advantages of arithmetic view

- 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

Comment slide: *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

Comment slide: *Speeding in Taiwan*

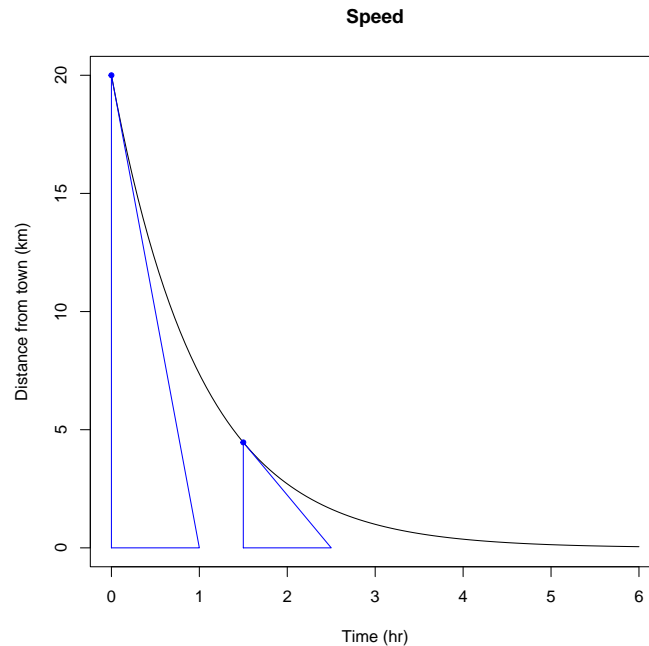
- Moral:
 - Units (km is *not* a speed)
 - Exponential decay
- Imagine now that I follow the signs exactly and unrealistically.
- Do I ever arrive in the (ideal) town of Speed?

- **Answer:** No. I am always an hour away!
- **Answer:** But I do get extremely close (in terms of distance)

Characteristic times

- Characteristic time is the *ratio* between the thing that is changing (units [widgets]) and the rate of change ([widgets/time]).
 - **Answer:** Units are [time]
- Exponential change is when the characteristic time stays constant:
 - I'm always 1 hour away from the town of Speed
 - So I'm approaching it exponentially

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:
 - 1 hr?
 - 1 wk?

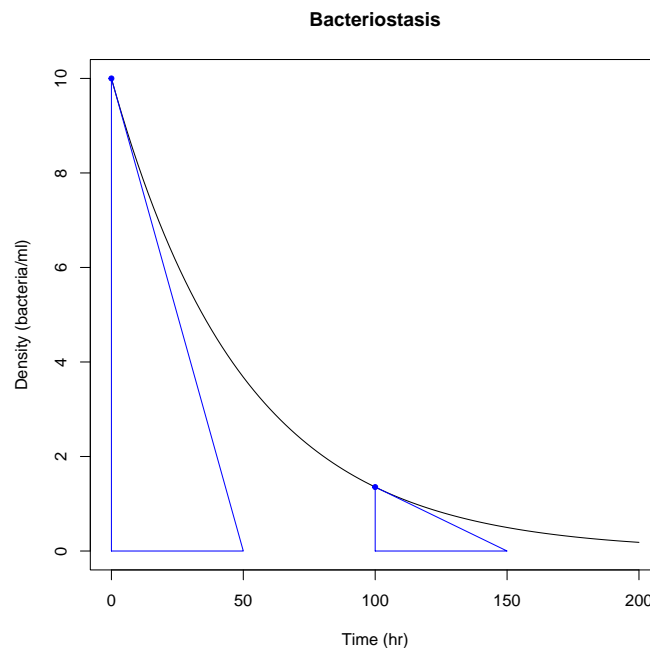
Bacteriostasis answers

- Bacteria wash out at the rate of 0.02/hr
 - Answer: This is the **rate of exponential decline**
 - 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 $r = 0.02/\text{hr}$
- Characteristic time is $T_c = 1/r = 50 \text{ hr}$
- It is useful to think about time scales in exponential change by *comparing* elapsed time to characteristic time
 - 1 hour is short (almost linear decline)
 - 1 week is long (many exponential changes)

Answer slide: *Characteristic times*



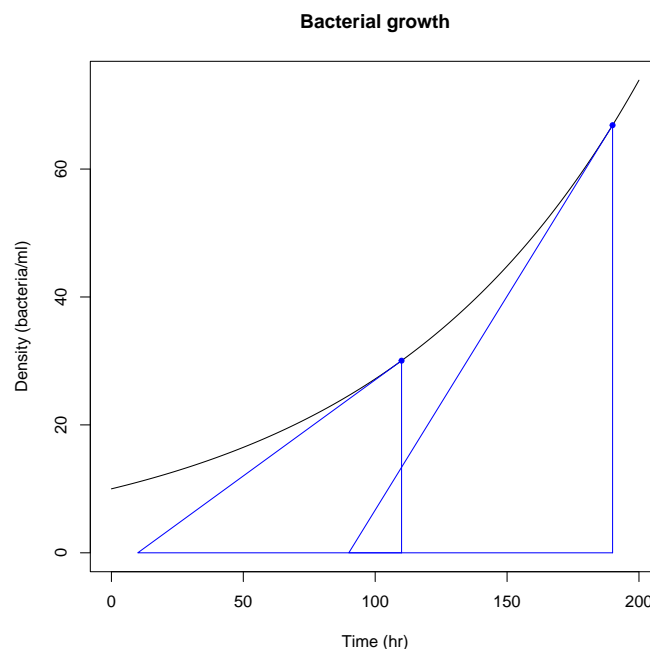
Euler's e

- 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 $N = N_0 \exp(rt) = N_0 \exp(t/T_c)$

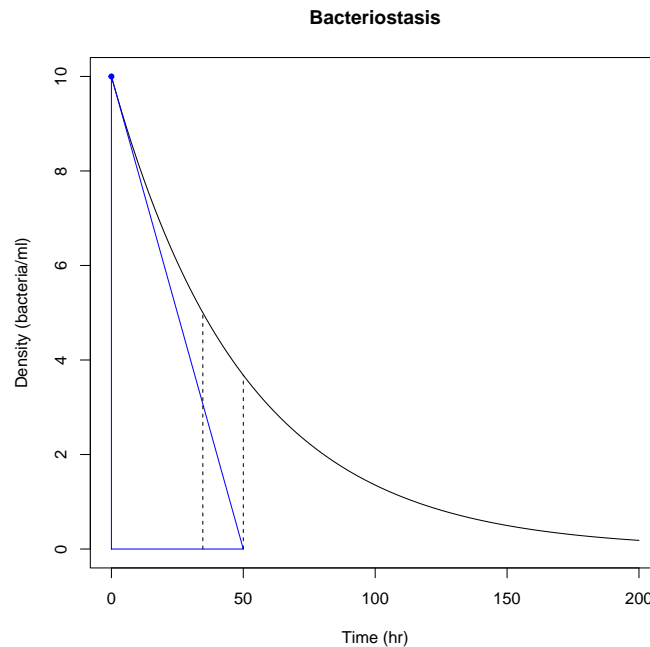
Answer slide: *Characteristic times*



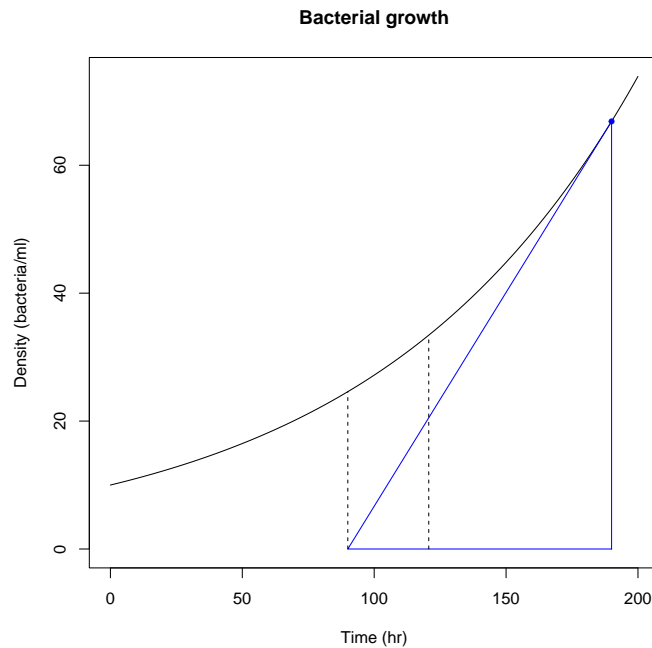
Half life and doubling time

- The characteristic time is how long it takes to change by a factor of e
 - Direct link to rate of instantaneous change.
- Half life (or doubling time) is how long to change (down or up) by a factor of 2
 - If it takes T_c time to change by a factor of e
 - It takes $\log_e(2)T_c \approx 0.69T_c$ to change by a factor of 2
- 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*



Answer slide: *Characteristic time and doubling time*



Summary

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