

# Formulas

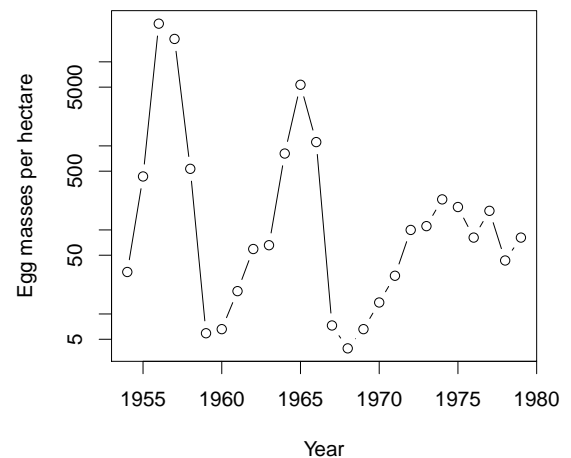
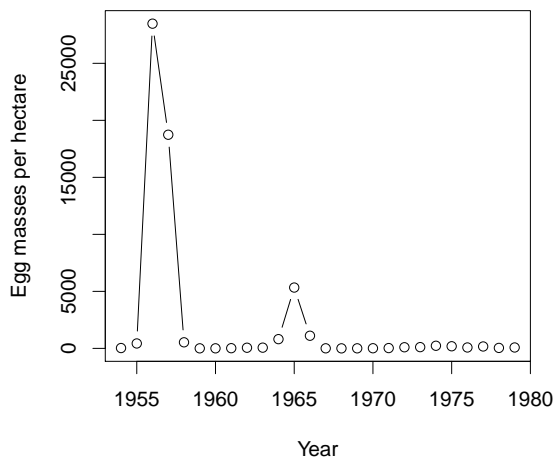
*discrete time growth:*

- $N_T = N_0 \lambda^T$
- $\lambda = f + p$
- $\mathcal{R} = f/(1 - p)$

*continuous time growth:*

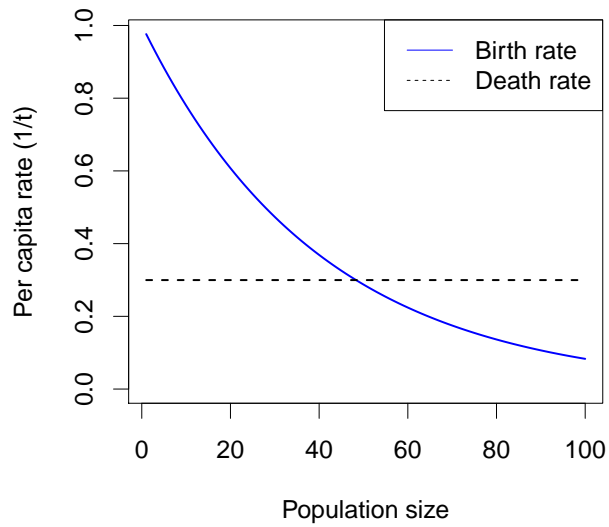
- $N(t) = N(0) \exp(rt)$
- $r = b - d$
- $\mathcal{R} = b/d$

1. Compared to the instantaneous rate 0.05/hr, the instantaneous rate 1.2/day:
  - A. Means exactly the same thing
  - B. Is not directly comparable, because they refer to different time steps
  - C. Is comparable, and refers to a larger (faster) rate
  - D. Is comparable, and refers to a smaller (slower) rate

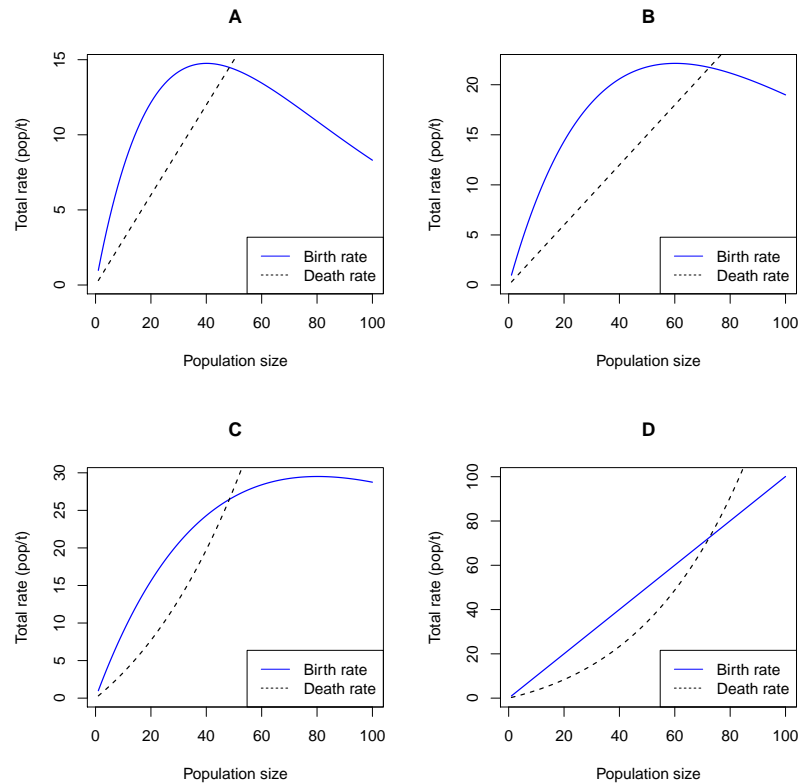


2. The picture above on the \_\_\_\_\_ shows population on a log scale. Compared to the other picture, it shows \_\_\_\_\_.
  - A. left; individual density instead of total density
  - B. left; the same numbers, but from a different perspective
  - C. right; individual density instead of total density
  - D. right; the same numbers, but from a different perspective

Use the picture below for the next three questions. It shows the assumptions made for a continuous-time birth-death model.



3. Which of the four pictures below could be generated by the same model as the picture above?



4. The model illustrated above predicts that the population will *decrease* when the population is:

- A. very small or very large
- B. very small (only)
- C. very large (only)
- D. between the two equilibria
- E. at the nonzero equilibrium

5. The highest *per capita* net growth rate ( $r$ ) in this model is seen when the population is:

- A. Near the zero equilibrium
- B. between the two equilibria
- C. Near the non-zero equilibrium
- D. very large

6. Which of the following best illustrates resource *depletion* as opposed to simple competition?

- A. Swallows using up all of the available holes in a cliff site for breeding so that no space is left
- B. Trees in a forest canopy growing so close together that no light gets through to the lower level
- C. Introduced desert weeds using rainwater so efficiently that trees in the area have no access to water
- D. Gypsy moths eating so many oak leaves that the trees die

7. Populations are *regulated* (kept under control) when their growth rate tends to \_\_\_\_\_ when the population \_\_\_\_\_.

- A. decrease; has been established for a long time
- B. decrease; becomes larger
- C. increase; has been established for a long time
- D. increase; becomes larger

Use this information for the next two questions. A researcher estimates that a moth population has a density of 10 pupae/ha in 2012, and finite rate of growth  $\lambda = 1.4$  (associated with a time step of one year). The sex ratio of the population is 2:1 (twice as many females as males at each stage).

8. If  $\lambda$  remains constant, what is the approximate density of pupae she will expect to see in 2020?

- A. 14 pupae/ha
- B. 27 pupae/ha
- C. 54 pupae/ha
- D. 74 pupae/ha
- E. 148 pupae/ha

9. What value of the instantaneous growth rate  $r$  corresponds to the finite growth model described in the question above?

- A. 0.34/yr
- B. 0.34 yr
- C. 1.4/yr
- D. 1.4 yr
- E. There is not enough information to tell

10. Cycling is most likely in a population where competition \_\_\_\_\_ depletion and acts \_\_\_\_\_ a delay.

- A. leads to; without
- B. does not lead to; without
- C. leads to; with
- D. does not lead to; with

*Use this information for the next four questions.* A reintroduced population of wolves, starting with 20 individuals in year 0, is growing continuously at a rate of 5%/year.

11. The characteristic time of exponential growth/decline for this population is

- A. 5 years
- B. 20 years
- C. 5 per year
- D. 20 per year

12. The doubling time of this population is

- A. Equal to the characteristic time
- B. The inverse of the characteristic time
- C. Shorter than the characteristic time
- D. Longer than the characteristic time
- E. Not enough information to answer

13. If the wolf population continues to grow exponentially, approximately when will it reach 200 individuals?

- A. 20 years
- B. 46 years
- C. 66 years
- D. 100 years
- E. Never

14. An ecologist wants to model this population with a discrete-time generation-based model, using a time step  $\Delta t = 4\text{yr}$ . Which of these is closest to the value of  $\lambda$  she should use to match the assumptions above?

- A. 1.05
- B. 1.20
- C. 1.21
- D. 1.22
- E. There is not enough information to answer this question

15. Which of the following is *not* a possible scenario for density-dependent population regulation?

- A. The birth rate decreases with density and the death rate increases
- B. The birth rate and death rate both increase, but the death rate increases faster
- C. The birth rate and death rate both decrease, but the birth rate decreases faster
- D. The death rate decreases with density and the birth rate increases

16. An ecologist believes that a population's fecundity decreases when crowded following the equation  $f(N) = (N/N_e)^\alpha$ . If  $N$  is measured in units of indiv/ha, then:

- A.  $N_e$  and  $\alpha$  are also in [indiv/ha]
- B.  $N_e$  is unitless, and  $\alpha$  is in [indiv/ha]
- C.  $N_e$  is in [indiv/ha], and  $\alpha$  is unitless
- D.  $N_e$  and  $\alpha$  are both unitless

17. A pile of radioactive material is decaying *continuously* at an instantaneous rate of 1% per minute. After two *hours*, what proportion is left?

- A. A little more than 98%
- B. Exactly 98%
- C. A little less than 98%
- D. About 30%
- E. None

Answer questions on this page *in pen*. *Briefly* show necessary work and equations. Points may be *deducted* for wrong information, even when the correct information is also there.

**18.** (4 points). A pack of marmots invades a previously vacant mountaintop. In 60 years, the population increases from 5 marmots to 1200 marmots. The instantaneous birth rate of the population is 0.5/yr. The average sex ratio is 3 females for every 2 males. For the purposes of this question, you can assume the population is growing exponentially, on average.

- a) Draw a plot showing the size of this population through time. Label and number your axes and say whether you are using log or linear scales
- b) What are the instantaneous growth rate of the population,  $r$ , and the instantaneous death rate,  $d$ ?

- c) What is the lifetime reproductive number  $\mathcal{R}$ ?

- d) If we were to model this population with discrete time steps of  $4$  years, what would be the finite growth rate  $\lambda$ ?

**19.** (4 points) Consider a population of antelopes that experiences an Allee effect and regulation.

a) Draw a plot of the *total* birth and death rates for the population. Show both lines on the same graph, using different line types to indicate birth and death. Label the lines directly or add a legend to the plot.

b) Indicate any equilibria on your plot, and say whether they are stable or unstable

c) Does the graph you've drawn represent a strong or a weak Allee effect? Explain why.

d) Give one plausible ecological reason that the Allee effect might occur.