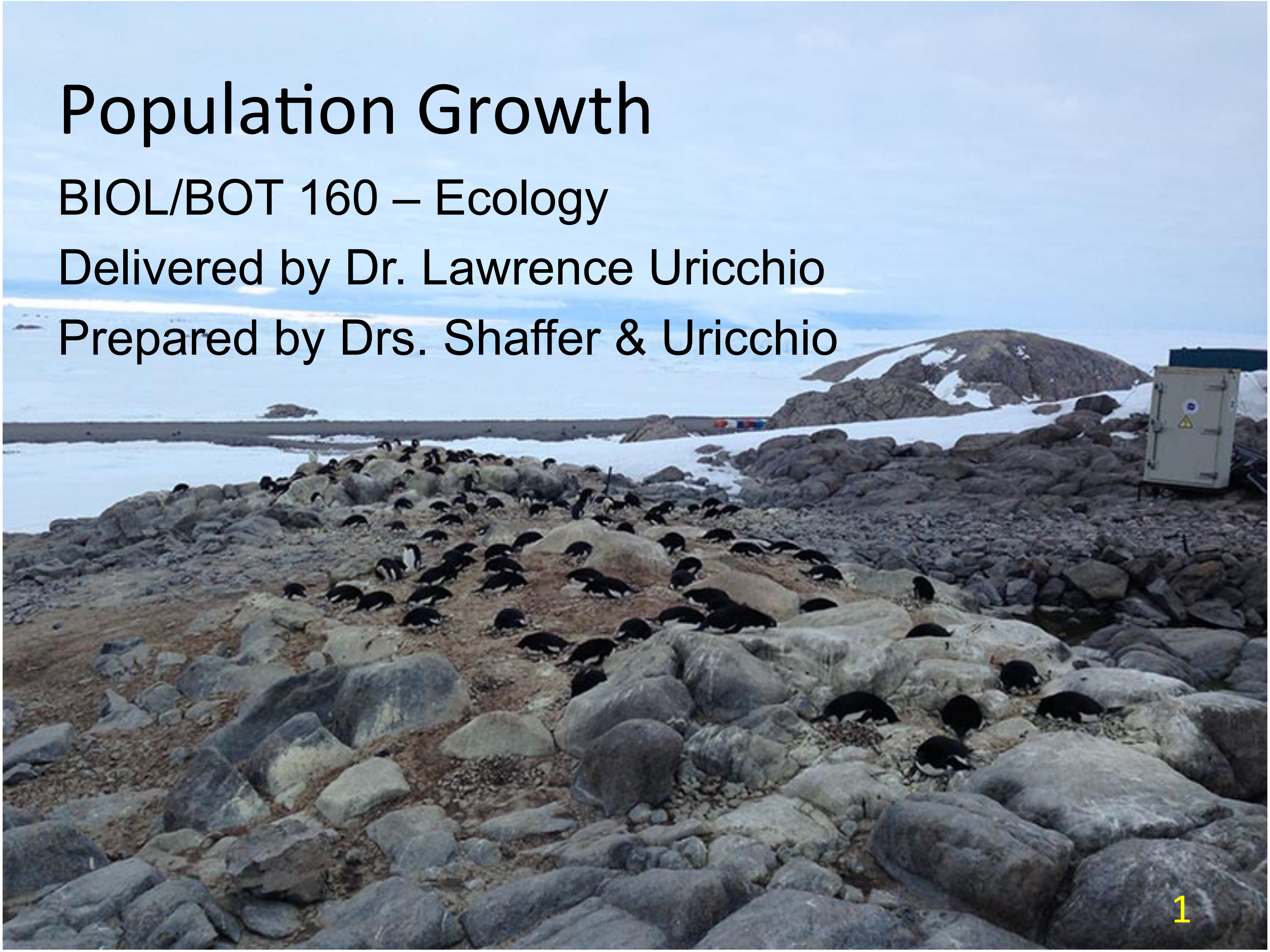


Population Growth

BIOL/BOT 160 – Ecology

Delivered by Dr. Lawrence Uricchio

Prepared by Drs. Shaffer & Uricchio

Midterm

- First midterm: one week from today (9/21)

- In addition to Professor Shaffer's normal office hours, I will hold a two-hour Q&A session on the morning of 9/20 (exact time TBD – will be in DH 547/548)

Recap from last session

- Populations are groups of *intrabreeding* individuals of the same species in the same location at the same time
- A metapopulation is a population of populations
- As population ecologists, we hope to understand the processes that control population size (*N*)
- We may seek to understand other characteristics of populations, such as
  - distribution in space and time
  - density
  - age structure

Learning objectives

- Students should be able to:
  - Calculate population growth rates from life tables/natality tables
  - Analyze life/natality tables to draw conclusions about survivorship & life history within populations
  - Explain the difference between exponential and logistic growth, and their relevance to determining population sizes
  - Understand how density dependent processes may impact population sizes and growth rates over time

Goal: make quantitative predictions about population sizes over time

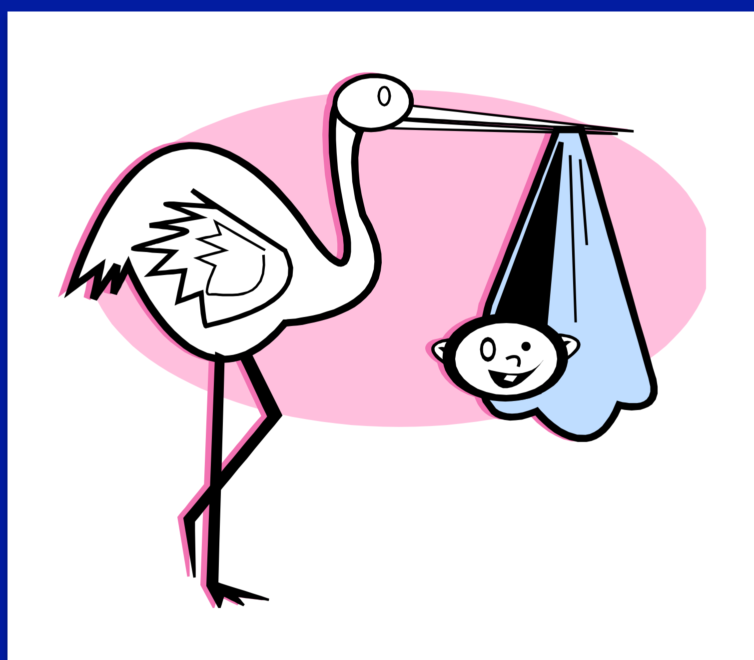
$$dN = [B + I] - [D + E]$$

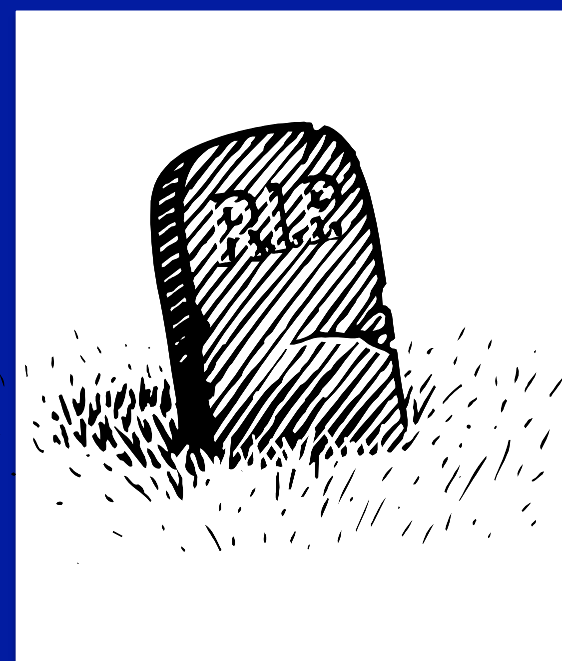
- *N* is population size
- *dN* is the change in population size
- *B* is births
- *I* is immigration
- *D* is deaths
- *E* is emigration

Let’s make some data-driven models!

First lets only consider:

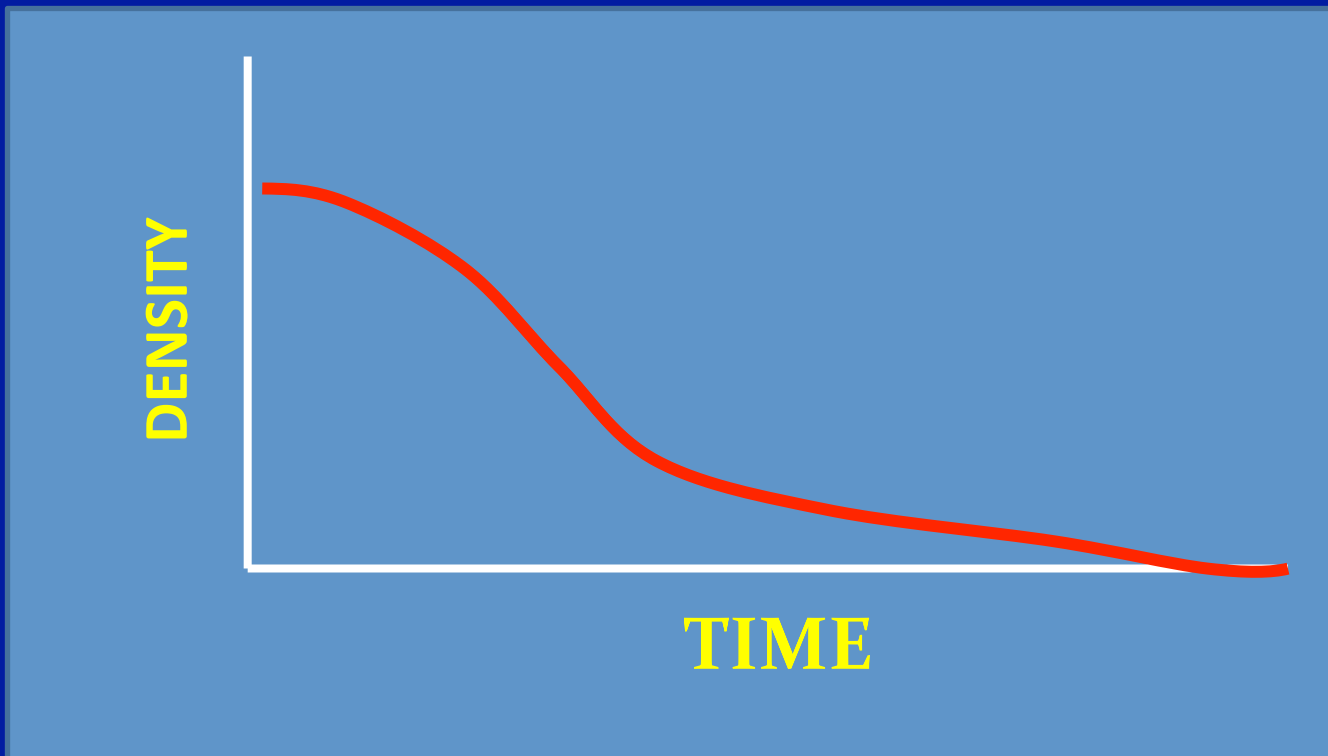
- *D* (deaths, which relate to survivorship)
- *B* (births, which relate to fecundity)





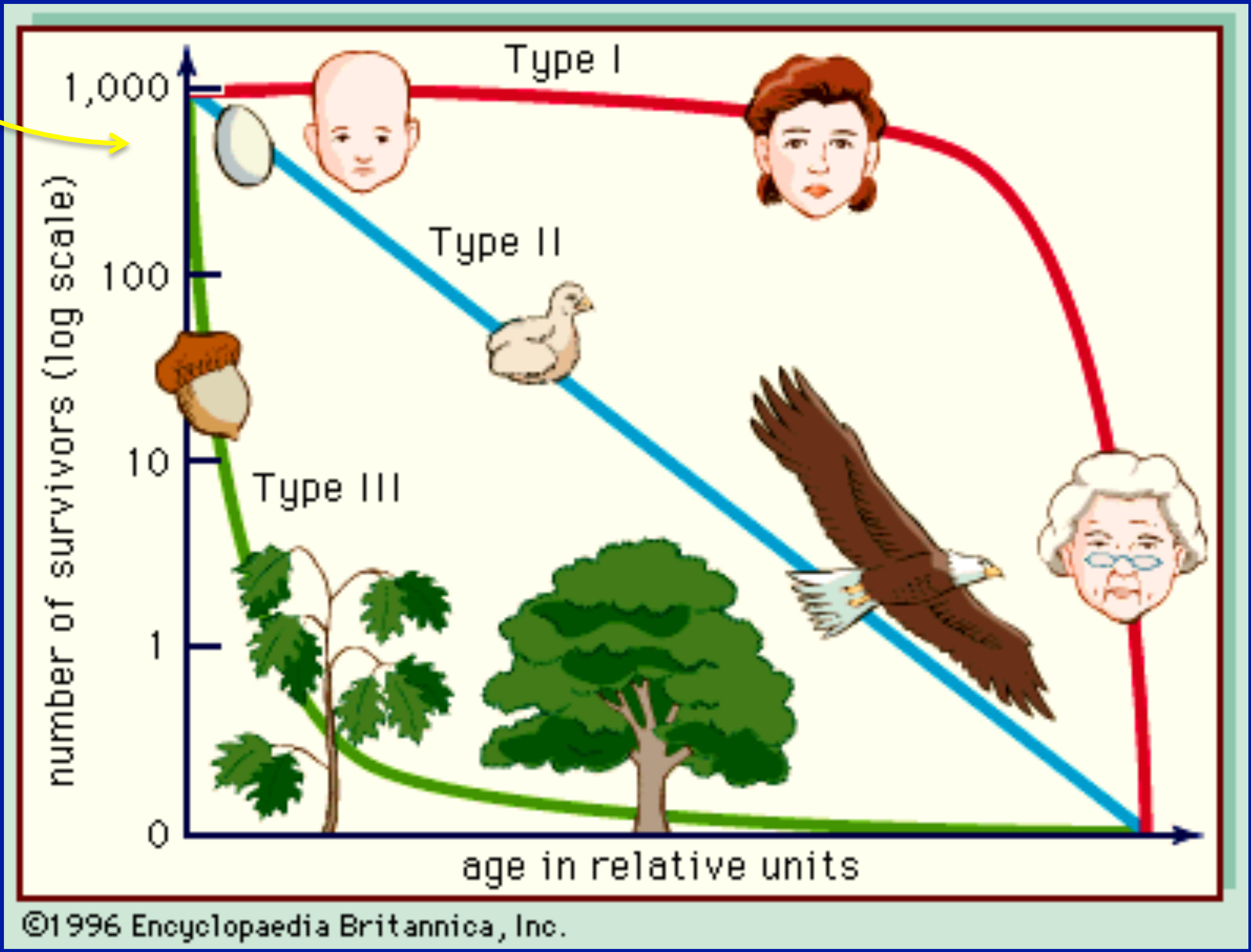
Survivorship

Follow number of survivors of a single cohort (i.e., a group of individuals all born around the same time) through time



Note: log scale

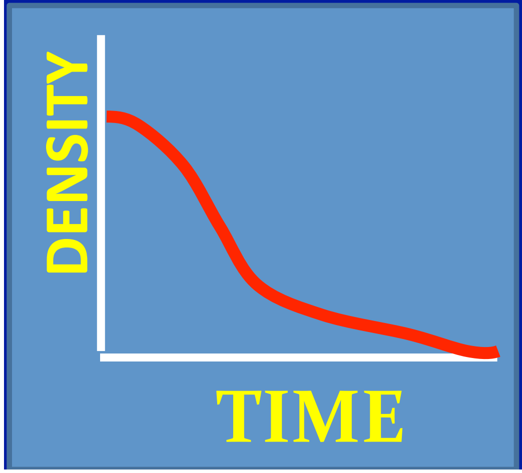
Survivorship Curves



Survivorship data: life table

Year | Number of Individuals

x	N_x	l_x	d_x
0	1000		
1	900		
2	600		
3	300		
4	100		
5	0		



Survivorship data: life table

$$l_x = \frac{N_x}{N_0}$$

Year	Number of Individuals	Proportion surviving	Number dying
x	N_x	l_x	d_x
0	1000	1.00	
1	900	0.9 =900/1000	
2	600	0.6 =600/1000	
3	300	0.3	
4	100	0.1	
5	0	0	

Survivorship data: life table

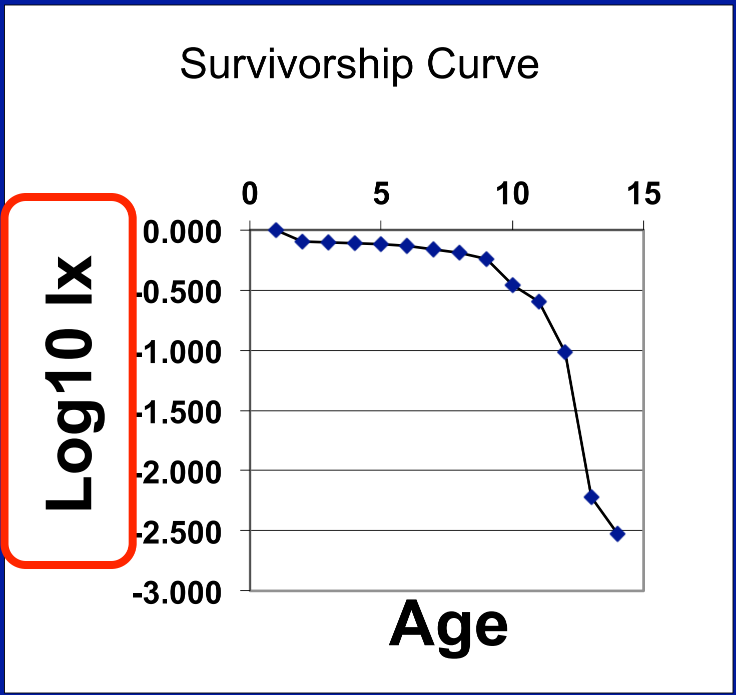
$$d_x = N_x - N_{x+1}$$

Year | Number of Individuals | Number dying

x	N_x	l_x	d_x	
0	1000	1.00	100	=1000-900
1	900	0.9	300	=900-600
2	600	0.6	300	
3	300	0.3	200	
4	100	0.1	100	
5	0	0	0	

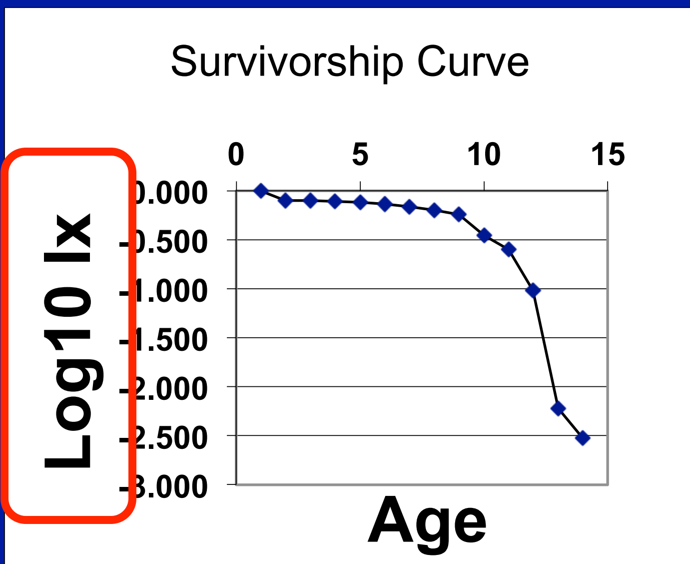
Dall Sheep

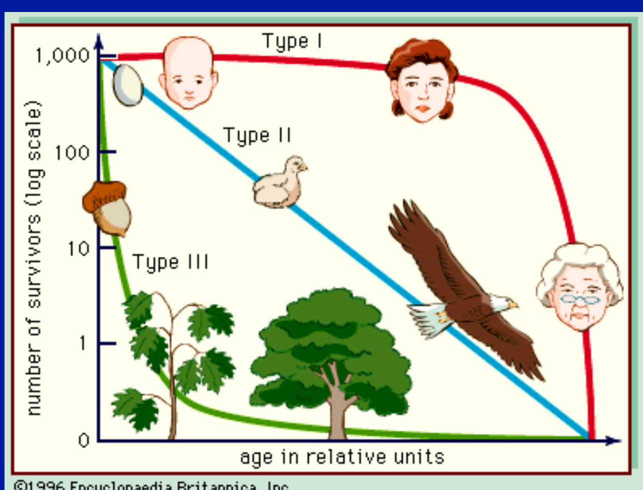
Dall Sheep



x	N_x	l_x	d_x	q_x
0	1000	1.000	199	0.199
1	801	0.801	12	0.015
2	789	0.789	13	0.016
3	776	0.776	12	0.015
4	764	0.764	30	0.039
5	734	0.734	46	0.063
6	688	0.688	48	0.070
7	640	0.640	69	0.108
8	571	0.571	132	0.231
9	349	0.349	187	0.536
10	252	0.252	136	0.540
11	96	0.096	90	0.938
12	6	0.006	3	0.500
13	3	0.003	3	1.000

Dall Sheep

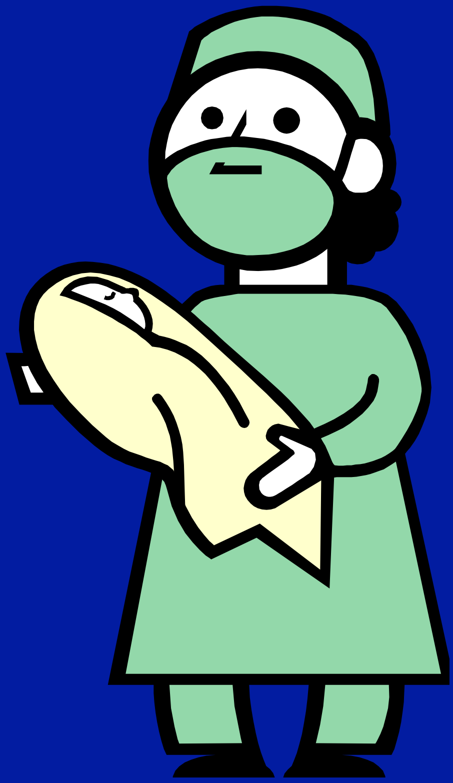




x	N_x	l_x	d_x	q_x
0	1000	1.000	199	0.199
1	801	0.801	12	0.015
2	789	0.789	13	0.016
3	776	0.776	12	0.015
4	764	0.764	30	0.039
7	640	0.640	69	0.108
8	571	0.571	132	0.231
9	349	0.349	187	0.536
10	252	0.252	136	0.540
11	96	0.096	90	0.938
12	6	0.006	3	0.500
13	3	0.003	3	1.000

Conclude Type 1

Now let's look at



Fecundity

- Reproductive output of an individual
- Will be summarized in a natality table

Natality Table

		Number of births per individual	Proportion of new individuals
x	l_x	m_x	$l_x m_x$
0	1.00	0	0
1	0.90	0.3	0.27
2	0.60	0.5	0.30
3	0.30	0.1	0.03
4	0.10	0	0
5	0	0	0

X=2

$$l_2 m_2 = l_2 * m_2$$

$$= 0.60 * 0.5$$

Natality Table – Compute Net Reproductive Value (R_0)

- Growth rate for a populations

$$R_0 = 0.60$$

x	l_x	m_x	$l_x m_x$
0	1.00	0	0
1	0.90	0.3	0.27
2	0.60	0.5	0.30
3	0.30	0.1	0.03
4	0.10	0	0
5	0	0	0
		TOTAL	0.60

What does R_0 tell you?

If $R_0 > 1$ • Population increasing

If $R_0 = 1$ • **Population not changing**

If $R_0 < 1$ • **Population decreasing**

What is happening with this population?

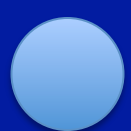
- Growth rate for a populations

$$R_0 = 0.60$$

x	l_x	m_x	$l_x m_x$
0	1.00	0	0
1	0.90	0.3	0.27
2	0.60	0.5	0.30
3	0.30	0.1	0.03
4	0.10	0	0
5	0	0	0
		TOTAL	0.60

Now lets make a *model*

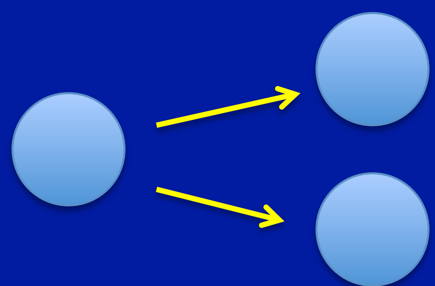
- Suppose that $R_0 = 2$
- This implies that each individual is replaced by 2 more individuals



$t = 0$

Now lets make a *model*

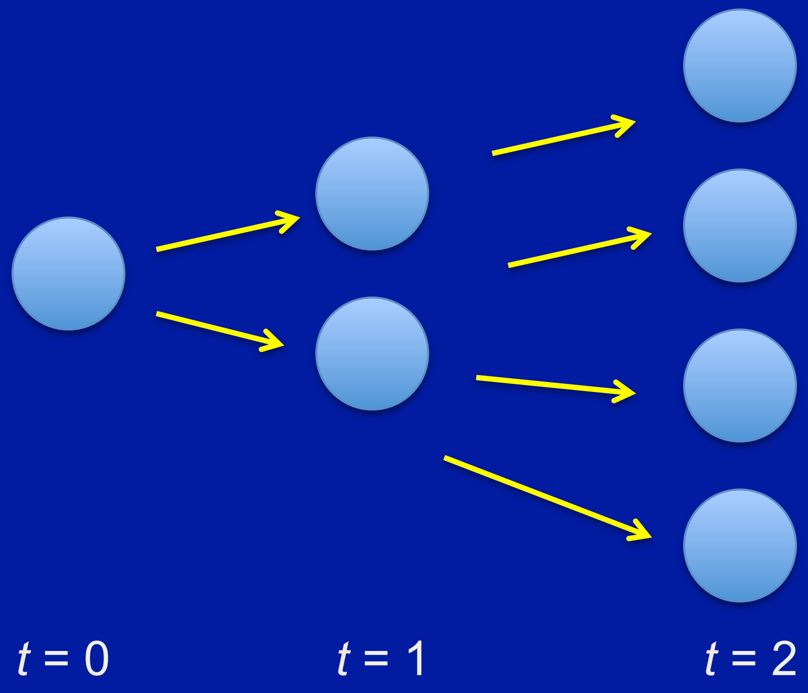
- Suppose that $R_0 = 2$
- This implies that each individual is replaced by 2 more individuals



$t = 0$ $t = 1$

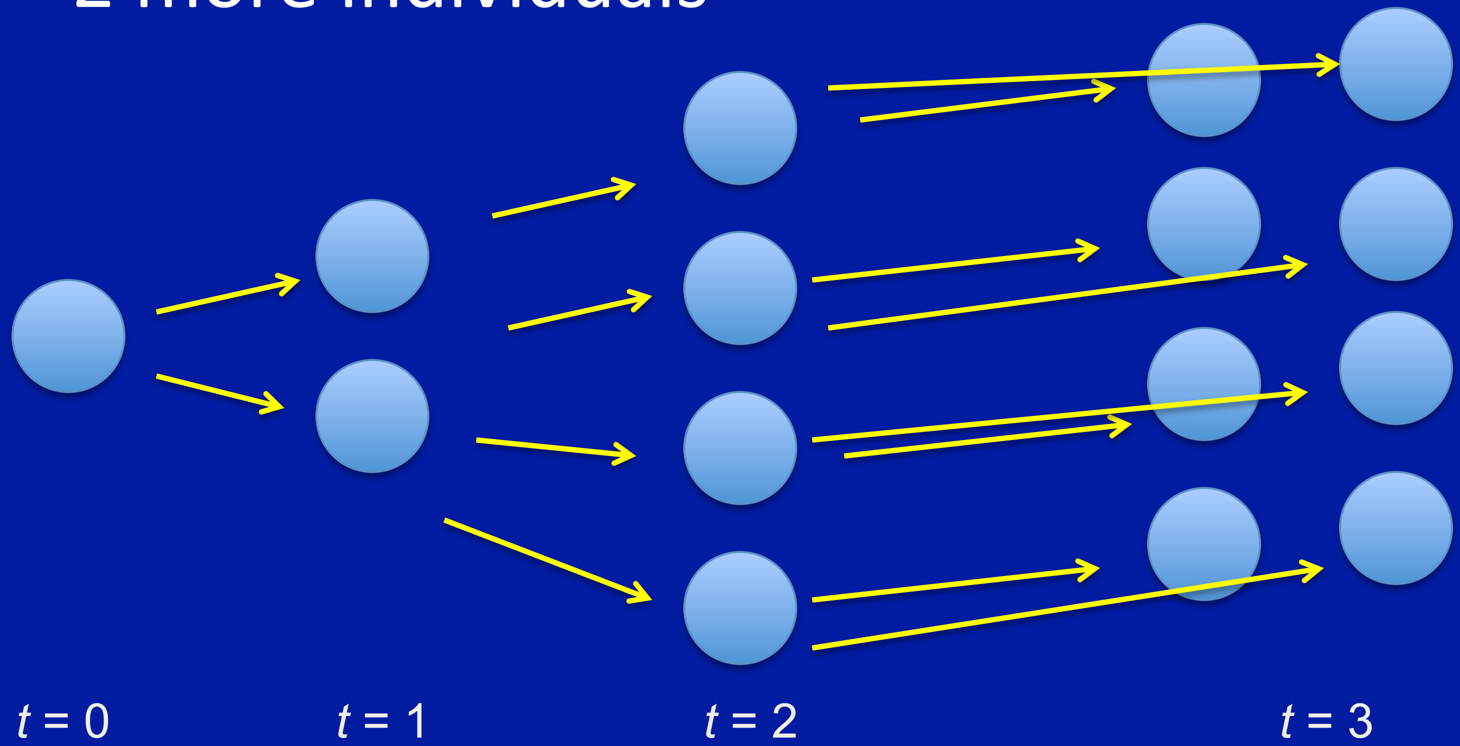
Now lets make a *model*

- Suppose that $R_0 = 2$
- This implies that each individual is replaced by 2 more individuals



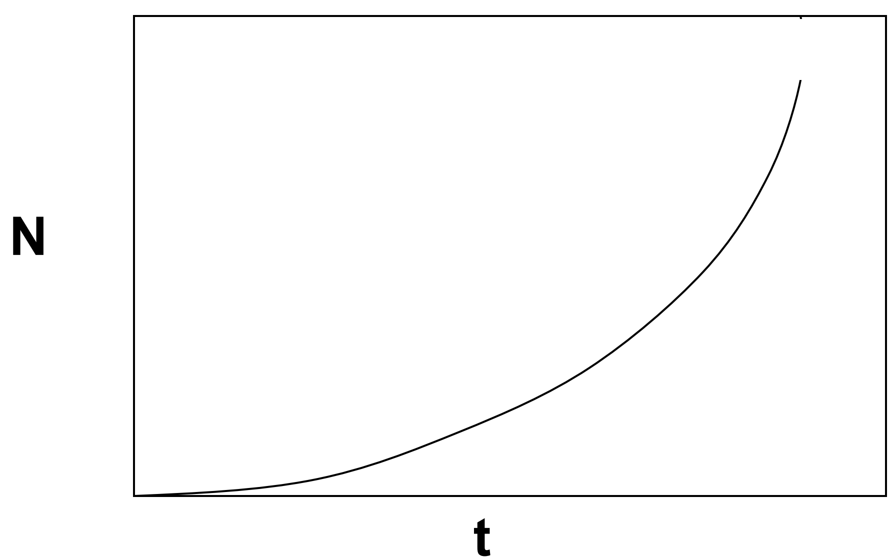
Now lets make a *model*

- Suppose that $R_0 = 2$
- This implies that each individual is replaced by 2 more individuals



Exponential population growth

- Malthus 1798: essay on human population growth
  - Food is necessary
  - Passion between sexes necessary and will remain unchecked
  - Population growth is geometric when unchecked



N = Number of individuals in population

t = time step

Exponential population growth

- Darwin's example with elephants:
  - Start with 1 pair of elephants
  - Elephants breed between 30-90 years of age
  - Typically have 6 offspring
  - After 750 years – 19 million elephants!

  - Clearly this is not what we see in nature – population growth is not usually unchecked

  - Darwin reasoned that whatever factors limit populations also drive natural selection

Let's compute the number of individuals in the next time interval

- Let's assume that the previous generation dies when the new generation is produced.
  - E.g. Invertebrates who lay eggs and then die.

Modeling geometric population growth

- We are interested in the relationship between population size and time – how does the size of the population vary with time?

- Tool Kit:

  N = population size

  t = time

  N_t = population size at time t

  N_0 = population size at start ($t = 0$)

  R_0 = rate of generation change

Let's compute the number of individuals in the next time interval

$$N_{x+1} = R_o * N_x$$

$$N_{0+1} = R_0 * N_0$$

$$N_1 = 1.32 * 500 = 660.0$$

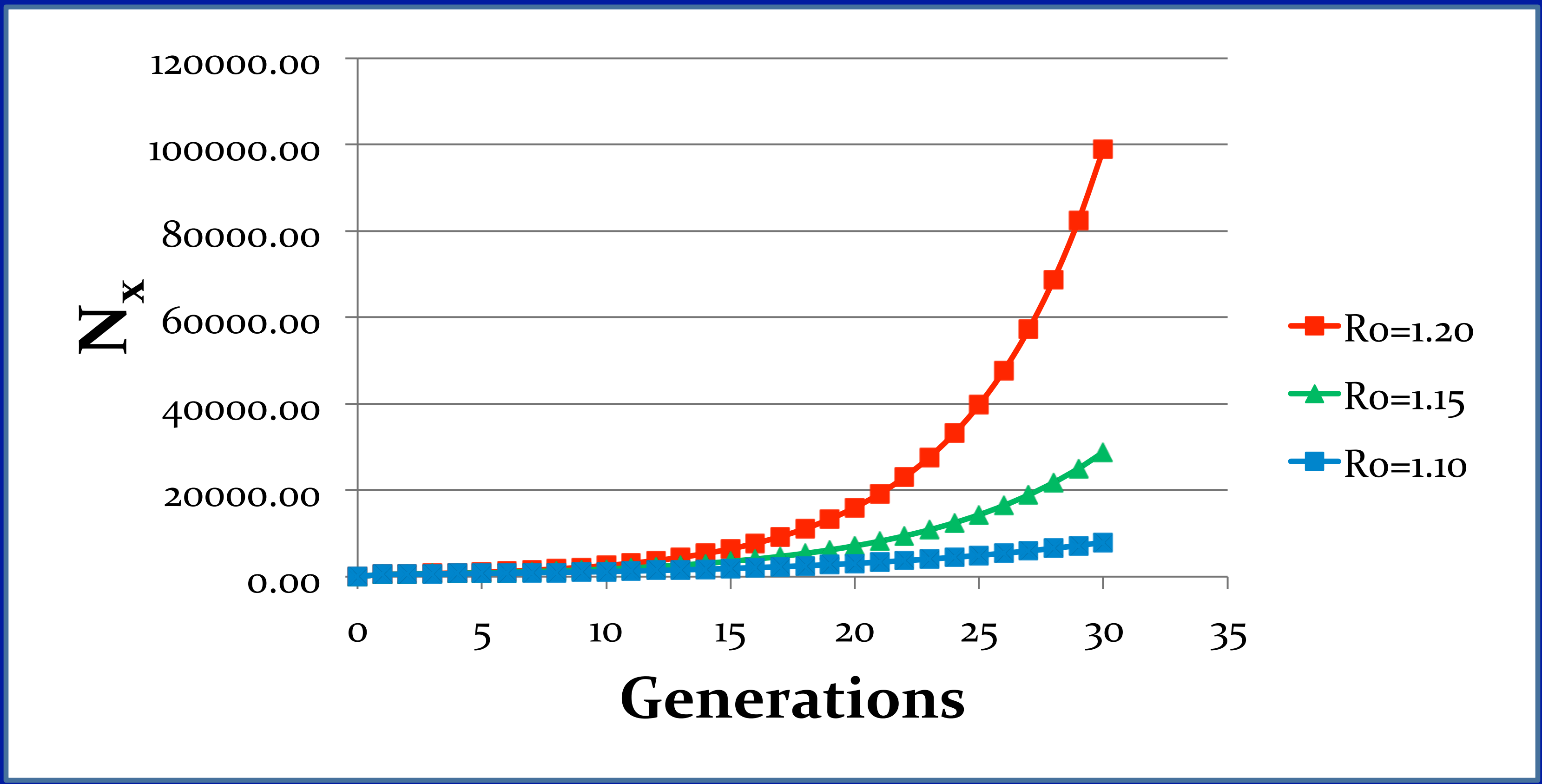
Starting Population size = 500

R_o	**1.32**
Years	**N_x**
0	500.0
1	
2	
3	
4	

So what would the population be in 10 generations?

Year	Formula	Population size
4	1.32*1150	1518
5	1.32*1518	2004
6	1.32*2004	2645
7	1.32*2645	3491
8	1.32*3491	4609
9	1.32*4609	6083
10	1.32*6083	8030

Small changes in R_o can have a large effect on growth



Growth with overlapping generations

Population size

Death rate

$$\frac{dN}{dt} = (b - d) * N$$

Birth rate

Change in population size over change in time

GAACK! Calculus!!!!

Remember that "d" just means "Change in"

Growth with overlapping generations

Birth rate Death rate

Instantaneous growth rate $r = b - d$

$$\frac{dN}{dt} = (b-d) * N$$

Growth with overlapping generations

Birth rate

Death rate

Instantaneous growth rate

$$r = b - d$$

$$\frac{dN}{dt} = rN$$

This ignores any influence from immigration or emigration

Continuous model of geometric population growth

- Examples of per capita growth rates (r) in nature:

	r	Doubling Time
Virus	110,000	3.3 minutes
Bacteria	21,000	17 minutes
Hydra	124	2 days
Cow	0.365	1.9 years
Humans	0.013	50 years

Growth with overlapping generations

$$\frac{dN}{dt} = rN \Rightarrow \frac{N_t}{N_0} = e^{rt}$$

$$N_t = N_0 e^{rt}$$

Incorporating stochastic effects into population growth models

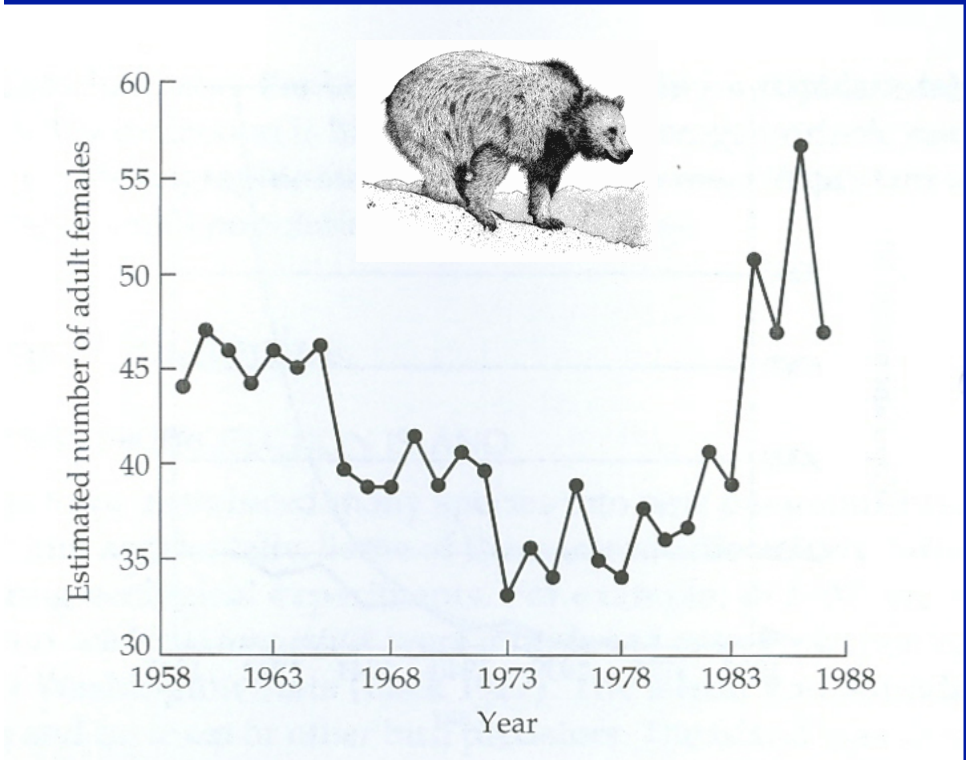
- Up until now we have been considering models that are deterministic
  - Dependent solely upon in put rates (b and d)
  - Constant birth and death rates

- However, we know that chance effects can alter birth and death rates
  - Stochasticity = random variation
  - Environmental (good and bad years)
  - Demographic (b and d rates whole numbers)

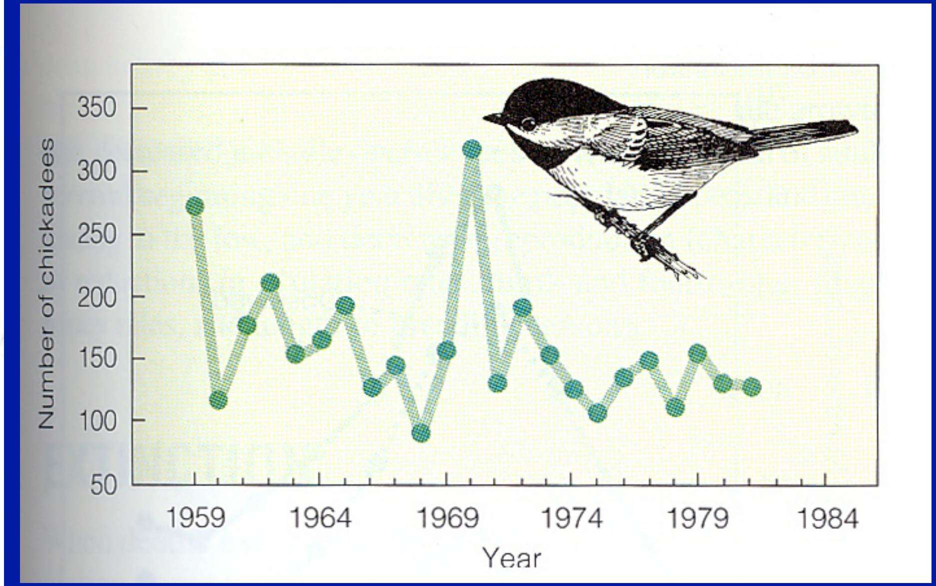
The effect of stochasticity on population dynamics

- Examples:

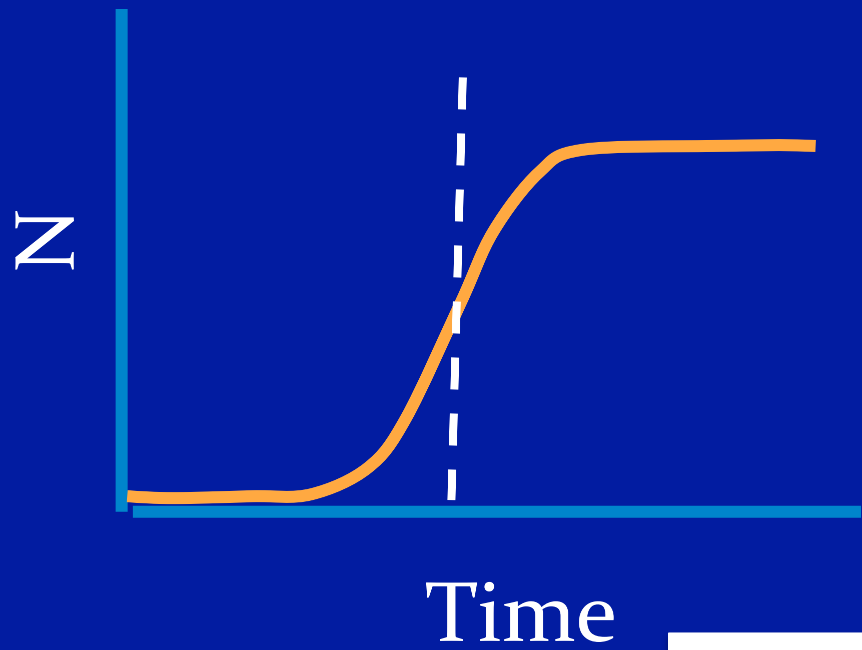
Grizzly Bears
- # adult females/year



Chickadees
chickadees/year



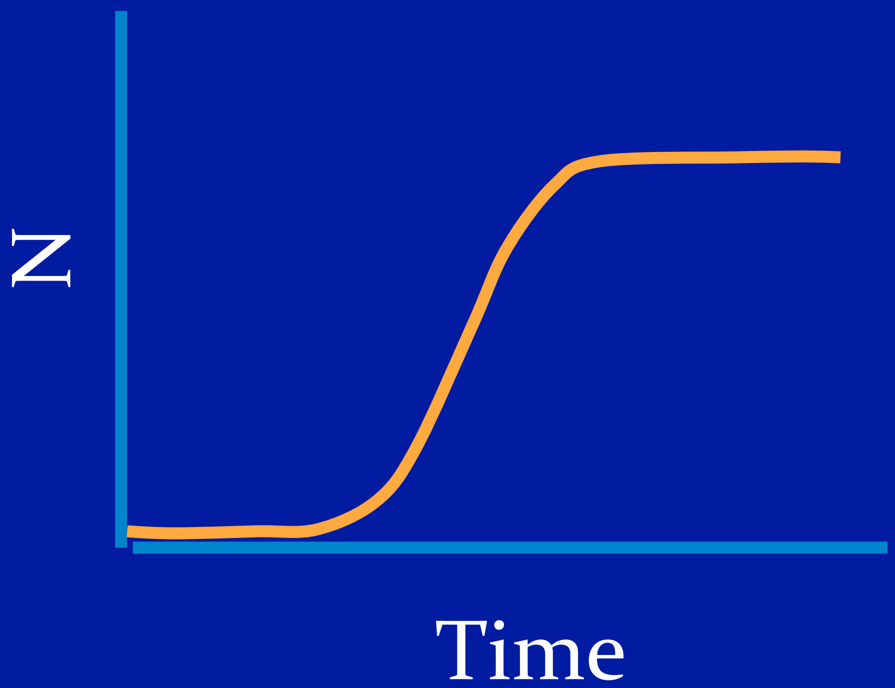
Constraints on Growth



$$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$$

Constraints on Growth

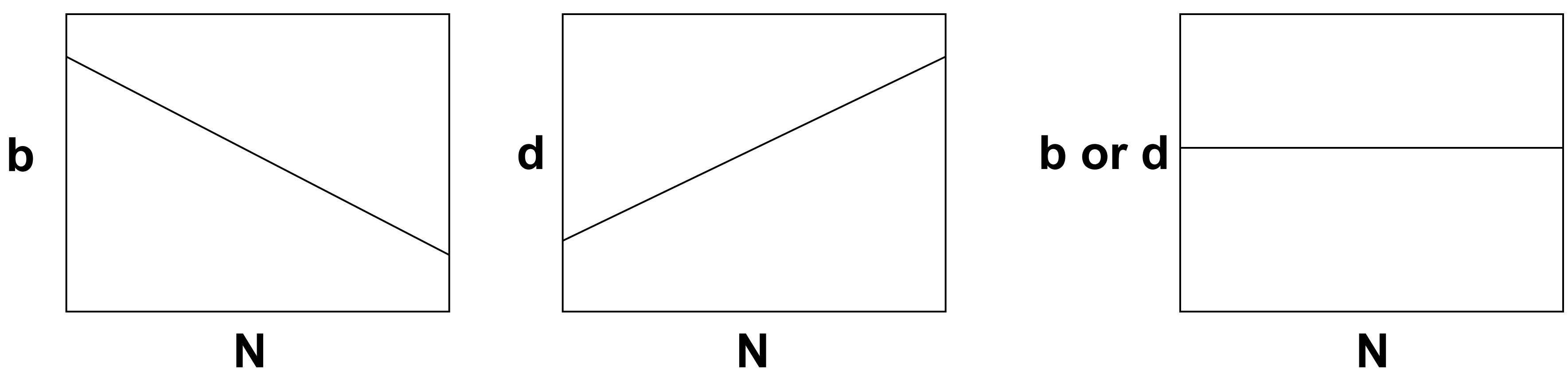
- Intraspecific competition
- Disease
- Lower clutch (i.e. egg number) size
- More stress



Intraspecific competition and density-dependence

- Density = # individuals/area
- Density-dependence: where b or d or some correlate change with density

Density – dependence in birth or death rates **Density – independence**

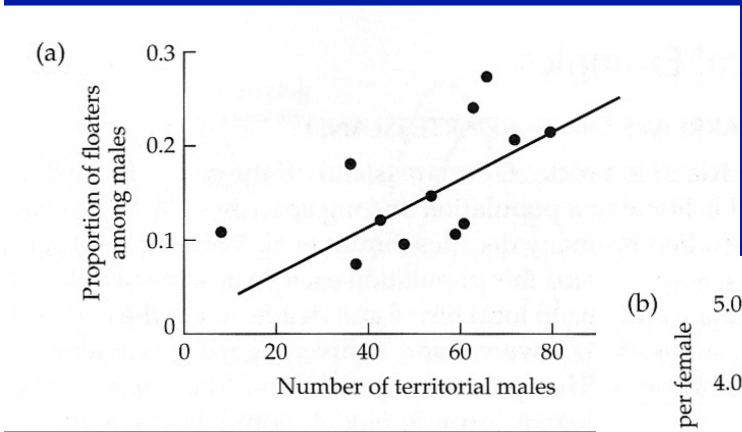


Intraspecific competition and density-dependence

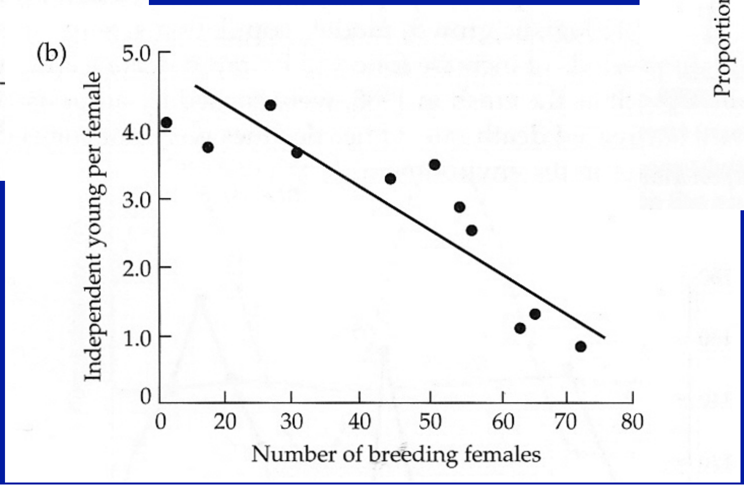
- Example with song sparrow:

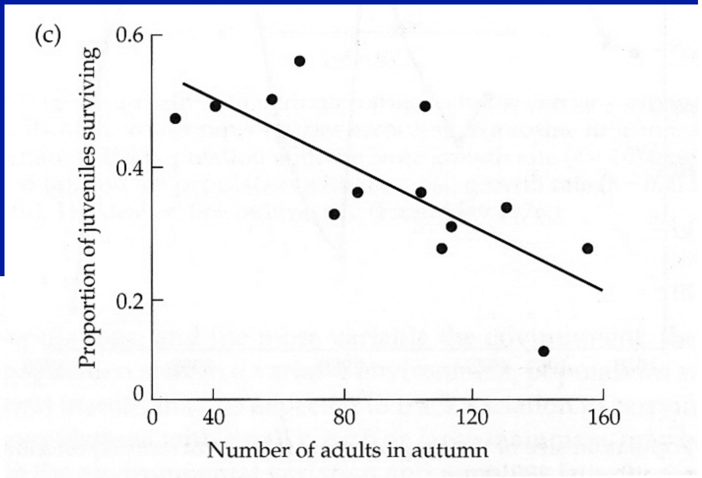
males without territories vs. # males with territories

Proportion of juveniles surviving vs. # adults



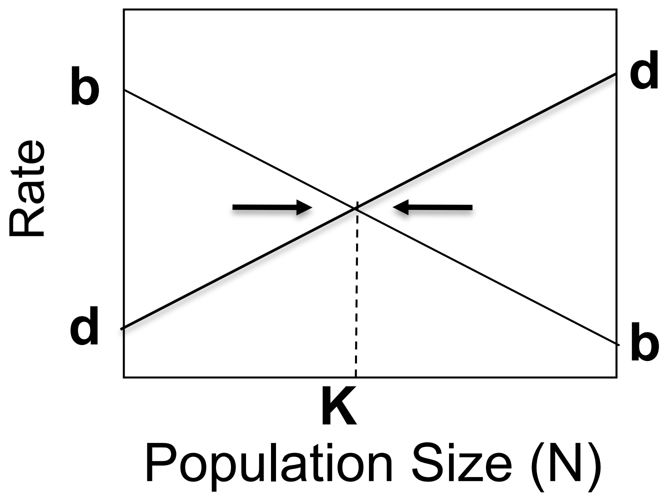
young/female vs. # females





Why is density-dependence important?

1. Density-dependence means that the per capita birth (b) and death (d) rate varies with density
   – this directly affects the per capita population growth rate (r)!
2. If d exceeds b, population is no longer growing:

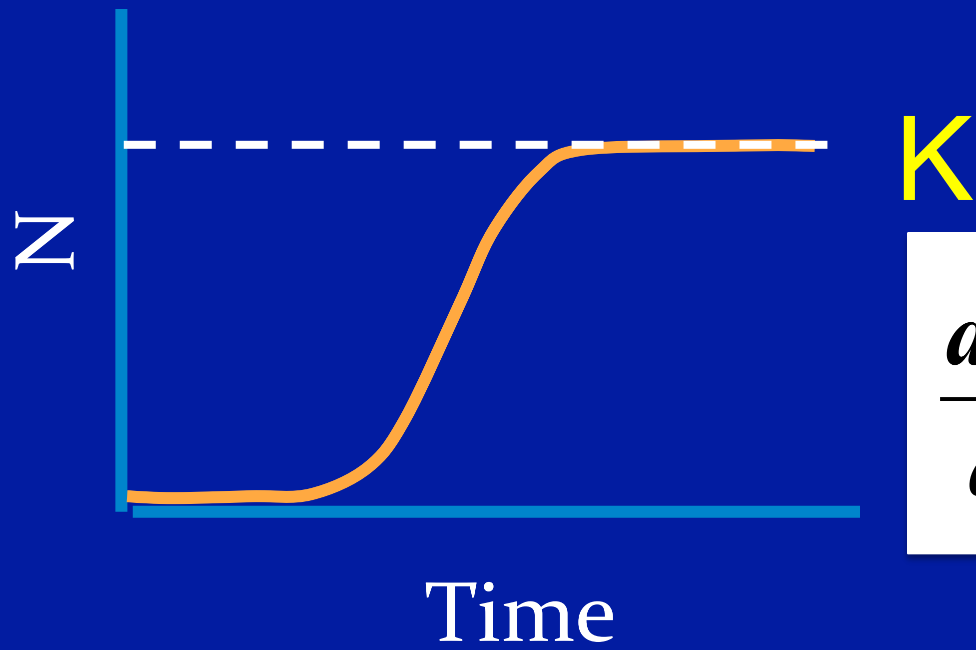


Recall: r = b – d

When r = 0 population is not growing

At r = 0 population reaches maximum density that can be supported by resources: carrying capacity = K

Carrying Capacity (K)

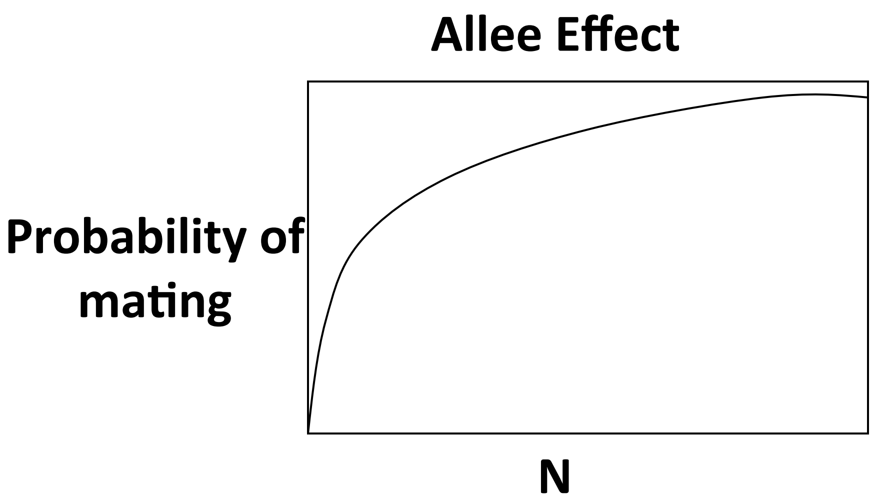


$$\frac{dN}{dt} = rN\left(\frac{K - N}{K}\right)$$

The carrying capacity (K) is the maximum number of individuals that the environment can hold and maintain

<u>**Intra**</u>specific mechanisms of density-dependence

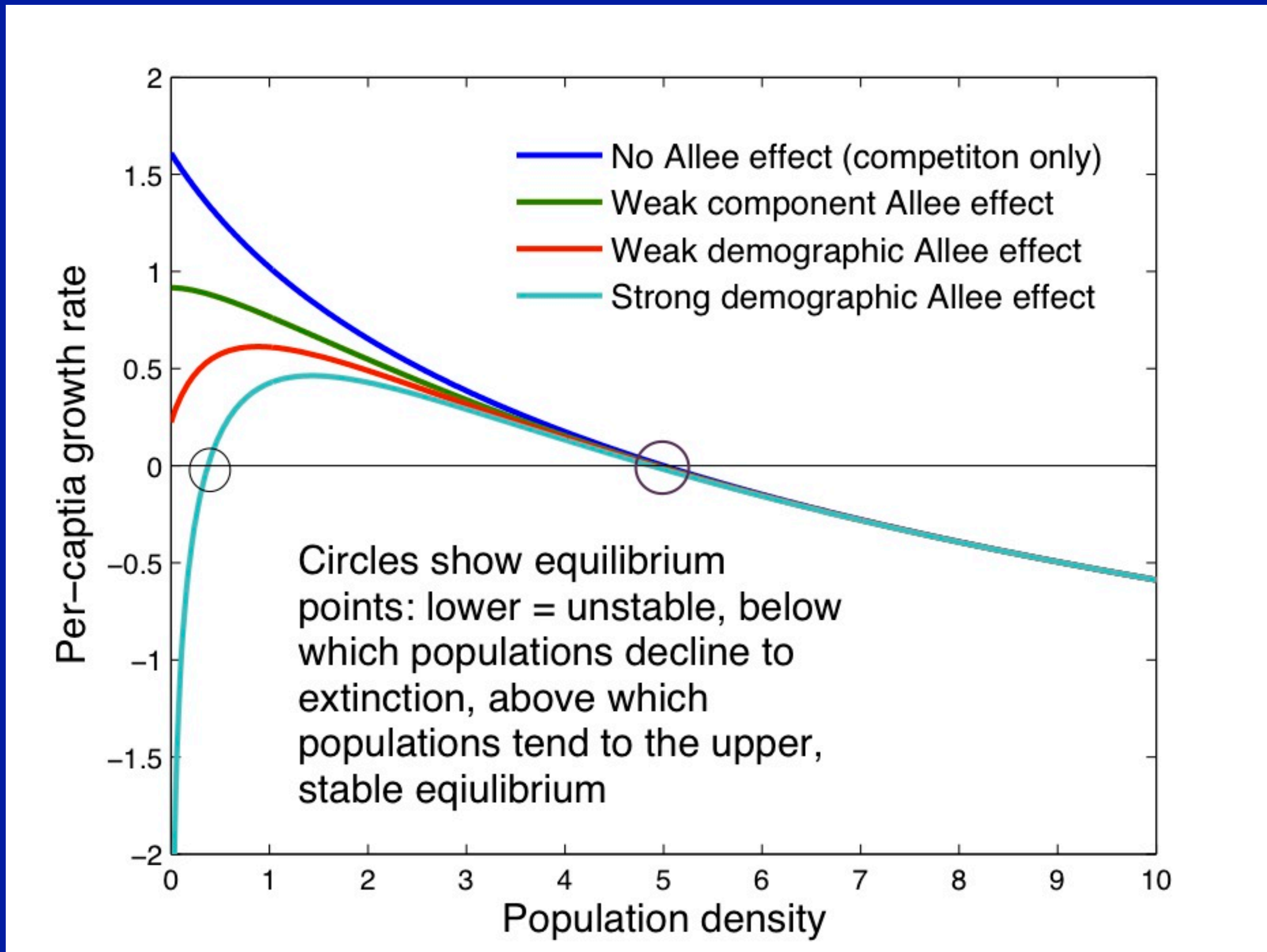
1. Space depletion (e.g. territories filled up)
2. Resource depletion
3. Allee effect (reverse density-dependence)



Allee Effect

- At low population density, decreases in growth rate (even population viability)
  - Low encounters with potential mates
  - Loss of social structure that influences cooperation in specific activities
    - feeding opportunities
    - territorial & predator defense
    - modifications of habitat
  - Impacts of genetic diversity
  - Loss of population to withstand stochastic variation

Allee Effect



Interspecific mechanisms of density-dependence

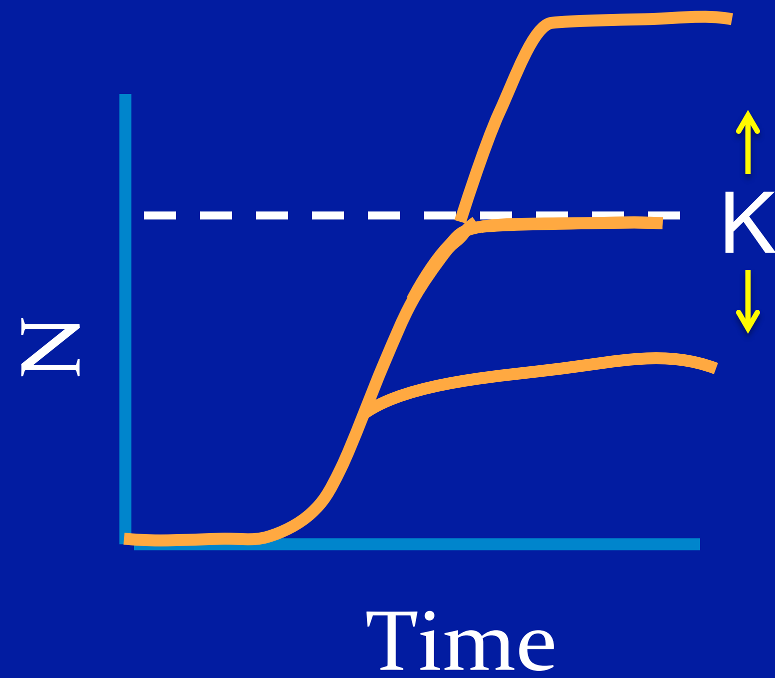
1. Parasitism, predation, disease, competition with other species

2. Search image predation (easier to capture more prey when they are more abundant)

What types of things can affect the carrying capacity?

- Increase
  - Increase in habitat
  - Increase in energy (e.g., prey)

- Decrease
  - Loss of habitat
  - Loss of energy
  - Introduction of competitor

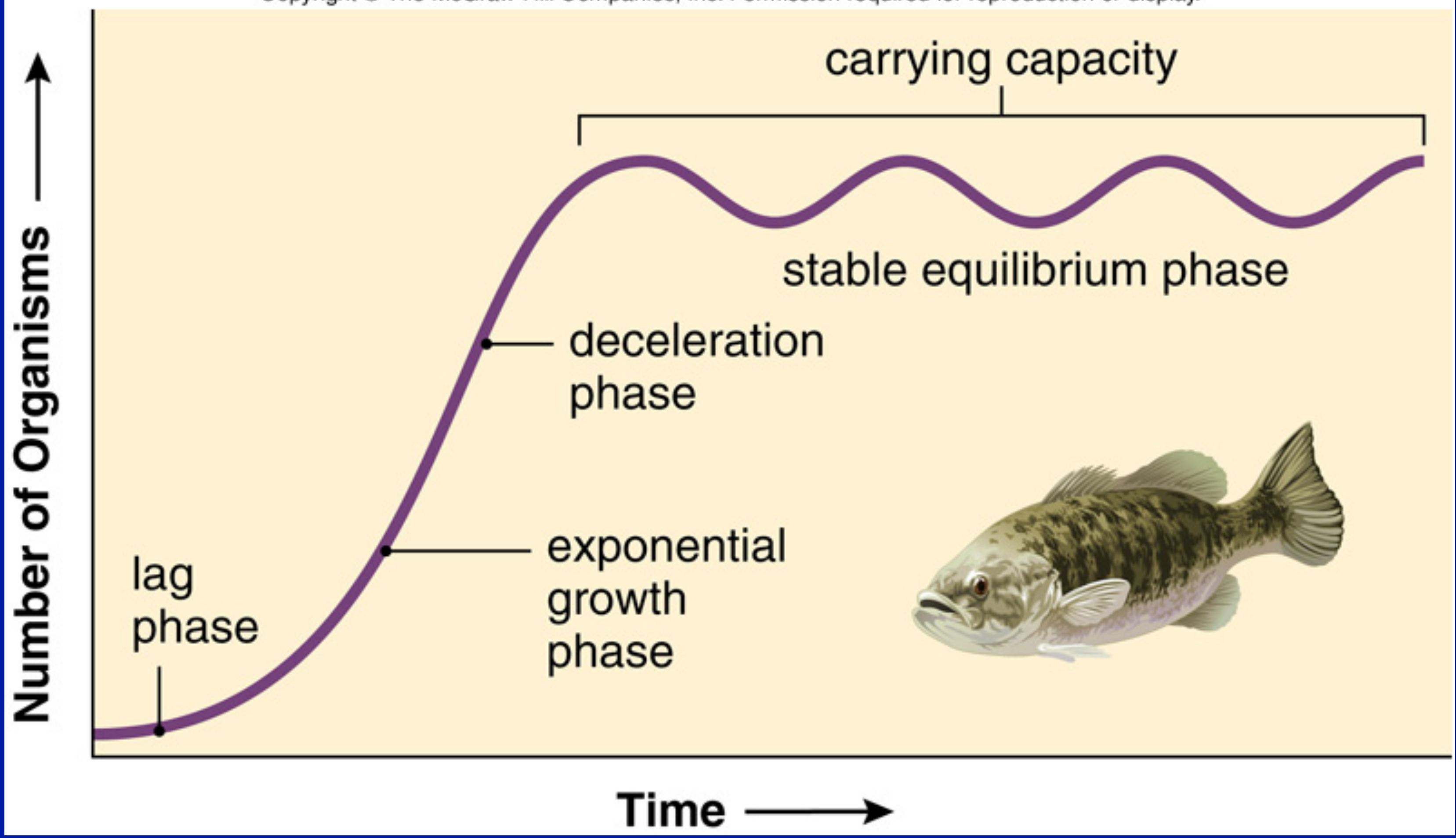


http://www.snh.org.uk/publications/on-line/naturallyscottish/dragonfly/importanthabitats.asp

Variable Carrying Capacity (K)

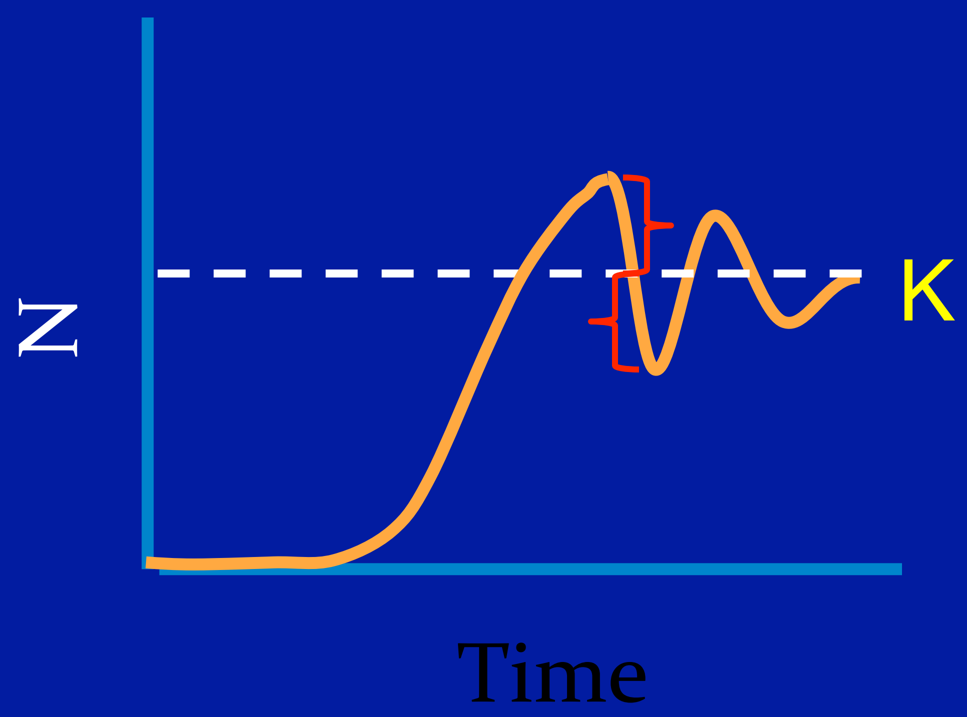
- Up to this point, we've only discussed the issue of a constant K
- K can (and likely does) vary with environmental factors
- Response in oscillations depends on size of r
- More variable the environment, the lower the average population

Variable Carrying Capacity (K)



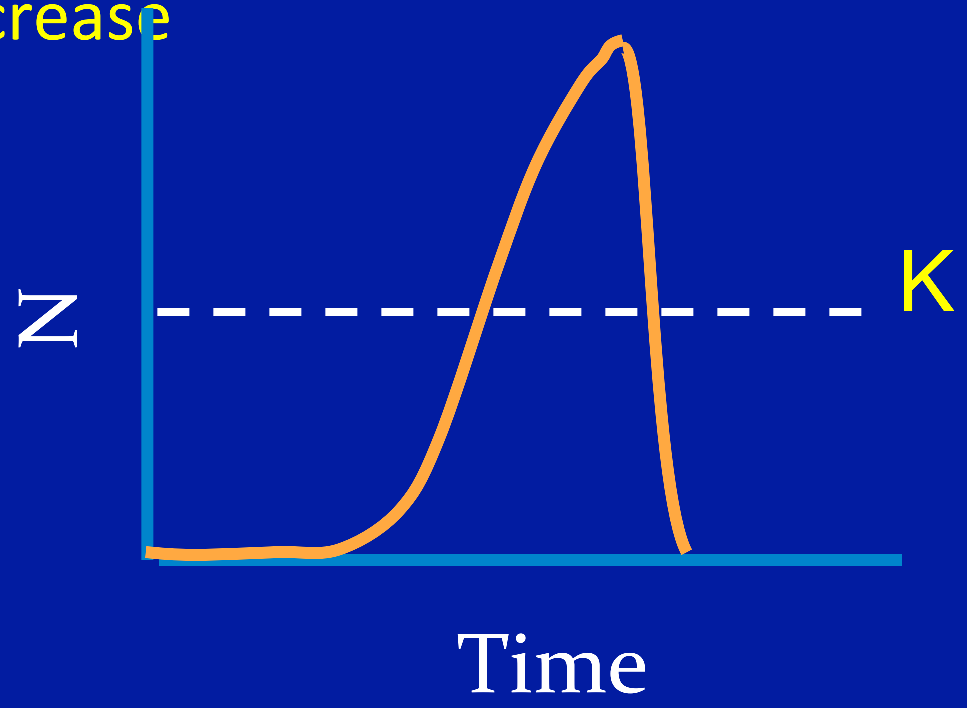
Effects of magnitude of change

- Differences above and below the line are roughly equal
  - Small decrease



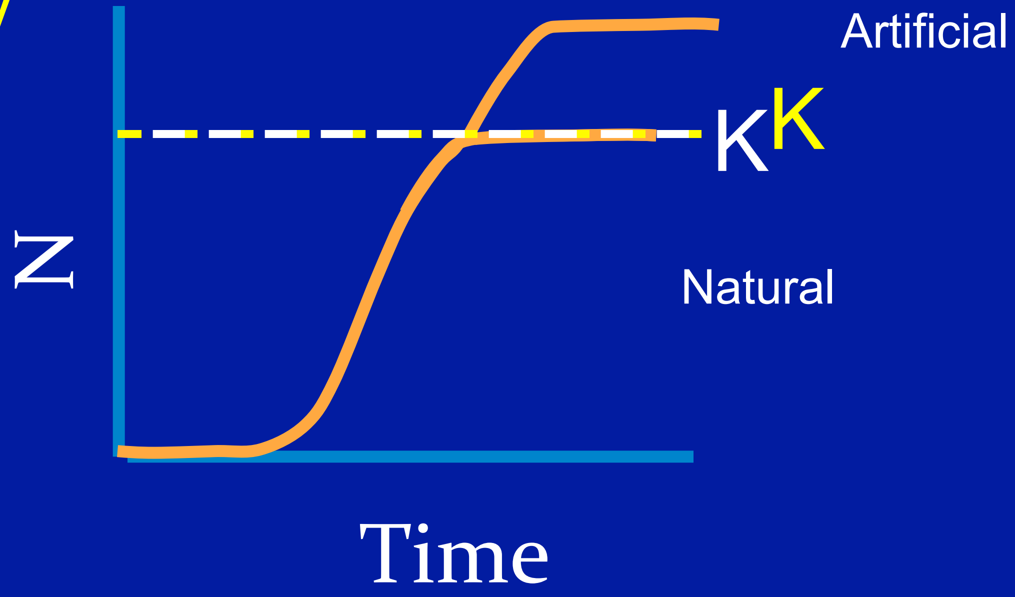
Effects of magnitude of change

- Differences above and below the line are roughly equal
  - Large Decrease



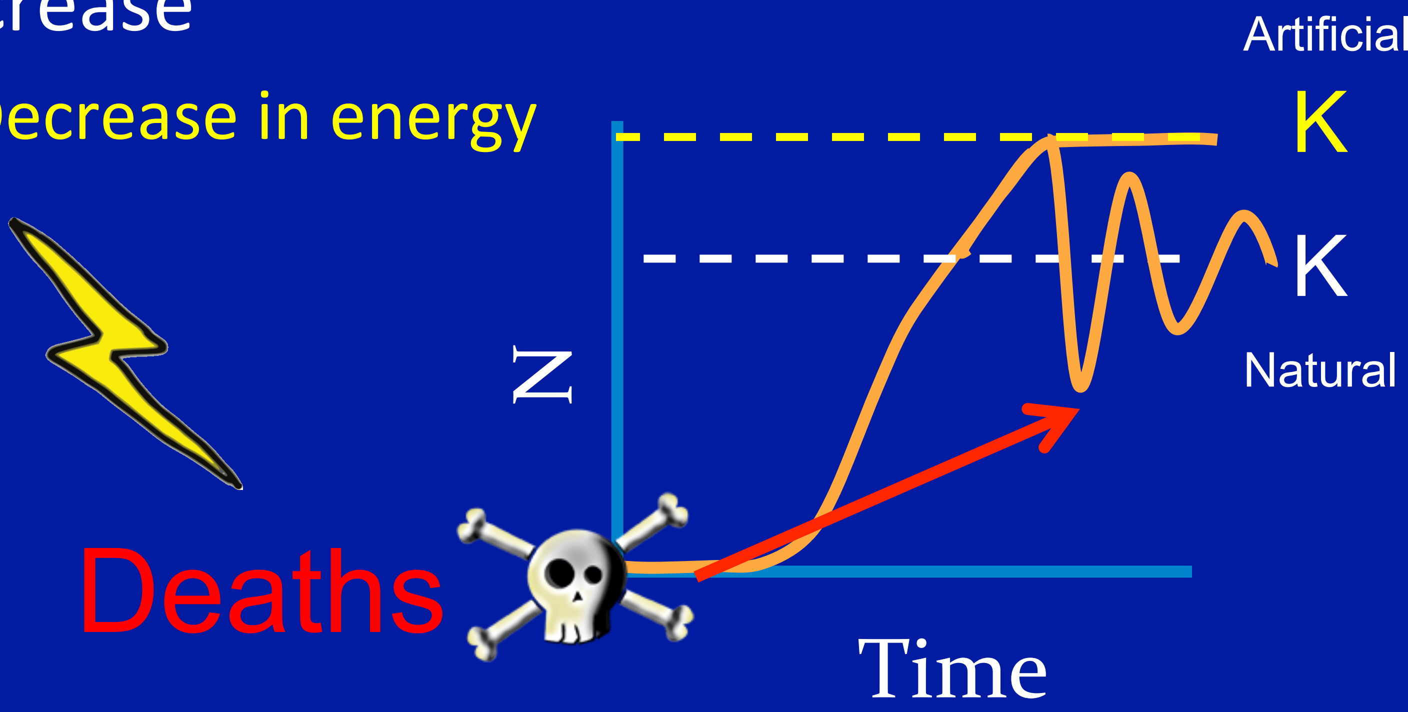
How might foreign aid affect a country?

- Increase
  - Increase in energy

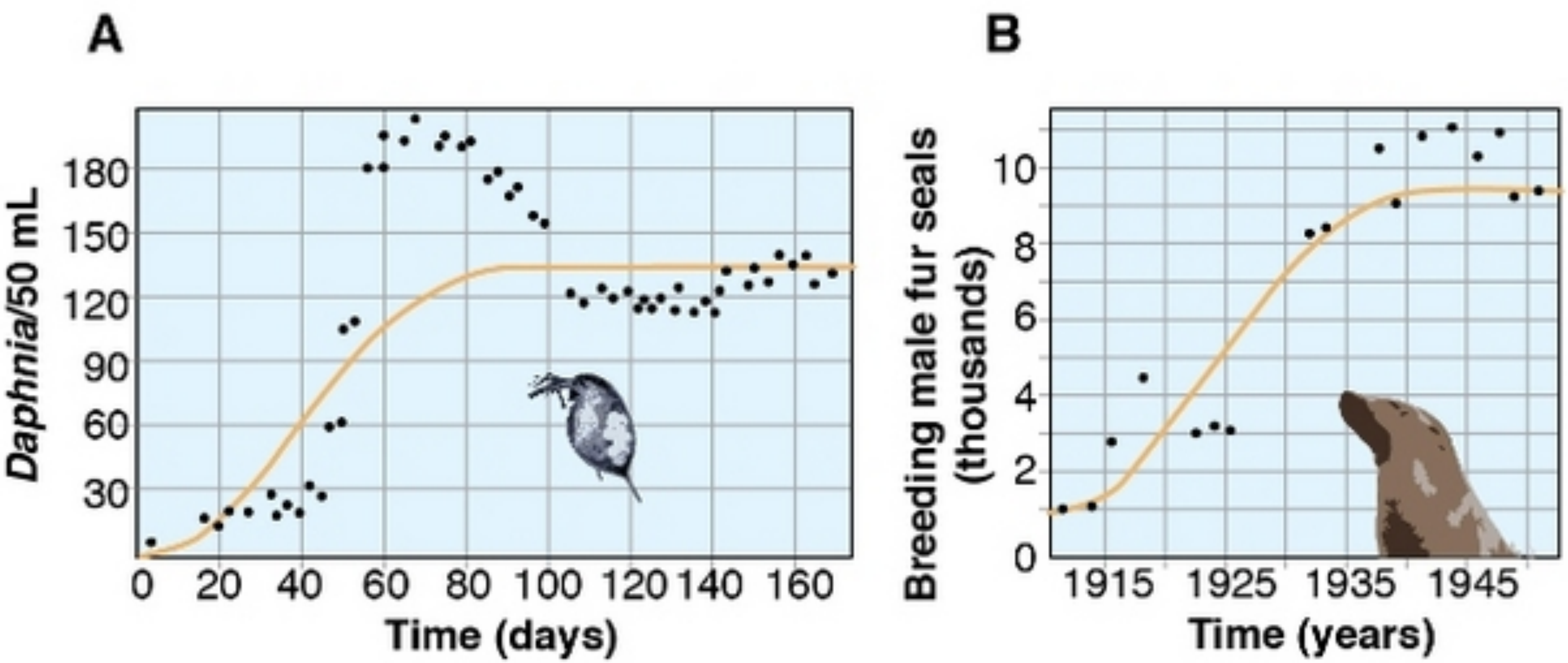


What would happen if the foreign aid was suddenly removed

- Decrease
  - Decrease in energy



Examples of Logistic Growing Populations



Learning objectives

- Students should be able to:
  - Calculate population growth rates from life tables/natality tables
  - Analyze life/natality tables to draw conclusions about survivorship & life history within populations
  - Explain the difference between exponential and logistic growth, and their relevance to determining population sizes
  - Understand how density dependent processes may impact population sizes and growth rates over time