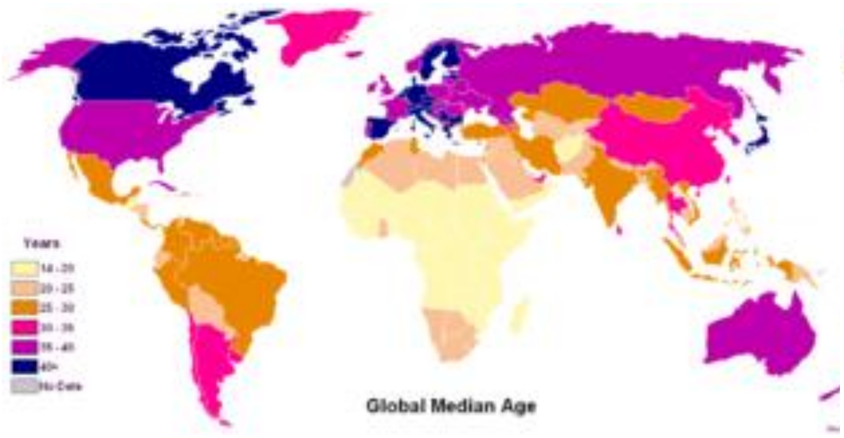
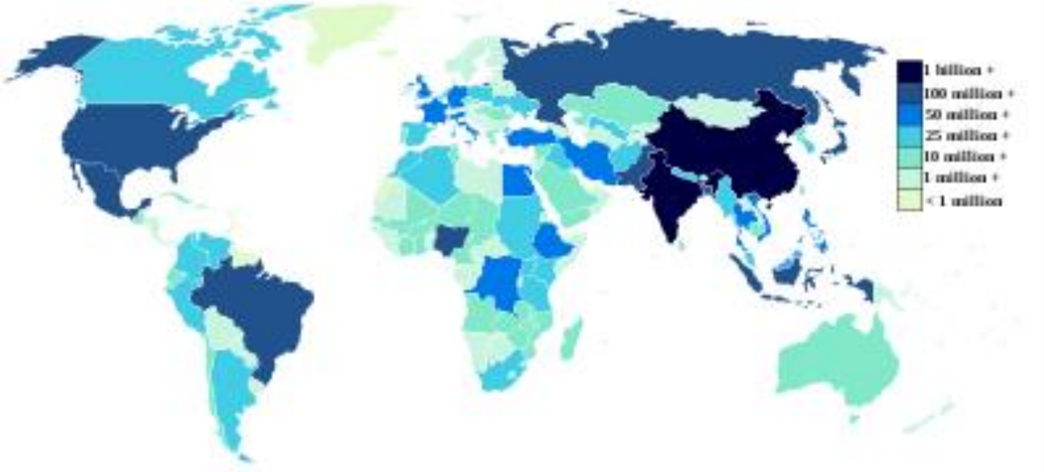
Properties of Populations

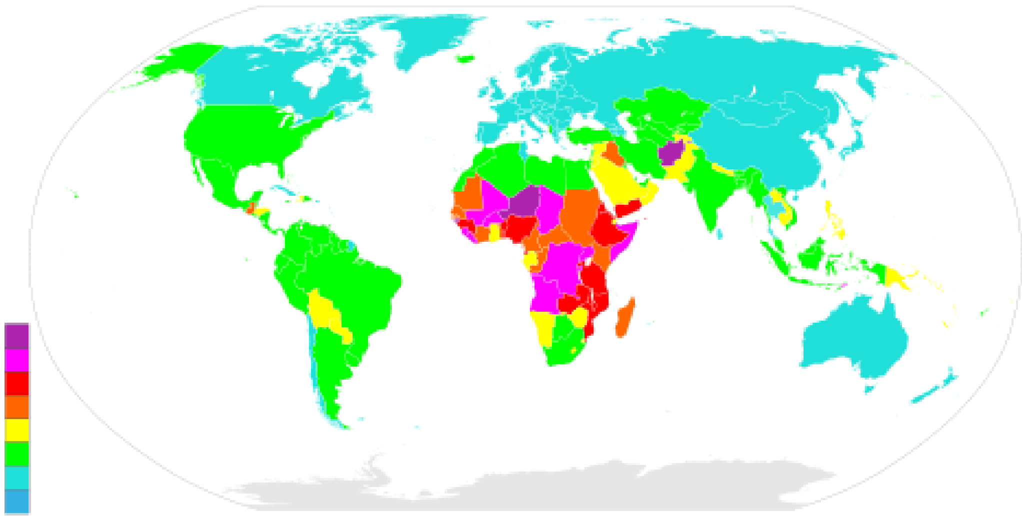
Age structure



Density

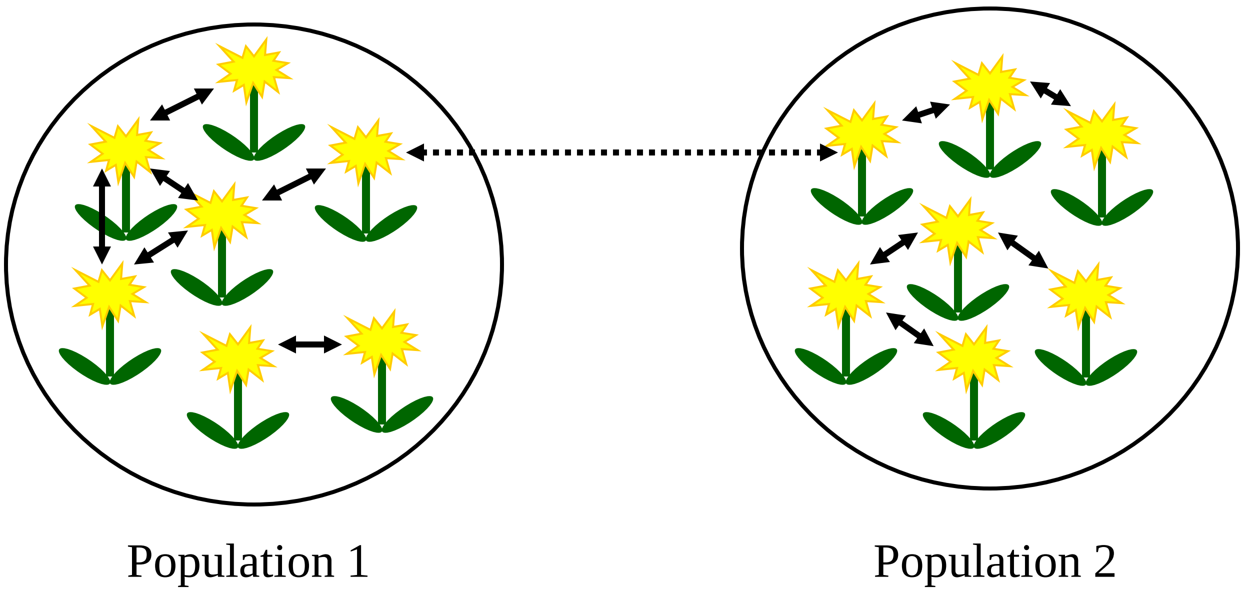


Fertility



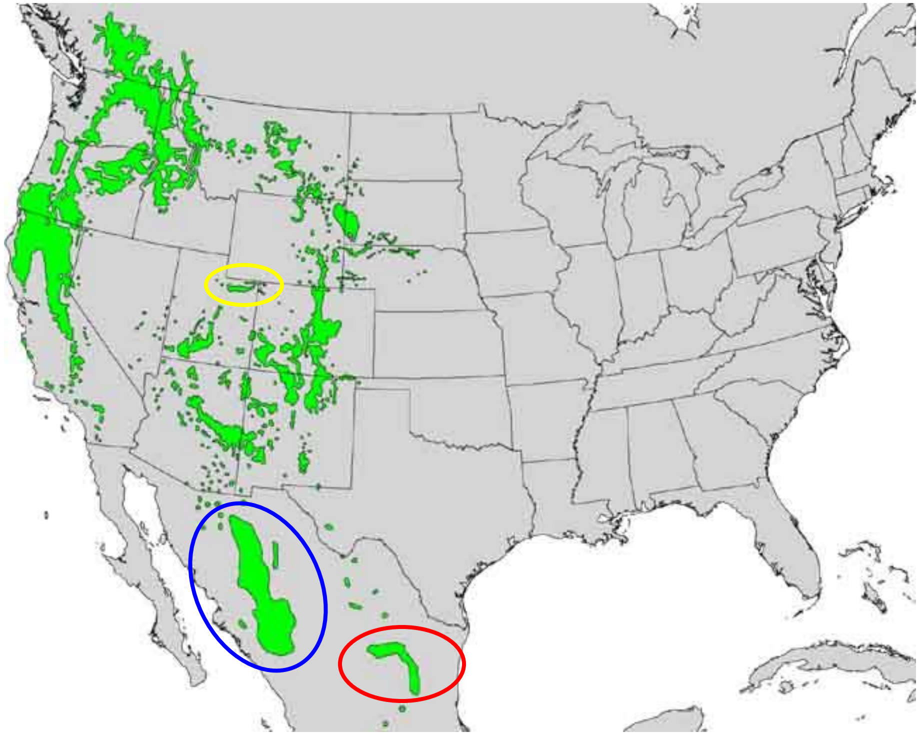
What is a population?

- A group of organisms of the same species that occupy a well defined geographic region and exhibit reproductive continuity from generation to generation; ecological and reproductive interactions are more frequent among these individuals than with members of other populations of the same species.



Real populations are messy

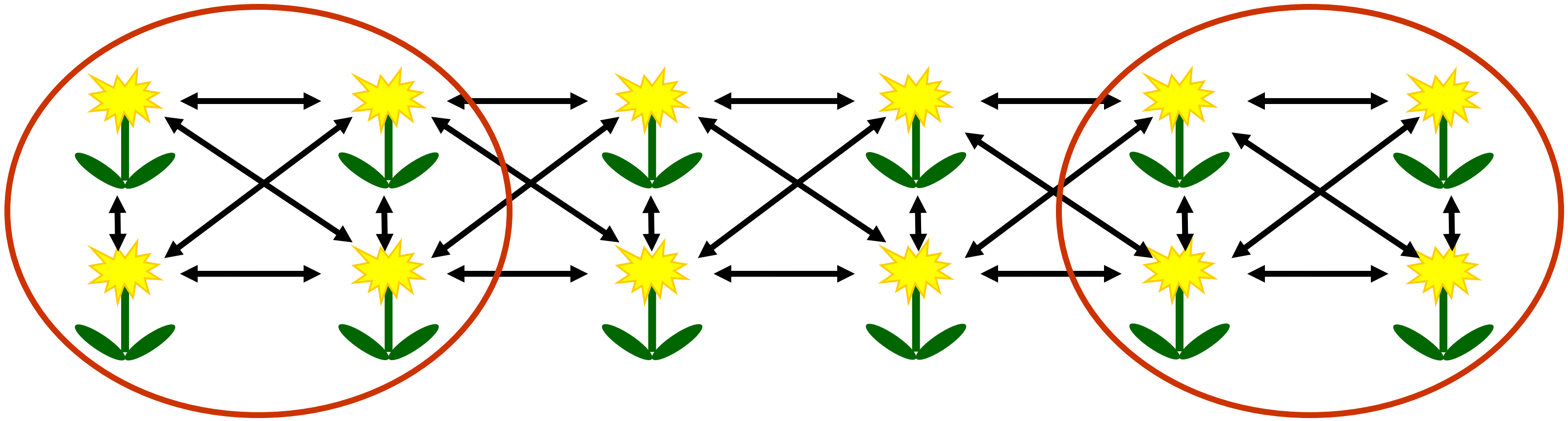
Geographic distribution of *P. ponderosa*



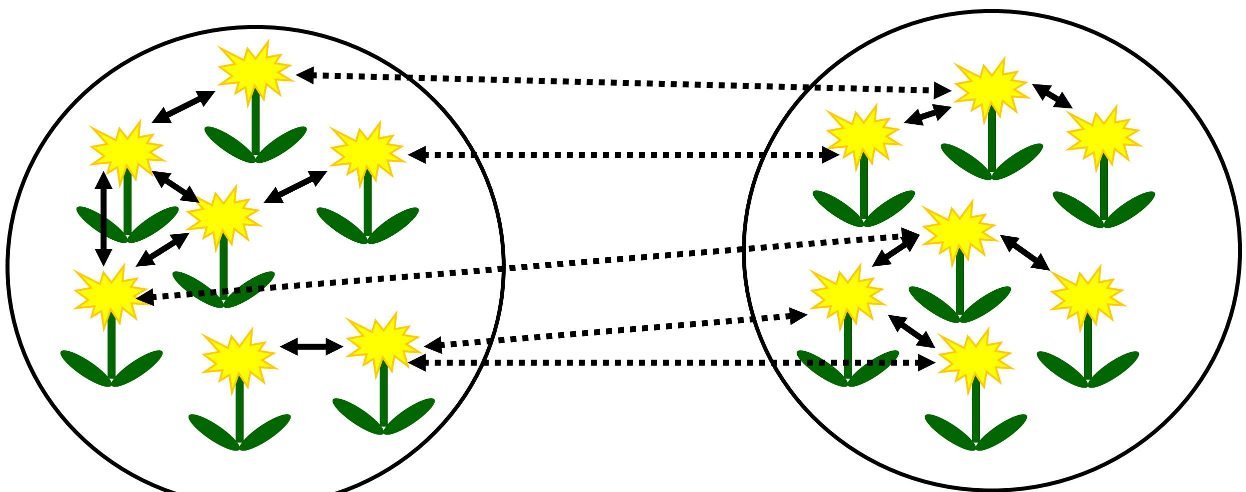
- Broken up into **populations**
- But divisions are not entirely clear

In the real world, defining populations isn't simple

- **Populations often do not have clear boundaries**



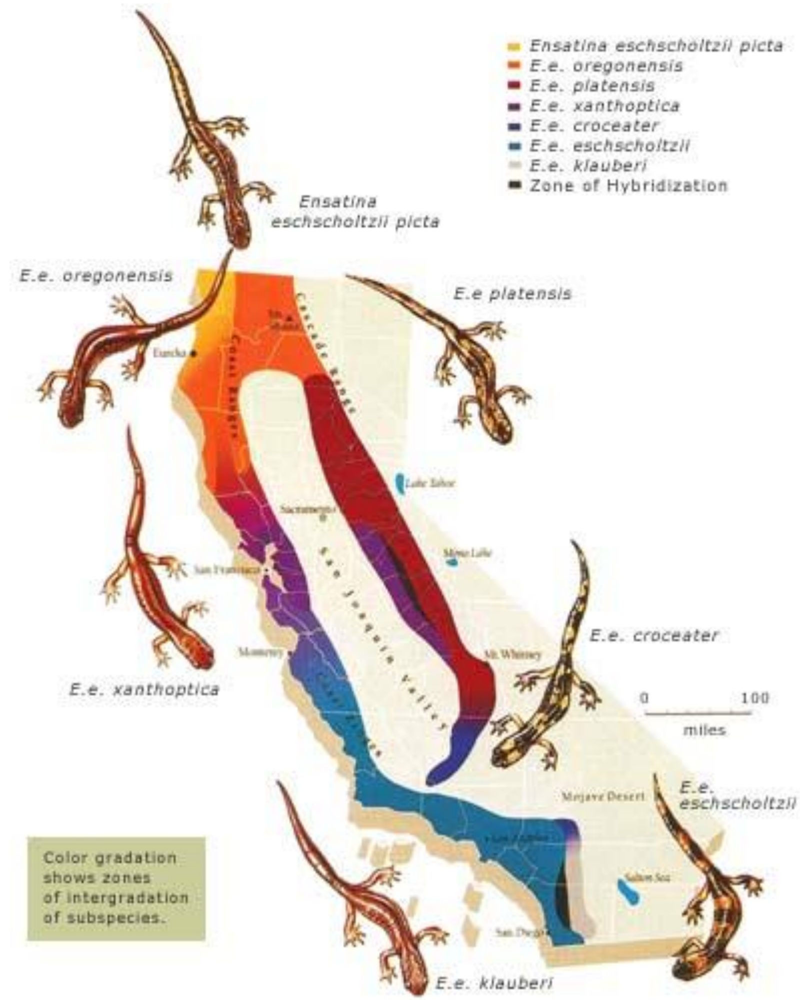
- **Even in cases with clear boundaries, movement may be common**



Habitat 1

Habitat 2

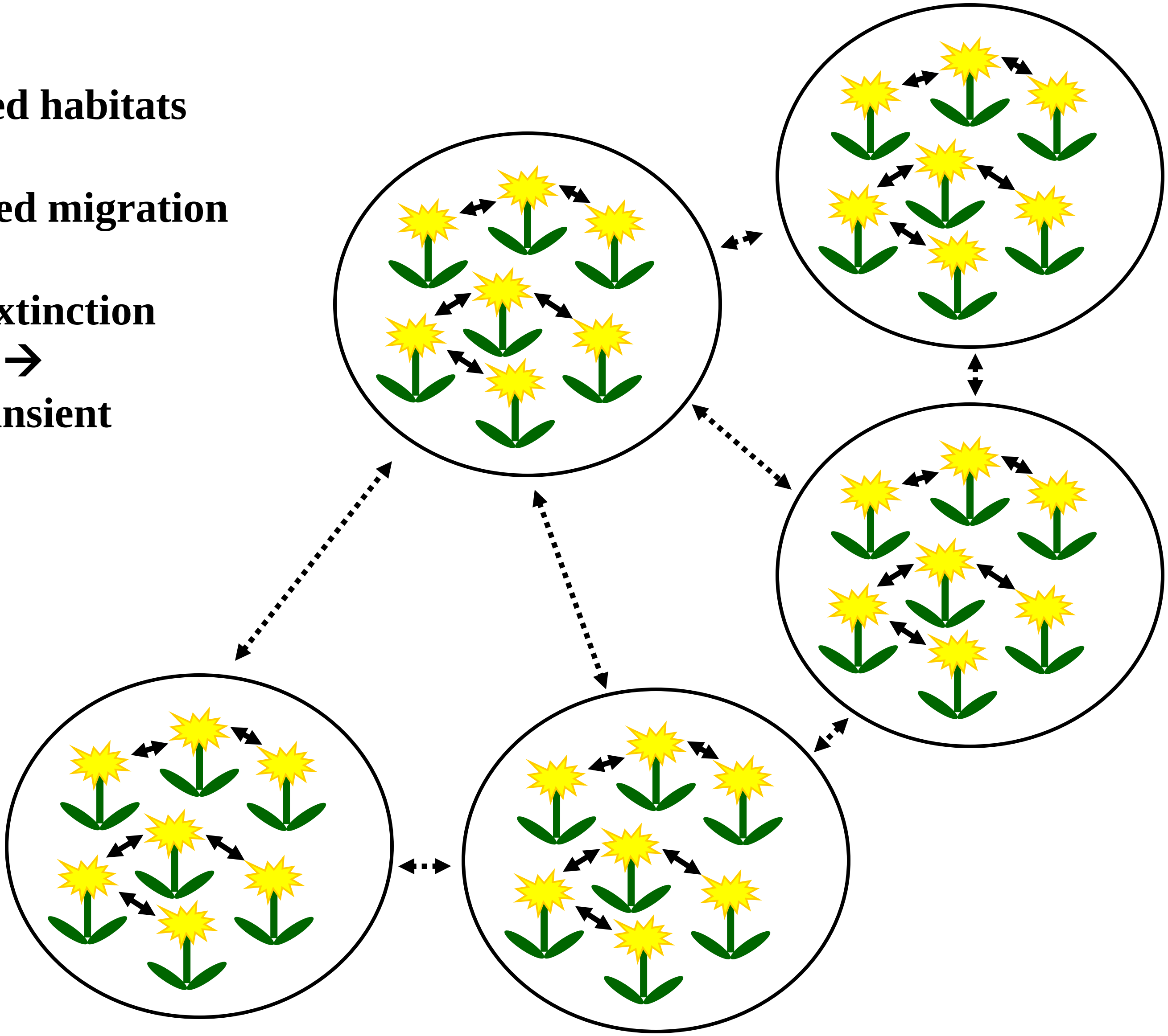
An extreme example…*Ensatina* salamanders



Not only are populations continuous, but so are species!

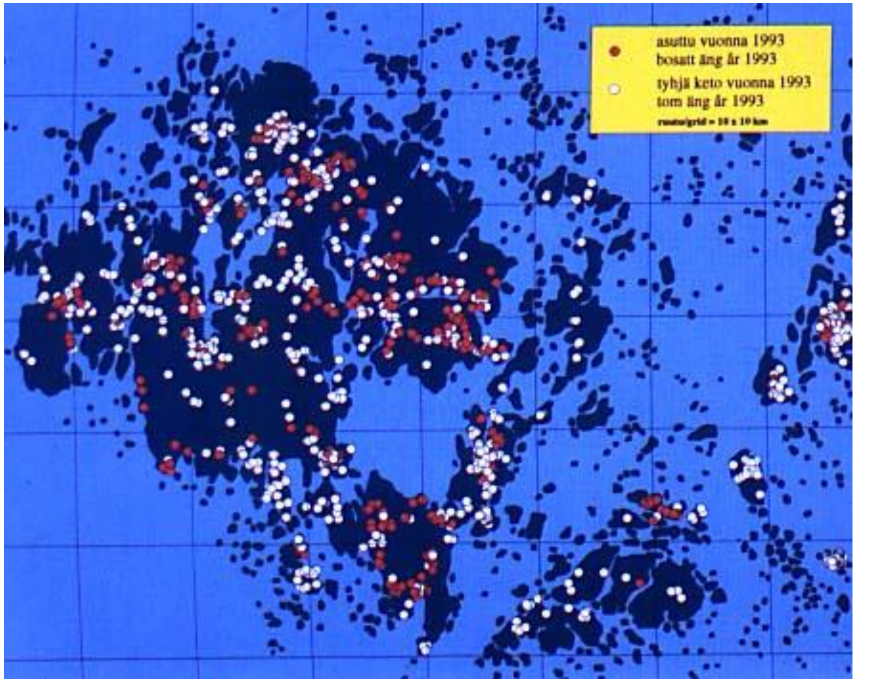
Metapopulations make things even more complicated

- Occur in fragmented habitats
- Connected by limited migration
- Characterized by extinction and recolonization → populations are transient



Glanville Fritillary in the Åland Islands

The glanville fritillary



Red dots indicate occupied habitat and
white dots empty habitat in 1993.
Picture by Timo Pakkala

Some Important Properties of Populations

1) Density – The number of organisms per unit area

2) Genetic structure – The spatial distribution of genotypes

3) Age structure – The ratio of one age class to another

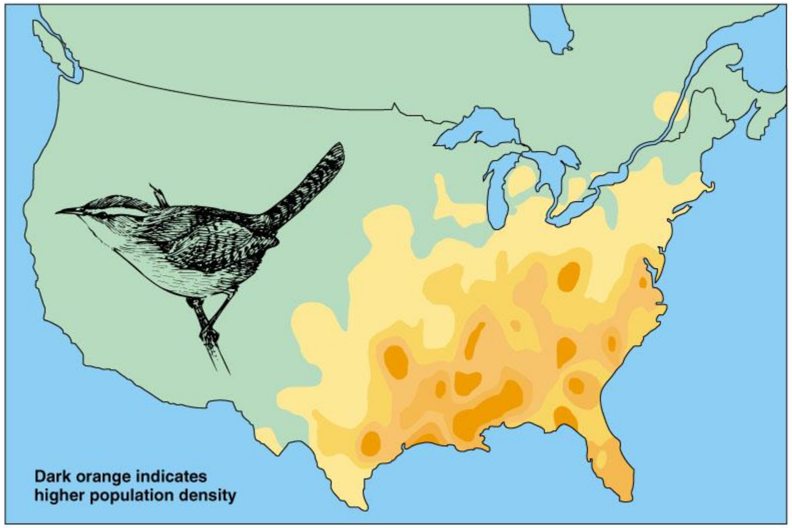
4) Growth rate – (Births + Immigration) – (Deaths + Emigration)

Describing populations I – Population density

United States at night

$$\rho_i = N_i / A_i$$

Population density of the Carolina wren

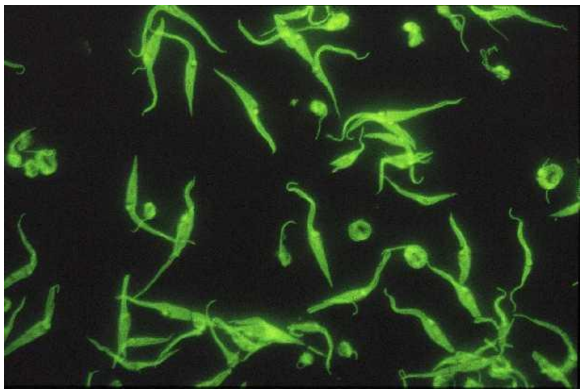


Copyright © 2003 Pearson Education, Inc., publishing as Benjamin Cummings.

Population density shapes:

- Strength of competition within species
- **Spread of disease**
- Strength of interactions between species
- Rate of evolution

Population density and disease, *Trypanasoma cruzi* (Chagas disease)



Trypanasoma cruzi (protozoan)

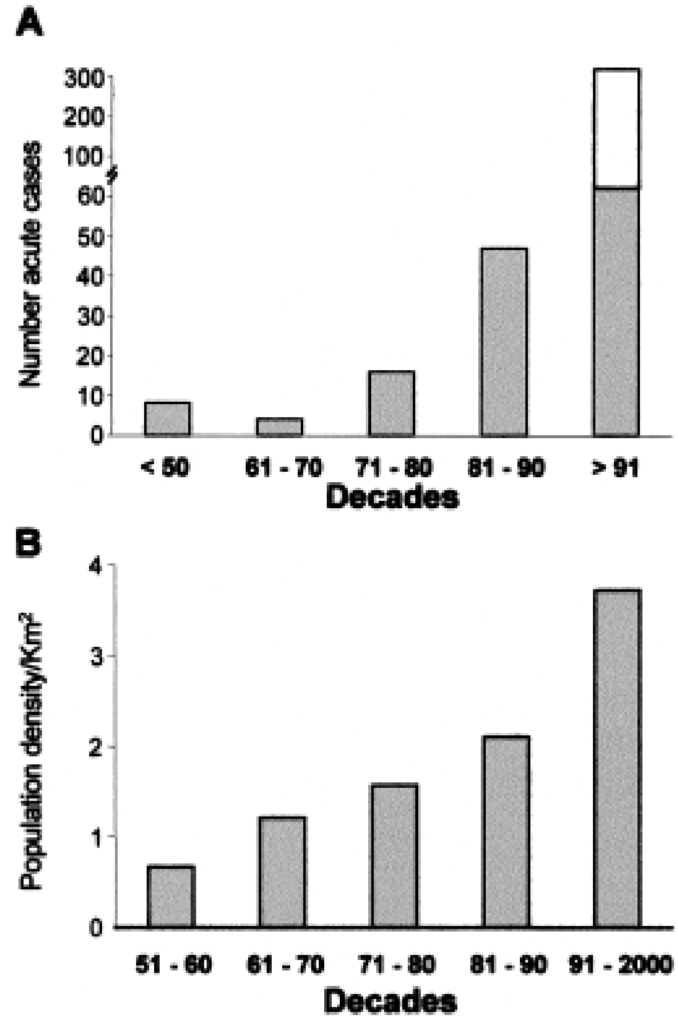
"Assassin bug" (vector)

Currently infects between 16,000,000 and 18,000,000 people and kills about 50,000 people each year

Population density and disease, *Trypanasoma cruzi*

A case study from the Brazilian Amazon

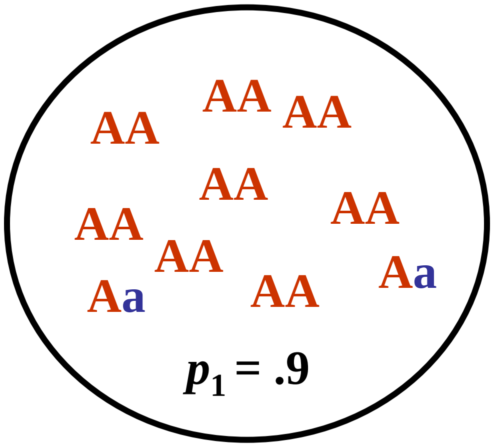
- **Since 1950, human population has increased ≈ 7 fold**
- **Since 1950, the number of infections has increased ≈ 30 fold**
- **Suggests that rates of infection are increasing with human density**



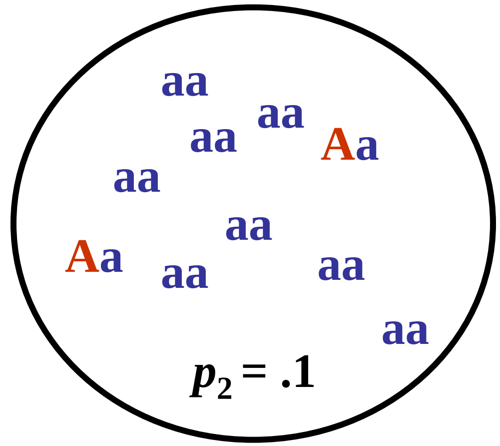
Antonio R.L. Teixeira, et. al., 2000.
Emerging infectious diseases. 7: 100-112.

Describing populations II – Genetic structure

Imagine a case with 2 alleles: A and a, with frequencies p_i and q_i, respectively



Population 1



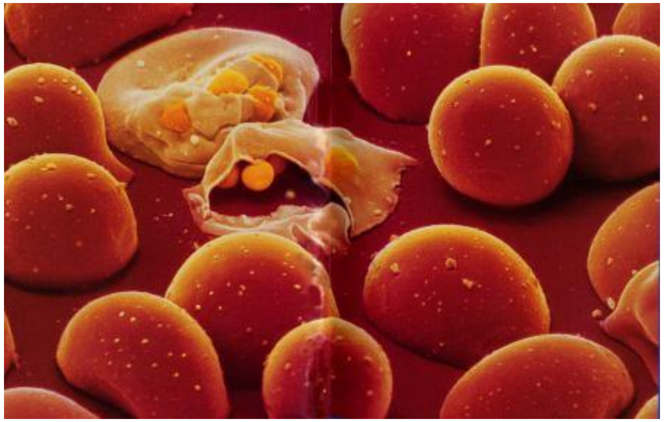
Population 2

$p_1 = 18/20 = .9$
$q_1 = 2/20 = .1 = 1\text{-}p_1$

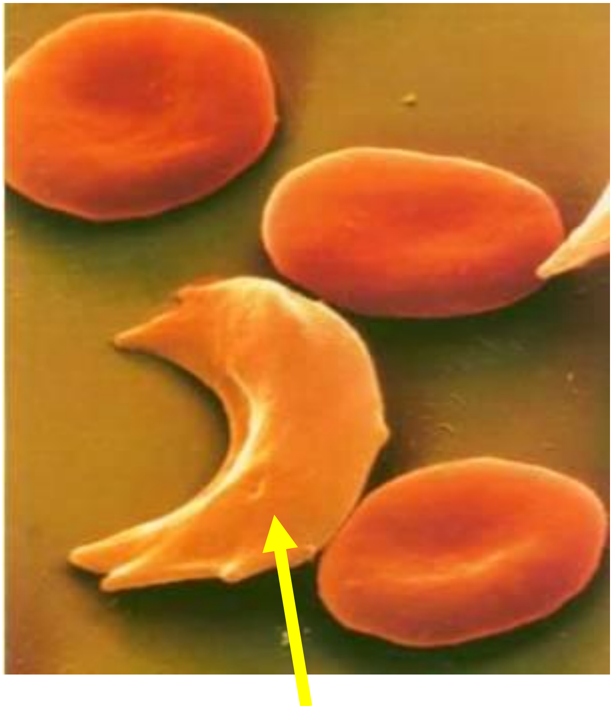
$p_2 = 2/20 = .1$
$q_2 = 18/20 = .9 = 1\text{-}p_2$

These populations exhibit genetic structure!

Sickled cells and malaria resistance



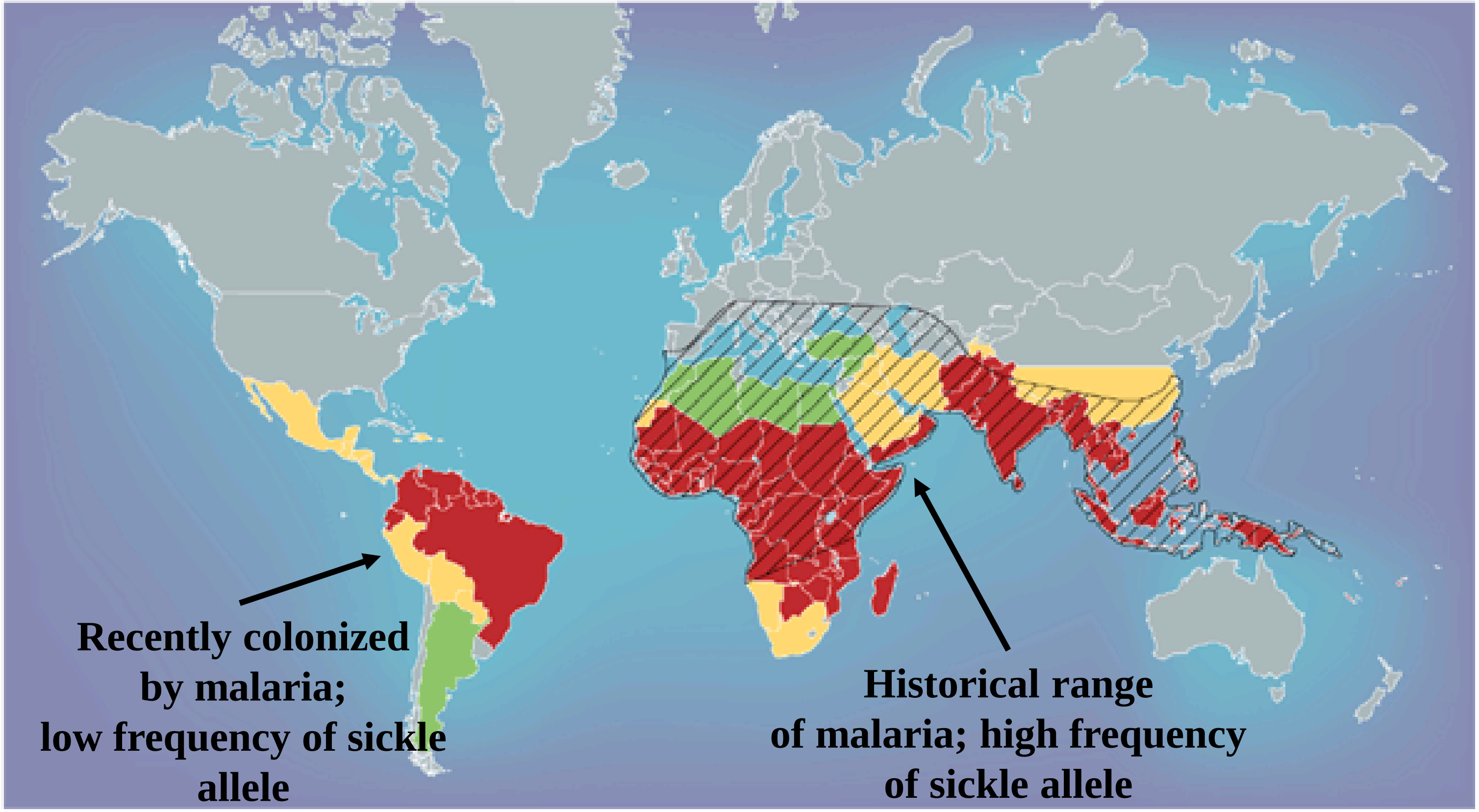
Malaria in red blood cells



A ‘sickled’ red blood cell

Genotype	Phenotype
AA	Normal red blood cells, malaria susceptible
Aa	Mostly normal red blood cells, malaria resistant
aa	Mostly sickled cells, very sick

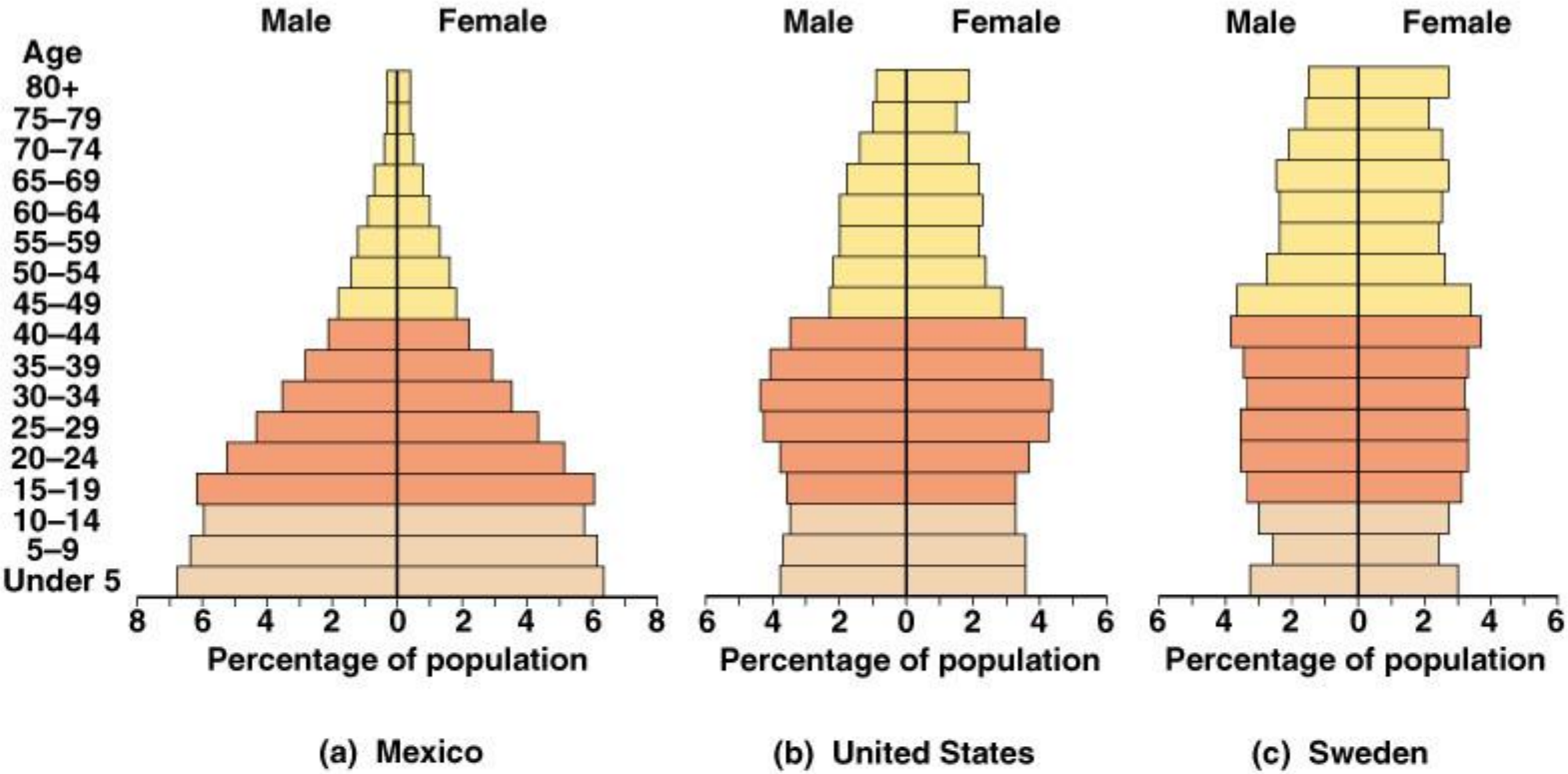
Global distribution of Malaria and the Sickle cell gene



Nature Reviews | Genetics

The frequency of the sickle cell gene is higher in populations where Malaria has been prevalent historically

Describing populations III – Age structure



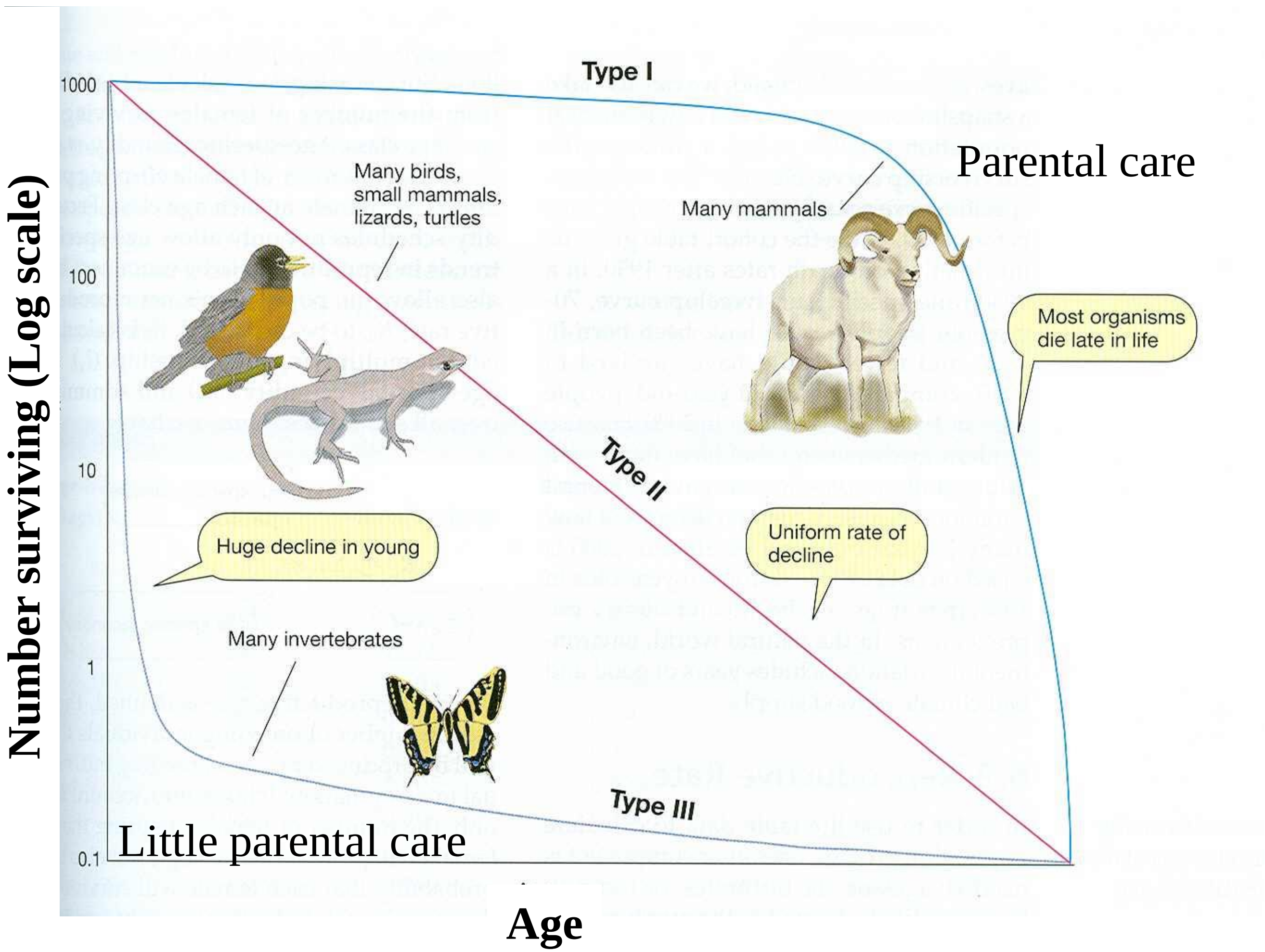
(a) Mexico (b) United States (c) Sweden

Copyright © 2003 Pearson Education, Inc., publishing as Benjamin Cummings.

What determines a population's age structure?

- Probability of death for various age classes
- Probability of reproducing for various age classes
- These probabilities are summarized using life tables

Mortality schedules: the probability of surviving to age *x*



We can quantify mortality schedules using life table

Quantifying mortality using life tables

Age class

Number alive at age x

Proportion surviving to age x

x	N_x	l_x
1	1000	1.000
2	916	.916
3	897	.897
4	897	.897
5	747	.747
6	426	.426
7	208	.208
8	150	.150
9	20	.020

How could you collect this data in a natural population?

Now let's work through calculating the entries

Calculating entries of the life table: l_x

The proportion surviving to age class x = The probability of surviving to age class x

$$l_x = N_x/N_0$$

Follow a single 'cohort'

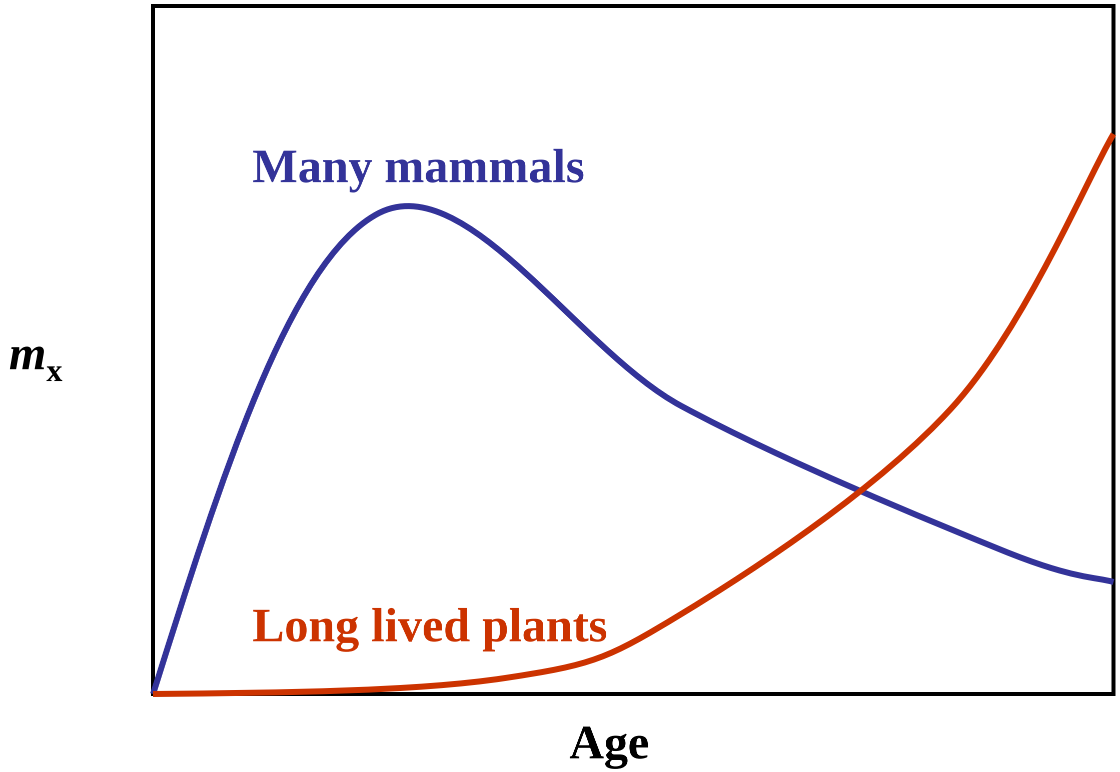
x	N_x	l_x
1	1000	1.000
2	916	$= N_2/N_1 = 916/1000 = .916$
3	897	$= N_3/N_1 = 897/1000 = .897$
4	897	$= N_4/N_1 = 897/1000 = .897$
5	747	$= N_5/N_1 = 747/1000 = .747$
6	426	$= N_6/N_1 = 426/1000 = .426$
7	208	$= N_7/N_1 = 208/1000 = .208$
8	150	$= N_8/N_1 = 150/1000 = .150$
9	20	$= N_9/N_1 = 20/1000 = .020$

What determines a population's age structure?

- Probability of death for various age classes ✓
- # of offspring produced by various age classes
- These probabilities are summarized using life tables

Fecundity schedules: # of offspring produced at age x

m_x = The expected number of daughters produced by mothers of age x



Fecundity can also be summarized using life tables

Summarizing fecundity using a life table

x	l_x	m_x
1	1	0
2	.8	0
3	.6	.5
4	.4	1
5	.2	5

This entry designates the EXPECTED # of offspring produced by an individual of age 4.

In other words, this is the AVERAGE # of offspring produced by individuals of age 4

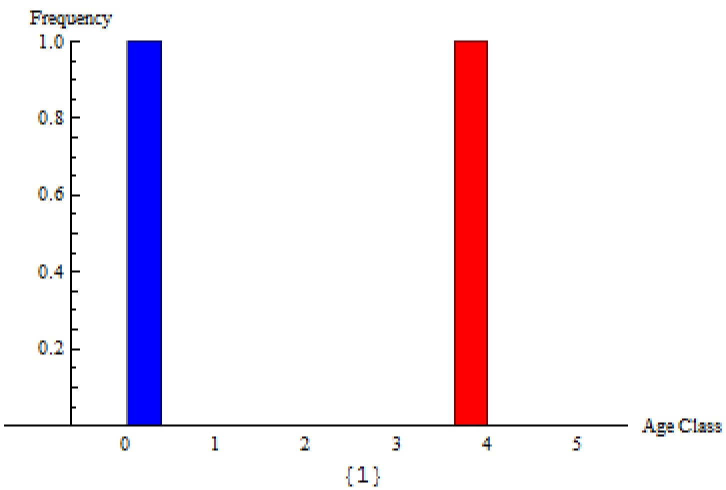
If l_x and m_x do not change, populations reach a stable age distribution

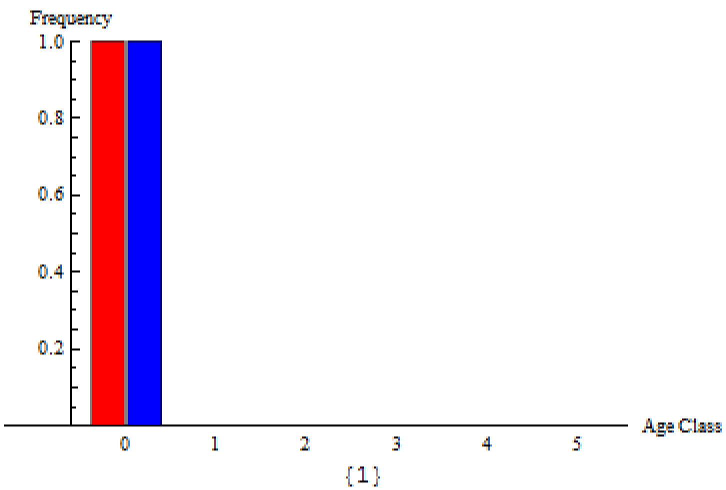
Population starting with all four year olds

Population starting with all one year olds

High juvenile but low adult mortality

Low juvenile but high adult mortality

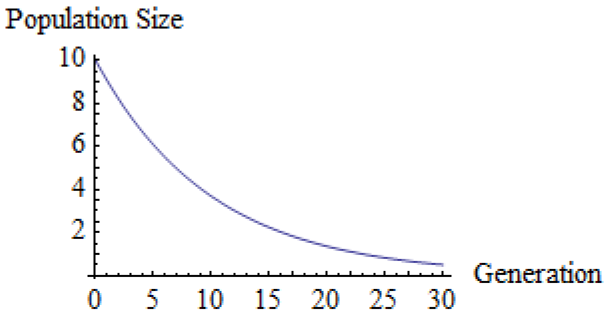




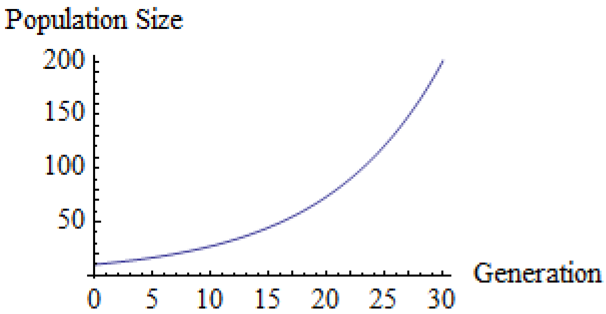
As long as l_x and m_x remain constant, these distributions would never change!

Describing populations IV – Growth rate

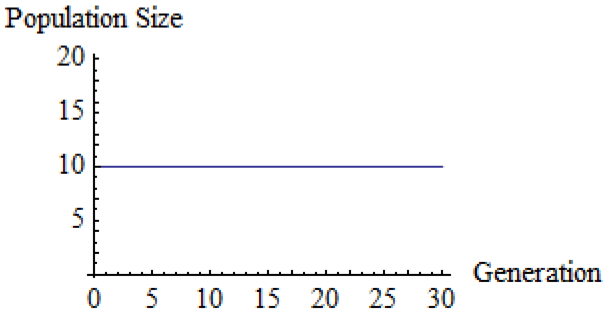
Negative growth



Positive growth

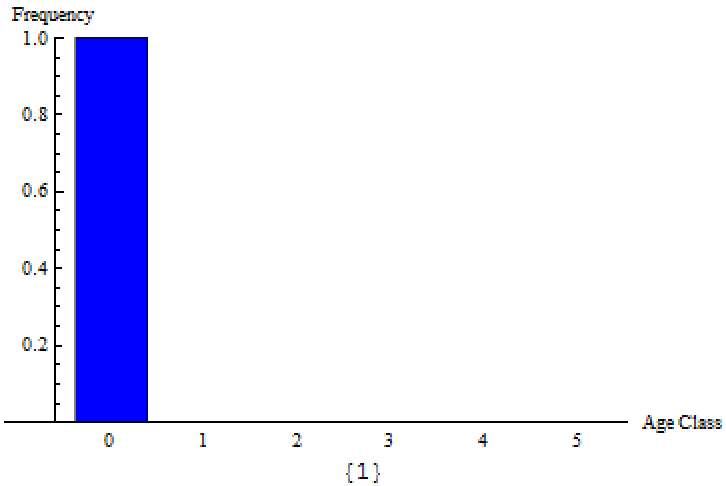


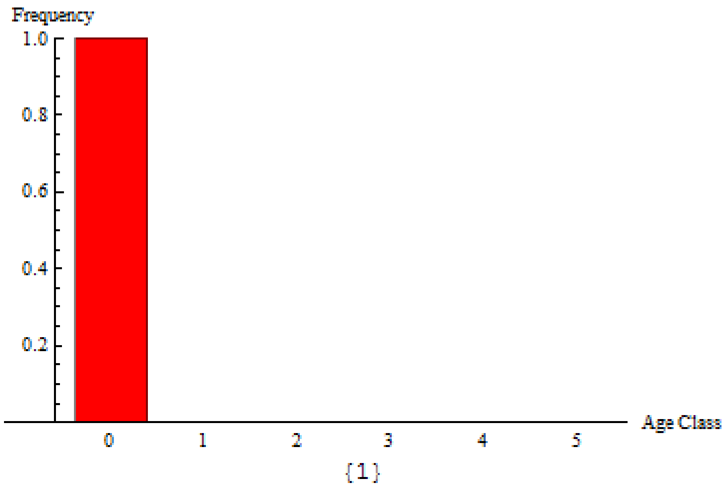
Zero growth

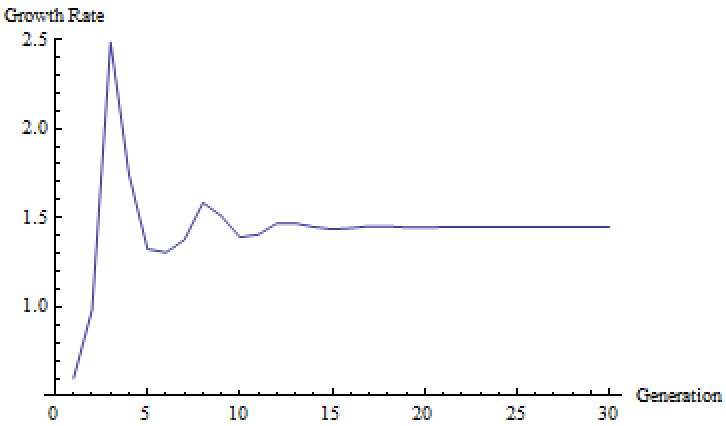


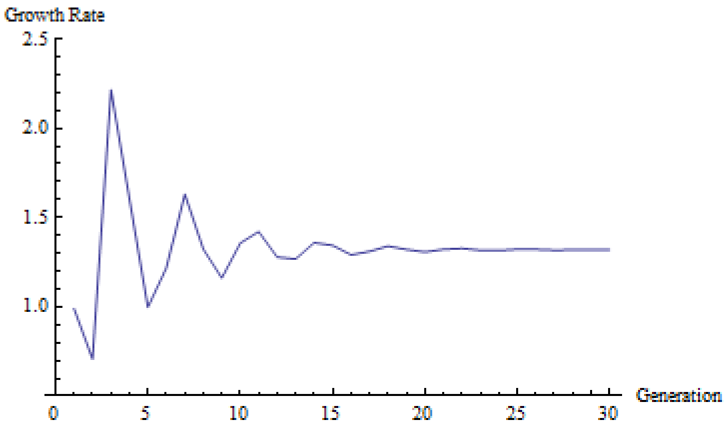
A population's growth rate can be readily estimated
***** if a stable age distribution has been reached *****

Why is a stable age distribution important?









Using life tables to calculate population growth rate

x	l_x	m_x	$l_x m_x$
1	**1**	**0**	**= 1*0 = 0**
2	**.75**	**0**	**= .75*0 = 0**
3	**.5**	**1**	**= .5*1 = .50**
4	**.25**	**4**	**= .25*4 = 1**

The first step is to calculate R_0:

$$R_0 = \sum l_x m_x$$

This number, R_0, tells us the expected number of offspring produced by an individual over its lifetime.

- If $R_0 < 1$, the population size is decreasing
- If $R_0 = 1$, the population size is steady
- If $R_0 > 1$, the population size is increasing

$$\boxed{R_0 = \sum l_x m_x = 1*0 + .75*0 + .5*1 + .25*4 = 1.5}$$

Using life tables to calculate population growth rate

x	l_x	m_x	$l_x m_x$
1	**1**	**0**	**0**
2	**.75**	**0**	**0**
3	**.5**	**1**	**.50**
4	**.25**	**4**	**1**

The second step is to calculate *G*

$$G = \frac{\sum_{x=1}^{k} l_x m_x x}{\sum_{x=1}^{k} l_x m_x}$$

This number, *G*, is a measure of the generation time of the population, or more specifically, the expected (average) age of reproduction

$$G = \frac{\sum_{x=0}^{k} l_x m_x x}{\sum_{x=0}^{k} l_x m_x} = \frac{1*0*1+.75*0*2+.5*1*3+.25*4*4}{1*0+.75*0+.5*1+.25*4} = \frac{5.5}{1.5} = 3.67$$

Using life tables to calculate population growth rate

<u>The last step is to calculate *r*</u>

$$r \approx \frac{\ln(R_0)}{G} = \frac{\ln(1.5)}{3.67} = .110$$

This number, *r*, is a measure of the population growth rate.

Specifically, *r* is the probability that an individual gives birth per unit time minus the probability that an individual dies per unit time.

➔ <u>Population growth rate depends on two things:</u>

1. **Generation time, *G***
2. **The number of offspring produced by each individual over its lifetime, R_0**

The importance of generation time

Imagine two different populations, each with the same R_0:

Population 1

x	l_x	m_x	$l_x m_x$
1	1	0	0
2	.75	0	0
3	.5	1	.50
4	.25	4	1

$R_{0,1} = 1.5$

$G_1 = 3.67$

$r_1 = .110$

Population 2

x	l_x	m_x	$l_x m_x$
1	1	1	1
2	.75	.667	.5
3	.5	0	0
4	.25	0	0

$R_{0,2} = 1.5$

$G_2 = 1.33$

$r_2 = .305$

The growth rate of population 2 is almost three times greater, even though individuals in the two populations have identical numbers of offspring!

Using *r* to predict the future size of a population

The change in population size, *N*, per unit time, *t*, is given by this differential equation:

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

$$\therefore$$

$$\int \frac{1}{N} dN = \int r dt$$

$$\therefore$$

$$\ln N = rt$$

$$\therefore$$

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

⋮

Using basic calculus

⋮

Gives us an equation that predicts the population size at any time *t*, N_t, for a current population of size N_0:

One of the most influential equations in the history of biology

What are the consequences of this result?

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

For population size to remain the same, the following must be true:

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

This is the concept of an *equilibrium*

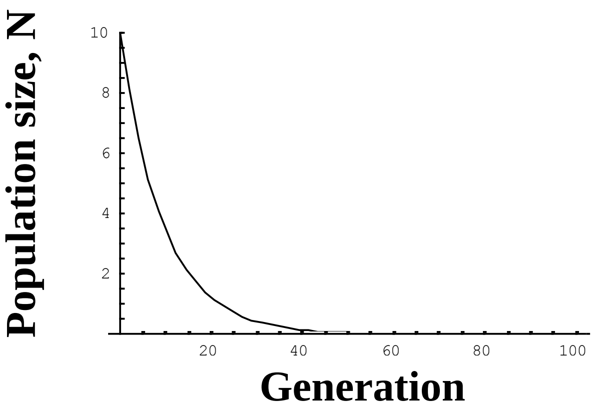
This can only be true if ???

What are the consequences of this result?

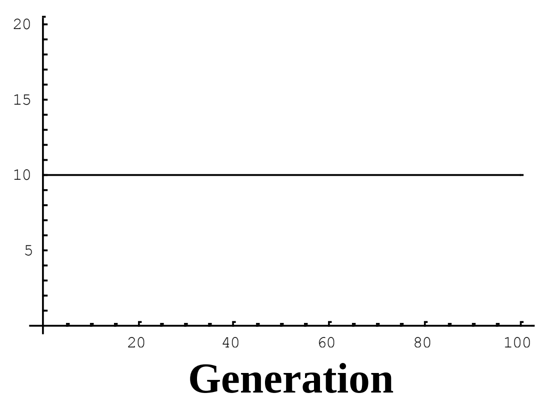
$$\boxed{N_t = N_0 e^{rt}}$$

If *r* is anything other than 0 (R_0 is anything other than 1), the population goes extinct or becomes infinitely large

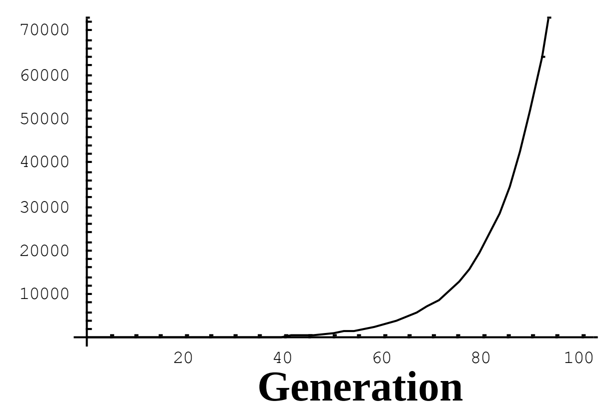
***r* = -.1**



***r* = 0**

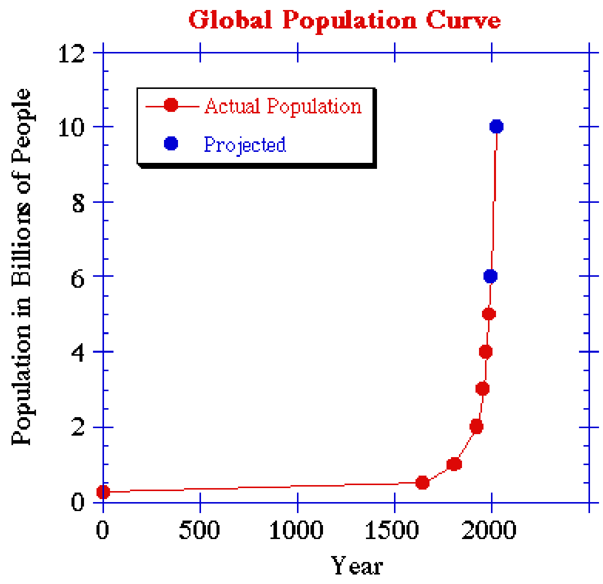


***r* = .1**



A real example of exponential population growth…

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



From 0-1500: Human population increases by ≈ 1.0 billion

From 1500-2000: Human population increases by ≈ 10.0 billion

This observation had important historical consequences…

Using life tables: A practice question

A team of conservation biologists is interested in determining the optimum environment for raising an endangered species of flowering plant in captivity. For their purposes, the optimum environment is the one that maximizes the growth rate of the captive population allowing more individuals to be released into the wild in each generation. To this end, they estimated life table data for two cohorts (each of size 100) of captive plants, each raised under a different set of environmental conditions. Using the data in the hypothetical life tables below, answer the following questions:

Population 1
(in environment 1)

x	N_x	l_x	m_x
1	100	1.0	0
2	50	.50	0
3	25	.25	8
4	10	.10	10

Population 2
(in environment 2)

x	N_x	l_x	m_x
1	100	1.0	2
2	50	.50	2
3	25	.25	0
4	10	.10	0

A. Using the data from the hypothetical life tables above, calculate the expected number of offspring produced by each individual plant over its life, R_0, for each of the populations.

B. Using the data in the life tables above, calculate the generation time for each of the populations.

C. Using your calculations in A and B, estimate the population growth rate, *r*, of the two populations. Which population is growing faster? Why?

D. Assuming the populations both initially contain 100 individuals, estimate the size of each population in five years.

E. If the sole goal of the conservation biologists was to maximize the growth rate of the captive population, which conditions (those experienced by population 1 or 2) should they use for their future programs?

*** We will work through this problem during the next class. Be prepared***