Biodiversity and **E**cology

Lecture III&IV Population Ecology

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Did Kyle convinced you to become an ecologist?

Population Ecology

The study of populations in relation to the environment, including environmental influences on population density and distribution, age structure, and variations in population size.

Population

group of individuals of a single species living in the same general area

The interactions between individuals and their environment shape the population

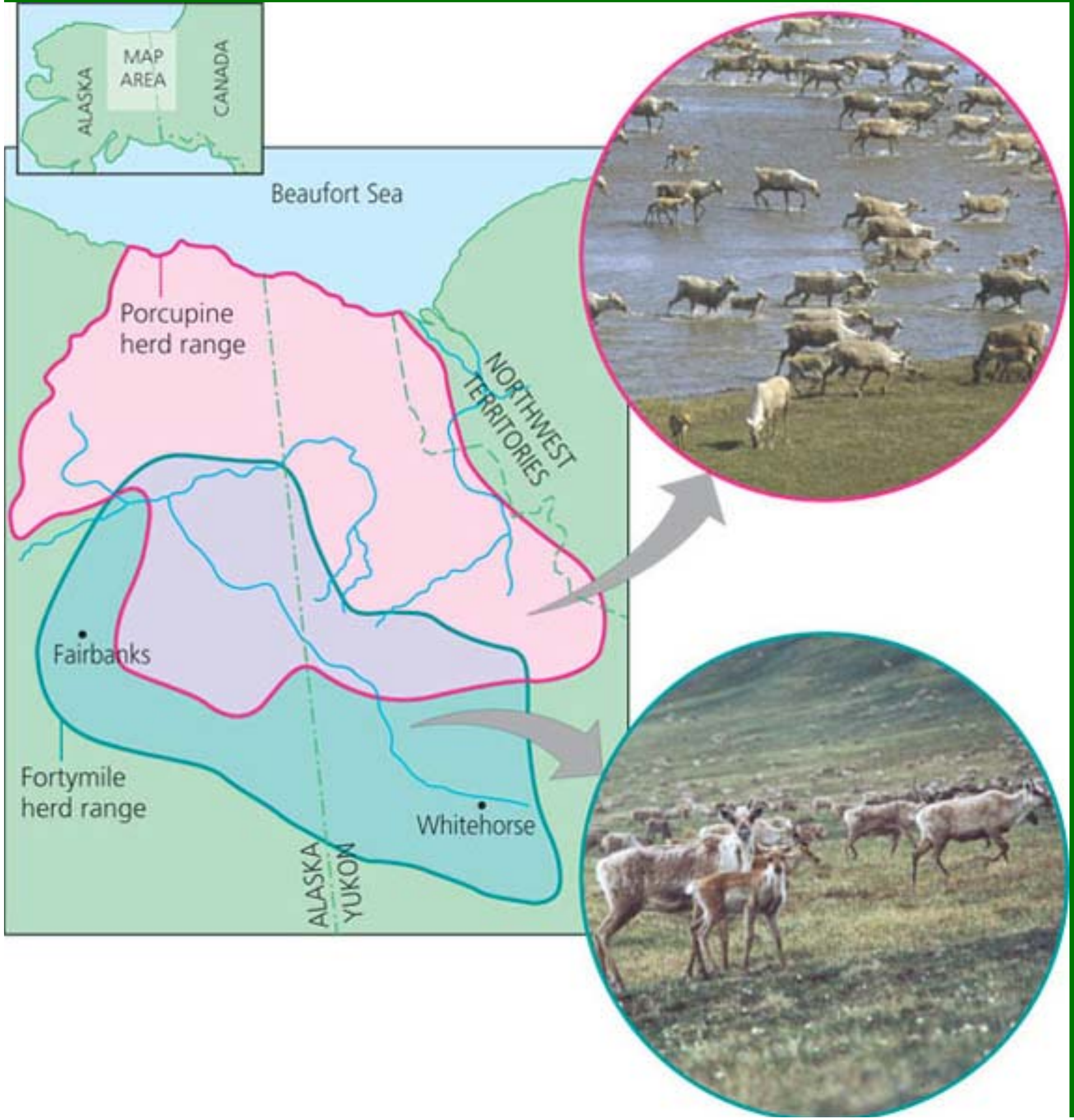
At any given moment, every population has specific boundaries and a specific size (the number of individuals living within those boundaries).

DENSITY
number of individuals per unit area or volume

DISPERSION
the pattern of spacing among individuals within the boundaries of the population

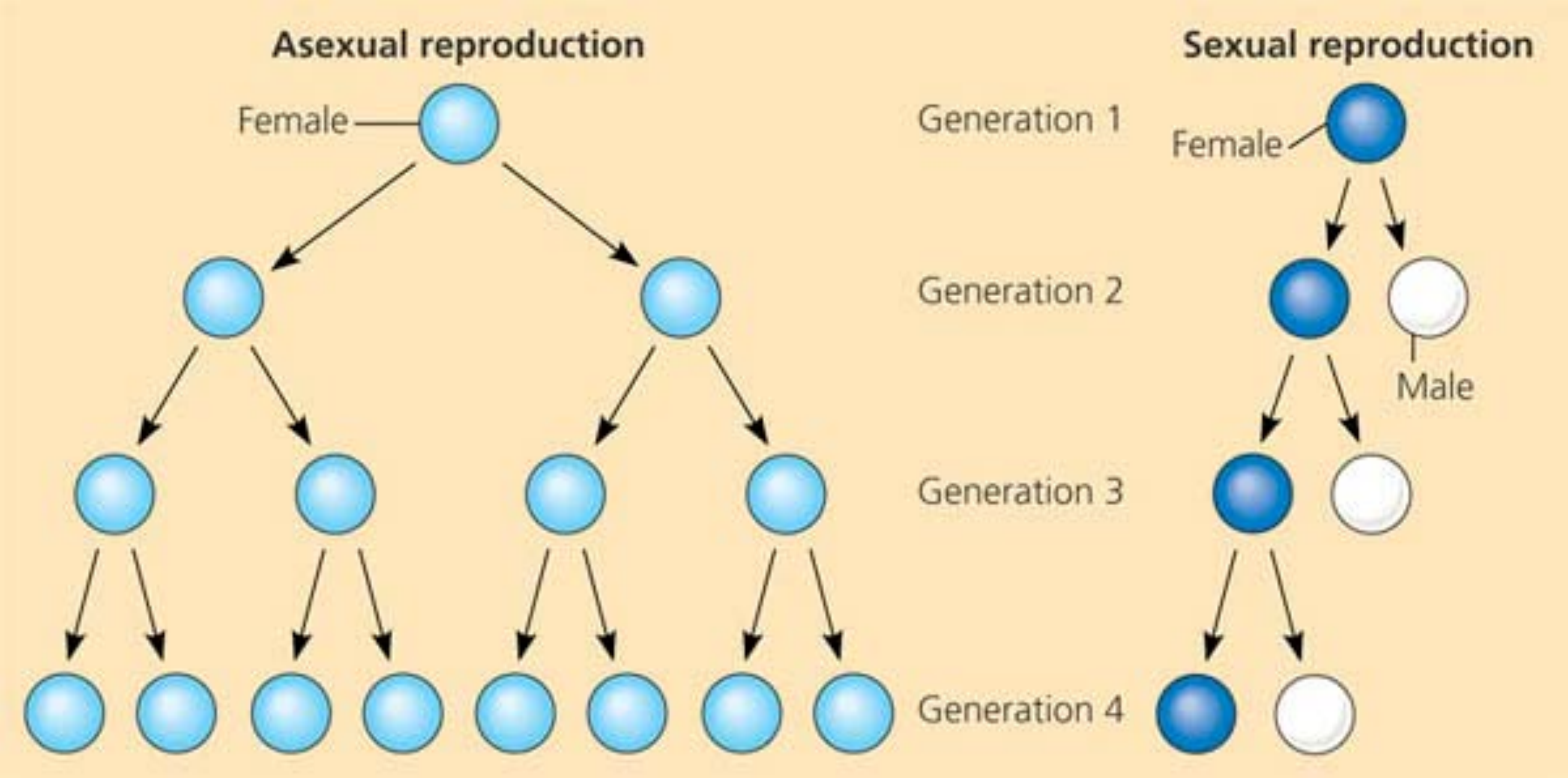
Population genetics

how populations change genetically over time

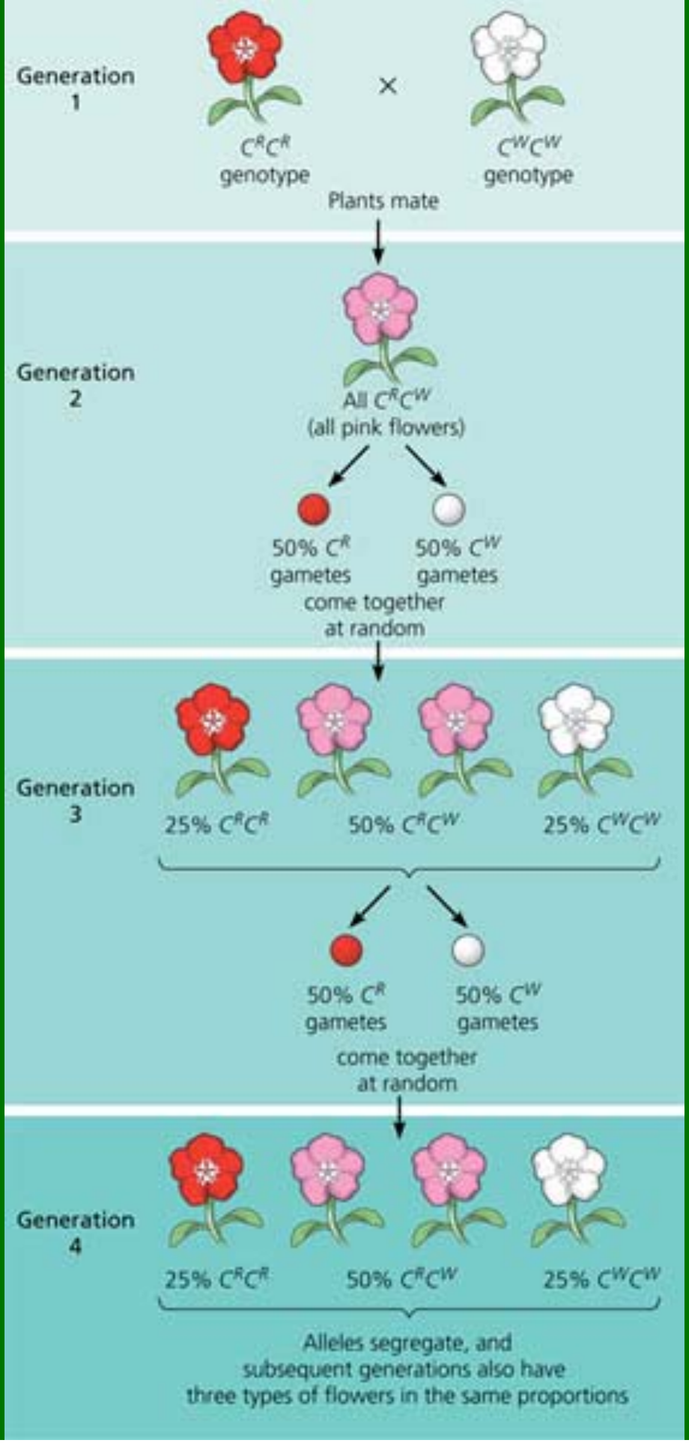


One species, two populations. These two caribou populations in the Yukon are not totally isolated—they sometimes share the same area. Nonetheless, members of either population are more likely to breed with members of their own population than with members of the other population.

Mutation and **sexual recombination** produce the variation that makes evolution possible

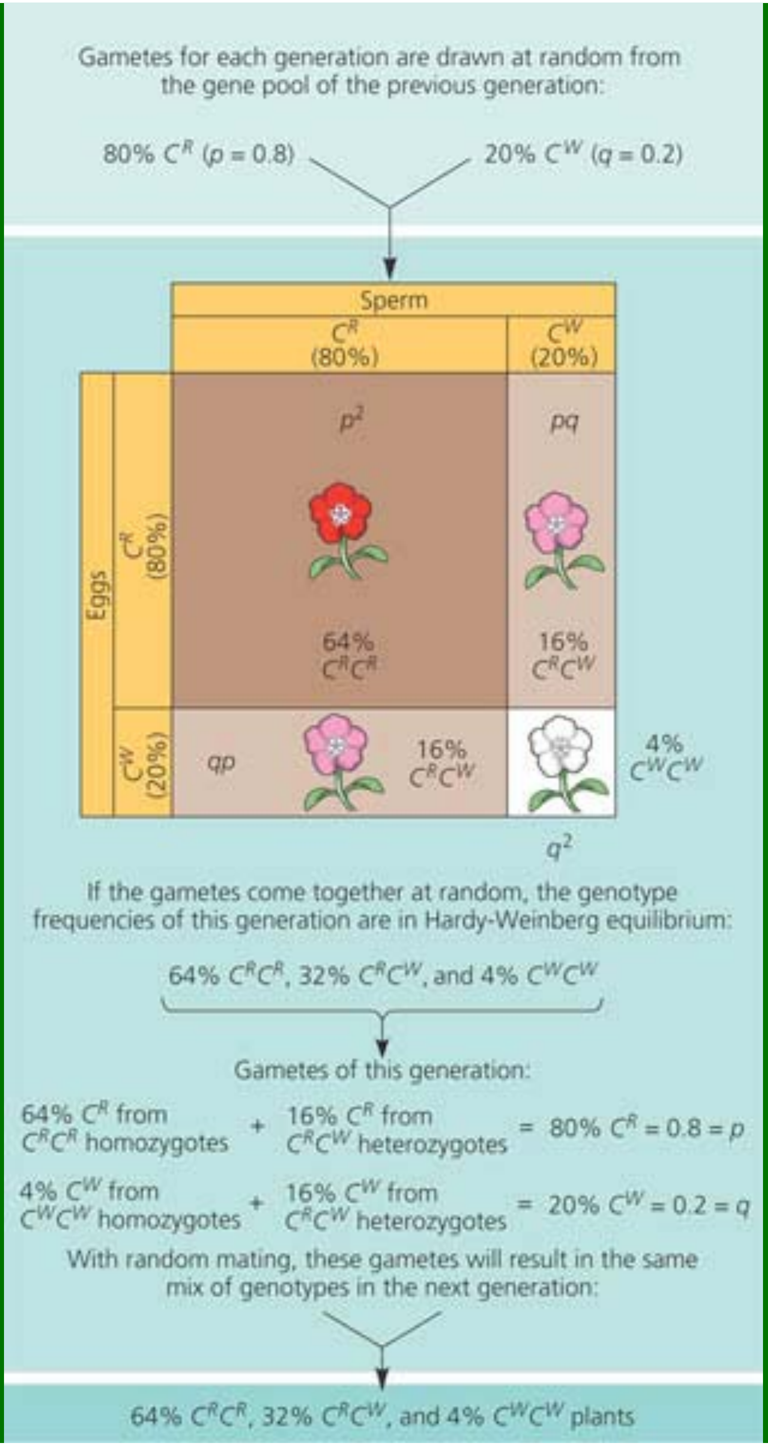

Asexual reproduction
Sexual reproduction
Female
Generation 1
Female
Generation 2
Male
Generation 3
Generation 4

How can we quantify the genetic variation within a population?



The Hardy–Weinberg Theorem

The theorem states that the frequencies of alleles and genotypes in a population′s gene pool remain constant from generation to generation, provided that only Mendelian segregation and recombination of alleles are at work



Gametes for each generation are drawn at random from the gene pool of the previous generation:

80% C^R ($p = 0.8$)

20% C^W ($q = 0.2$)

If the gametes come together at random, the genotype frequencies of this generation are in Hardy-Weinberg equilibrium:

64% C^RC^R, 32% C^RC^W, and 4% C^WC^W

Gametes of this generation:

64% C^R from C^RC^R homozygotes + 16% C^R from C^RC^W heterozygotes = 80% $C^R = 0.8 = p$

4% C^W from C^WC^W homozygotes + 16% C^W from C^RC^W heterozygotes = 20% $C^W = 0.2 = q$

With random mating, these gametes will result in the same mix of genotypes in the next generation:

64% C^RC^R, 32% C^RC^W, and 4% C^WC^W plants

$$\underbrace{(p + q)}_{\text{Allele frequencies of male gametes}} \times \underbrace{(p + q)}_{\text{Allele frequencies of female gametes}} = \underbrace{p^2 + 2pq + q^2}_{\text{Genotype frequencies in the next generation}}$$

$$p^2 + 2pq + q^2 = 1$$

If you know p, or q you can know how many heterozygous...etc

Conditions for Hardy–Weinberg Equilibrium

1. **Extremely large population size.** The smaller the population, the greater the role played by chance fluctuations in allele frequencies from one generation to the next, known as genetic drift.

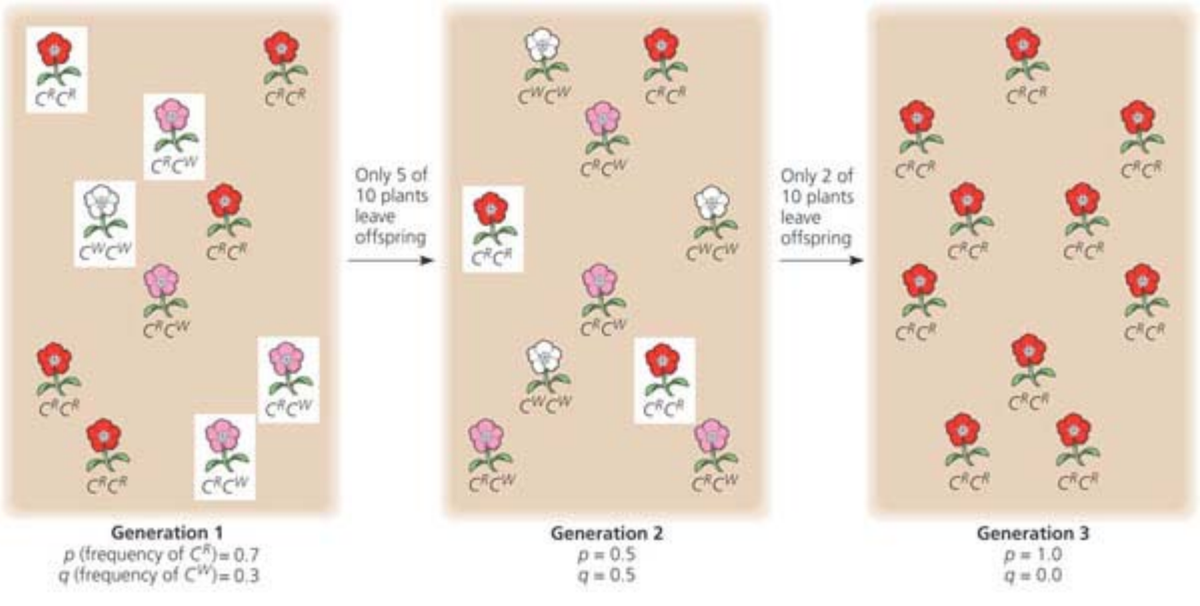
2. **No gene flow.** Gene flow, the transfer of alleles between populations, can alter allele frequencies.

3. **No mutations**. By introducing or removing genes from chromosomes or by changing one allele into another, mutations modify the gene pool.

4. **Random mating.** If individuals preferentially choose mates with certain genotypes, including close relatives (inbreeding), random mixing of gametes does not occur.

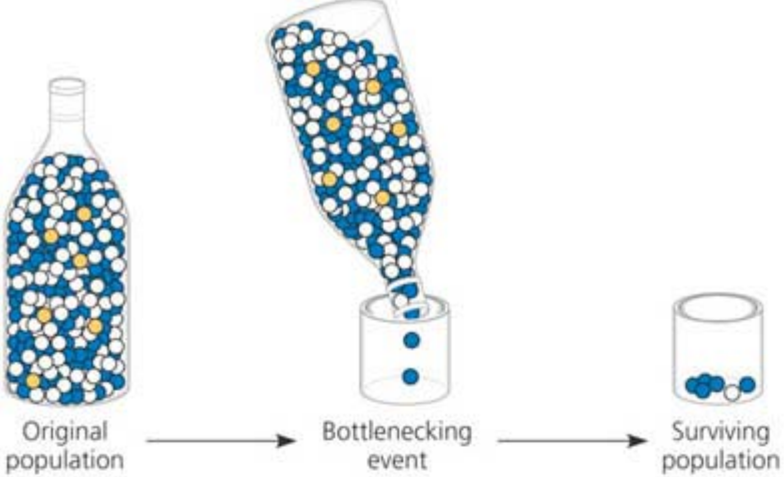
5. **No natural selection**. Differential survival and reproductive success of individuals carrying different genotypes will alter allele frequencies.

Genetic drift



Unpredictable fluctuations in allele frequencies from one generation to the next because of a population′s finite size.

Bottleneck effect



(a) Shaking just a few marbles through the narrow neck of a bottle is analogous to a drastic reduction in the size of a population after some environmental disaster. By chance, blue marbles are over-represented in the new population and gold marbles are absent.

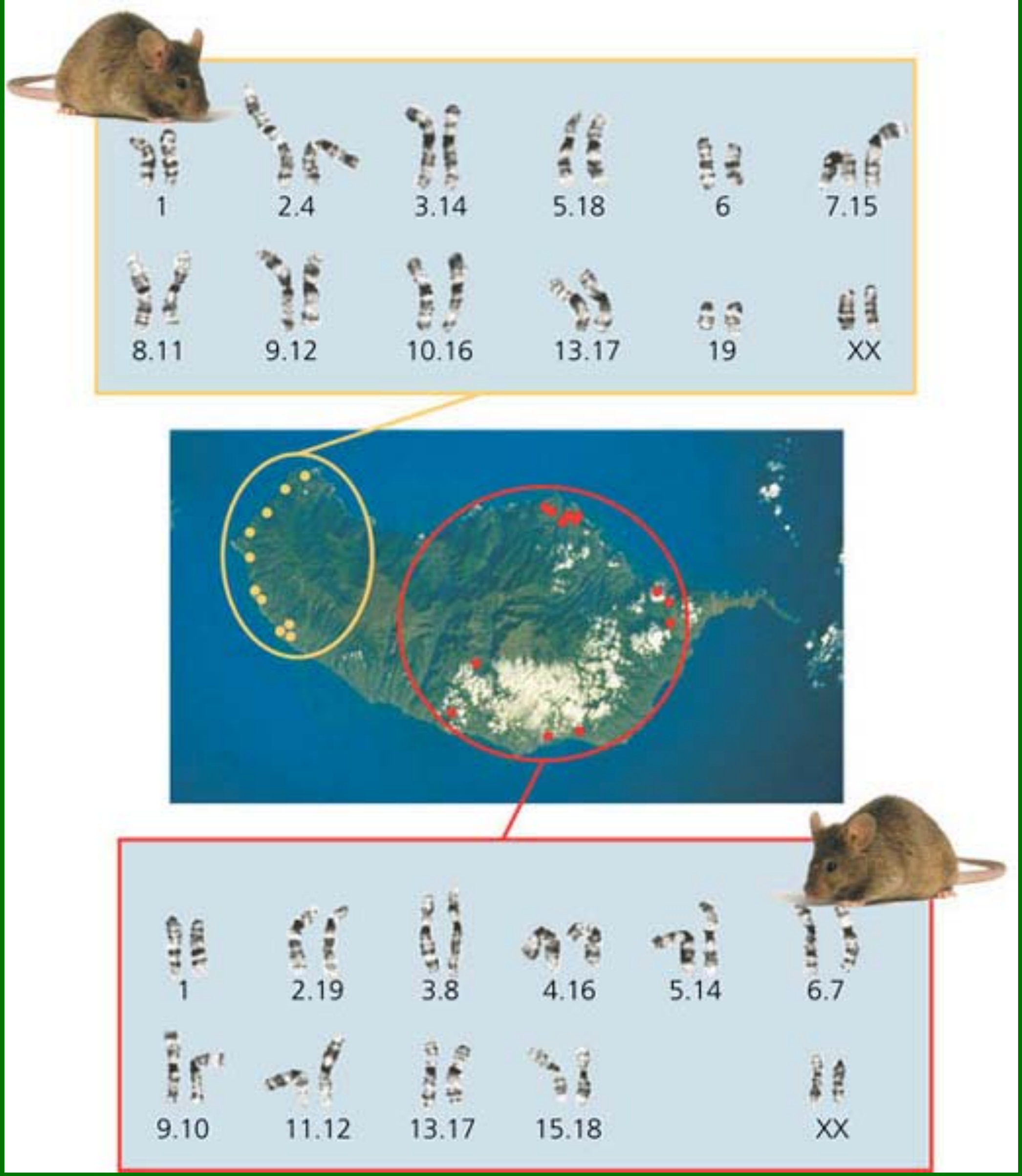
(b) Similarly, bottlenecking a population of organisms tends to reduce genetic variation, as in these northern elephant seals in California that were once hunted nearly to extinction.

Genetic drift resulting from the reduction of a population, typically by a natural disaster, such that the surviving population is no longer genetically representative of the original population.

founder effect

Genetic drift that occurs when a few individuals become isolated from a larger population, with the result that the new population’s gene pool is not reflective of the original population.

Geographic variation in chromosomal mutations.



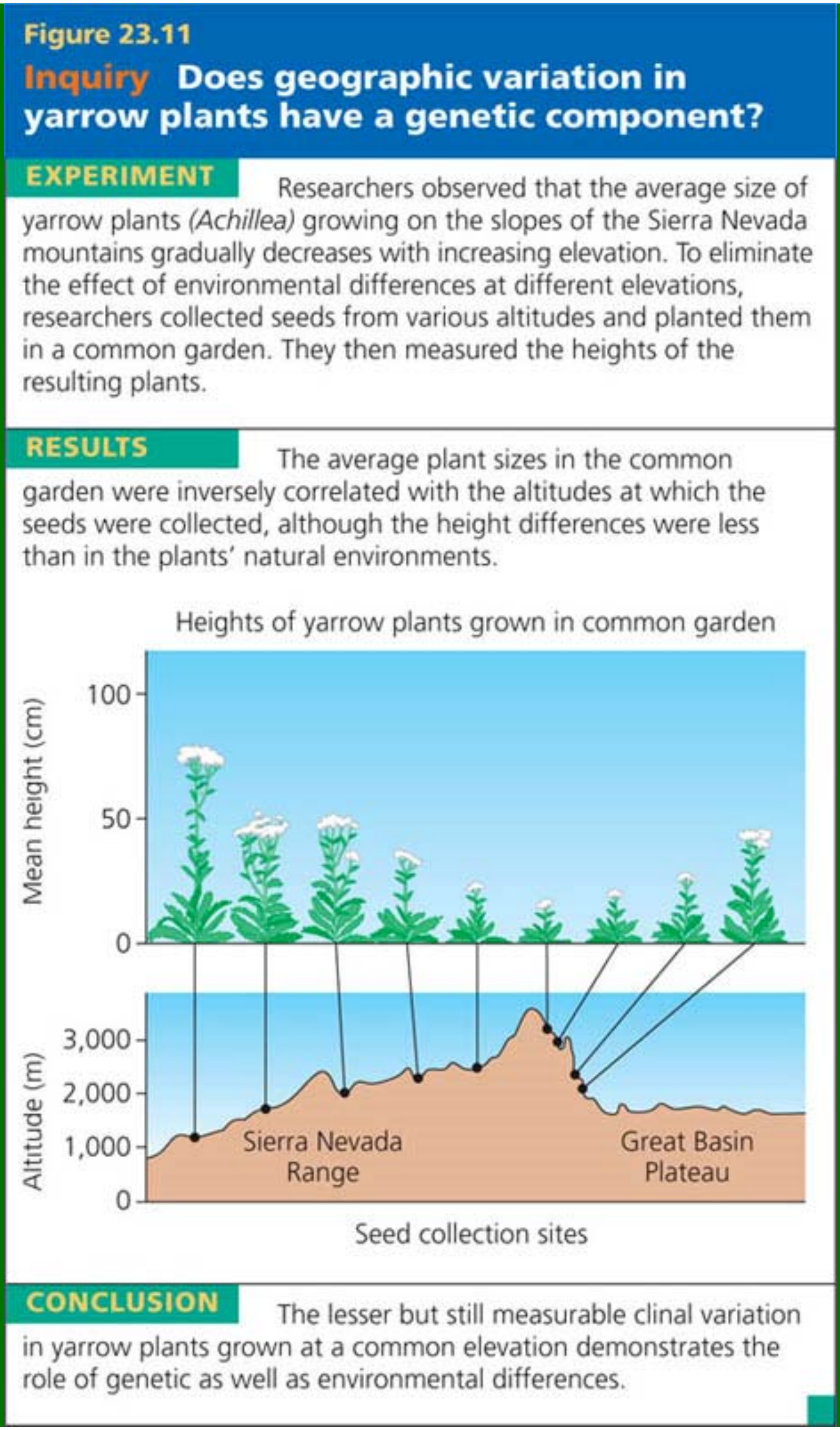


Figure 23.11

Inquiry Does geographic variation in yarrow plants have a genetic component?

EXPERIMENT Researchers observed that the average size of yarrow plants *(Achillea)* growing on the slopes of the Sierra Nevada mountains gradually decreases with increasing elevation. To eliminate the effect of environmental differences at different elevations, researchers collected seeds from various altitudes and planted them in a common garden. They then measured the heights of the resulting plants.

RESULTS The average plant sizes in the common garden were inversely correlated with the altitudes at which the seeds were collected, although the height differences were less than in the plants' natural environments.

Heights of yarrow plants grown in common garden

CONCLUSION The lesser but still measurable clinal variation in yarrow plants grown at a common elevation demonstrates the role of genetic as well as environmental differences.

Environment
X
Genotype

gene flow

Genetic additions to or substractions from a population resulting from the movement of fertile individuals or gametes.

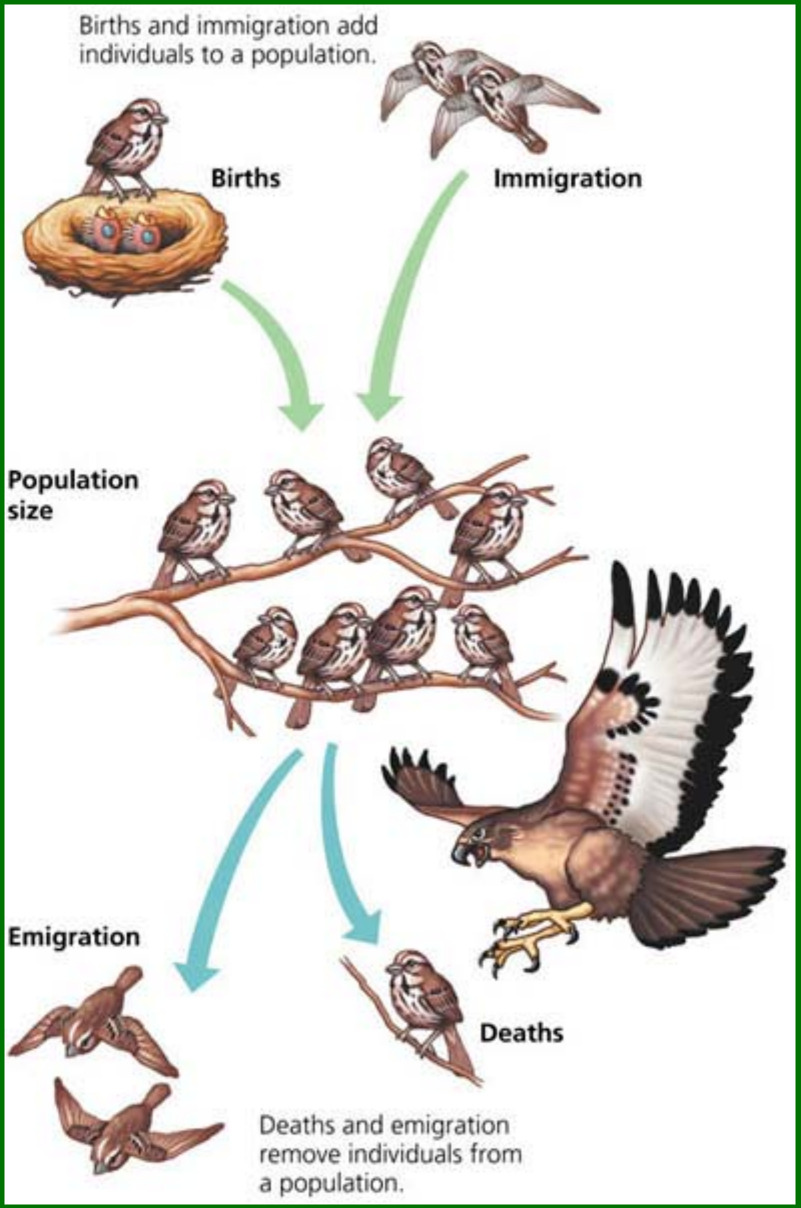
A population can be described in terms of its density and its dispersion

Density is a dynamic property of a population

births
migration
deaths

↓

population size


Births and immigration add individuals to a population.

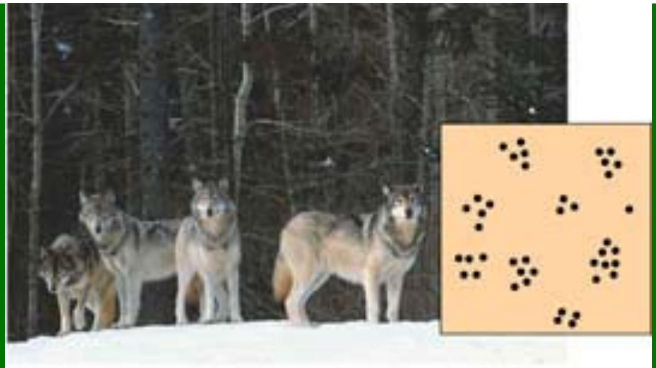
Deaths and emigration remove individuals from a population.

Local densities may vary considerably within a population's geographic range.

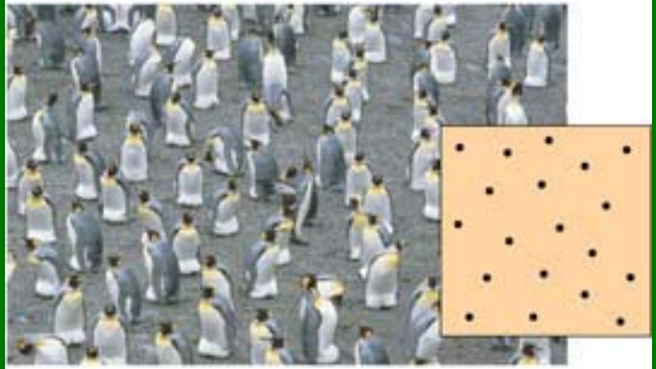
Depending on the distribution of resources and predators, different dispersion patterns result within the range of a population

Territoriality: A behavior in which an animal defends a bounded physical space against encroachment by other individuals, usually of its own species. Territory defense may involve direct aggression or indirect mechanisms such as scent marking or singing.

Patterns of Dispersion



(a) Clumped. For many animals, such as these wolves, living in groups increases the effectiveness of hunting, spreads the work of protecting and caring for young, and helps exclude other individuals from their territory.



(b) Uniform. Birds nesting on small islands, such as these king penguins on South Georgia Island in the South Atlantic Ocean, often exhibit uniform spacing, maintained by aggressive interactions between neighbors.

(c) Random. Dandelions grow from windblown seeds that land at random and later germinate.

CLUMPED

individuals aggregate in patches.

UNIFORM

individuals are evenly spaced.

RANDOM

the position of each individual is independent of the others.

CLUMPED CLUMPED UNIFORM

CLUMPED CLUMPED UNIFORM

Measuring Population Density

Direct measurement: counting the individuals

Indirect measurement: mark-recapture method

The number of tagged individuals relative to that of all individuals captured allows estimates of population size to be made:

Ntagged+re-captured/Ncaptured = Ntagged/N

N = Ntagged/(Ntagged+re-captured/Ncaptured)

N = Ntagged * Ncaptured/(Ntagged+re-captured)

Repeated application allows estimates of changes in population size

Populations are dynamic, they grow and decline.

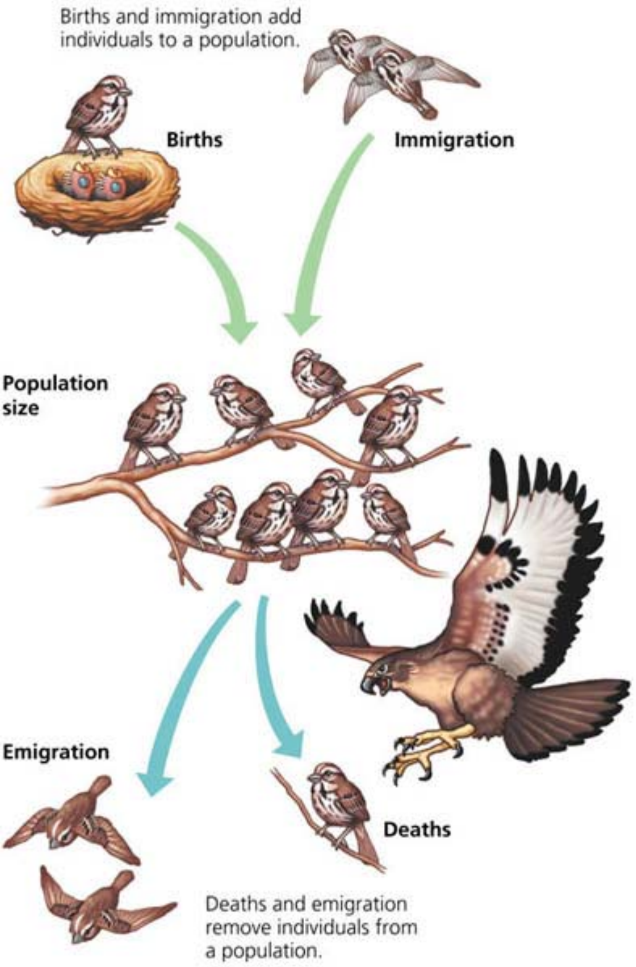
Demography is the study of the vital statistics of populations and how they change over time

Demography studies factors that affect population size and predict changes in population size.

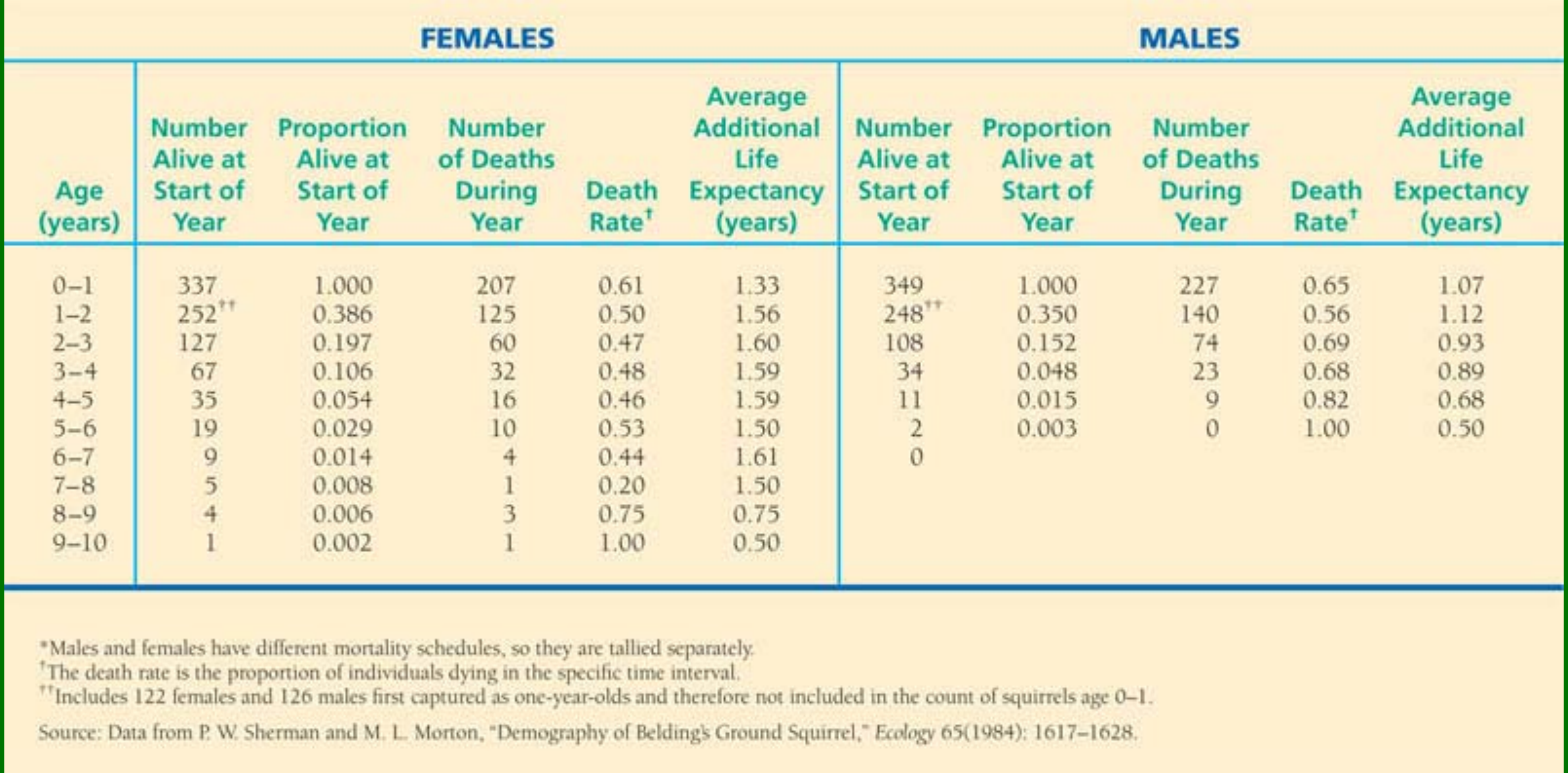
additions occur through birth & immigration,
subtractions occur through death & emigration.

Life tables and reproductive tables are the basic tools.

A **life table** is an age-specific summary of the survival pattern in a population



The best way to construct a life table is to follow the fate of a cohort , a group of individuals of the same age, from birth until all are dead.



	FEMALES					MALES				
Age (years)	Number Alive at Start of Year	Proportion Alive at Start of Year	Number of Deaths During Year	Death Rate[†]	Average Additional Life Expectancy (years)	Number Alive at Start of Year	Proportion Alive at Start of Year	Number of Deaths During Year	Death Rate[†]	Average Additional Life Expectancy (years)
0–1	337	1.000	207	0.61	1.33	349	1.000	227	0.65	1.07
1–2	252[††]	0.386	125	0.50	1.56	248[††]	0.350	140	0.56	1.12
2–3	127	0.197	60	0.47	1.60	108	0.152	74	0.69	0.93
3–4	67	0.106	32	0.48	1.59	34	0.048	23	0.68	0.89
4–5	35	0.054	16	0.46	1.59	11	0.015	9	0.82	0.68
5–6	19	0.029	10	0.53	1.50	2	0.003	0	1.00	0.50
6–7	9	0.014	4	0.44	1.61	0				
7–8	5	0.008	1	0.20	1.50					
8–9	4	0.006	3	0.75	0.75					
9–10	1	0.002	1	1.00	0.50					

*Males and females have different mortality schedules, so they are tallied separately.

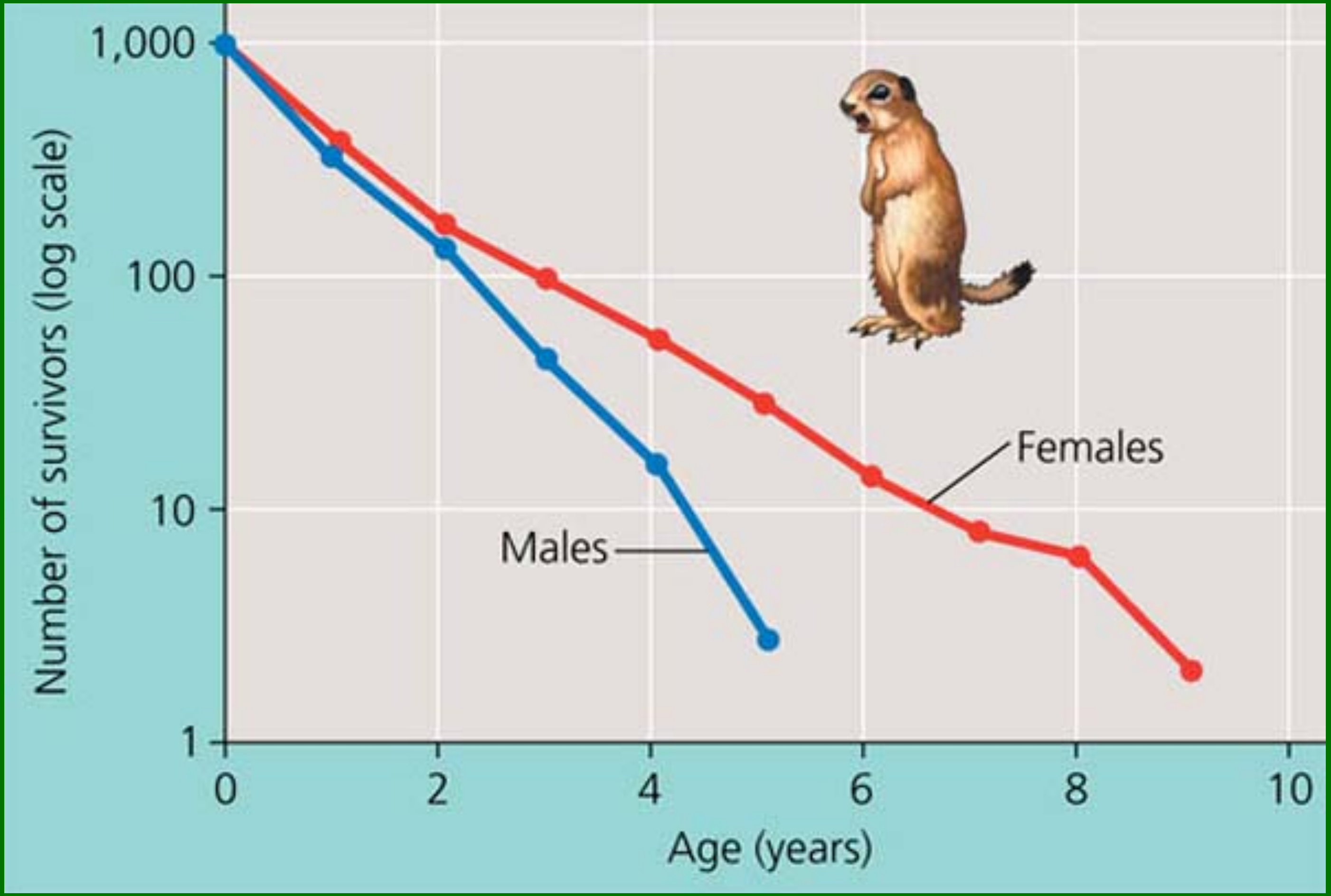
[†] The death rate is the proportion of individuals dying in the specific time interval.

[††] Includes 122 females and 126 males first captured as one-year-olds and therefore not included in the count of squirrels age 0–1.

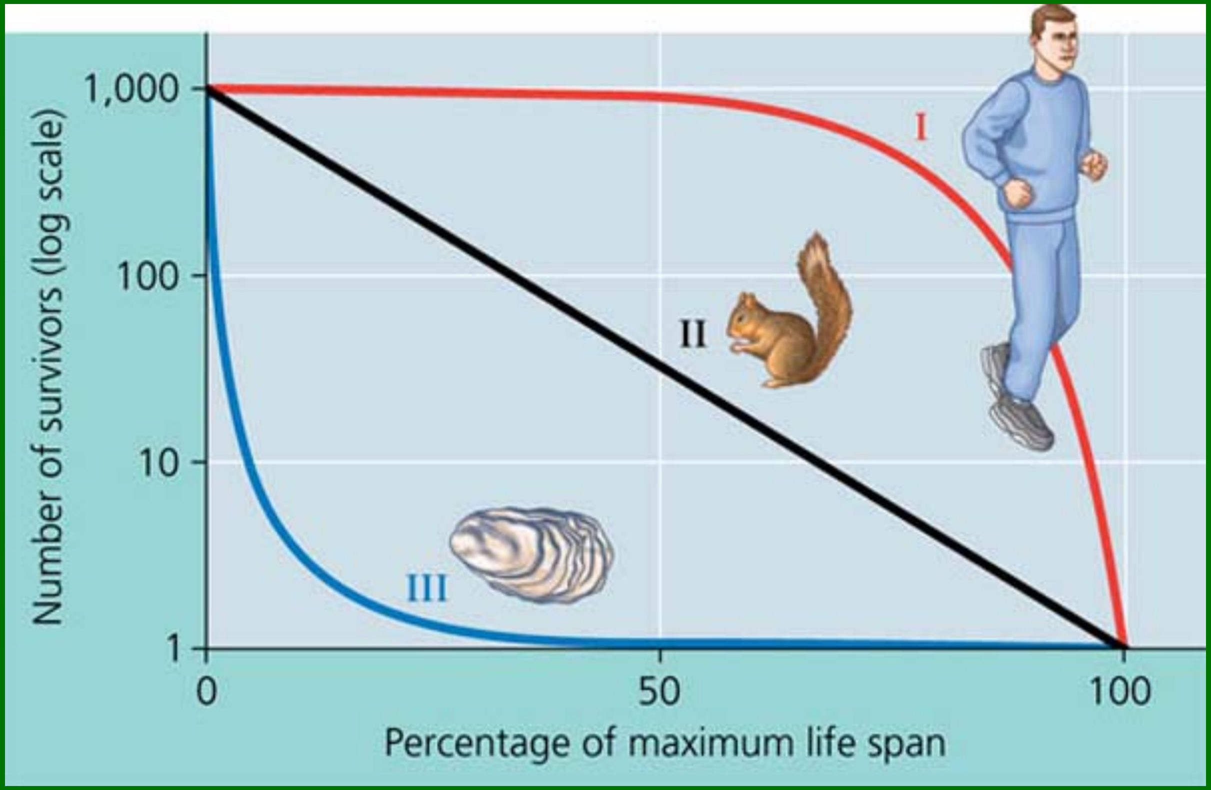
Source: Data from P. W. Sherman and M. L. Morton, "Demography of Belding's Ground Squirrel," *Ecology* 65(1984): 1617–1628.

Survivorship curve

A plot of the number of members of a cohort that are still alive at each age; way to represent age–specific mortality.



survivorship curves can be classified into three general types



high death rate
early in life
(oysters).
III

constant
mortality
(squirrels).
II

low death rate
early in life
(humans).
I

Reproductive Rates

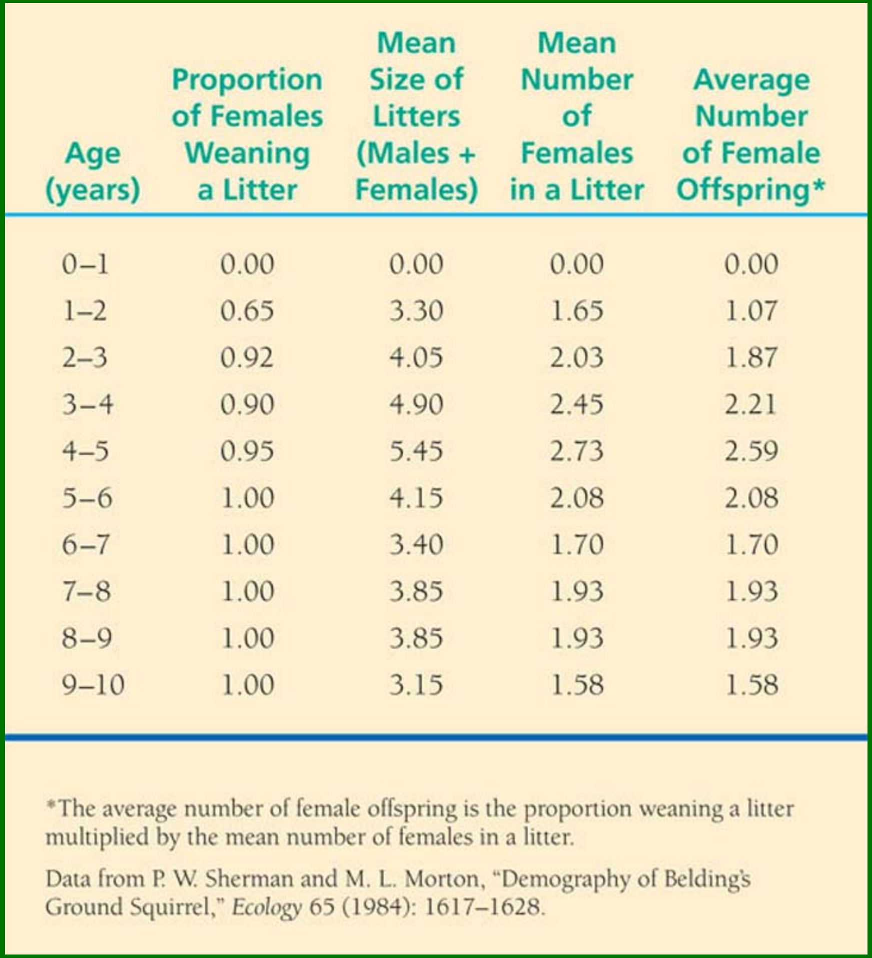
Demographers who study sexually reproducing species generally ignore males and concentrate on females in a population because only females produce offspring.

Demographers view populations in terms of females giving rise to new females; males are important only as distributors of genes.

The simplest way to describe the reproductive pattern of a population is to ask how reproductive output varies with the ages of females.

An age–specific summary of the reproductive rates in a population

An age–specific summary of the reproductive rates in a population
Reproductive Table



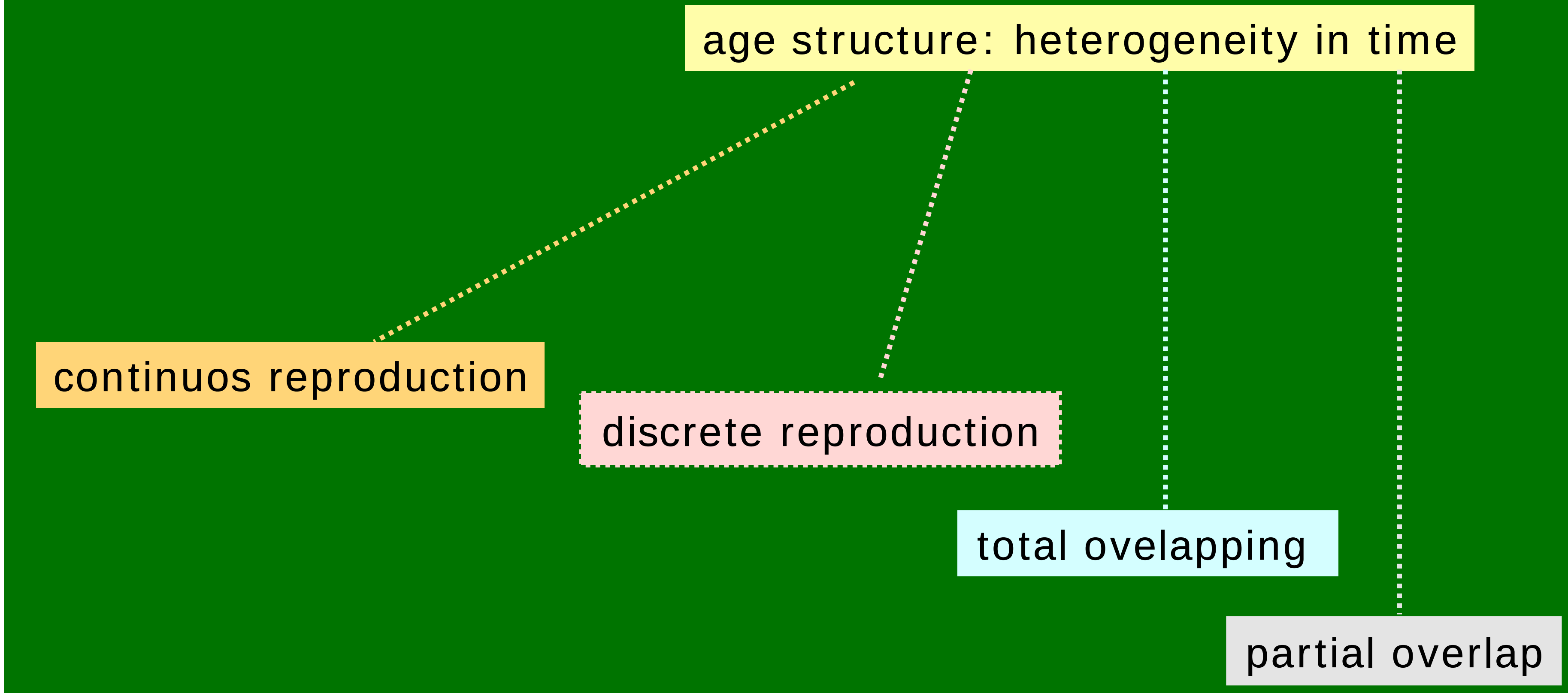
Age (years)	Proportion of Females Weaning a Litter	Mean Size of Litters (Males + Females)	Mean Number of Females in a Litter	Average Number of Female Offspring*
0–1	0.00	0.00	0.00	0.00
1–2	0.65	3.30	1.65	1.07
2–3	0.92	4.05	2.03	1.87
3–4	0.90	4.90	2.45	2.21
4–5	0.95	5.45	2.73	2.59
5–6	1.00	4.15	2.08	2.08
6–7	1.00	3.40	1.70	1.70
7–8	1.00	3.85	1.93	1.93
8–9	1.00	3.85	1.93	1.93
9–10	1.00	3.15	1.58	1.58

*The average number of female offspring is the proportion weaning a litter multiplied by the mean number of females in a litter.

Data from P. W. Sherman and M. L. Morton, "Demography of Belding's Ground Squirrel," *Ecology* 65 (1984): 1617–1628.

Populations has a temporal and spatial continuity

Density and Dispersion



age structure: heterogeneity in time

continuos reproduction

discrete reproduction

total ovelapping

partial overlap

1-How population Grow

2-How populations evolve

3-Fluctuations and population cycles

Population Growth models

1. The exponential model of population growth describes an idealized population in an unlimited environment

2. The logistic model of population growth incorporates the concept of limiting resources (*carrying capacity*)

maximum stable population size a particular environment can support

Exponential Population Growth model

A change in population size is based on the following verbal equation:

Change in population size during time interval = Births during time interval – Deaths during time interval

Using mathematical notation we can express this relationship as follows:

If N represents population size, and t represents time, then ΔN is the change in population size and Δt is the change in time:

$$\Delta N/\Delta t = B - D$$

where B is the number of births and D is the number of deaths in the population, or:

$$\Delta N/\Delta t = bN - dN$$

where b and d are the per capita birth and death rates, and $B = bN$; $D = dN$

Difference between the per capita birth rate and per capita death rate

per capita rate of increase, or r: $r = b - d$

ZPG= A period of stability in population size, when the per capita birth rate and death rate are equal.

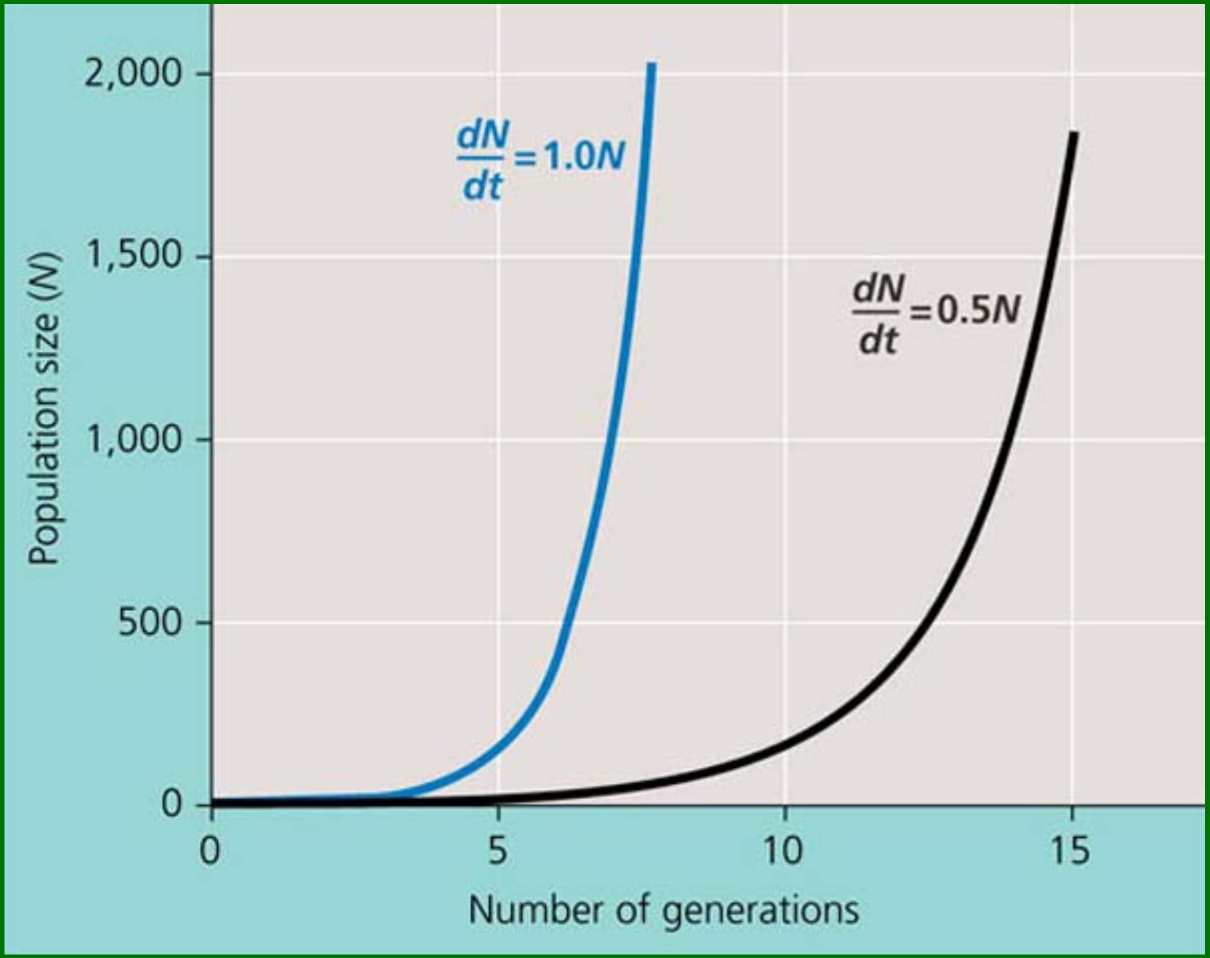
Under ideal conditions, the per capita population growth may assume the maximum growth rate for the species (rmax). Exponential population growth is the consequence.

The equation for exponential growth is

$dN/dt = r_{max}N$

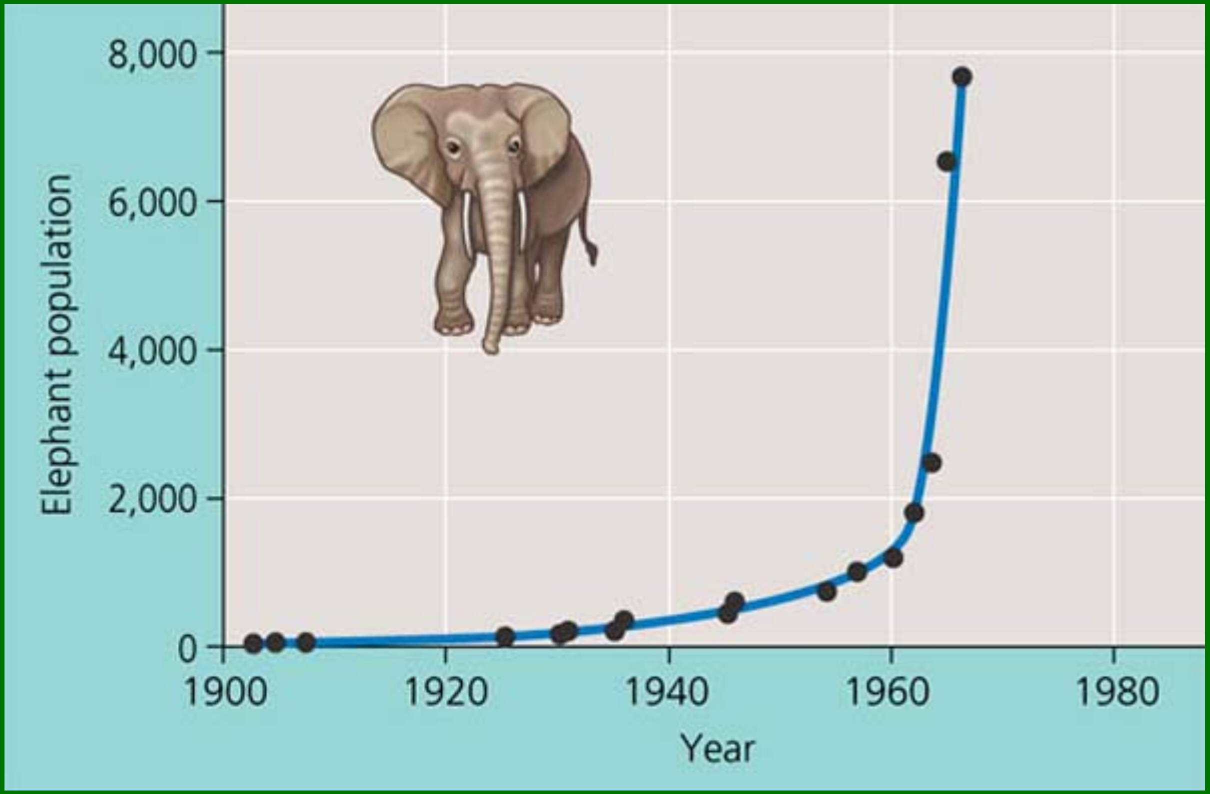
Exponential growth is constrained only by life history properties and is called the intrinsic growth rate.

exponential population growth $\frac{dN}{dt} = r_{max}N$



the steepness depends on the intrinsic growth rate rmax

exponential population growth



The J–shaped curve of exponential growth is characteristic of some populations that are introduced into a new or unfilled environment or whose numbers have been drastically reduced by a catastrophic event and are rebounding (African elephant population of Kruger National Park, South Africa)

logistic growth model

carrying capacity (K) : the maximum population size that a particular environment can support.

A model describing population growth that levels off as population size approaches carrying capacity

K varies over space and time with the abundance of limiting resources

As population size approaches K, per capita birth rate will decline, and eventually per capita death rates may increase. Either of these or both together result in a decreasing r

logistic growth model

The logistic growth equation

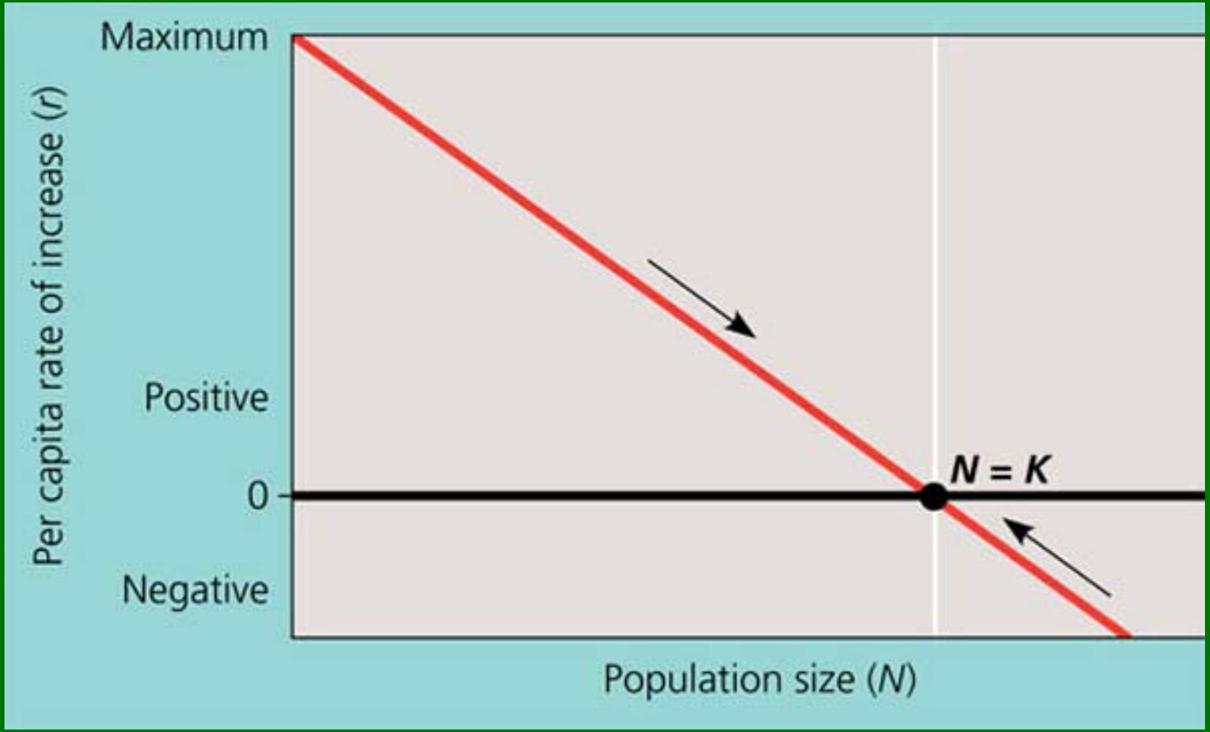
- incorporate changes in growth rate as population size nears the carrying capacity (N grows towards K).

-The logistic population growth model incorporates the effect of population density on the per capita rate of increase, r.

expression that reduces the rate of increase as N increases

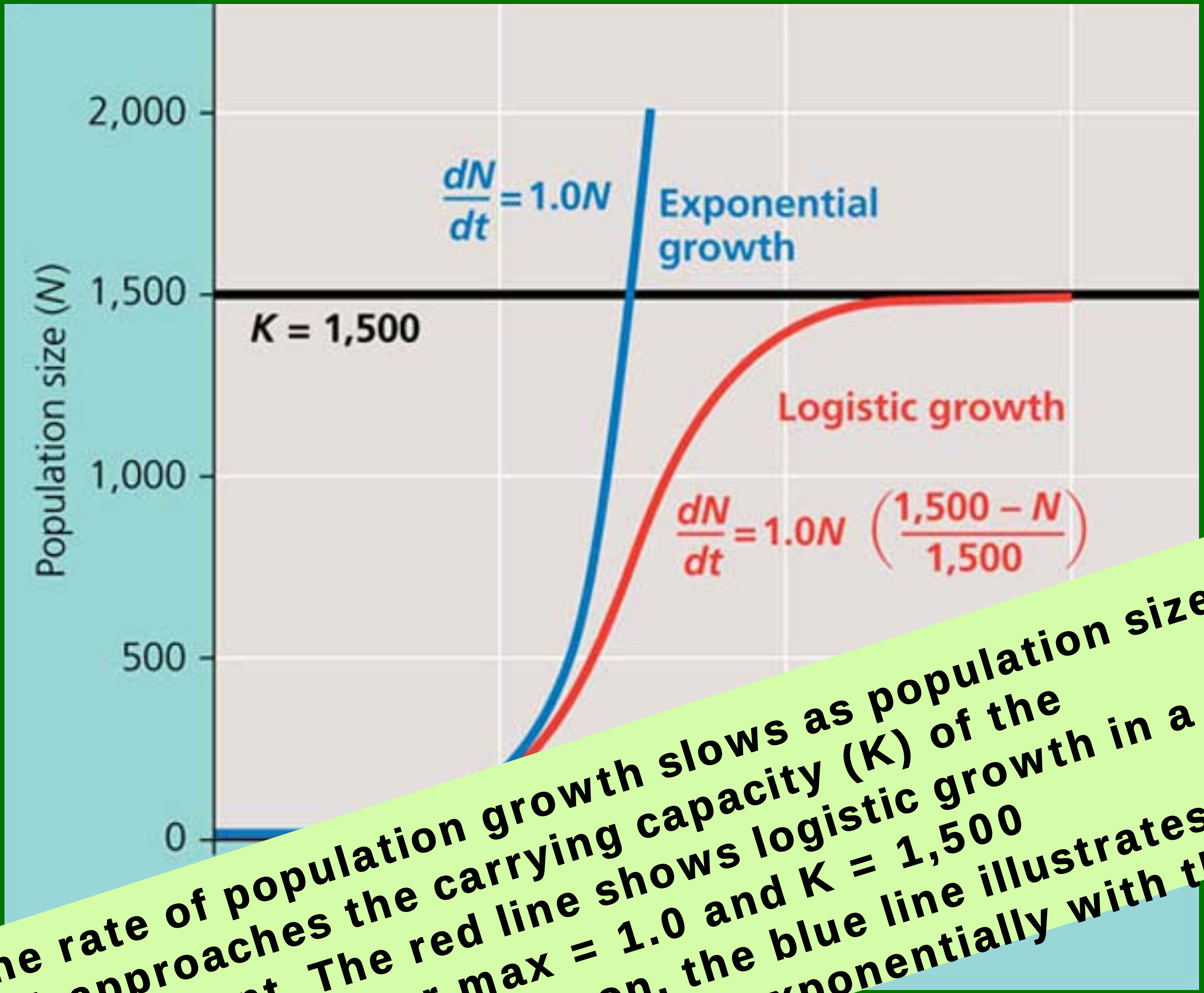
$$dN/dt = rmaxN \left(\frac{K-N}{K} \right)$$

logistic growth model



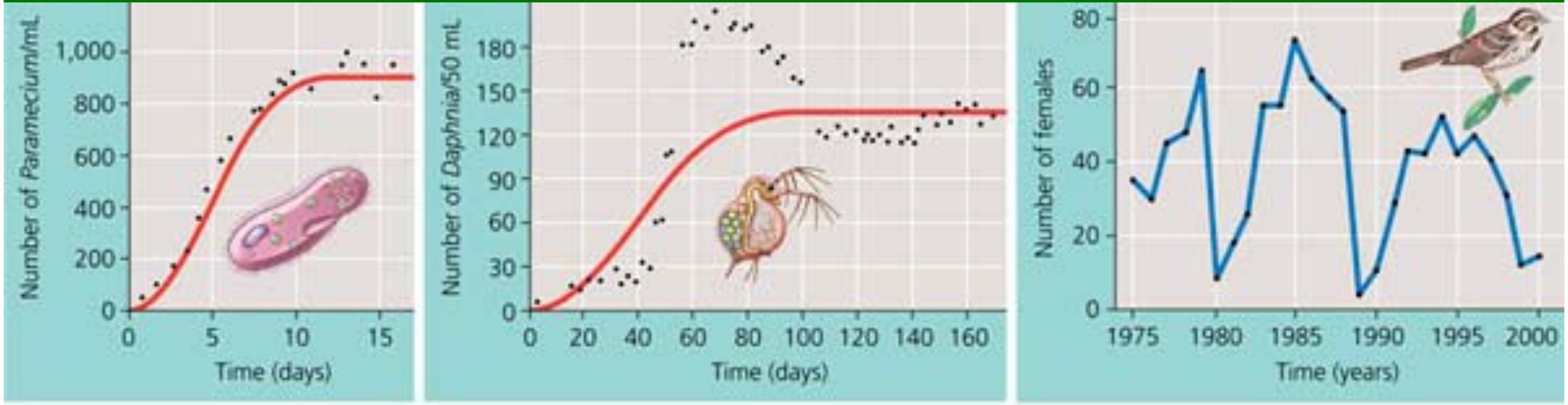
$$\frac{dN}{dt} = r_{\max} N \left(\frac{K - N}{K} \right)$$

Population growth predicted by the logistic model.



The rate of population growth slows as population size (N) approaches the carrying capacity (K) of the environment. The red line shows logistic growth in a population where r max = 1.0 and K = 1,500 individuals. For comparison, the blue line illustrates a population continuing to grow exponentially with the same r max.

How well do these populations fit the logistic growth model?



(a) A *Paramecium* population in the lab. The growth of *Paramecium aurelia* in small cultures (black dots) closely approximates logistic growth (red curve) if the experimenter maintains a constant environment.

(b) A *Daphnia* population in the lab. The growth of a population of *Daphnia* in a small laboratory culture (black dots) does not correspond well to the logistic model (red curve). This population overshoots the carrying capacity of its artificial environment and then settles down to an approximately stable population size.

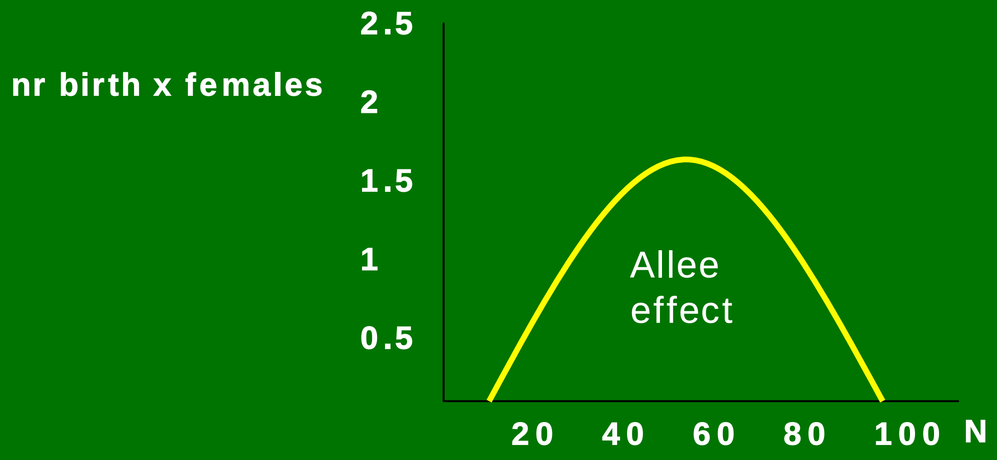
(c) A song sparrow population in its natural habitat. The population of female song sparrows nesting on Mandarte Island, British Columbia, is periodically reduced by severe winter weather, and population growth is not well described by the logistic model.

Some of the assumptions built into the logistic model do not apply to all populations.

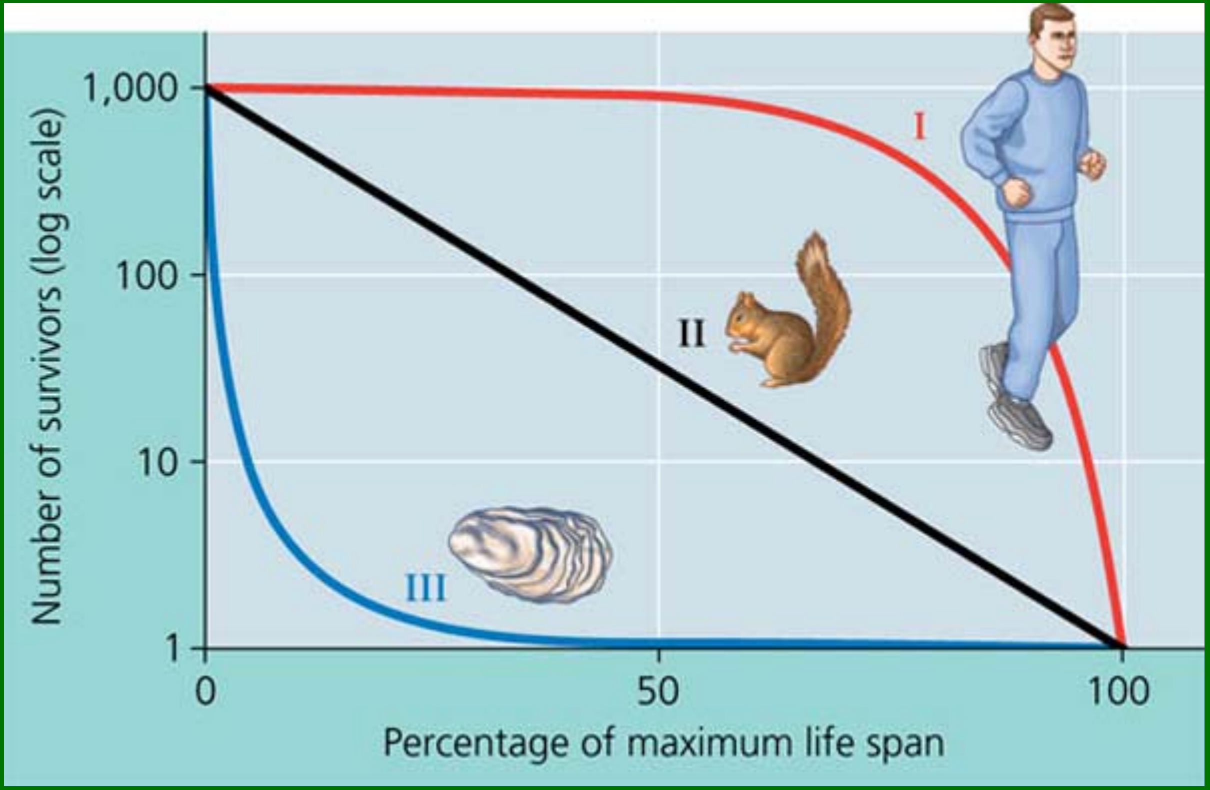
Frequent deviations from the basic model assumptions include:

(1) Allee effects, individuals have a more difficult time surviving or reproducing at small population size

(2) lag time before the negative effects of an increasing population size are realized



The logistic model predicts different growth rates for different populations, relative to carrying capacity.



high reproductive rates
unpredictable enviroment
type III survivorship curve

low reproductive rates
predictable environment
type I

The **life history traits** that natural selection favours may vary with population density and environmental conditions

In K-selection, organisms live and reproduce around K, and are sensitive to population density. They tend to invest mainly into survival of a small number of offspring and self.

In r-selection, organisms occur in variable environments in which population densities fluctuate well below K. Such populations tend to invest mainly into high rates of reproduction.

break!

...compromising!

es. If you want lots of offspring you will live shorter and viceversa...

Life History Theory and the intrinsic growth rate

Life history traits are products of natural selection

The traits that affect an organism’s schedule of investment into reproduction and survival make up its life history.

Limited resources mandate trade-offs between investments into reproduction and survival

Some organisms, such as the agave plant,exhibit big-bang reproduction, where large numbers of offspring are produced in each episode of reproduction, after which the individual often dies.

This is also known as semelparity.

other organisms produce only a few offspring during repeated reproductive episodes.

This is iteroparity or repetead reproduction.

Life-histories represent an evolutionary resolution of several conflicting demands.

Sometimes this conflict can be made visible, and we see trade-offs between survival and reproduction when resources are limited.

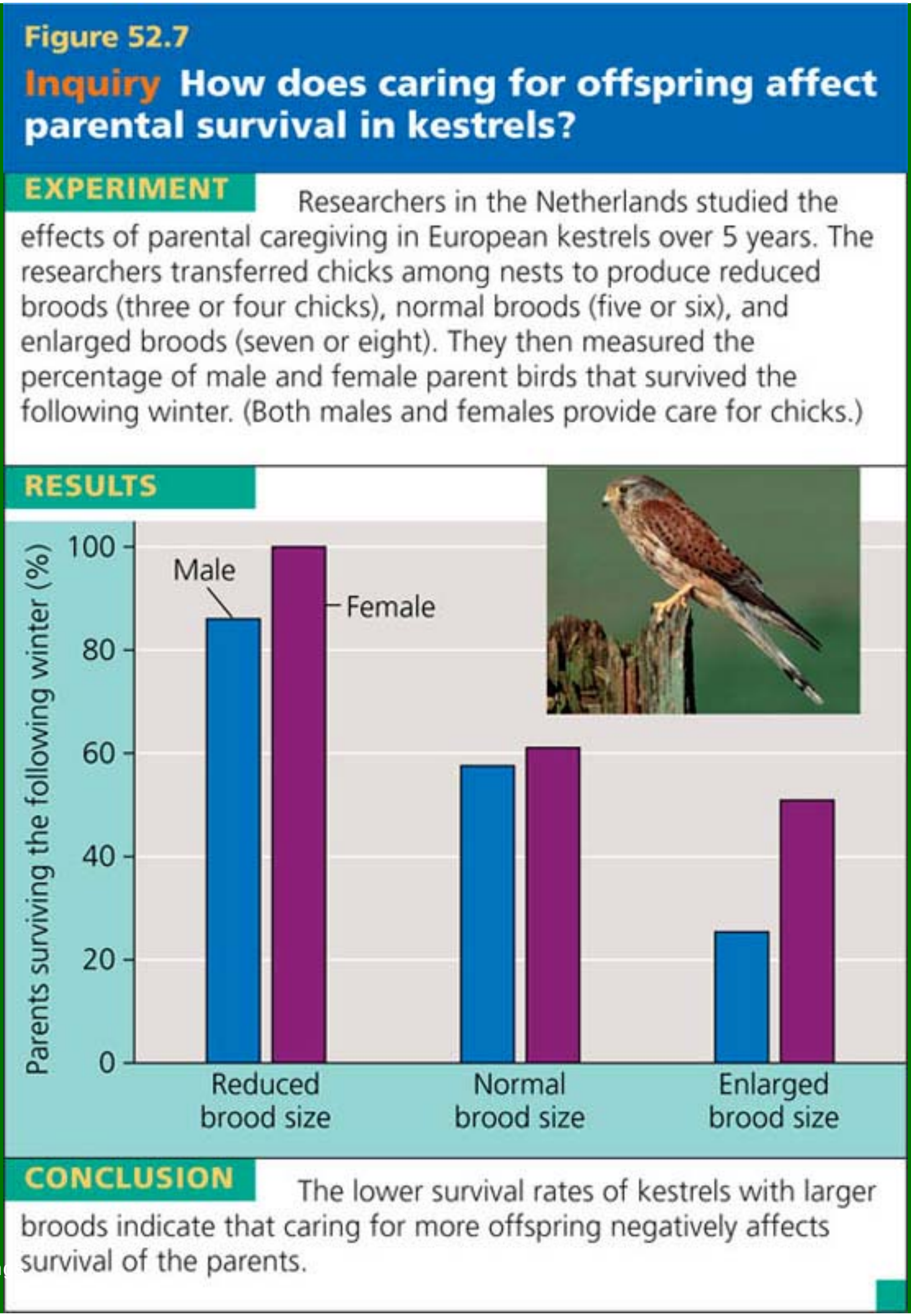


Figure 52.7

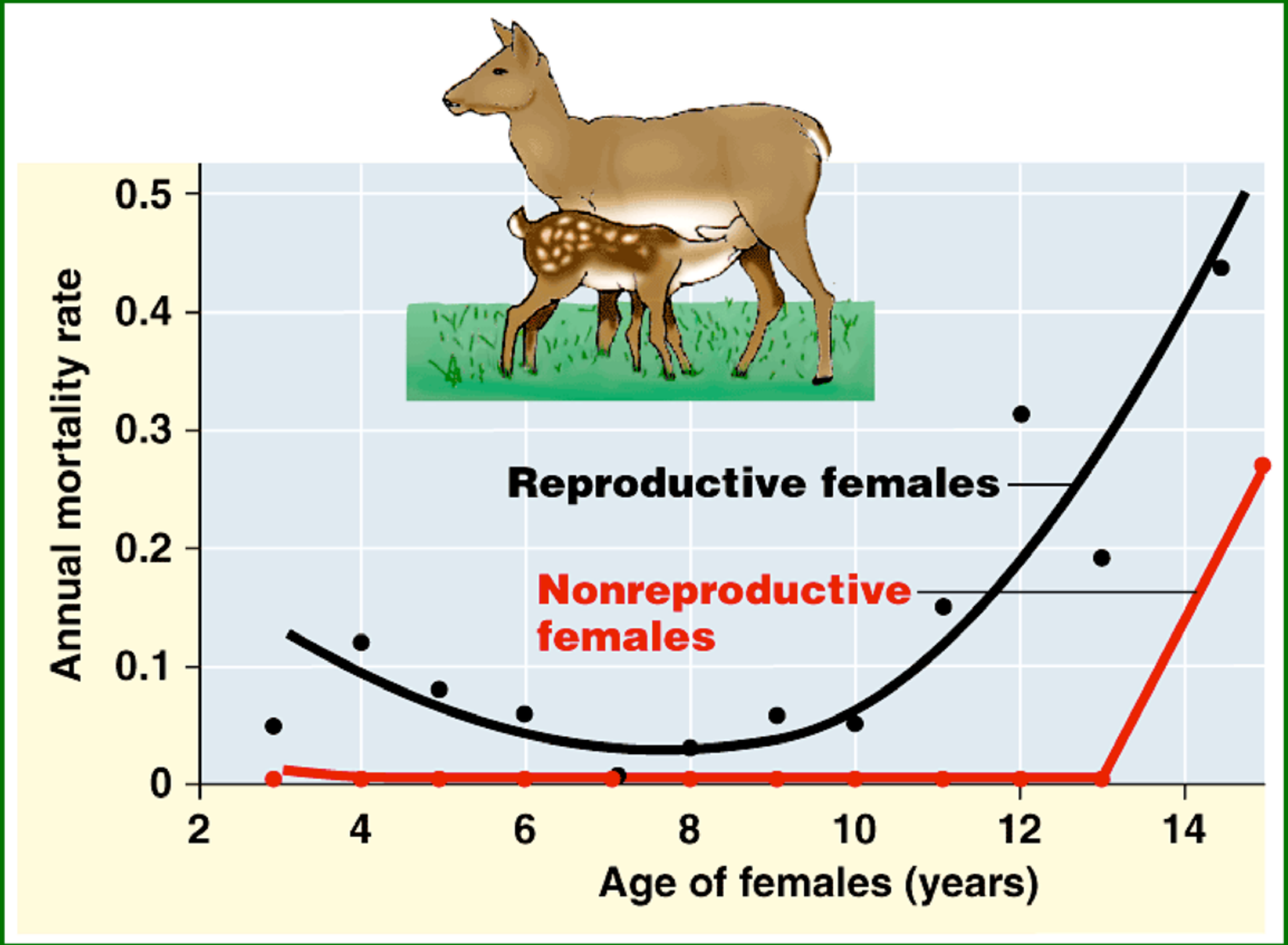
Inquiry How does caring for offspring affect parental survival in kestrels?

EXPERIMENT Researchers in the Netherlands studied the effects of parental caregiving in European kestrels over 5 years. The researchers transferred chicks among nests to produce reduced broods (three or four chicks), normal broods (five or six), and enlarged broods (seven or eight). They then measured the percentage of male and female parent birds that survived the following winter. (Both males and females provide care for chicks.)

RESULTS

CONCLUSION The lower survival rates of kestrels with larger broods indicate that caring for more offspring negatively affects survival of the parents.

female red deer show an increased mortality rate in winters following reproductive episodes.



Selective pressures also influence the trade–off between the number and size of offspring.

(a) Most weedy plants, such as this dandelion, grow quickly and produce a large number of seeds, ensuring that at least some will grow into plants and eventually produce seeds themselves.

(b) Some plants, such as this coconut palm, produce a moderate number of very large seeds. The large endosperm provides nutrients for the embryo, an adaptation that helps ensure the success of a relatively large fraction of offspring.

Three basic life history decisions

When to start reproducing

How many offspring to produce per reproductive episode

How many times to reproduce

1-How population Grow

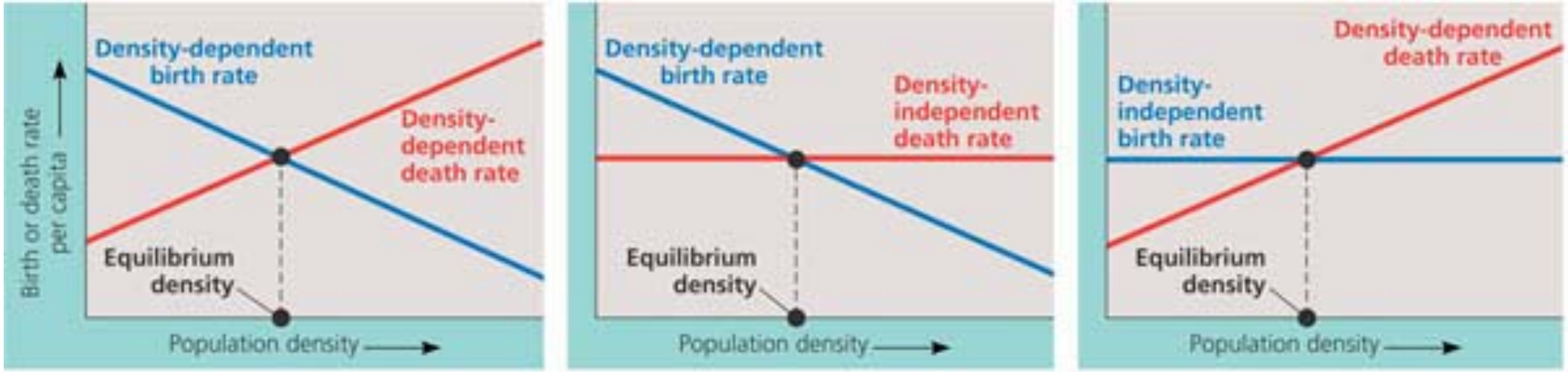
2-How populations evolve

3-Fluctuations and population cycles

Populations are regulated by a complex interaction of biotic and abiotic influences

Factors limiting Population growth

effects of increasing population density

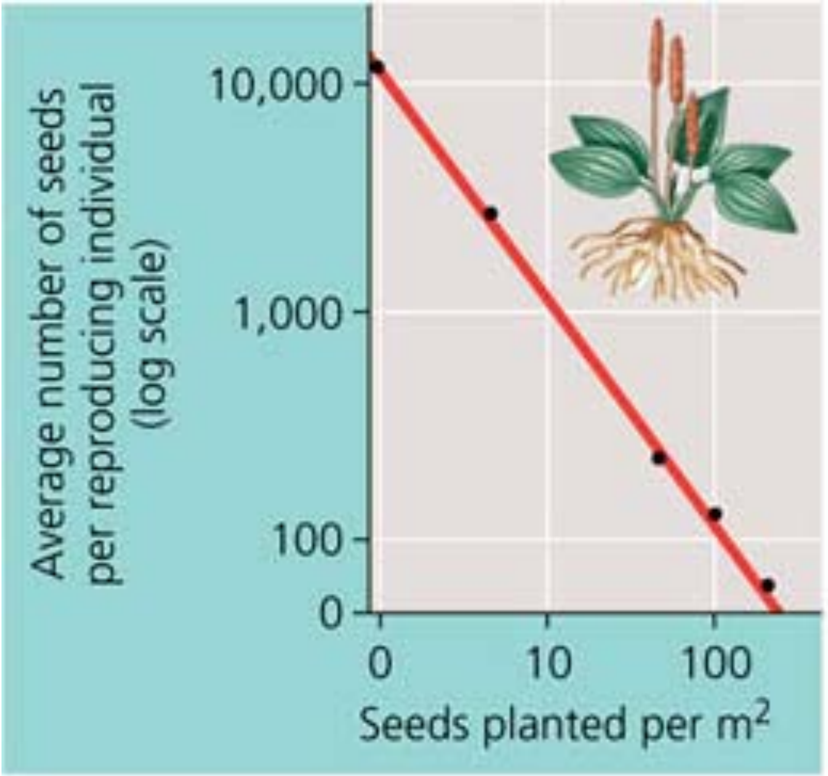


(a) Both birth rate and death rate change with population density.

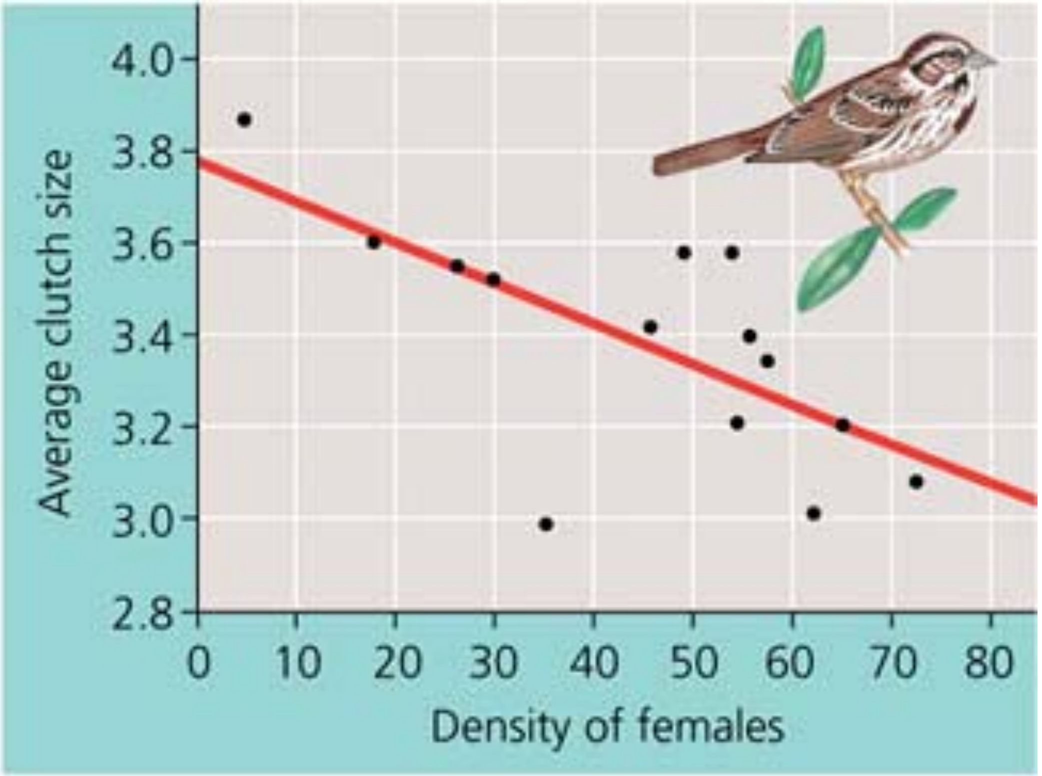
(b) Birth rate changes with population density while death rate is constant.

(c) Death rate changes with population density while birth rate is constant.

Resource limitation in crowded populations can stop population growth by reducing reproduction.

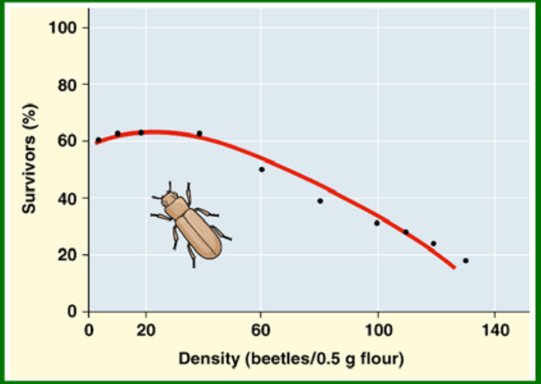


(a) Plantain. The number of seeds produced by plantain (*Plantago major*) decreases as density increases.



(b) Song sparrow. Clutch size in the song sparrow on Mandarte Island, British Columbia, decreases as density increases and food is in short supply.

Intraspecific competition for food can reduce survival.



Territoriality, defense of a space, may set a limit on density.

Predation may also be a density dependent factor.

Disease can also regulate population growth, because it spreads more rapidly in dense populations.

1-How population Grow

2-How populations evolve

3-Fluctuations and population cycles

Interactions between biotic and abiotic factors influence population size

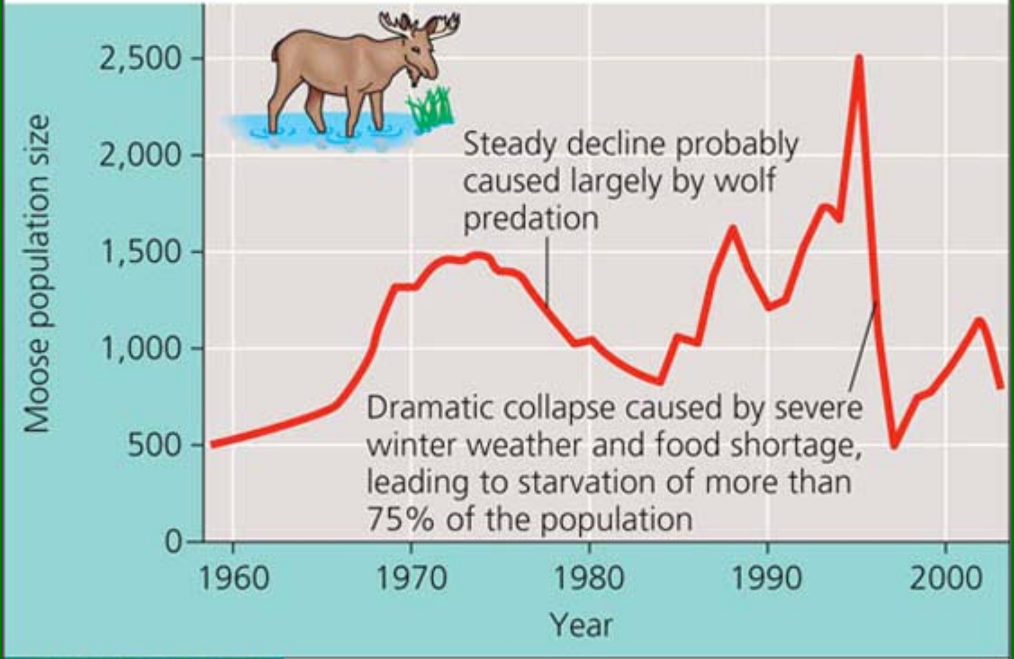
Population Dynamics

Figure 52.18

Inquiry How stable is the Isle Royale moose population?

FIELD STUDY Researchers regularly surveyed the population of moose on Isle Royale, Michigan, from 1960 to 2003. During that time, the lake never froze over, and so the moose population was isolated from the effects of immigration and emigration.

RESULTS Over 43 years, this population experienced two significant increases and collapses, as well as several less severe fluctuations in size.

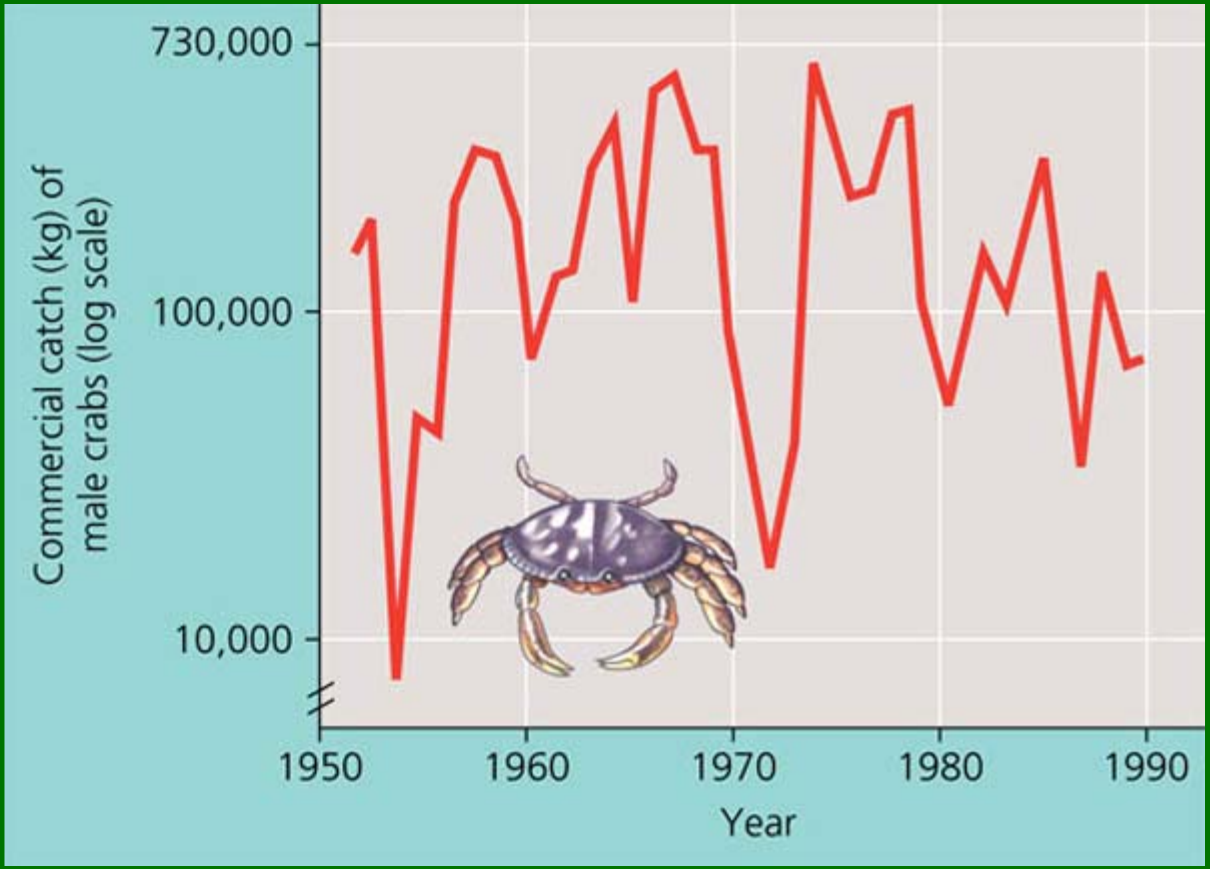


Steady decline probably caused largely by wolf predation

Dramatic collapse caused by severe winter weather and food shortage, leading to starvation of more than 75% of the population

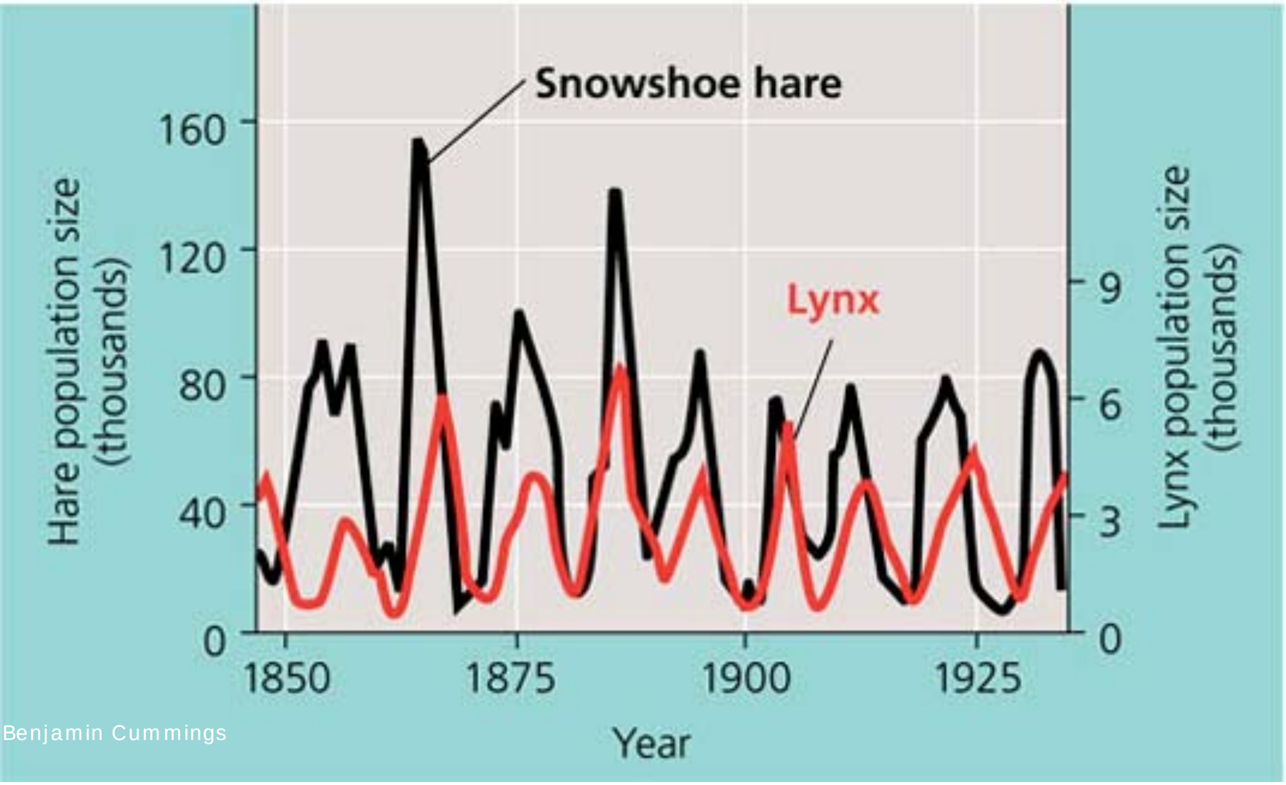
CONCLUSION The pattern of population dynamics observed in this isolated population indicates that various biotic and abiotic factors can result in dramatic fluctuations over time in a moose population.

Extreme population fluctuation



POPULATION CYCLES

Some populations have regular boom-and-bust cycles



Lotka-Volterra model is the simplest model of predator-prey interactions (Lotka,1925; Volterra,1926):

$$\begin{cases} \frac{dH}{dt} = rH - aHP \\ \\ \frac{dP}{dt} = bHP - mP \end{cases}$$

exponential
unlimited growth
when 0 predators

It has two variables (P, H) and several parameters:

H = density of prey

P = density of predators

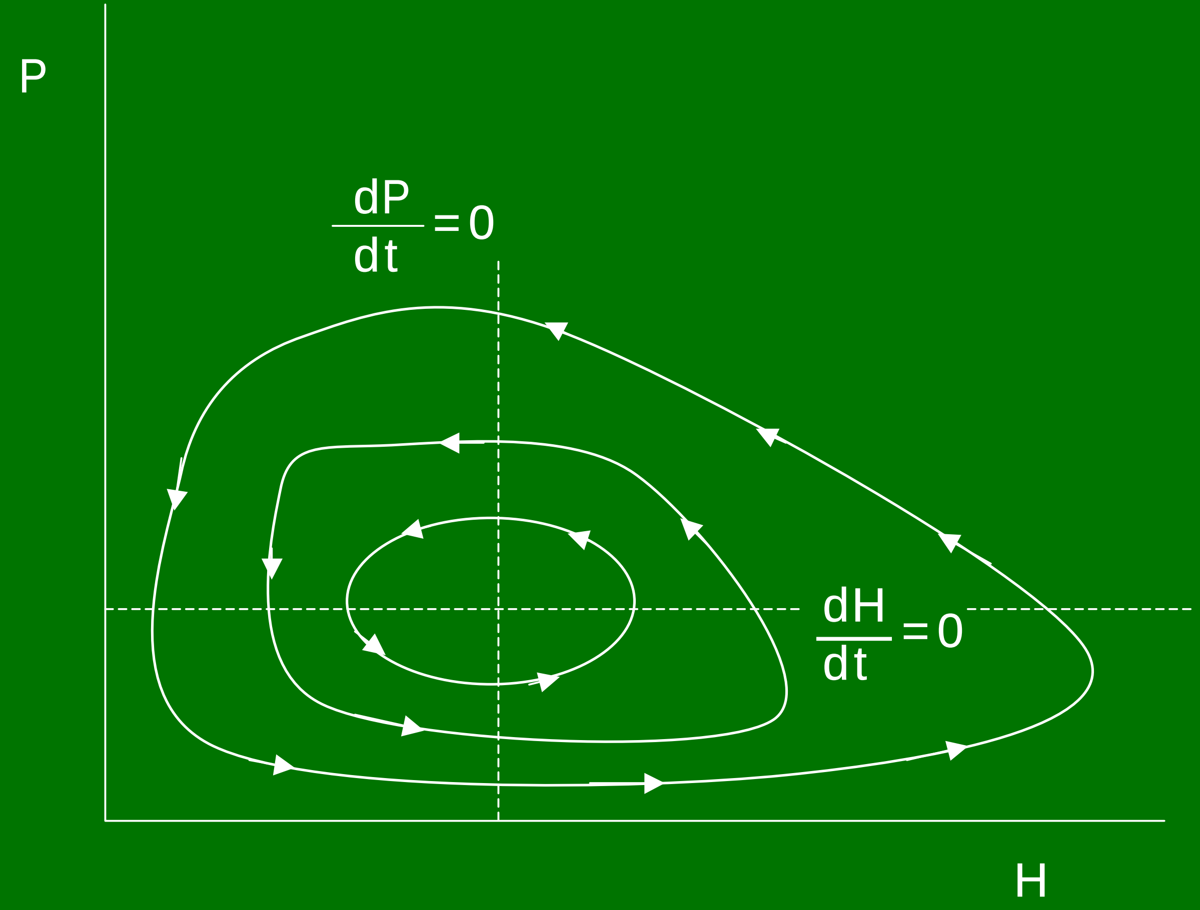
r = intrinsic rate of prey population increase (birth-death)

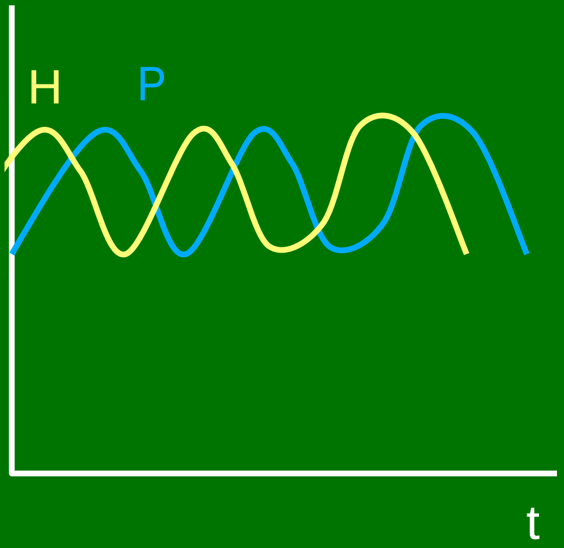
a = predation rate coefficient

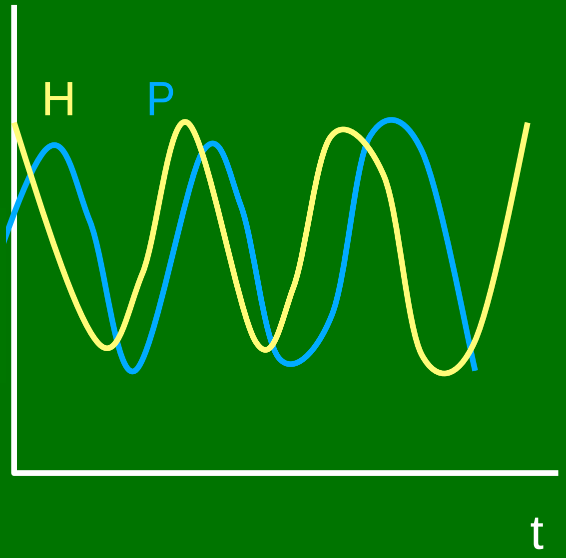
b = reproduction rate of predators per 1 prey eaten

m = predator mortality rate

relative changes in prey predator density for 3 initial conditions







The only difference is in initial density of prey

The model of Lotka and Volterra is not very realistic.

no competition among prey or predators.

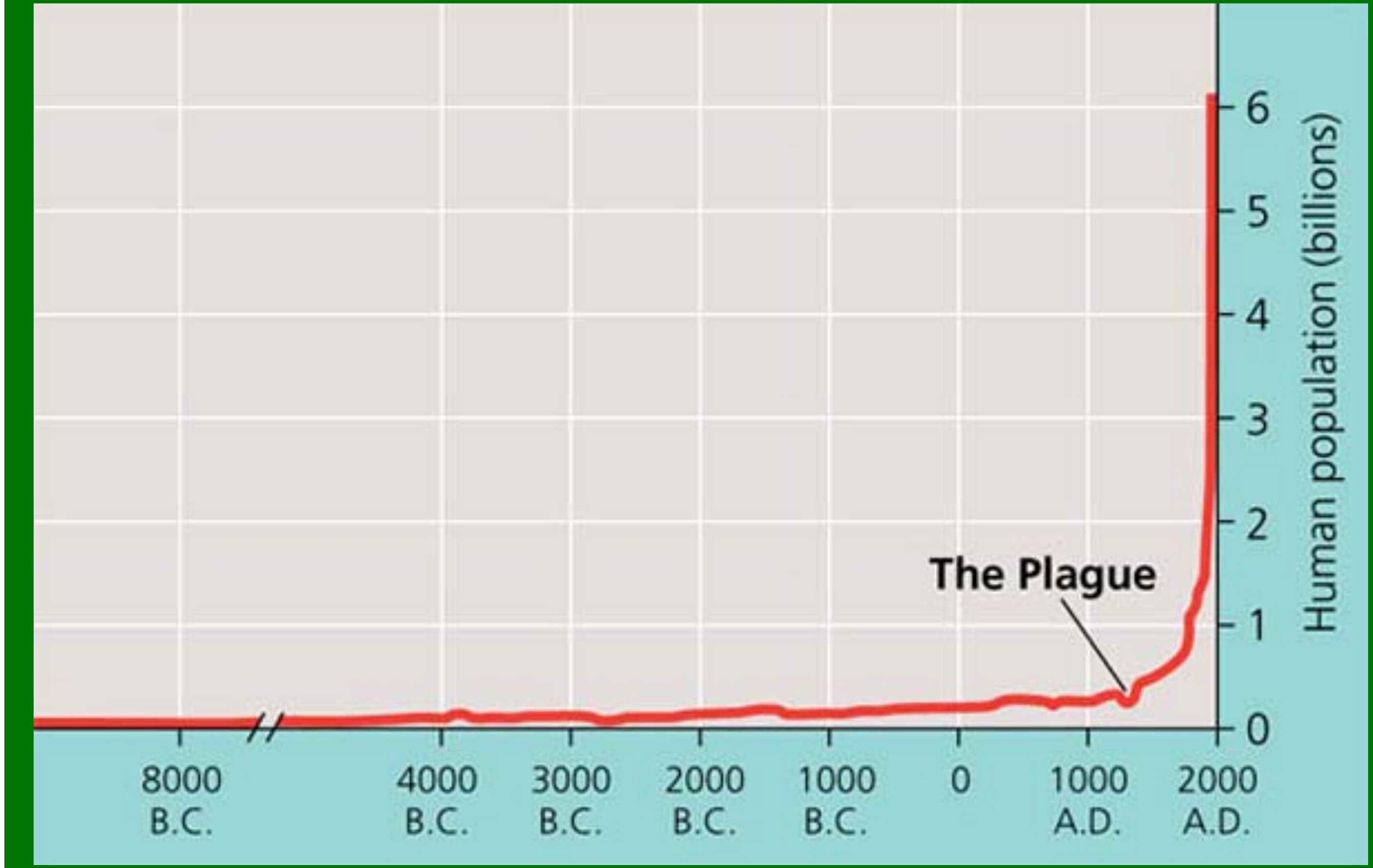
...prey population may grow infinitely without any resource limits.

...Predators have no saturation: their consumption rate is unlimited.

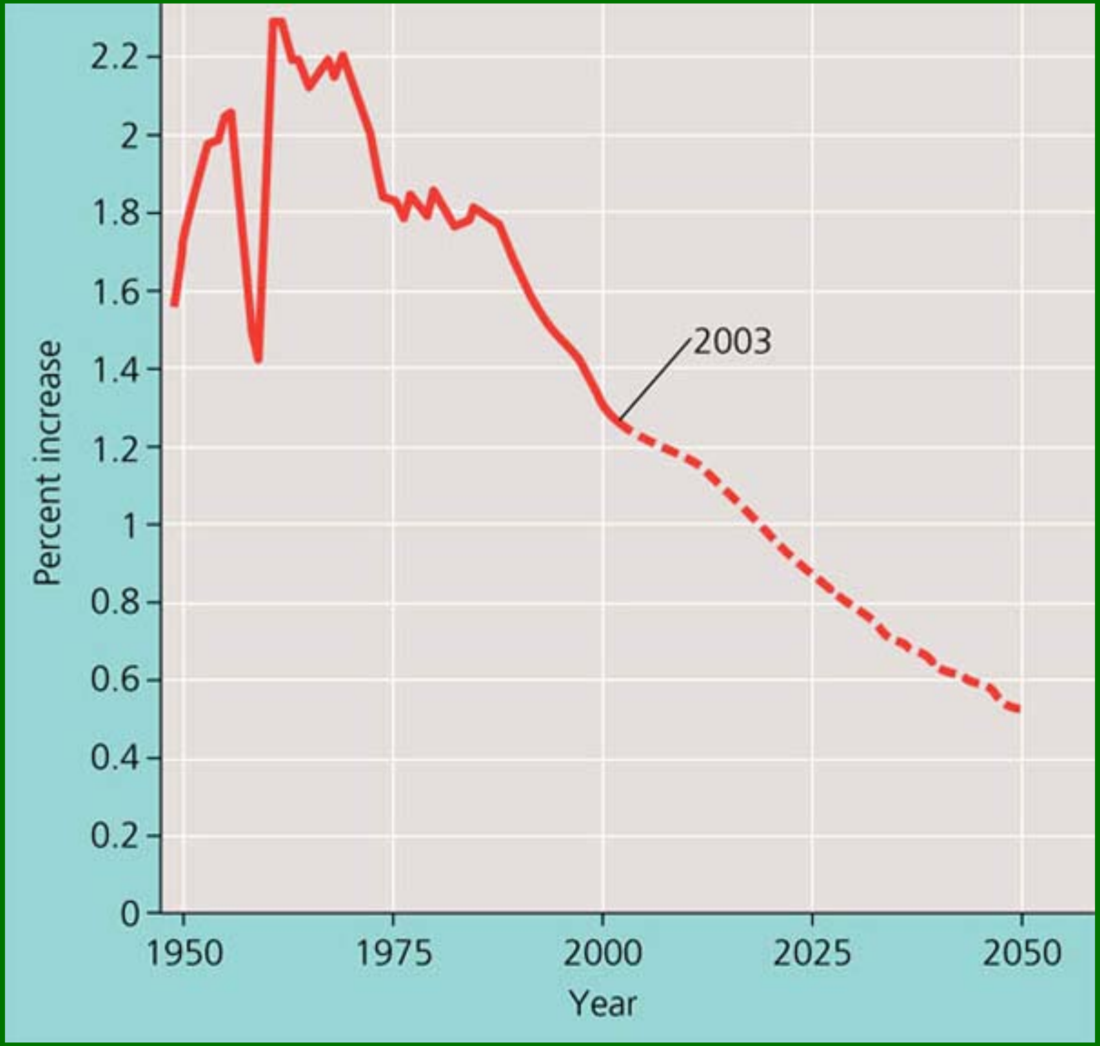
The rate of prey consumption is proportional to prey density.
No asymptotic stability.

However numerous modifications of this model exist which make it more realistic.

Human Population Growth: The human population has been growing almost exponentially for three centuries



In 1650 500 million people inhabited Earth, population doubled to 1 billion between 1850 and 1930, an doubled again by 1975 to 4 billion. We are now over 6 billion people.



It takes only four years for world population growth to add the equivalent of another United States.

Population ecologists predict a population of 7.3–8.4 billion people on Earth by the year 2025.

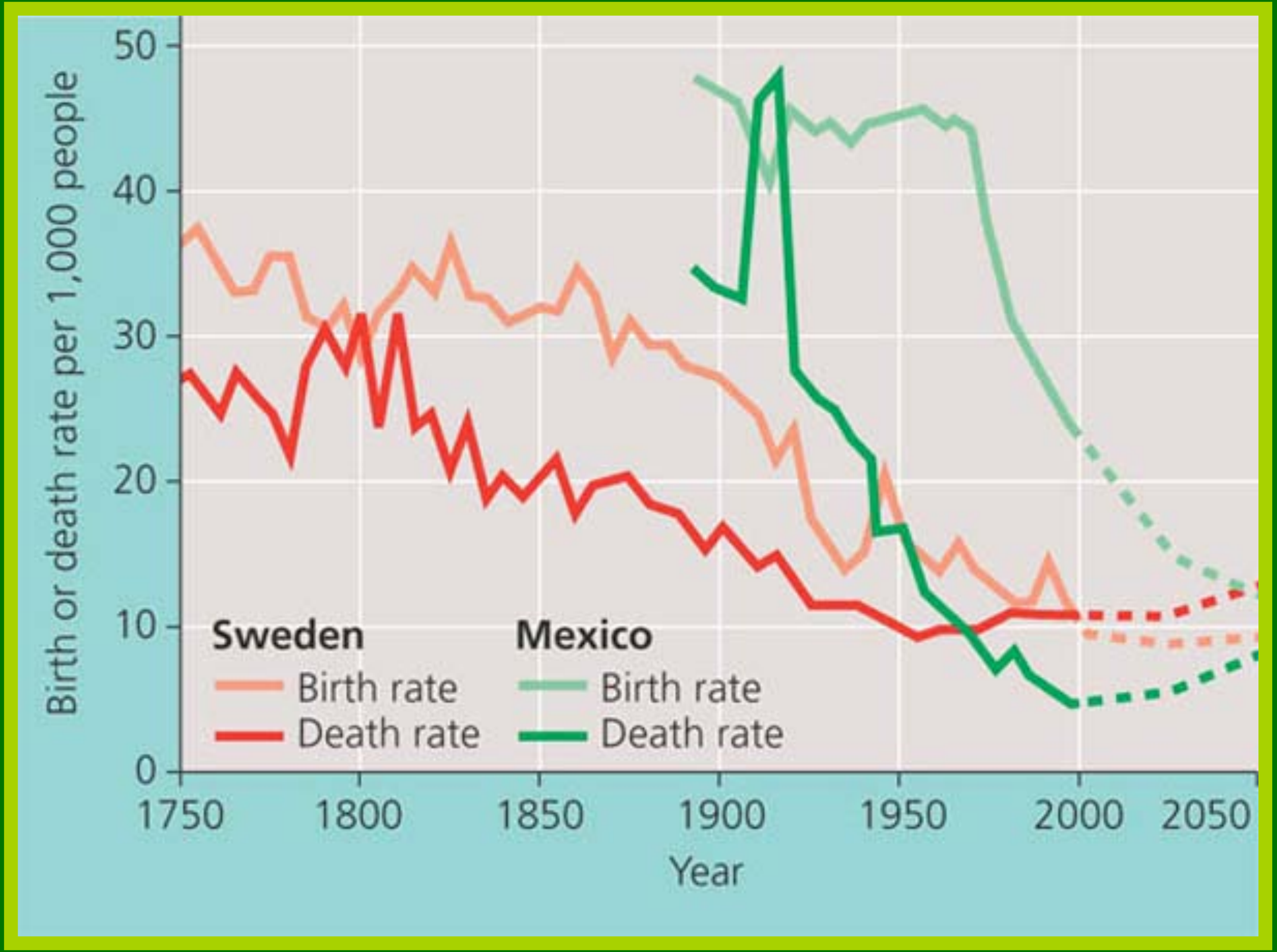
Stable populations and the Demographic Transition

A regional human population can exist in one of 2 ZPG configurations to maintain population stability.

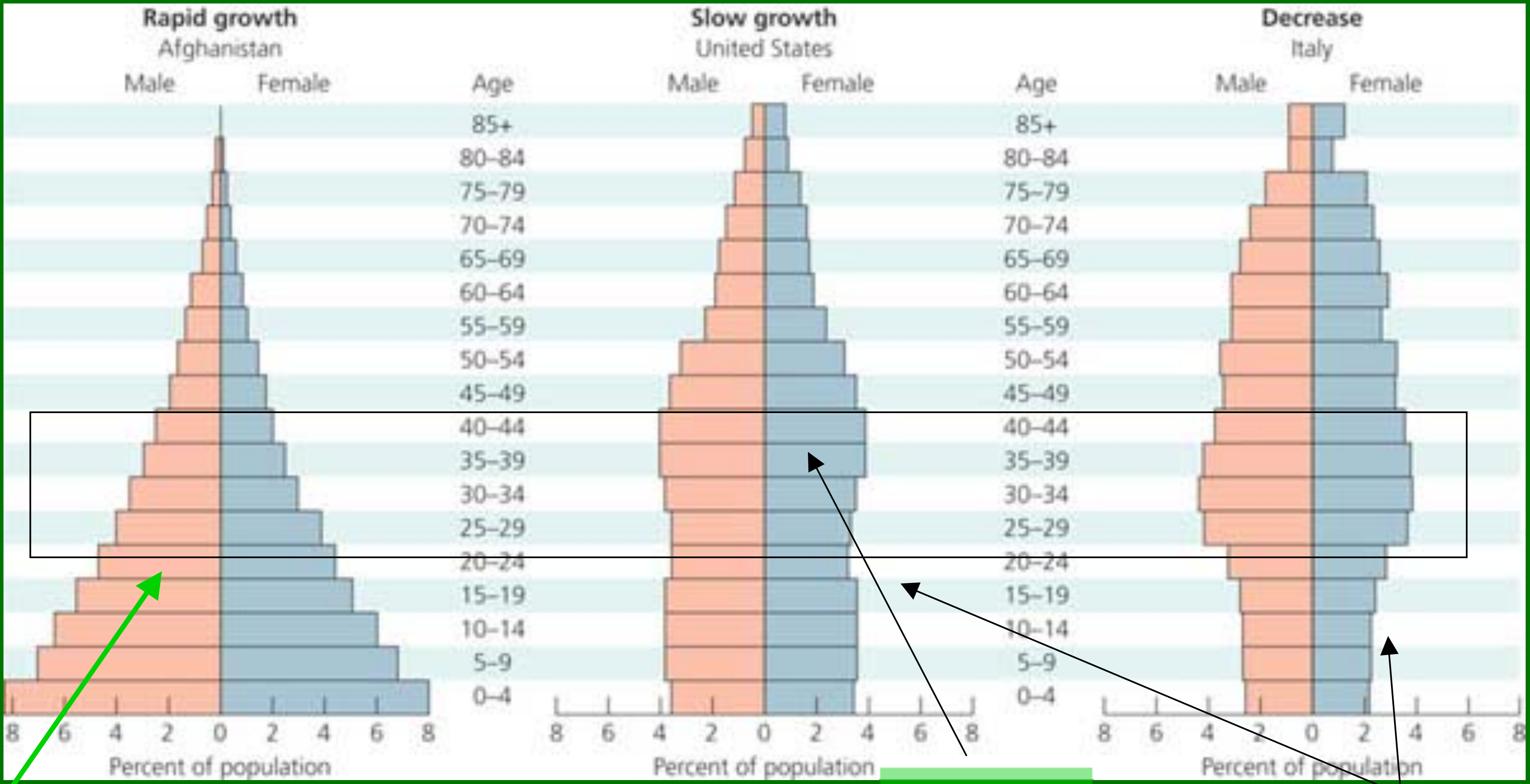
Zero population growth = high birth rates – high death rates.

Zero population growth = low birth rates – low death rates

The movement from the first toward the second state is called the demographic transition.



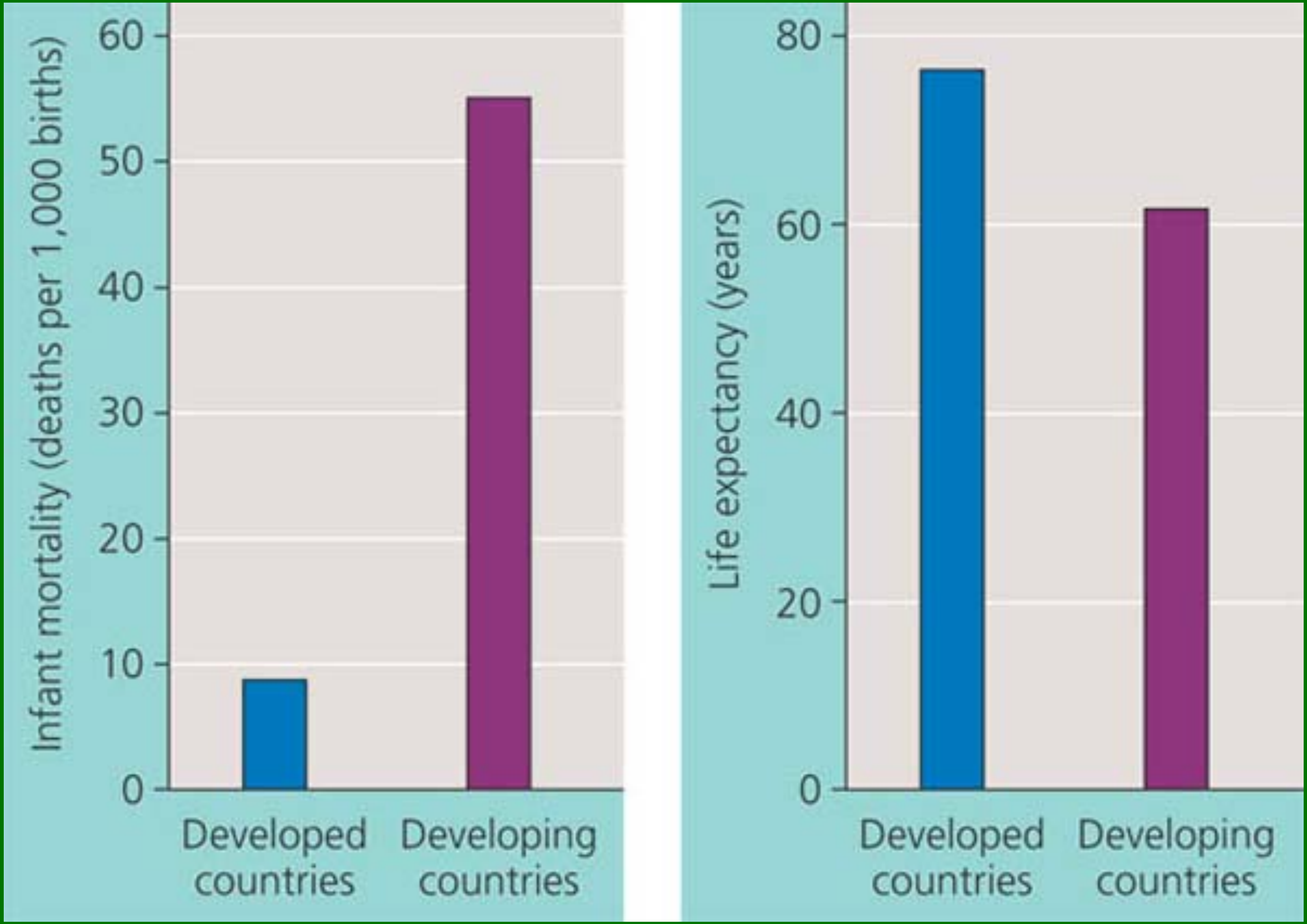
Age structure is the relative number of individuals of each age.
Age structure diagrams can reveal a population’s growth trends, and can point to future social conditions.



Lack of employment

The baby boom

Social security and Medicare problem


Infant mortality (deaths per 1,000 births)
60
50
40
30
20
10
0
Developed countries
Developing countries
Life expectancy (years)
80
60
40
20
0
Developed countries
Developing countries

Estimating Earth's carrying capacity for humans is a complex problem

Predictions of the human population vary from 7.3 to 10.7 billion people by the year 2050. Will Earth be overpopulated then? Is it overpopulated now?

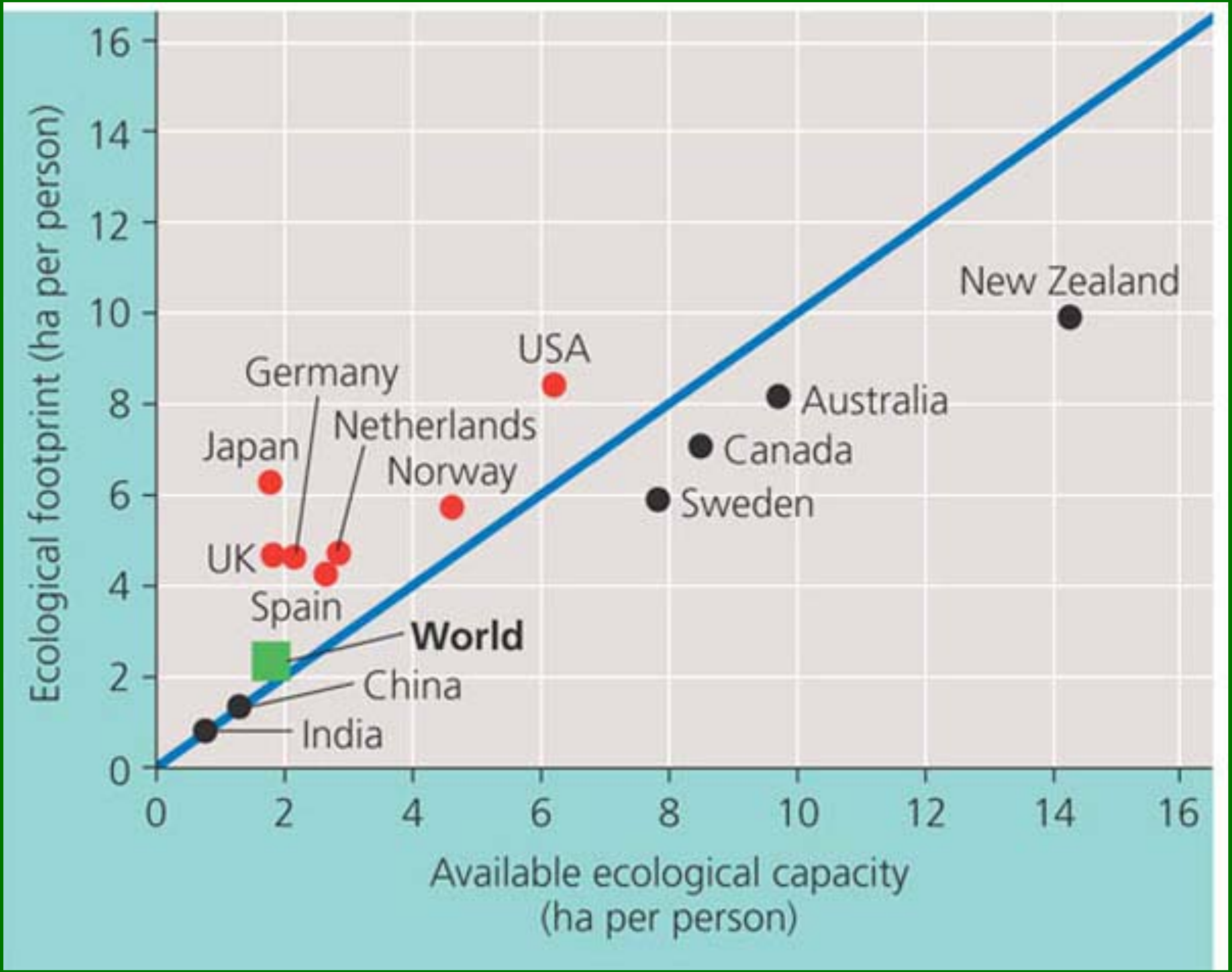
Wide range of estimates for carrying capacity.

Estimates can be based on food, but human agriculture limits assumptions on available amounts.

Ecological footprint.

Humans have multiple constraints besides food (fuel, water, wood).

The concept an of ecological footprint uses the idea of multiple constraints.


Ecological footprint (ha per person)
0
2
4
6
8
10
12
14
16
Available ecological capacity (ha per person)
0
2
4
6
8
10
12
14
16
New Zealand
USA
Germany
Australia
Netherlands
Japan
Canada
Norway
Sweden
UK
Spain
World
China
India

For each country, we can calculate the aggregate land and water area in various ecosystem categories.

Six types of ecologically productive areas are distinguished in calculating the ecological footprint:

Arable land (land suitable for crops).

Pasture.

Forest.

Ocean.

Built-up land.

Fossil energy land (land required for vegetation to absorb the CO2 produced by burning fossil fuels)

There is about 2 ha per person (1.7 ha if we wish to reserve land for conservation)

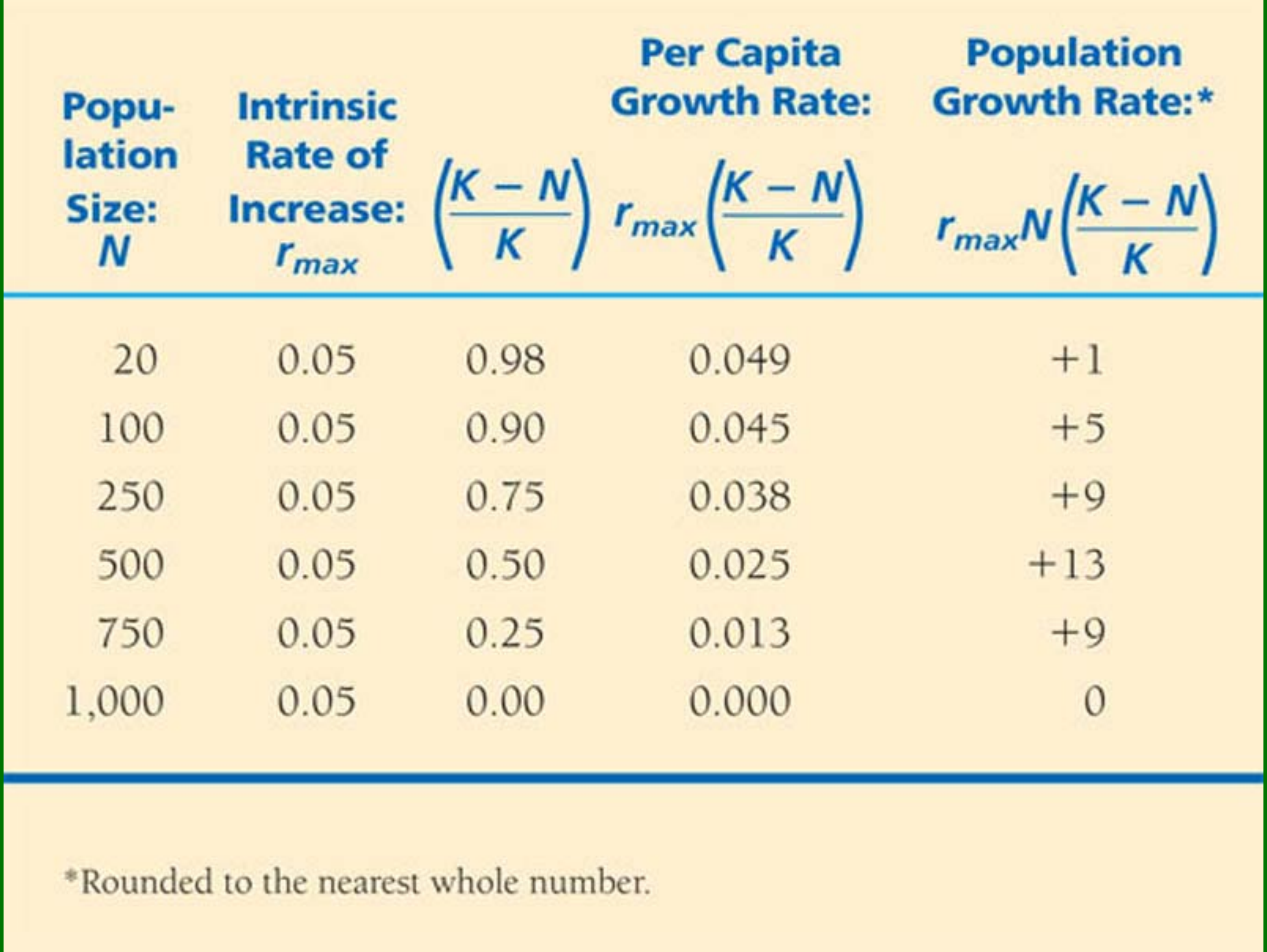
- Ecological footprints for 13 countries suggest that the world is near its carrying capacity

- Current malnutrition and famines result mainly from unequal distribution, rather than insufficient production of food.

- Environments can support a larger number of herbivores than carnivores: if everyone ate as much meat as the wealthiest people in the world, less than half of the present world population could be fed on current food harvests

At more than 6 billion people, the world is already in ecological deficit.

The End



Population Size: N	Intrinsic Rate of Increase: r_{max}	$\left(\frac{K-N}{K}\right)$	Per Capita Growth Rate: $r_{max}\left(\frac{K-N}{K}\right)$	Population Growth Rate:* $r_{max}N\left(\frac{K-N}{K}\right)$
20	0.05	0.98	0.049	+1
100	0.05	0.90	0.045	+5
250	0.05	0.75	0.038	+9
500	0.05	0.50	0.025	+13
750	0.05	0.25	0.013	+9
1,000	0.05	0.00	0.000	0

*Rounded to the nearest whole number.