Population Ecology

Chapter 52

- Population ecology is the study of populations in relation to the environment
  - Includes environmental influences on population density and distribution, age structure, and variations in population size

Definition of a Population

- A population is a group of individuals of the same species living in the same general area

Density and Dispersion

- Density
  - Is the number of individuals per unit area or volume
- Dispersion
  - Is the pattern of spacing among individuals within the boundaries of the population

Population density results from interplay of processes that add individuals and those that remove them from the population.

Immigration and **birth** add individuals whereas **death** and **emigration** remove individuals.

Patterns of Dispersion

- Environmental and social factors
  - Influence the spacing of individuals in a population

Patterns of dispersion: clumped

- Clumped dispersion
  - Individuals aggregate in patches
  - Grouping may be result of the fact that multiple individuals can cooperate effectively (e.g. wolf pack to attack prey or antelope to avoid predators) or because of resource dispersion (e.g. mushrooms clumped on a rotting log)

Clumped organisms




Pattern of dispersion: uniform

- Uniform dispersion

  Individuals are evenly distributed

  Usually influenced by social interactions such as territoriality

Uniformly distributed Penguins

Pattern of dispersion: random

- Random dispersion: position of each individual is independent of other individuals (e.g. plants established by windblown seeds).
- Uncommon pattern.

Randomly distributed ferns

Demography

- Demography is the study of the vital statistics of a population and how they change over time
- Death rates and birth rates
  - Are of particular interest to demographers

Life Tables

- Life table is an age-specific summary of the survival pattern of a population (first developed by the insurance industry)

- Constructed by following the fate of a cohort (age-class of organisms) from birth to death.

Life table

- Life table built by determining number of individuals that die in each age group and calculating the proportion of the cohort surviving from one age to the next.
- Data for life tables hard to collect for wild populations.

Table 52.1 Life Table for Belding's Ground Squirrels *(Spermophilus beldingi)* at Tioga Pass, in the Sierra Nevada Mountains of California*

	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.

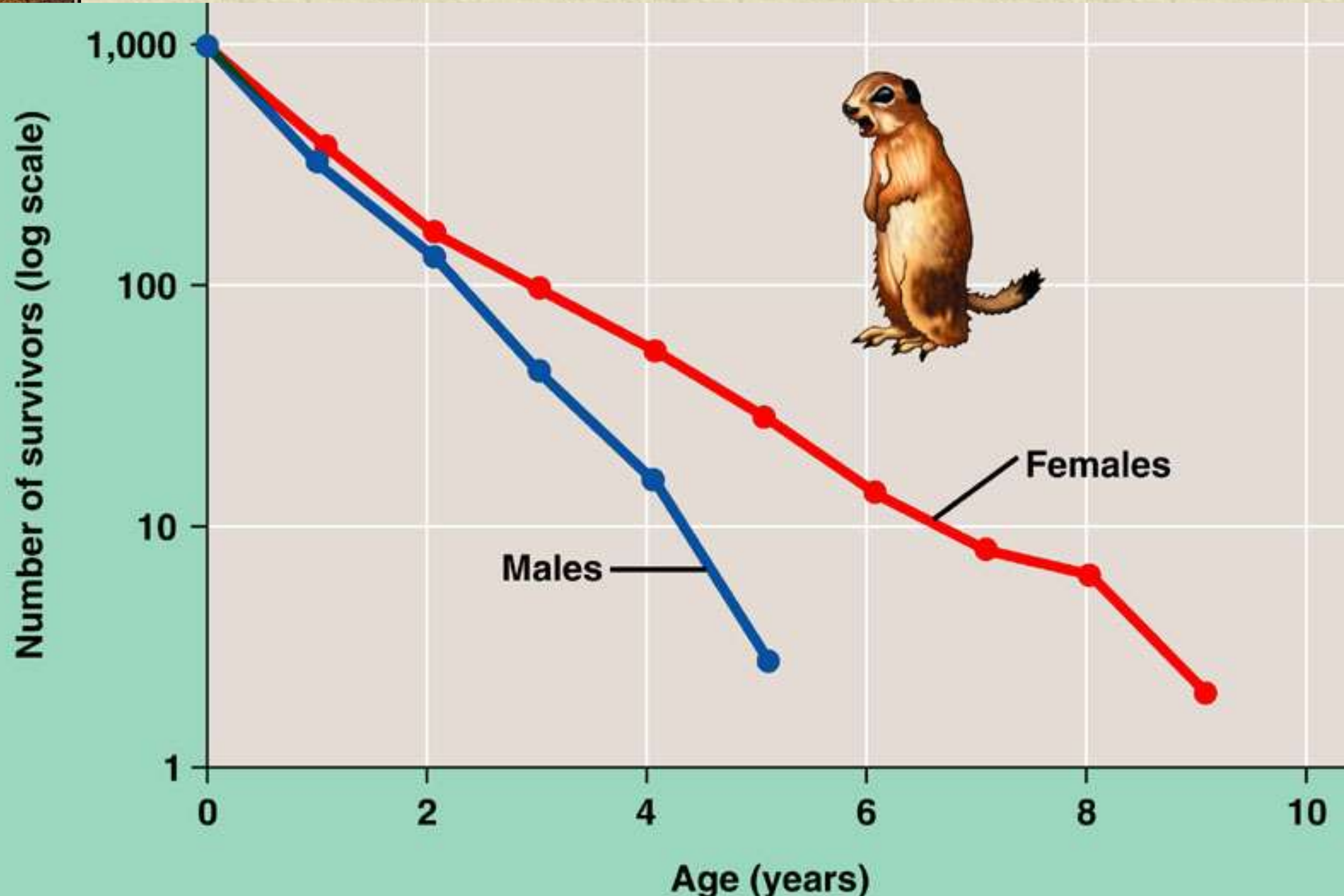
Source: Data from P. W. Sherman and M. L. Morton, "Demography of Belding's Ground Squirrel," *Ecology* 65(1984): 1617–1628.

- Life table for ground squirrels shows death rate for males is higher than that for females.
- Also, notice that mortality rate is quite consistent from one year to the next.

Survivorship Curves

Data in a life table can be represented graphically by a survival curve.

Curve usually based on a standardized population of 1000 individuals and the X-axis scale is logarithmic.



1,000
100
10
1
Number of survivors (log scale)
Females
Males
0
2
4
6
8
10
Age (years)

- Survivorship curves can be classified into three general types

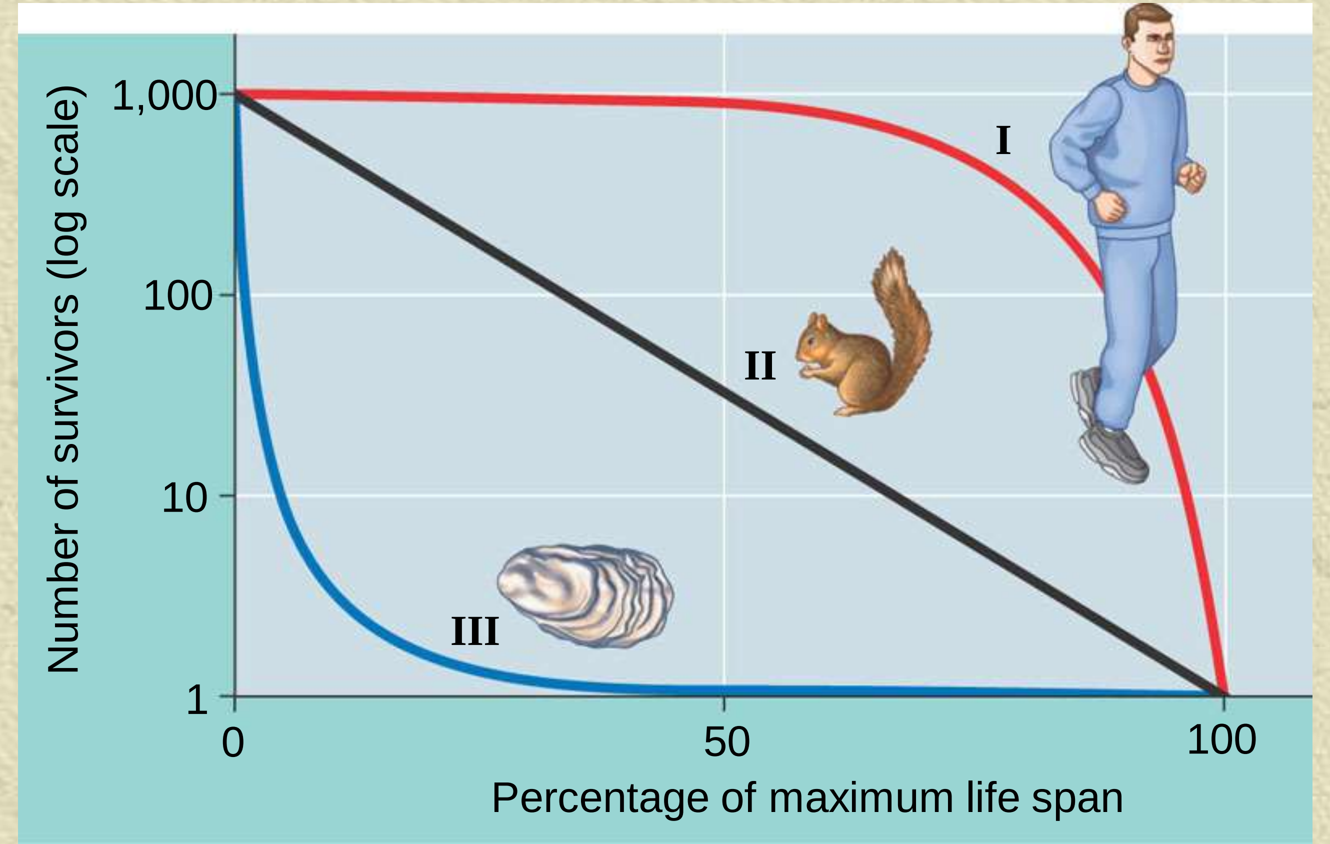


Figure 52.5

Type I curve

- Type I curve typical of animals that produce few young but care for them well (e.g. humans, elephants). Death rate low until late in life where rate increases sharply as a result of old age (wear and tear, accumulation of cellular damage, cancer).

Type II curve

- Type II curve has fairly steady death rate throughout life (e.g. rodents).
- Death is usually a result of chance processes over which the organism has little control (e.g. predation)

Type III curve

- Type III curve typical of species that produce large numbers of young which receive little or no care (e.g. Oyster).
- Survival of young is dependent on luck. Larvae released into sea have only a small chance of settling on a suitable substrate. Once settled however, prospects of survival are much better and a long life is possible.

Reproductive Rates

- A reproductive table, or fertility schedule is an age-specific summary of the reproductive rates in a population.

- Measured over life span of a cohort. The fertility schedule ignores males.

Reproductive Table

- The table tallies the number of females produced by each age group.
- Product of proportion of females of a given age that are breeding and the number of female offspring of those breeding females.

Table 52.2 Reproductive Table for Belding's Ground Squirrels at Tioga Pass

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.

Table 52.2

Life History

- Study of life histories focuses on explaining why organisms differ in their reproductive patterns.

Life History Traits

- Life history traits are products of natural selection.
- Life history traits are evolutionary outcomes reflected in the development, physiology, and behavior of an organism.
- The current life history reflects the fact that organisms in the past that adopted this strategy left behind on average more surviving offspring than individuals who adopted other strategies.

Life history diversity

- Some species exhibit **semelparity**, or "big-bang" reproduction. These species reproduce once and die (bamboo, salmon, century plant).

Century Plant

Semelparous reproduction

- Semelparous reproduction often an adaptation to erratic climatic conditions.
- Suitable breeding conditions occur rarely and organisms devote all their resources to reproduction when conditions are good (e.g. century plant).

Iteroparous reproduction

- Some species exhibit **iteroparity**, or repeated reproduction and produce offspring repeatedly over time.
- E.g. humans, cats, birds.

Iteroparous reproduction

- Iteroparous reproduction occurs when organisms have good prospects of reproducing in the future (i.e., they are long-lived).
- Characteristic of larger organisms and those that experience more stable environmental conditions.

“Trade-offs” and Life Histories

- Organisms have finite resources, which lead to trade-offs between survival and reproduction
- For example kestrels whose broods were artificially enlarged had reduced overwinter survivorship. Conversely, birds whose broods were reduced had higher overwinter survivorship.

Quantity vs. Quality of offspring

- Organisms face tradeoffs between the **number** and **quality** of young they can produce because they have only a limited quantity of resources to invest.
- The choice is basically between a few large or many small 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.

Population growth

- Occurs when birth rate exceeds death rate (duh!)
- Organisms have enormous potential to increase their populations if not constrained by mortality.
- Any organism could swamp the planet in a short time if it reproduced without restraint.

Per Capita Rate of Increase

- If immigration and emigration are ignored, a population’s growth rate (per capita increase) equals the per capita birth rate minus the per capita death rate

- Equation for population growth is

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

- Where N = population size, b is per capita birth rate and d is per capita death rate. $\Delta N/\Delta t$ is change in population N over a small time period t.

- The per capita rate of population increase is symbolized by r.
- $r = b - d$.
- r indicates whether a population is growing ($r > 0$) or declining ($r < 0$).

- Ecologists express instantaneous population growth using calculus.
- Zero population growth occurs when the birth rate equals the death rate r = 0.
- The population growth equation can be expressed as $$\frac{dN}{dt} = rN$$

Exponential population growth (EPG)

- Describes population growth in an idealized, unlimited environment.

- During EPG the rate of reproduction is at its maximum.

- The equation for exponential population growth is

$$\frac{dN}{dt} = r_{max}N$$

The J-shaped curve of exponential growth

- Is characteristic of some populations that are rebounding

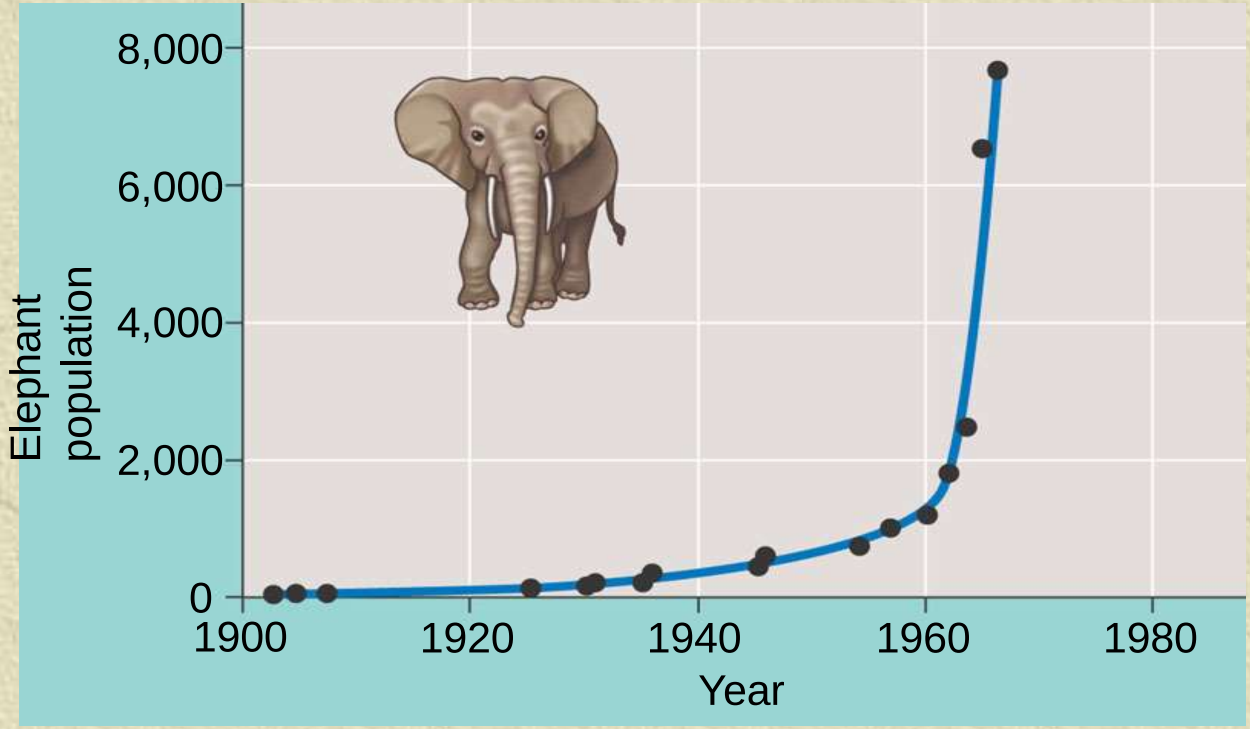


Figure 52.10

Logistic Population Growth

- Exponential growth cannot be sustained for long in any population.

- A more realistic population model limits growth by incorporating carrying capacity.

- Carrying capacity (*K*) is the maximum population size the environment can support

The Logistic Growth Model

- In the logistic population growth model the per capita rate of increase declines as carrying capacity is approached.
- We construct the logistic model by starting with the exponential model and adding an expression that reduces the per capita rate of increase as N increases

- The logistic growth equation includes *K*, the carrying capacity (number of organisms environment can support)

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

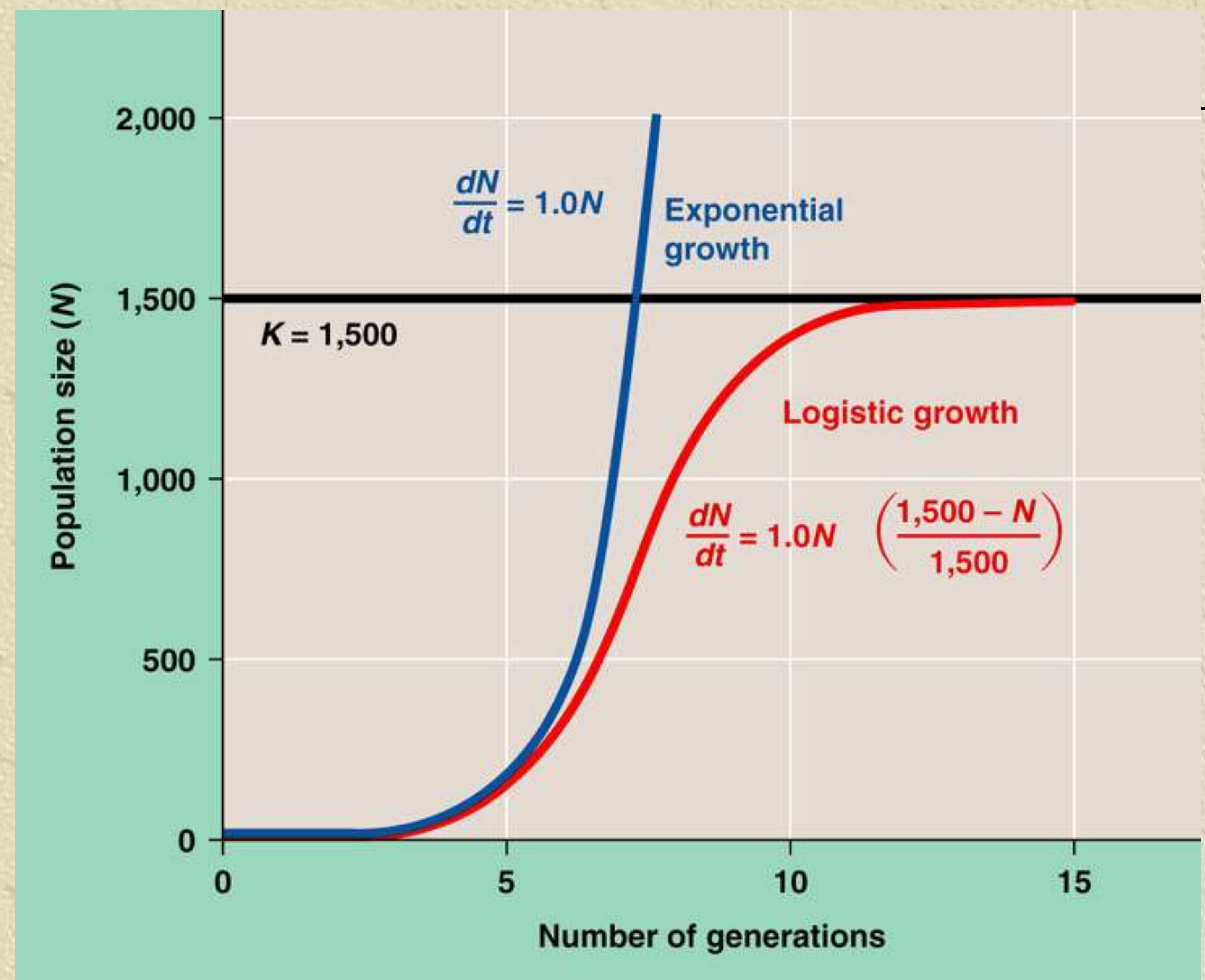
As population size (N) increases, the equation ((K-N)/K) becomes smaller which slows the population's growth rate.

Table 52.3 A Hypothetical Example of Logistic Population Growth, Where $K = 1{,}000$ and $r_{max} = 0.05$ per Individual per Year

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.

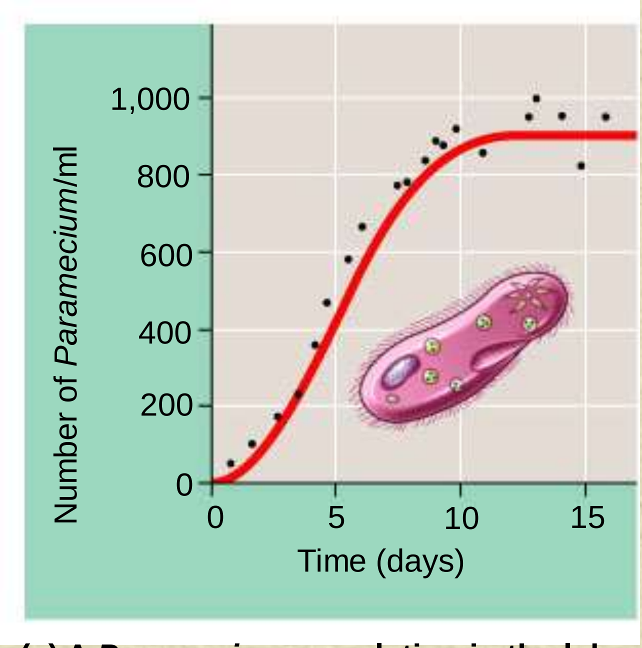
Logistic model produces a sigmoid (S-shaped) population growth curve.



- Logistic model predicts different per capita growth rates for populations at low and high density. At low density population growth rate driven primarily by r the rate at which offspring can be produced. At low density population grows rapidly.
- At high population density population growth is much slower as density effects exert their effect.

The Logistic Model and Real Populations

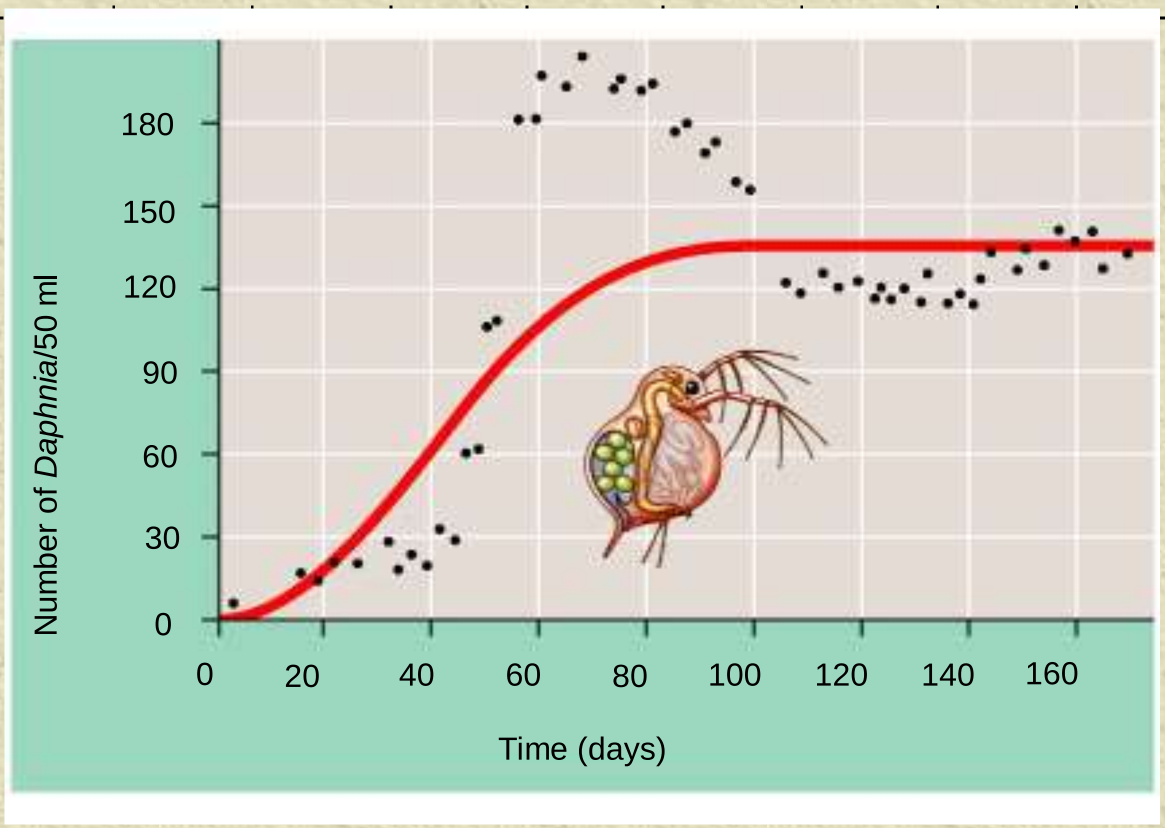
- The growth of laboratory populations of paramecia fits an S-shaped curve



(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.

Figure 52.13a

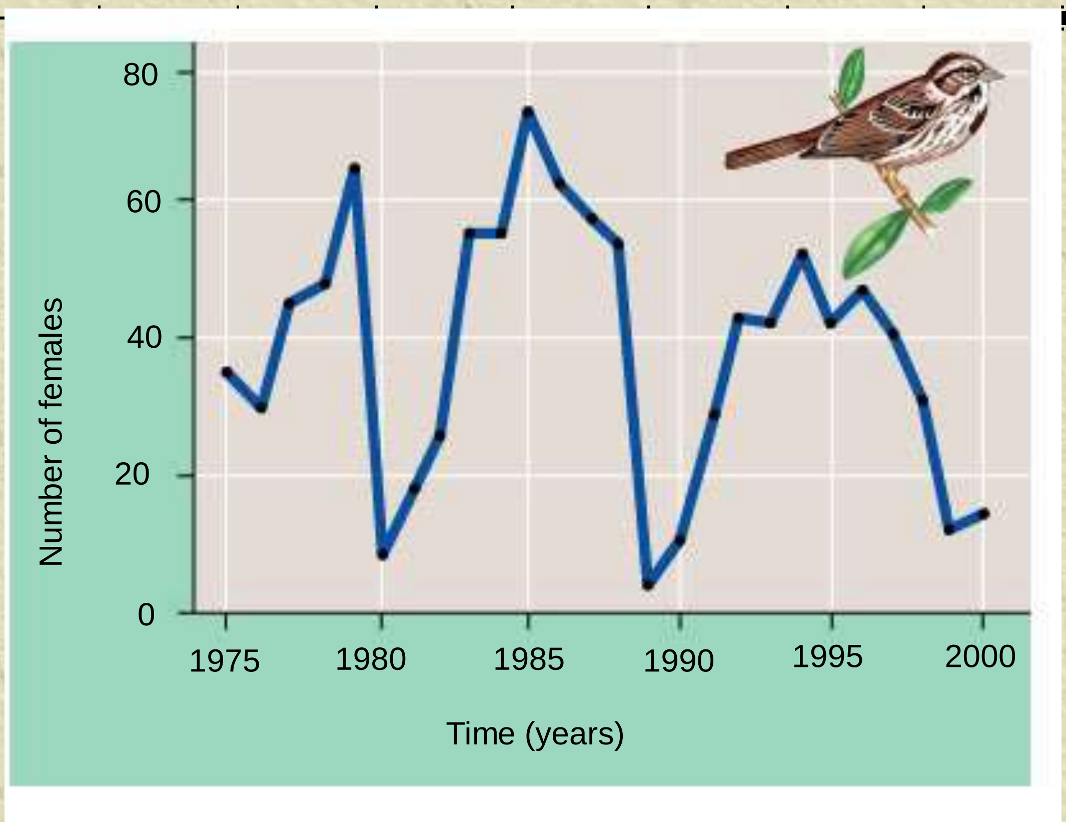
Some populations overshoot *K* before settling down to a relatively stable density



(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.

Figure 52.13b

Some populations fluctuate greatly around *K*.



(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.

Figure 52.13c

The Logistic Model and Life Histories

- Life history traits favored by natural selection may vary with population density and environmental conditions.

- At low density, per capita food supply is relatively high. Selection for reproducing quickly (e.g by producing many small young) should be favored.

- At high density selection will favor adaptations that allow organisms to survive and reproduce with few resources. Expect lower birth rates.

- *K*-selection, or density-dependent selection
  - Selects for life history traits that are sensitive to population density
- *r*-selection, or density-independent selection
  - Selects for life history traits that maximize reproduction

- The concepts of *K*-selection and *r*-selection have been criticized by ecologists as oversimplifications.
- Most organisms exhibit intermediate traits or can adjust their behavior to different conditions.

Population regulation

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

Population Change and Population Density

- In density-independent populations birth rate and death rate do not change with population density.
- For example, in dune fescue grass environmental conditions kill a similar proportion of individuals regardless of density.

- In contrast in density-dependent populations birth rates fall and death rates rise with population density.
- Density-dependent population regulation much more common than density-independent

In density-dependent population either birth rate or death rate or both may be density dependent.