

Population growth and regulation

Potential for population increase

- It is quite high
- A single bacterium can reproduce by fission every 20 min, in 36 hours there will be enough bacteria to form a layer foot deep over the entire world
- A pair of elephants could produce a population of 19 million in 750 years

How do populations grow?

We can envision a population consisting of few individuals living in an ideal, unlimited environment; the only restrictions: inherent physiological limitations due to life history

- The population will increase in size with:

$$\begin{array}{l} \text{Change in population} \\ \text{size during time interval} \end{array} = \underbrace{\text{Births} + \text{Immigration} - \text{Deaths} - \text{Emigration}}_{\text{during time interval}}$$

Verbal equation of population growth

For simplicity:

$$\begin{array}{l} \text{Change in population} \\ \text{size during time interval} \end{array} = \begin{array}{l} \text{Births during} \\ \text{time interval} \end{array} - \begin{array}{l} \text{Deaths during} \\ \text{time interval} \end{array}$$

Geometric/Exponential Models

- Populations in which reproduction is restricted to a particular season of the year have non-overlapping generations. Their growth is modeled using geometric equations (time interval is discrete)
- In populations in which reproduction happens continuously, their growth can be modeled using exponential equations (time interval is continuous)

Exponential model

$$\begin{array}{l} \text{Change in population} \\ \text{size during time interval} \end{array} = \begin{array}{l} \text{Births during} \\ \text{time interval} \end{array} - \begin{array}{l} \text{Deaths during} \\ \text{time interval} \end{array}$$

Let N = population size; t = time, ΔN = change in population size;
 Δt = change in time

Then now we have:

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

Where:

B= No. of births in the population during the time interval

D= No. of deaths in the population during the time interval

We can now express births and deaths as the average number of births and deaths per individual during a specified time interval:

b = per capita birth rate

d = per capita death rate

We can obtain the numbers of births and deaths in a population by multiplying the per capita birth rate times the population size and the per capita death rate times the population size.

Hence, we can revise the population growth equation using the per capita rates:

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

We combine the per capita birth and death rates into the per capita growth rate:

$$r = b - d$$

A population grows when r is positive, declines when r is negative, or stays the same when $r = 0$

We can now rewrite the equation using the per capita growth rate:

$$\Delta N/\Delta t = rN$$

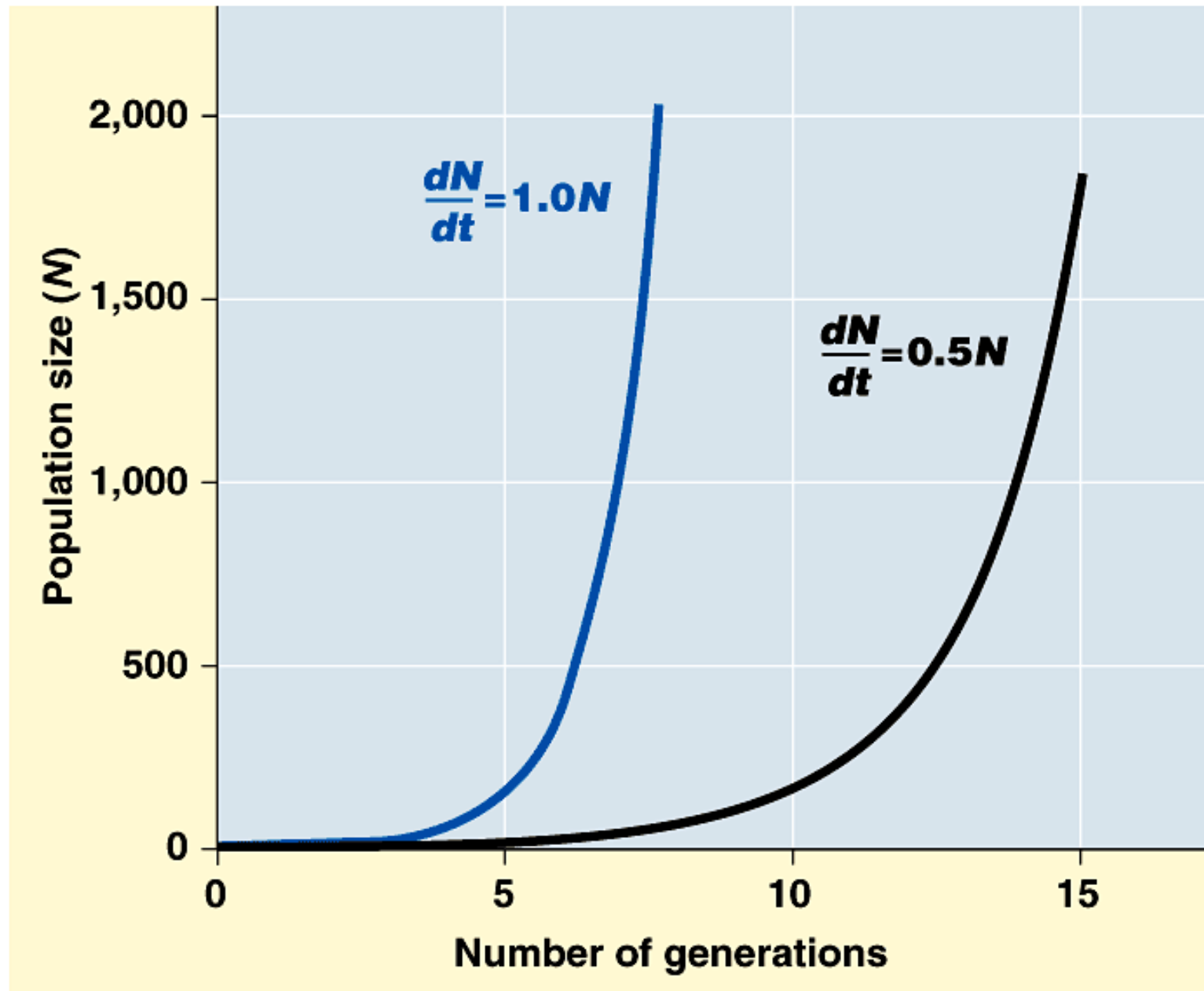
Because the time interval is continuous during exponential growth, we can use differential calculus notation to express the equation as follows:

$$dN/dt = rN$$

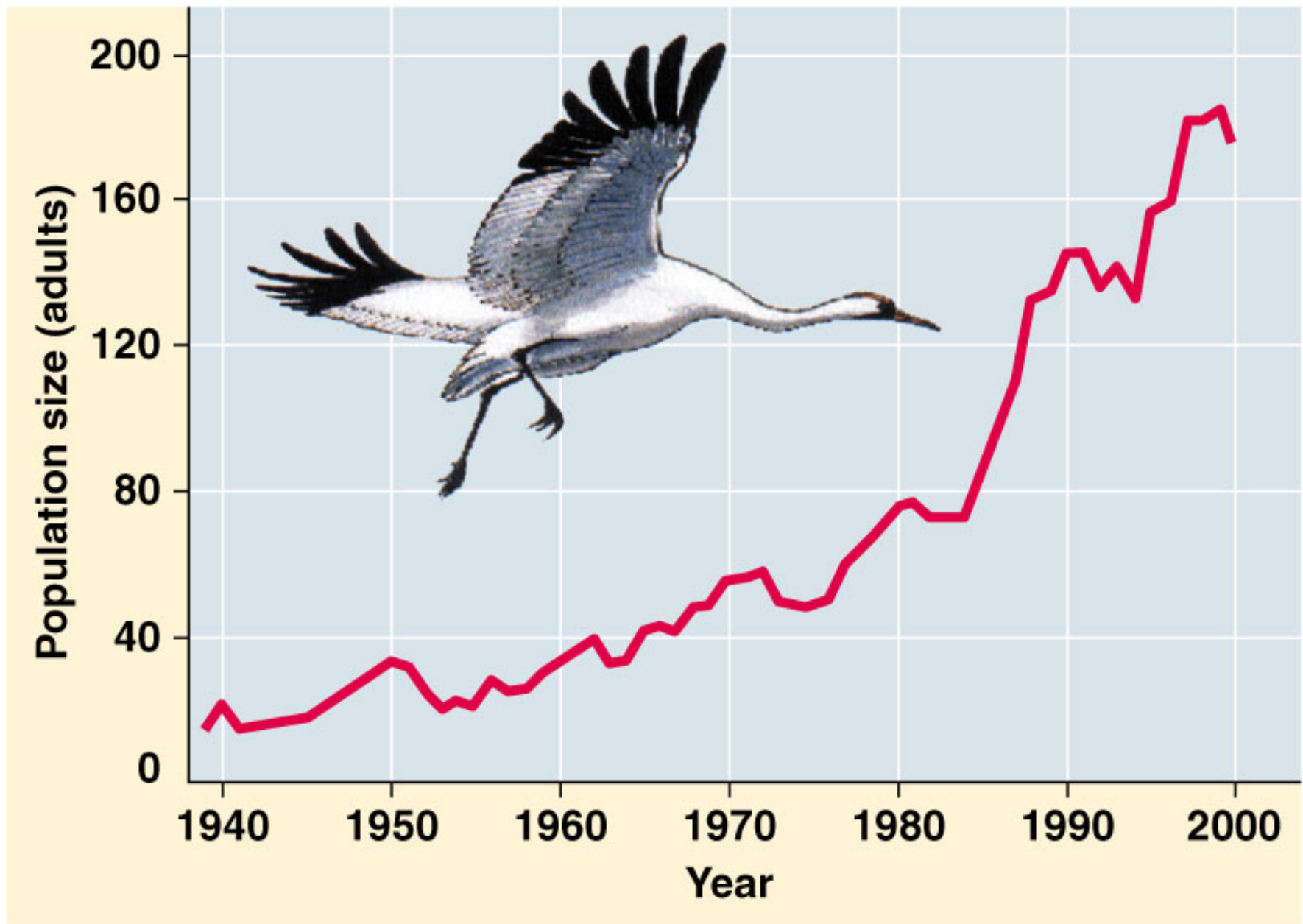
In a population increasing under ideal environmental conditions, the per capita growth rate may assume the maximum growth rate for the species called intrinsic rate of increase, r_{max} . The equation for exponential population growth is then:

$$dN/dt = r_{max}N$$

Population growth predicted by the exponential model



Example of exponential population growth in nature



Logistic model

- No population can grow exponentially indefinitely
- Populations persist on a finite amount of available resources
- Ultimately there is a limit to the numbers of individuals that can occupy a habitat
- Carrying capacity (K) is the maximum population size that a particular environment can support with no degradation of the habitat
 - K is not fixed, it can vary across time and space

Logistic model

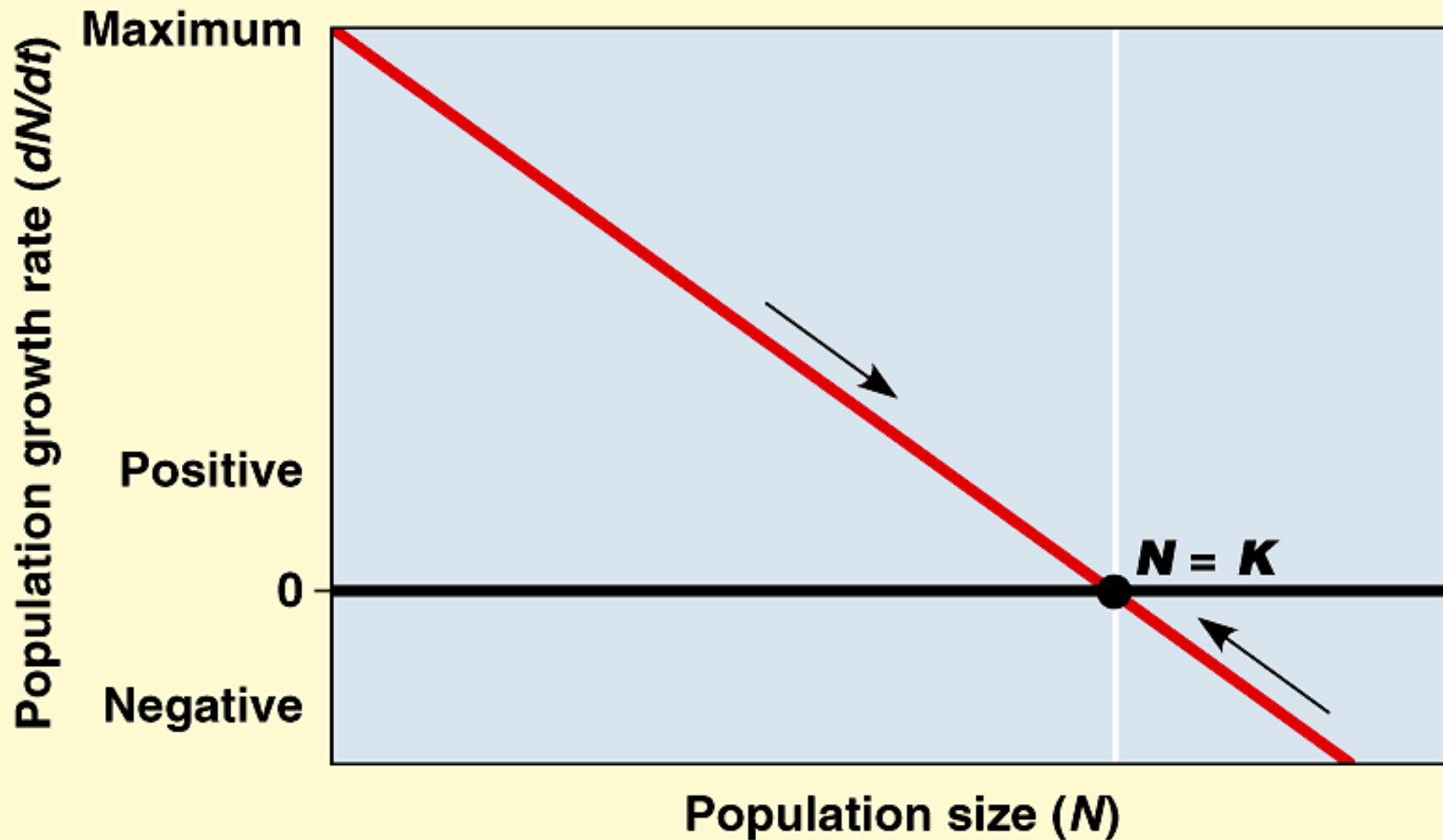
- Incorporates the effect of population density on the per capita rate of increase, allowing the rate to vary from a maximum at low population size to zero as carrying capacity is reached

Logistic equation

- Maximum sustainable population size is K
- $K - N$ tells us how many additional individuals can the environment sustain
- $(K - N)/K$ tells us what fraction of K is still available for population growth
- Hence:

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

Reduction of population growth rate with increasing population size (N)



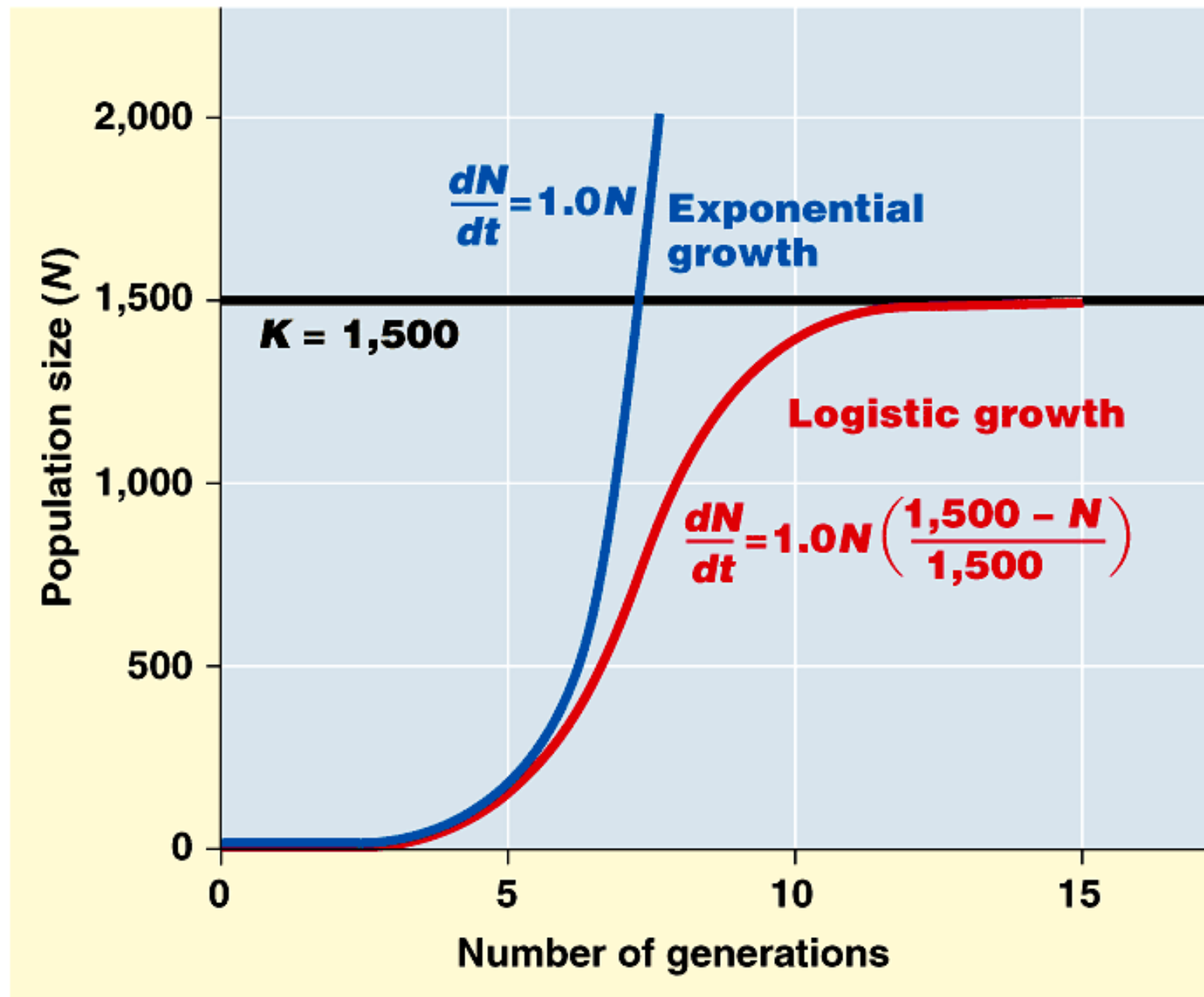
A Hypothetical Example of Logistic Population Growth, Where $K=1,000$ and $r_{max}=0.05$ per Individual per Year

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

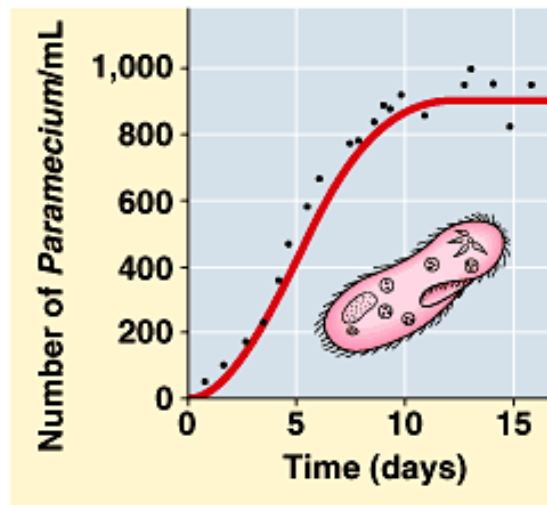
Population Size (N)	Intrinsic Rate of Increase (r_{max})	$\left(\frac{K - N}{K}\right)$	Rate of Population Increase (dN/dt)	ΔN^*
20	0.05	0.98	0.049	+1
100	0.05	0.90	0.045	+5
250	0.05	0.75	0.038	+9
500	0.05	0.50	0.025	+13
750	0.05	0.25	0.013	+9
1,000	0.05	0.00	0.000	0

* ΔN is rounded to the nearest whole number.

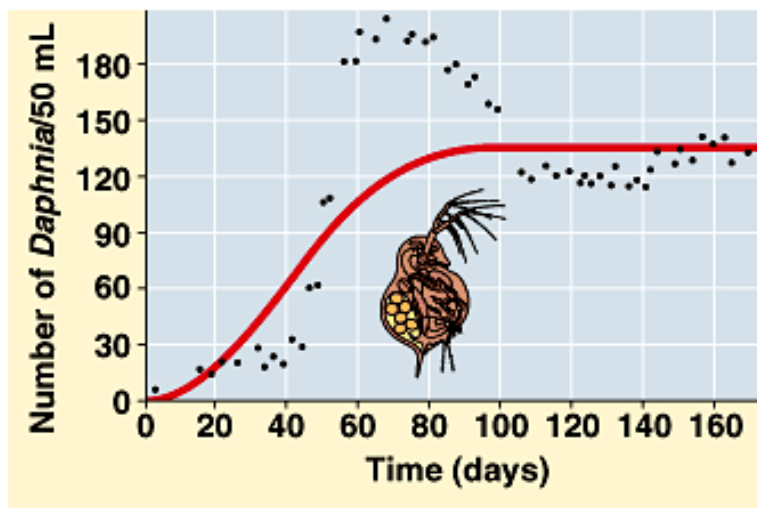
Population growth predicted by the logistic model



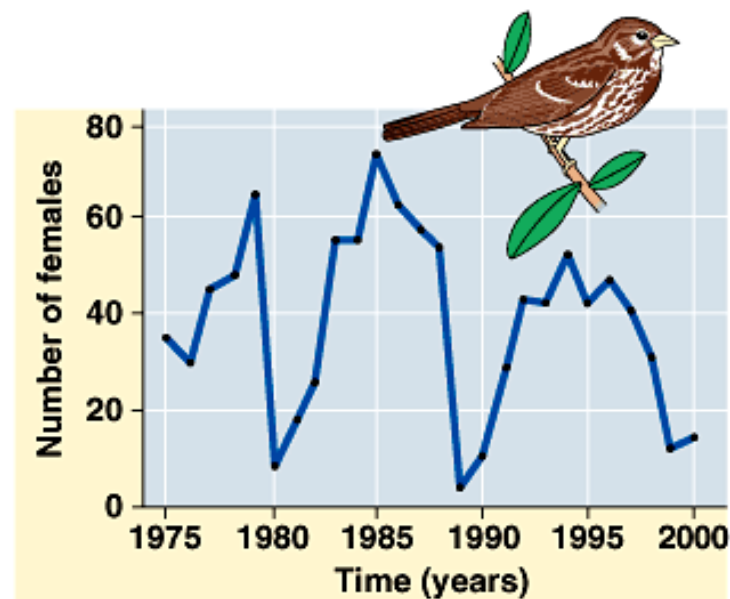
How well do these populations fit the logistic population growth model?



(a) A *Paramecium* population in the lab



(b) A *Daphnia* population in the lab

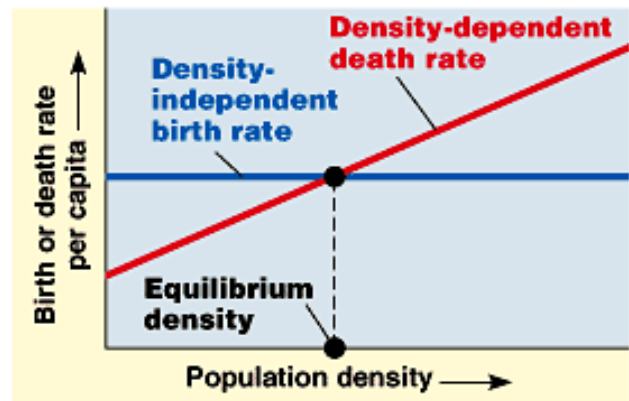
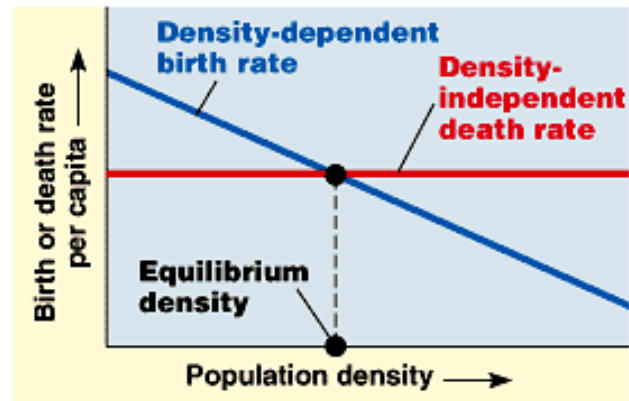
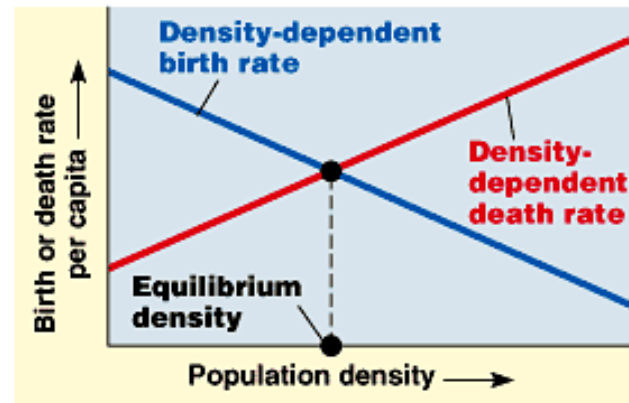


(c) A song sparrow population in its natural habitat

Population limiting factors

- First step is to understand how births and deaths change as population density rises
- Density dependent birth or death rates change with population density. Only ones that regulate population growth
- Density independent birth or death rates do not change with population density. They influence population growth

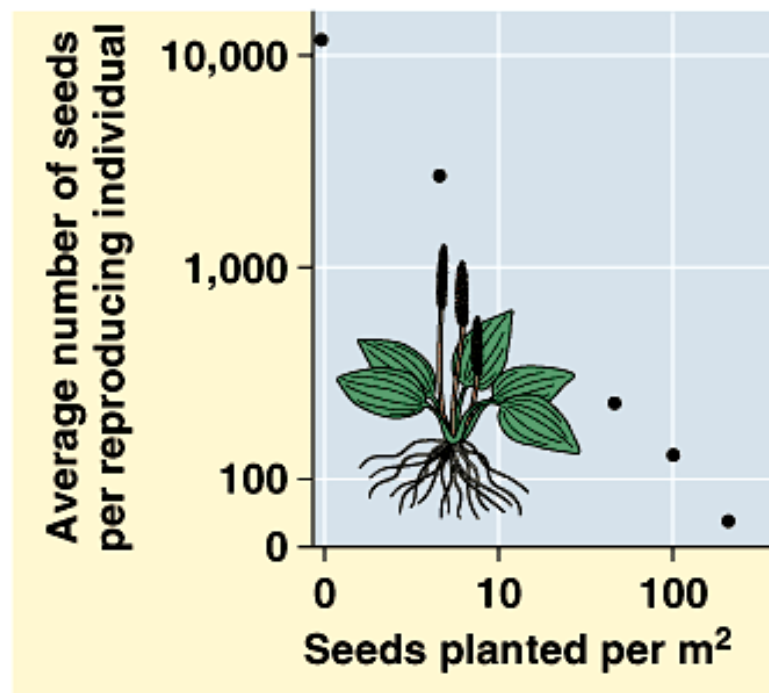
Graphic model showing how equilibrium may be determined for population density



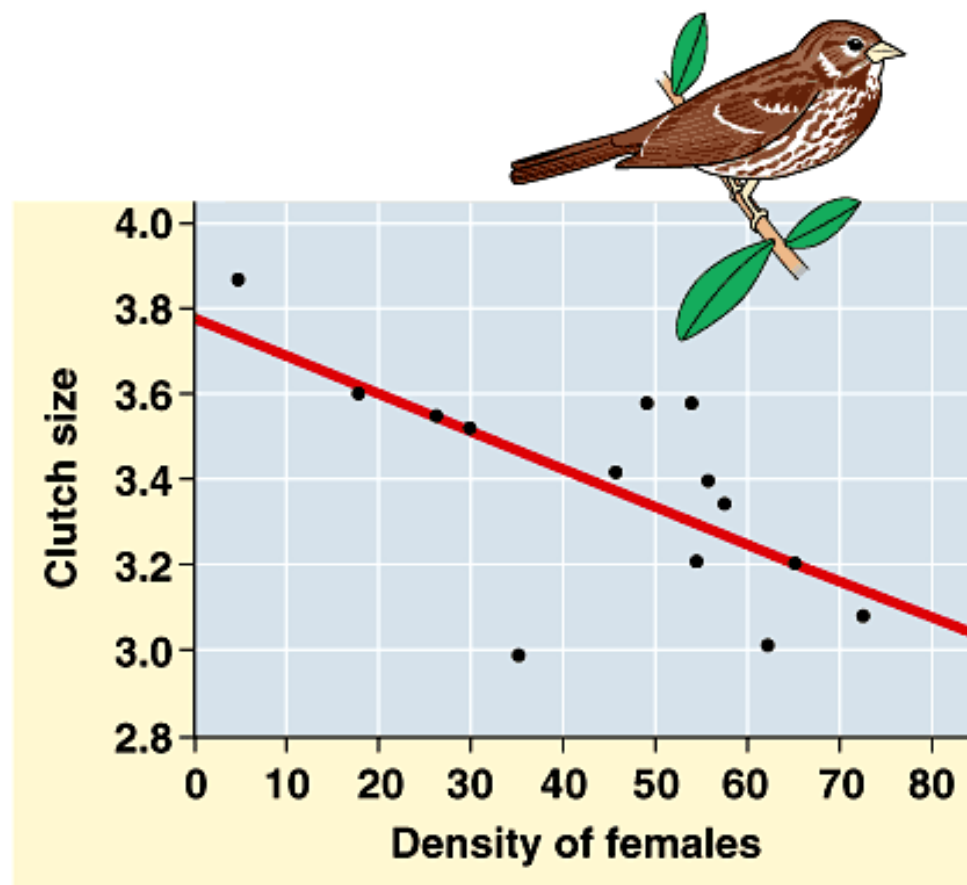
Population limiting factors

- Next step is to determine the mechanisms behind the density dependence or independence
- Density dependent mechanisms:
 - Competition for food, territories
 - Predation
 - Disease
 - Parasites
 - Increase in aggressive behavior/stress
- Density independent mechanisms
 - Severe weather
 - Variable, unpredictable weather

Decreased fecundity at high population densities

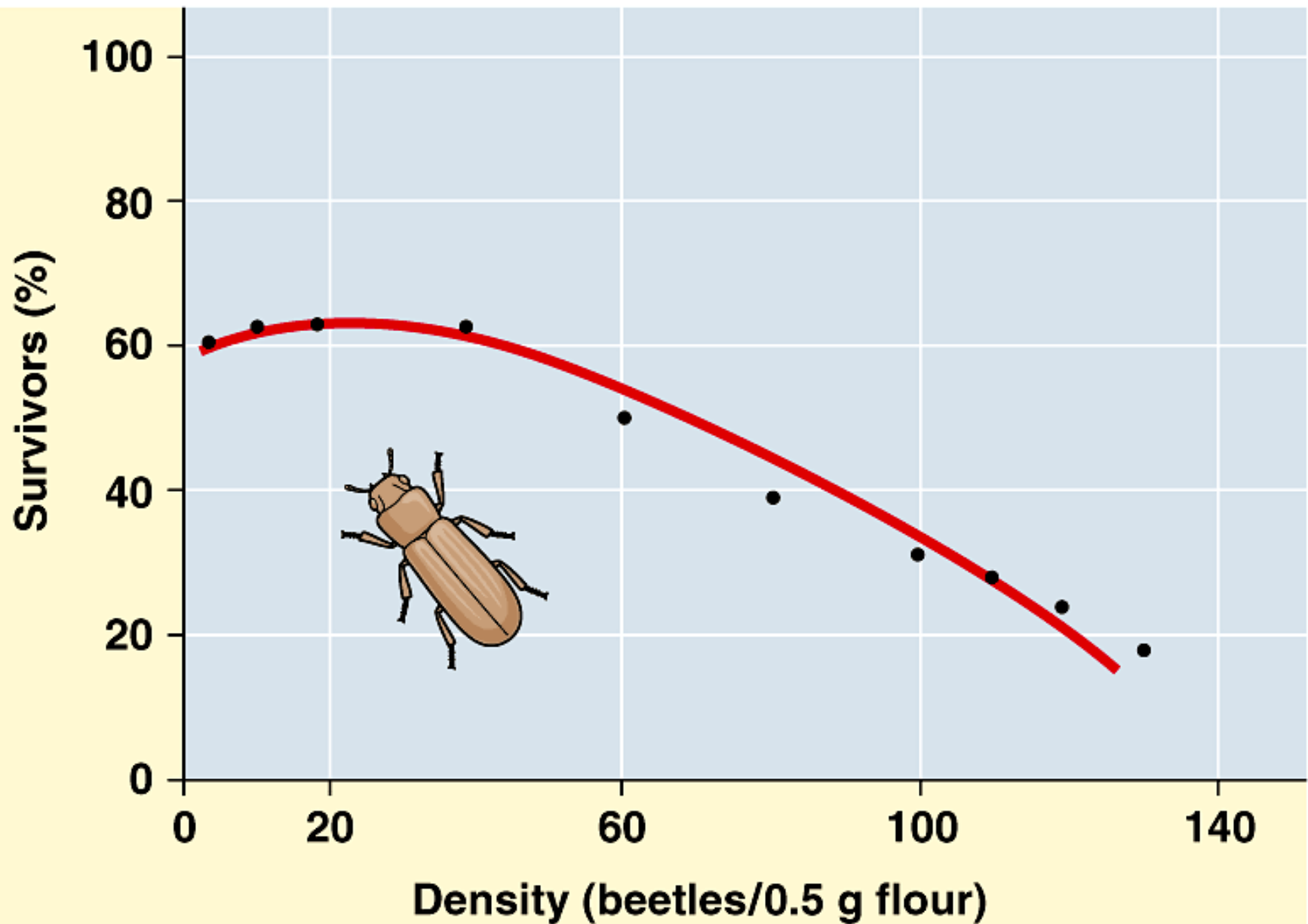


(a) Plantain



(b) Song sparrow

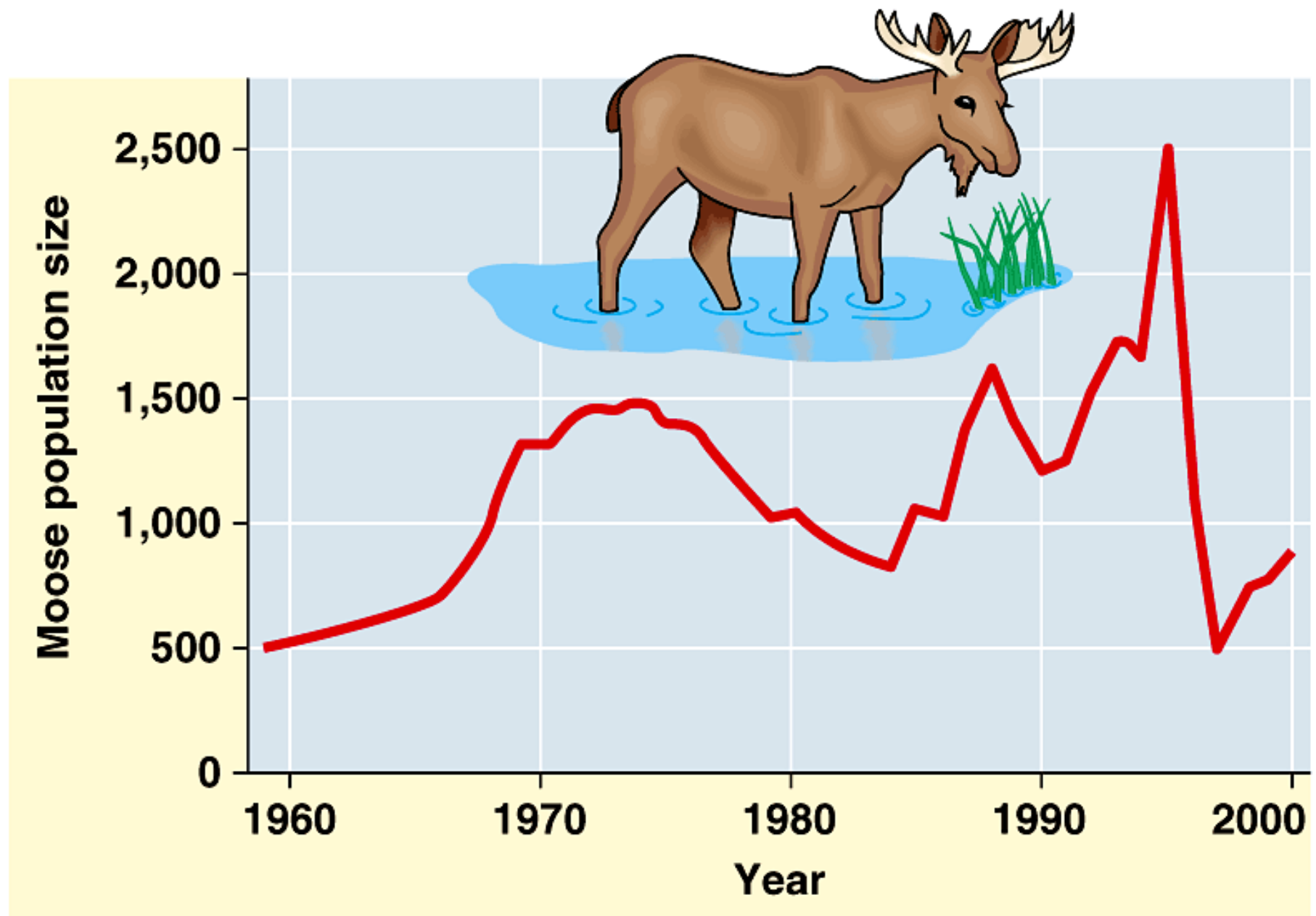
Decreased survivorship at high population densities



Population limiting factors

- Populations are dynamic through time and space

Long-term study of the moose (*Alces alces*) population of Isle Royale, Michigan



Extreme population fluctuations

