9

Population Growth and Regulation
Model assumptions: Exponential growth

- No I or E
- Constant $b$ and $d$ (density independent)
- No genetic structure
- No age or size structure
- No time lags (continuous model)
9 Population Growth and Regulation

- Effects of population density on population growth
- Logistic growth model
Population growth rates can be influenced by both density-dependent and density-independent factors.
Some factors are a function of population density, other are not dependent on density—density-independent factors.

Factors such as temperature and precipitation, and disturbances such as floods or hurricanes.

In the insect *Thrips imaginis*, population size fluctuation is correlated with temperature and rainfall (Davidson and Andrewartha 1948).
Figure 9.12 Weather Can Influence Population Size

![Graph showing the number of thrips per rose over years from 1932 to 1946. The graph compares observed and predicted numbers. Peaks in 1938 and 1939.](image)
In natural populations, favorable conditions result in exponential growth of populations, but...

Exponential growth cannot continue indefinitely. There are limits to population growth.
Density-dependent factors: Cause birth rates, death rates, and dispersal rates to change as the density of the population changes.

As densities increase birth rates often decrease, death rates increase, and dispersal from the population (emigration) increases, all of which tend to decrease population size.
Population regulation occurs when density-dependent factors cause population to increase when density is low and decrease when density is high.

Ultimately, food, space, or other essential resources are in short supply and population size decreases.
Regulation refers to the effects of factors that tend to increase $\lambda$ or $r$ when the population size is small and decrease $\lambda$ or $r$ when the population size is large.

Density-independent factors can have large effects on population size, but they do not regulate population size.
Density dependence has been documented in some natural populations.

In song sparrows, the number of eggs laid per female decreased with density, as did the number of young that survived (Arcese and Smith 1988).
Figure 9.14 A Examples of Density Dependence in Natural Populations

(A)

<table>
<thead>
<tr>
<th>Number of breeding females</th>
<th>Independent young per female</th>
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<tr>
<td>0</td>
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</tr>
<tr>
<td>10</td>
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</tr>
<tr>
<td>70</td>
<td>4.5</td>
</tr>
<tr>
<td>80</td>
<td>5.0</td>
</tr>
</tbody>
</table>

(Fed)

(Control)

ECOLOGY, Figure 9.14 (Part 1)
Density-dependent mortality has been observed in some populations.

Yoda et al. (1963) planted soybeans at various densities and found that at the highest planting densities, many of the seedlings had died by 93 days of age.
Figure 9.14B Examples of Density Dependence in Natural Populations

(B)

![Graph showing density dependence](image)

**ECOLOGY, Figure 9.14 (Part 2)**
In an experiment where eggs of the flour beetle *Tribolium confusum* were placed in glass tubes, death rates increased as the density of eggs increased.
Figure 9.14 C  Examples of Density Dependence in Natural Populations

(C)

![Graph showing the relationship between egg density and death rate with a brown beetle illustration.](Image)

ECOLOGY, Figure 9.14 (Part 3)
Density dependence can be detected even in populations whose abundance is largely controlled by density-independent factors.

Smith (1961) replotted Davidson and Andrewartha’s data (1948): Change in population size from one time period to the next versus size of the population at the start of the time period.
Figure 9.15 Density Dependence in *Thrips imaginis*
Figure 9.16 Population Growth Rates May Decline at High Densities (Part 2)

(B)

- Population growth rate ($r$) vs. Density ($Daphnia/cm^3$)

- The graph shows a negative linear relationship between population growth rate and density.

ECOLOGY, Figure 9.16 (Part 2)
Derivation: continuous logistic population growth
The result is in the *logistic equation*:

\[
\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right)
\]

\(N = \text{population density}\)
\(r = \text{per capita growth rate}\)
\(K = \text{carrying capacity}\)
Logistic Growth

The logistic equation incorporates limits to growth and shows how a population may stabilize at a maximum size, the carrying capacity.

**Logistic growth**: Population increases rapidly at first, then stabilizes at the carrying capacity, $K$.

**Carrying capacity**: the maximum population size that can be supported by the environment.
Figure 9.18 Logistic and Exponential Growth Compared

Exponential growth: \( \frac{dN}{dt} = rN \)

Logistic growth: \( \frac{dN}{dt} = rN \left(1 - \frac{N}{K}\right) \)
Figure 9.17 An S-shaped Growth Curve in a Natural Population

![Graph showing an S-shaped growth curve with years on the x-axis and number of trees on the y-axis, demonstrating population growth over time.](image_url)
Logistic Growth

In the exponential growth equation \( \frac{dN}{dt} = rN \), \( r \) is assumed to be constant.

In the logistic model, we assume that \( r \) declines linearly as density \( (N) \) increases.
When densities are low, logistic growth is similar to exponential growth.

When $N$ is small, $(1 - N/K)$ is close to 1, and a population with logistic growth increases at a rate close to $r$.

As density increases, growth rate approaches zero.
Model assumptions

There are logistic growth models for populations with overlapping and discrete generations.
Derivation: discrete logistic population growth
Model assumptions

- No I or E
- Linear density dependence (of b and/or d on population)
- Constant carrying capacity
- No genetic structure
- No age or size structure
- No time lag
Pearl and Reed (1920) derived the logistic equation and used it to predict a carrying capacity for the U.S. population, using census data.

The logistic curve fit the U.S. data well, through 1950. After that, however, the actual population size differed considerably from the predicted curve.
Figure 9.19  Fitting a Logistic Curve to the U.S. Population Size

Pearl and Reed’s logistic curve
U.S. census data used by Pearl and Reed
Estimates of U.S. population size, 1920–2004

Carrying capacity estimated by Pearl and Reed

ECOLOGY, Figure 9.19
Pearl and Reed recognized that if conditions changed—for example, if agricultural productivity increased—the population could increase beyond the predicted carrying capacity.

Some ecologists have shifted to the concept of the ecological footprint: The total area required to support a human population.
Figure 9.21  United Nations Projections of Human Population Size

- Best estimate
- High projection
- Low projection


Human population size (billions): 0, 2, 4, 6, 8, 10, 12
Many people have tried to estimate human carrying capacity.

This requires assumptions about how people would live and how technology would influence our future.

Estimates range from fewer than 1 billion to more than 1,000 billion.
If everyone used the amount of resources used by people in the U.S. in 1999, the world could support only 1.2 billion people.

If everyone used the amount of resources used by people in India in 1999, the world could support over 14 billion people.
The environmental impact of a population is called its **ecological footprint**.

Ecological footprints are calculated from national statistics on agricultural productivity, production of goods, resource use, population size, and pollution.

The area required to support these activities is then estimated.
In the U.S. the average ecological footprint was 9.7 hectares per person in 1999 and there were 1,800 million hectares of productive land available.

This suggests that the carrying capacity of the U.S. in 1999 was 186 million; the actual population was 279 million, a 50% overshoot.