19 Populations in ecosystems

19.1 Populations and ecosystems

Learning objectives

- → Define the terms environment, biotic, abiotic, and biosphere.
- → Explain what is meant by an ecosystem.
- → Explain what is meant by the terms population, community, and habitat.
- → Explain what a niche is.

Specification reference: 3.7.4

Hint

Many students confuse the terms biotic and abiotic. Biotic refers to living things, for example, predation or competition between different species or individuals of one species. Abiotic refers to non-living factors, such as temperature, rainfall, or light intensity.

▲ **Figure 1** *Woodland ecosystem*

Study tip

Population is a very important concept that needs to be understood. It comes up in many areas of biology, including genetics and evolution.

In this chapter we shall look at how living organisms form communities within ecosystems through which energy is transferred and elements are recycled.

We shall learn how populations of different species live in communities and how competition for survival arises both within and between these populations. We shall also see how populations within a single community are affected by living and non-living factors in an ecosystem.

Ecology is the study of the inter-relationships between organisms and their environment. The environment includes both non-living (**abiotic**) factors, such as temperature and rainfall, and living (**biotic**) factors, such as competition and predation.

Ecosystems

Ecosystems are dynamic systems made up of a community and all the non-living factors of its environment. Ecosystems can range in size from very small to very large. Within an ecosystem there are two major processes to consider:

- the flow of energy through the system
- the cycling of elements within the system.

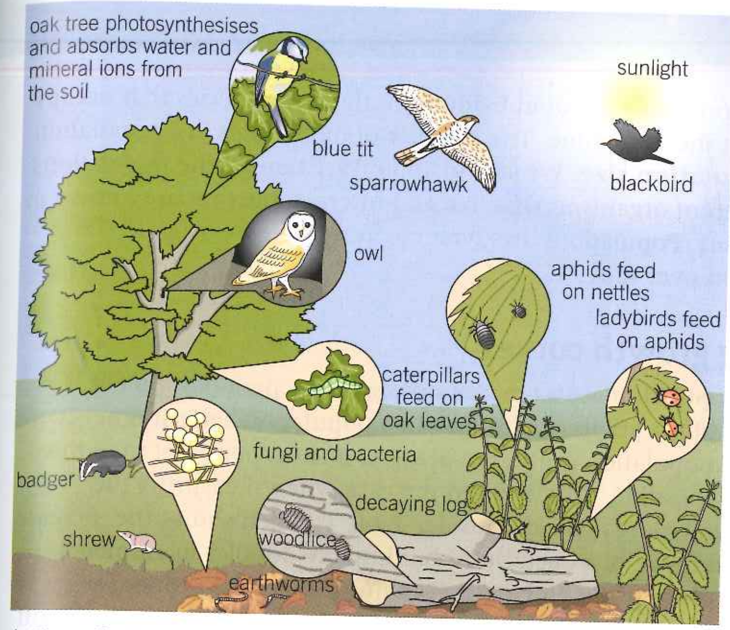
An example of an ecosystem is a freshwater pond or lake. It has its own community of plants to collect the necessary sunlight energy to supply the organisms within it. Nutrients such as nitrate ions and phosphate ions are recycled within the pond or lake. There is little or no loss or gain between it and other ecosystems. Another example of an ecosystem is an oak woodland (Figure 2). Within each ecosystem, there are a number of species. Each species is made up of a group of individuals that make up a **population**.

Populations

A **population** is a group of individuals of one **species** that occupy the same habitat at the same time and are potentially able to interbreed. An ecosystem supports a certain size of population of a species called the **carrying capacity**. The size of a population can vary as a result of:

- the effect of abiotic factors
- interactions between organisms, for example, intraspecific and interspecific competition and predation.

In the different habitats of an oak woodland there are populations of nettles, worms, green woodpeckers, beetles, etc. The boundaries of a population are often difficult to define. In our oak woodland, for example, all the mature green woodpeckers can breed with one another and so form a single population. Populations of different species form a **community**.



▲ **Figure 2** *Part of an oak woodland ecosystem*

Community

A **community** is defined as all the populations of different species living and interacting in a particular place at the same time. Within an oak woodland, a community may include a large range of organisms, such as oak trees, hazel shrubs, bluebells, nettles, sparrowhawks, blue tits, ladybirds, aphids, woodlice, earthworms, fungi, and bacteria (Figure 2).

Habitat

A **habitat** is the place where an organism normally lives and is characterised by physical conditions and the other types of organisms present. Within an ecosystem there are many habitats. For example, in an oak woodland, the leaf canopy of the trees may be a habitat for blue tits while a decaying log is the habitat for woodlice. A stream flowing through the woodland provides a very different habitat, within which aquatic plants and water beetles live. For a water vole, the stream and its banks are its habitat. Within each habitat there are smaller units, each with their own microclimate. These are called **microhabitats**. The mud at the bottom of the stream may be the microhabitat for a bloodworm while a crevice on the bark of an oak tree may be the microhabitat for a lichen.

Ecological niche

A **niche** describes how an organism fits into the environment. A niche refers to where an organism lives and what it does there. It includes all the biotic and abiotic conditions to which an organism is adapted in order to survive, reproduce and maintain a viable population. Some species may appear very similar, but their nesting habits or other aspects of their behaviour will be different, or they may show different levels of tolerance to environmental factors, such as a pollutant or a shortage of oxygen or nitrates. No two species occupy exactly the same niche. This is known as the competitive exclusion principle.

Hint

Organisms are found in places where the local environmental conditions fall within the range that their adaptations enable them to cope with.

Study tip

Make sure that you can accurately define the basic ecological terms described in this topic.

▲ **Figure 3** *This lake is an example of a habitat*

Summary questions

In the following passage, state the word that best replaces each of the numbers in brackets.

The study of the interrelationships between organisms and their environment is called (1). An ecosystem is a more or less self-contained functional unit made up of all the living or (2) features and non-living or (3) features in a specific area. Within each ecosystem are groups of different organisms, called a (4), which live and interact in a particular place at the same time. A group of organisms occupying the same place at the same time is called a (5), and the place where they live is known as a (6). The population size of a species that an ecosystem can support is known as (7).

19.2 Variation in population size

Learning objectives

- Describe the factors that determine the size of a population.
- Describe the abiotic factors that affect the size of a population.
- Explain how each of these factors influence population size.

Specification reference: 3.7.4

▲ **Figure 1** *A population of lesser flamingos*

Hint

Humans exist in populations just like other species and therefore the rules also apply to us.

▲ **Figure 2** *The collared dove only arrived in Britain in the 1950s but its population has increased rapidly since then*

Maths link

MS 2.5, see Chapter 22.

A population is a group of individuals of the same species that occupy a habitat at the same time. The number of individuals in a population is the **population size**. We saw in Topic 19.1 that all the populations of the different organisms that live and interact together are known as a community. Populations are dynamic in that they vary in size and composition over time.

Plotting growth curves

Where a population grows in size slowly over a period of time it is possible to plot a graph of numbers in a population against time. Where the population grows rapidly over a short period of time this may not be possible. This is often the case when measuring the growth of microorganisms. Consider Table 1 which shows the increase in population size of a bacterium that initially doubles its numbers each hour. If we try to plot a graph of numbers against time using a time scale that allows us to differentiate each point, the curve runs off the graph after the point plotted at 4 hours (Figure 3).

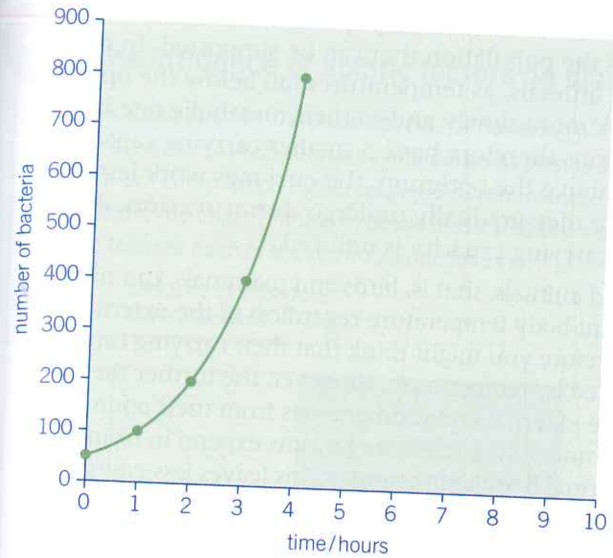
In these cases it is necessary to use a logarithmic scale to represent the number of bacteria. The logarithms of bacterial numbers are shown in Table 1. When the graph of log bacterial numbers is plotted against time all points can be represented on the graph (Figure 4) and we can see that the rate of growth starts to slow after 8 hours.

Population size

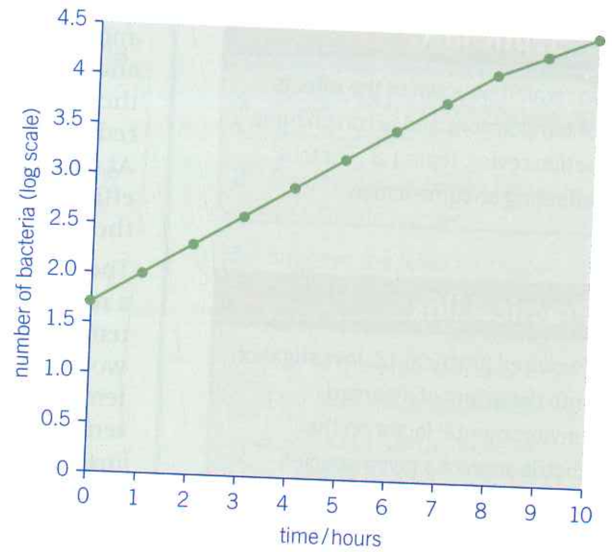
Imagine a situation in which a single photosynthetic bacterial cell, capable of asexual reproduction, is placed in a newly created pond. It is summer and so there is plenty of light and the temperature of the water is around 12 °C – mineral nutrients have been added to the water. In these circumstances the bacterial cell divides rapidly because

▼ **Table 1**

Time/hours	Number of bacteria	Log number of bacteria
0	50	1.7
1	100	2.0
2	200	2.3
3	400	2.6
4	800	2.9
5	1 600	3.2
6	3 200	3.5
7	6 400	3.8
8	12 800	4.1
9	20 300	4.3
10	31 500	4.5



▲ **Figure 3** *Graph of number of bacteria against time*



▲ **Figure 4** *Graph of log number of bacteria against time*

all the factors needed for the growth of the population are present. There are no **limiting factors**. In time, however, things change. For example:

- Mineral ions are consumed as the population becomes larger.
- The population becomes so large that the bacteria at the surface prevent light reaching those at deeper levels.
- Other species are introduced into the pond, carried by animals or the wind, and some of these species may use the bacteria as food or compete for light or minerals.
- Winter brings much lower temperatures and lower light intensity of shorter duration.

In short, the good life ends and the going gets tough. As a result the growth of the population slows, and possibly ceases altogether, and the population size may even diminish. Over the winter the population is likely to reach a relatively constant size. There are many factors, living (biotic) and non-living (abiotic), which affect this population size. Changes in these factors will influence the rate of growth and the size of the population.

In summary, no population continues to grow indefinitely because certain factors limit growth, for example, the availability of food, light, water, oxygen and shelter, and the accumulation of toxic waste, disease and predators. Each population has a certain size, the **carrying capacity**, that can be sustained over a relatively long period and this is determined by these limiting factors.

Abiotic factors

The abiotic conditions that influence the size of a population include:

- **temperature**. Each species has a different optimum temperature at which it is best able to survive. The further away from this

▲ **Figure 5** *A population of migrating birds, like these terns, fluctuates seasonally*

Hint

Remember that the size of any population is eventually determined by a limiting factor.

Hint

A species can only live within a certain range of abiotic factors and this range differs from species to species.

Synoptic link

To remind yourself of the effects of temperature and pH on enzyme action revisit Topic 1.8, Factors affecting enzyme action.

Practical link

Required practical 12. Investigation into the effect of a named environmental factor on the distribution of a given species.

optimum, the fewer individuals in a population are able to survive and the smaller is the population that can be supported. In plants and cold-blooded animals, as temperatures fall below the optimum, the enzymes work more slowly and so their metabolic rate is reduced. Populations therefore have a smaller carrying capacity. At temperatures above the optimum, the enzymes work less efficiently because they gradually undergo **denaturation**. Again the population's carrying capacity is reduced.

The warm-blooded animals, that is, birds and mammals, can maintain a relatively constant body temperature regardless of the external temperature. Therefore you might think that their carrying capacity would be unaffected by temperature. However, the further the temperature of the external environment gets from their optimum temperature, the more energy these organisms expend in trying to maintain their normal body temperature. This leaves less energy for individual growth and so they mature more slowly and their reproductive rate slows. The carrying capacity of the population is therefore reduced.

- **Light**. As the ultimate source of energy for most **ecosystems**, light is a basic necessity of life. The rate of photosynthesis increases as light intensity increases. The greater the rate of photosynthesis, the faster plants grow and the more spores or seeds they produce. Their carrying capacity is therefore potentially greater. In turn, the carrying capacity of animals that feed on plants is potentially larger.
- **pH**. This affects the action of enzymes. Each enzyme has an optimum pH at which it operates most effectively. A population of organisms is larger where the appropriate pH exists and smaller, or non-existent, where the pH is different from the optimum.
- **Water and humidity**. Where water is scarce, populations are small and consist only of species that are well adapted to living in dry conditions. Humidity affects the **transpiration** rates in plants and the evaporation of water from the bodies of animals. Again, in dry air conditions, the populations of species adapted to tolerate low humidity will be larger than those with no such adaptations.

In general terms, when any abiotic factor is below the optimum for a population, fewer individuals are able to survive because their adaptations are not suited to the conditions. If no individuals have adaptations that allow survival, the population becomes extinct.

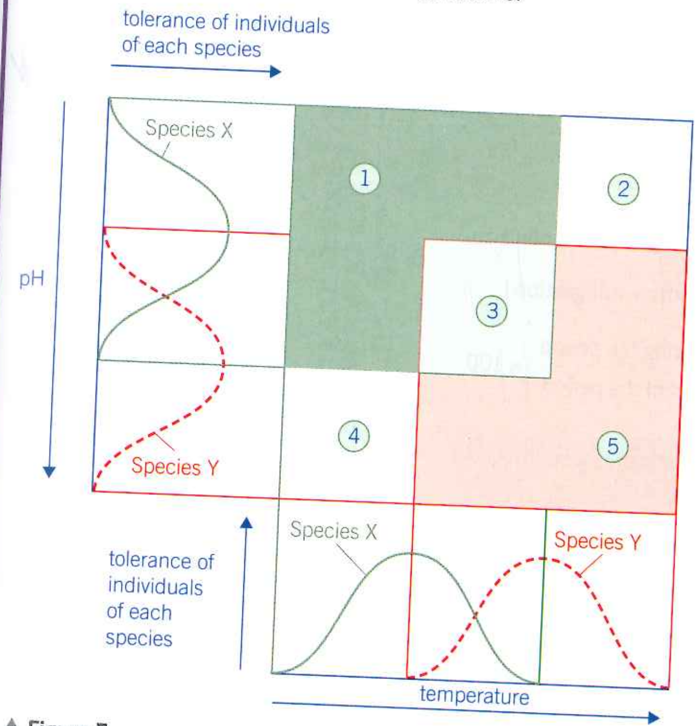
▲ **Figure 6** *This cactus is adapted to survive in conditions where water is scarce. Its population in dry regions is therefore relatively large as there is little competition from other species, most of which are not adapted to survive in such conditions*

Maths link

MS 0.5 and 3.2, see Chapter 22.

The influence of abiotic factors on plant populations

Species X and species Y are two species of flowering plants. Each is able to tolerate different temperatures and different pHs. In this way they avoid direct competition by occupying different niches. This is called niche separation. The chart (Figure 7) below illustrates the way each species is able to tolerate each of these two abiotic factors.



▲ **Figure 7**

1. State the numbered box that best fits each of the descriptions below.
   a. Only a population of species X is found.
   b. Both temperature and pH allow a population of both species to exist.
   c. The temperature is too high for a population of species X and the pH is too low for a population of species Y.
   d. There is competition between species X and species Y.
2. Explain why there is no population of either species in box 4.

Summary questions

1. Explain why populations never grow indefinitely.
2. Distinguish between biotic and abiotic factors.
3. Suggest the level and type of abiotic factor that is most likely to limit the population size of the organisms and their habitats given below.
   a. Ground plants on a forest floor
   b. Hares in a sandy desert
   c. Bacteria on the summit of a high mountain.
4. Table 2 shows the estimated world population over the past 12 000 years.

▼ **Table 2**

Time / years before present (BP)	Estimated human population / billions
0	600
2 000	200
4 000	35
6 000	20
8 000	10
10 000	5
12 000	1

   a. Explain the benefits of using a logarithmic scale for population numbers when plotting a graph of these data.
   b. Calculate to three significant places the log values for the human population in each case.
   c. Plot a suitable graph to show the growth of the human population over the past 12 000 years.

Maths link

MS 0.3 and 3.1, see Chapter 22.

The growth and size of human populations

The human population has doubled in less than 50 years and now totals over 7 billion. The basic factors that affect the growth and size of human populations are the **birth rate** and the **death rate**. It is the balance between these two factors that determines whether a human population increases, decreases or remains the same.

Individual populations are further affected by **migration**, which occurs when individuals move from one population to another. There are two types of migration:

- **immigration**, where individuals join a population from outside
- **emigration**, where individuals leave a population.

Again it is a balance between these two components that affects population size.

population growth = (births + immigration) − (deaths + emigration)

$$\text{percentage population growth rate (in a given period)} = \frac{\text{population change during the period}}{\text{population at the start of the period}} \times 100$$

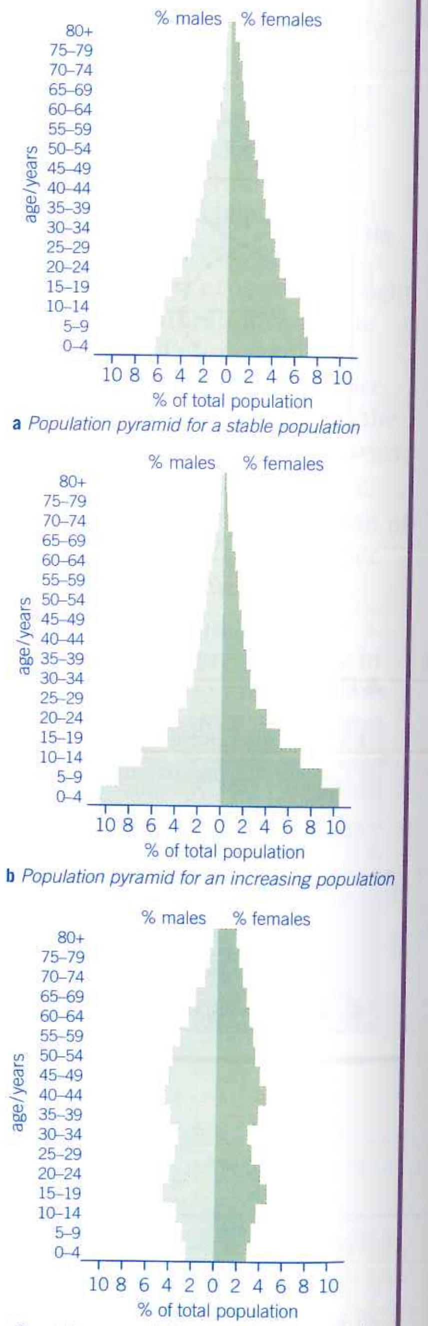
1 The figures below show some population statistics for a country.
Total population at the start of 2007 = 1 000 000
Birth rate in 2007 = 25 per 1000 of population
Death rate in 2007 = 20 per 1000 of population
Calculate the percentage population growth for this country in 2007. Show your working.

As the future size of a human population depends upon the number of females of child-bearing age, it is useful to know the age and gender profile of a population. This is displayed graphically by a series of stacked bars representing the percentages of males and females in each age group. These graphs, called age **population pyramids**, give useful information on the future trends of different populations. Three typical types of population are represented in the age population pyramids in Figure 10. These are:

- **stable population** (Figure 10a), where the birth rate and death rate are in balance and so there is no increase or decrease in the population size.
- **increasing population** (Figure 10b), where there is a high birth rate, giving a wider base to the population pyramid (compared to a stable population) and fewer older people, giving a narrower apex to the pyramid. This type of population is typical of economically less developed countries.
- **decreasing population** (Figure 10c), where there is a lower birth rate (narrower base of the population pyramid) and a lower mortality rate leading to more elderly people (wider apex to pyramid). This type of population occurs in certain economically more developed countries, such as Japan.

As countries have developed economically their human populations have, so far, displayed a pattern of growth known as demographic transition. This pattern can be divided into four stages depending on the birth rate, death rate and total population size. The relationship between these four stages and the birth rates, death rates and total population are illustrated in Figure 11.

▲ **Figure 9** *The human population now exceeds 7 billion*



a Population pyramid for a stable population

b Population pyramid for an increasing population

c Population pyramid for a decreasing population

▲ **Figure 10** *Age population pyramids*

2 Using Figure 11, suggest which of the four stages (1, 2, 3 or 4) best applies to each of the descriptions below.

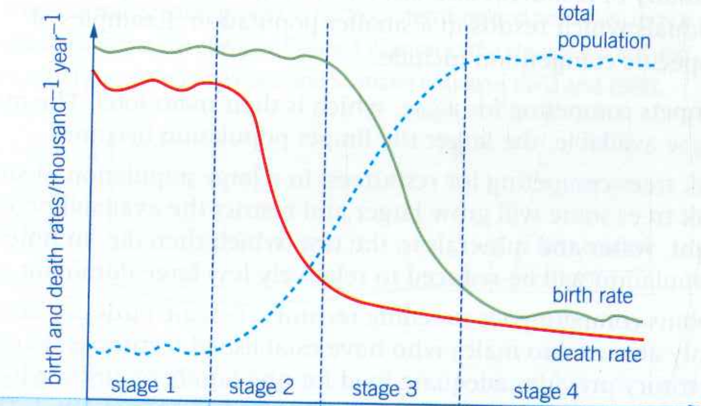
a A country that has a rapidly falling birth rate and a relatively low death rate.

b A country in which there is a high birth rate but much starvation and periodic epidemic disease.

c A country where there have been many years of improved nutrition, far less infectious disease and a large number of children.

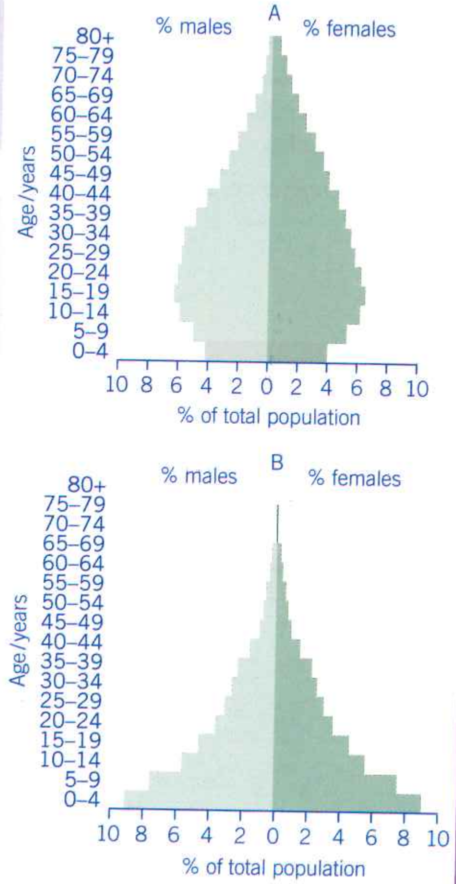
d Britain 20 000 years ago when famine and disease led to regular population crashes.

e Britain today.



total population	small and stable	early expansion	late expansion	large and stable
birth rate	high	high	decreasing	low
death rate	high	decreasing	low	low

▲ **Figure 11** *Demographic transition*



▲ **Figure 12** *Age population pyramids A and B*

3 Figure 12 shows two age population pyramids: A and B. Suggest which stage of the demographic transition model shown in Figure 11 each pyramid represents. Give reasons for your answer in each case.