Bio Factsheet

Number 5

An Idiot's Guide to Populations

A population is a group of organisms of one species in a particular location. The location may be defined by natural boundaries (eg. an island) or defined by the researcher (eg a particular field). We may therefore refer to "the population of frogs in a valley" or "the population of moths in an orchard".

What Determines Population Size?
Changes in population size are caused by:

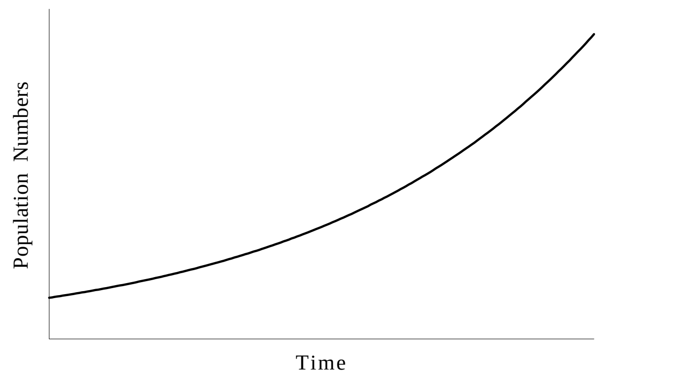
Births
Deaths
Migration

What determines whether a population increases, decreases or remains constant is the balance between these factors.

Population Growth
Neglecting migration, populations will increase if the birth-rate is greater than the death-rate. Since members of a species of breeding age will normally replace themselves by a greater number of offspring, populations will tend to increase unless prevented by unfavourable conditions.

The simplest type of population growth occurs when both birth and death rates are approximately **constant** (with, of course, the birth rate exceeding the death rate). An equivalent way of looking at this is to say that the number of births and deaths is directly proportional to the number of individuals in the population; in other words, if the population size doubled, so would the numbers of births and deaths. This leads to **exponential growth** (see Fig 1)

Fig 1. Exponential population growth



An important characteristic of populations growing exponentially is that they have a **constant doubling time**. This means that if it takes 2 years for a population to increase from 15 individuals to 30 individuals, in another 2 years it will increase from 30 to 60, and in two years after that it will increase from 60 to 120. Table 1 shows the rates of natural increase and doubling times for selected species.

Exponential population growth quickly leads to a massive explosion in numbers. Exponential growth can only be maintained as long as resources (food, space etc.) are effectively unlimited. This will be the case while the population is relatively small, or when a new area with no resident competitors is being colonised.

Table 1. Doubling times for selected species

Species	Common name	Rate of increase (individual/day)	Doubling time
E.coli	Bacterium	58.7	17 minutes
Hydra	Hydra	0.34	2 days
R. norvegicus	Brown rat	0.0148	46.8 days
B. taurus	Domestic cow	0.001	1.9 years
A. marina	Mangrove	0.00055	3.5 years
N. fusca	Southern beech	0.000075	25.3 years

What Stops Growth?
The factors that reduce or stop population growth must act by reducing the birth rate and/or increasing the death rate. They are known collectively as **environmental resistance.** These factors may be categorised in two ways:

Biotic or **Abiotic.**
Density dependent or **Density independent**

Abiotic factors include things like climate and weather as well as environmental pollution. Their effect does not have to be negative - unduly warm or wet weather may actually favour some species.

Biotic factors may be due to competition within the species for food and territory, competition with another species for resources, predation or parasitism. They may act very indirectly - what happens to a species in one part of a food web is likely to influence the numbers of many others in the same web.

These factors may effectively combine - for example, a change in climate may reduce plant growth, which will lead to a reduced food supply for herbivores; this reduced supply may lead to increased competition for resources.

Density Independent factors are those whose effect does not change proportionately when the population increases or declines. This does not mean they must always affect the same *numbers* of the species - it means they must always affect roughly the same *percentage*. Abiotic factors will usually be density independent.

Density Dependent factors, then, change in their proportionate effect as population numbers change - most will have a much greater proportionate effect on a large population. For example, competition for resources both within and between species will not have a noticeable effect if the species concerned is sparse and there is plenty of land and food to go round. Common density dependent factors include space, food, intraspecific competition (i.e. competition between individuals in the same species), predation and parasitism.

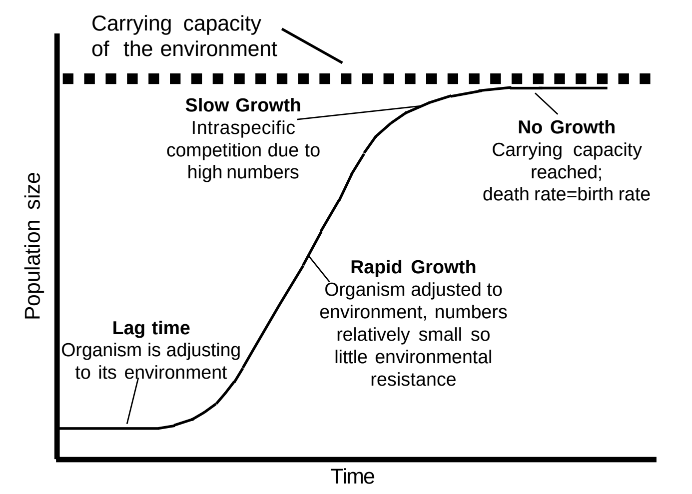
Exam Hint: *Be specific in your use of terms such as "exponential growth". Marks are awarded only for a completely correct use - exponential growth occurs when there is a constant doubling time, not just if growth is rapid.*

Density dependent factors, however, usually exert a regulatory effect - they act to reduce the rate of increase as the population grows larger. This is usually modelled by considering the death rate to increase proportional to population size (due to disease, predation, parasitism and poor nutrition) and the birth rate to decrease proportional to population size (decreasing resource availability means that less energy is available for reproduction).

The rate of natural increase will then also be dependent on population size. For small populations, the rate of increase will be similar to exponential growth, but as numbers increase, the rate of increase slows. The rate of increase will eventually become zero - at this point, births are exactly balanced by deaths and the population has reached the **carrying capacity of the environment;** this is **maximum population size that can be sustained by a particular environment.**

Fig 2 illustrates the **sigmoidal growth curve** which is the result of taking into account these density dependent factors. The rate of growth of the population is the gradient of the curve; it can be seen that as the population approaches the carrying capacity, the rate of growth becomes very slow.

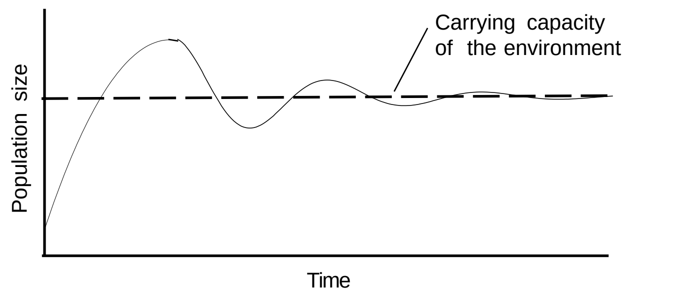
Fig 2. Sigmoidal Growth Curve



Time Delays
The effect of changing conditions will usually not be felt instantaneously; the gestation period, seasonal breeding patterns and the time required to reach reproductive maturity all guarantee a time-delay. For example, in a tropical rainforest, density-dependent mortality of mahogany trees may occur at the seedling stage, but the effect on reproduction may not be felt until 50 years later when the trees begin to flower.

The precise effect of this depends on the growth rate as well as the lag time. Populations with a short lag time and low birth and death rates will behave more or less according to the standard sigmoid curve, since few births or deaths occur in the lag time because of the low rate and shortness of the time. The population will approach the carrying capacity smoothly. With either a longer lag time or a higher birth and death rate, more significant numbers of births and deaths occur in the lag time. This leads to the population overshooting then undershooting the carrying capacity (Fig 3).

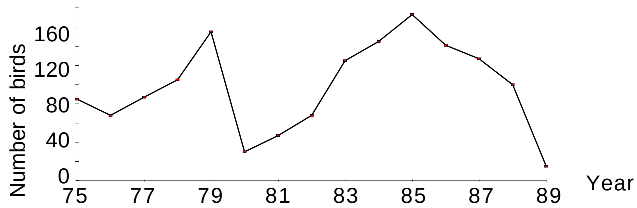
Fig 3. Oscillating numbers approaching carrying capacity



Variable Carrying Capacity
The carrying capacity is determined by the availability of resources. This availability is itself subject to the influence of climate and weather, as well as pollution and other man-made influences. The seasonal cycle provides the simplest example of this. The response of species to this depends, again, on birth and death rates. Species with a high rate of increase (such as insects) will tend to vary closely following the carrying capacity, whereas those with a low rate of increase (such as mammals) tend to stay approximately constant. In an environment with a constant carrying capacity, species numbers will be higher than in an environment with a variable carrying capacity with the same average.

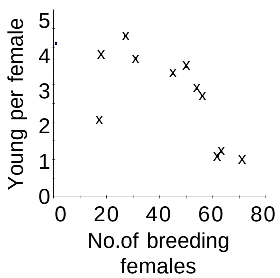
Case study: Mandarte Island song sparrow

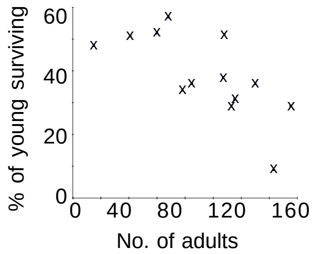
The colony of song-sparrows on Mandarte Island (near British Columbia) has been studied over a number of decades. It is an almost isolated population (on average, one new female migrant joins the population per year). The graph shows the sparrow population since 1975.



This population is clearly not following a sigmoidal or exponential growth pattern, which indicates that density independent factors are very important; the decline in the late eighties, for example, was attributable to the increased death rate in a very cold winter.

However, there is still evidence of density-dependent factors, as is illustrated in the graphs below.





The first of these graphs illustrates that the larger the number of breeding females, the fewer the young each female has - i.e. the birth rate is density dependent. The second graph shows that the higher the number of adult birds present, the lower the percentage of young surviving to adulthood; this is an example of a density dependent death rate.

Experimental studies confirmed that availabilty of food was the limiting factor for the birth rate; when extra food was provided for the sparrows, reproduction increased by a factor of four.

Exam Hint: *If an examination question requires an explanation for the behaviour of a population, it is important to be specific - consider the limiting factors that apply to the species under consideration.*

For example, the number of mice in a laboratory tank with an adequate food supply is likely to be limited by space availability, or a build up of waste material. In contrast, natural populations are more likely to be limited by predation, food availability and climate.

Population dynamics for two species

The interaction between two or more different species is often the dominant influence on the numbers of both. There are two main types of interaction - **interspecific competition** (i.e. competition between species) and **predation**. **Parasitism** may be considered as a special case of predation.

These models are highly simplified, in that they assume a closed relationship between two species - no other species competes for resources and no other species is a predator of the same prey species.Also, in practice, both types of interaction may occur between a given pair of species; for example, pike and perch compete to feed on roach, but pike also prey on perch. Any predictions are therefore at best a crude approximation.

Competition

Interspecific competition occurs when two species depress one another's growth rates. There are three subtypes of competition:-

Exploitation competition occurs when populations are sharing a (scarce) resource - an example of this is desert plants competing for water.

Interference competition occurs when an individual or population acts directly to harm members of the other species or prevent them accessing resources. Examples of this include ant colonies killing invaders who attempt to use the same food supplies, and birds maintaining a territory.

Pre-emptive competition involves competing for space - for example nesting positions or attachment sites to rocks.

The extent to which the species affect one another may not be symmetrical - for example, in a situation in which rabbits and sheep are competing for grazing, the addition of five extra sheep would have a much greater effect on the rabbit population than the addition of five extra rabbits would have on the sheep population.

Other factors may affect the population of both species - for example, they may have a common predator which preys preferentially on one or other species, or the two species may be affected in different ways or to a different extent by climatic conditions.

Interspecific competition can have three outcomes:-

- One or other species is a more successful competitor and the other becomes locally extinct
- The numbers of each species settle to a constant, stable value
- The species are matched competitors. They can coexist temporarily, but eventually, some chance fluctuation in numbers will give the advantage to one and leave the other to extinction

The outcome is determined by the carrying capacities for each species as well as their effect on each other. If a species is to survive, its carrying capacity must be large enough compared to that of its competitor to offset the effects of competition. So if species A experiences very strong competition from species B, it will only survive if the carrying capacity of A is much larger than the carrying capacity of B. So if both species compete strongly with each other, they both need to have the larger carrying capacity to survive!

This leads to the **principle of competitive exclusion** which states "complete competitors cannot coexist". In other words, the species must have some differences in resource use if they are to coexist.

Predation

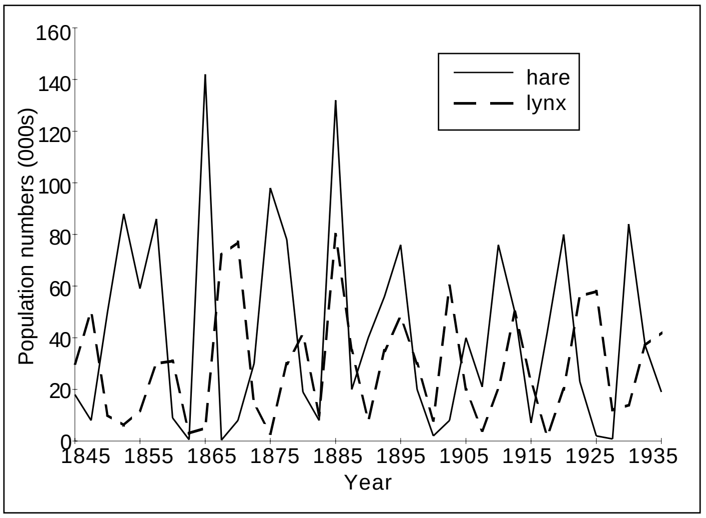
Assuming one species preys solely on another, when prey numbers are high, a large number of them will be caught by predators. This will lead to an increase in the predator population. This increase in predators will reduce the numbers of prey. The reduced numbers of prey lead to a food shortage for the predators, so their numbers in turn reduce. The reduced predator numbers allow the prey numbers to increase again.

This model leads to cyclic oscillations in the numbers of both species . Key characteristics of the cycles are as follows:

- The numbers of predators will in general be smaller than those of prey,since they are higher in the food chain
- The amplitude of the oscilllations will be smaller for predators, since adding one extra predator influences prey numbers more than adding one extra prey influences predator numbers.
- The predator cycle is delayed compared to the prey cycle. The amount of delay is the time required for the predator's birth rate to respond to the change in conditions - i.e. the lag-time considered earlier.
- The length of the predator's cycle may be slightly longer than the prey's. This is again due to the lag time; the predator being higher up the food chain will usually have a longer gestation period and take longer to attain reproductive maturity.

Fig 4 shows the variation in population of the snowshoe hare and the Canada lynx over 90 years. The basic cyclic pattern may be clearly seen here, although some of the catastrophic die-backs in the hare population taking place in the 19th century seem more likely to be due to other factors - such as disease or a collapse in the hare's food supply - rather than predation. It is also interesting to note that at some points the hare population drops to substantially below the lynx's. In theory, this would lead to a massive fall in lynx numbers, but in practice, it is likely the lynx found other prey.

Fig 4. Population cycles for hare and lynx



Parasitism

The interaction between parasite and host is similar to that between predator and prey, with the parasite functioning as the predator. However, one key difference is immediately apparent; the parasite has an interest in keeping the host alive at least long enough for it to reproduce and/or find a new host. The balance of numbers would also be expected to be different - it is possible for a host to have more than one parasite.

It is clear that a reduction in host numbers will lead to a reduction in parasite numbers, since there is a limit to how many parasites any one host can hold and survive, and when a host dies, its parasite dies with it. However, the effect of parasite numbers on host numbers is not so clear cut; the extent to which parasites increase the mortality rate or decrease the reproductive fitness of their hosts is highly dependent on the particular parasite and host, as well as on the number of parasites per host. Certainly a very high parasite population will cause the host population to decline.

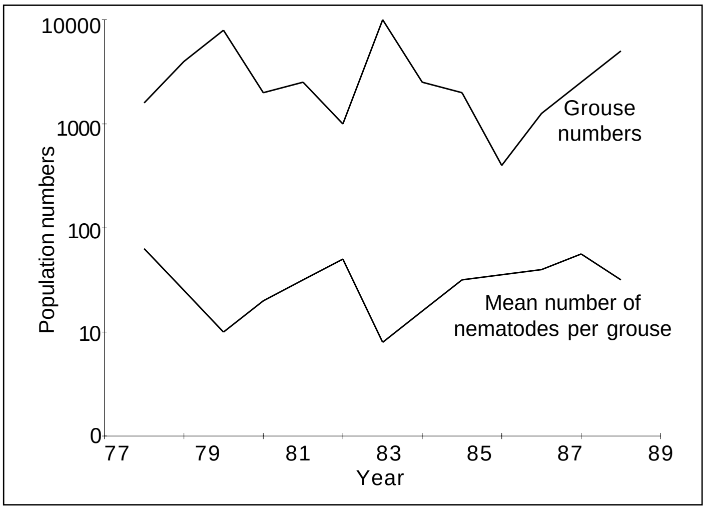
Exam Hint: *A population showing cyclic behaviour is not necessarily part of a predator-prey or host-parasite interaction; competition can lead to this behaviour as well.*

Fig 5 shows the variation in populations of red grouse and its parasite, the nematode worm. bird over a 13 year period. The graph shows average number of parasites per bird, not total parasite numbers; the latter could be obtained by multiplying the mean number of parasites by the number of birds. The parasites' eggs pass out of the grouse with faeces. The eggs will hatch in a warm, moist environment to produce larvae, which moves to the growing tip of a heather plant, where it is consumed by a new host. This complicates the model, since hatching of eggs and survival of larvae are independent of the grouse, and will be determined by factors such as climate and weather.

A high degree of parasitisation in the grouse leads to increased winter mortality, increased failure of eggs to hatch and increased chick mortality - so it is to be expected that nematode numbers will affect grouse numbers in a similar way to a predator affecting the prey. The graph bears this out; the characteristic cycles (of period about 5 years) can be seen, with peaks in nematodes following peaks in grouse.

> ***Exam Hint:*** *Exam questions may require you to deduce which is the predator species and which the prey; you need to recall that the prey species will usually have higher numbers since they are at a lower trophic level. Remember that this is not the same for parasite and host interactions!*

Fig 5. Population cycles for red grouse and nematodes



> ***Exam Hint:*** *High scoring candidates will demonstrate that they appreciate the limitations of the model, and make observations about, for example, predators finding other prey when there is a scarcity of their main prey.*

Estimating Population Size

It is impossible to study populations unless we have a way of estimating their size. We will consider two experimental methods - **sampling** and **mark-release-recapture**.

Sampling involves actually counting the number of organisms in, say, 5 randomly chosen seperate areas of, say $0.25m^2$. Averaging the numbers gives us an estimate for the number of organisms per $0.25m^2$ throughout the area. We can then estimate the total number of organisms in the population by using the formula

$$\textbf{Total number} = \frac{\textbf{Average number in sample}}{\textbf{Area used in sample}} \times \textbf{Total area}$$

So if, for example, there was an average of 7.2 organisms in our sampled areas of $0.25m^2$, and the area of the region we wished to consider was $100m^2$, the estimate for the total number would be:

$$\text{Total} = \frac{7.2}{0.25} \times 100 = 2880$$

The sources of error here are:

- Our sampled areas may not be typical of the population as a whole
- It is possible to make errors in counting the organisms in the sample area

Mark - release-recapture is used for moving organisms. It involves the following procedure: -

- capture a number of organisms
- mark each of them (without harming them)
- release them
- after a period of time, capture another sample of organisms
- note how many of the second sample have been marked.

The total population can then be estimated using the formula

$$\textbf{Total Number} = \frac{\textbf{Number in first sample} \times \textbf{Number in second sample}}{\textbf{Number marked in second sample}}$$

So if, for example, the first sample consisted of 20 organisms which were captured and marked and the second sample, taken a week later, consisted of 30 organisms of which 2 had already been marked, our estimate for the total would be:

$$\text{Total} = \frac{20 \times 30}{2} = 300$$

The sources of error here are:

- If the time between samples is too short, the marked organisms may not have mixed back in with the rest of the population
- If the time between samples is too long, the population may have changed
- The marking may in some way affect the organism's survival

Practice Questions

1. In an investigation to estimate the population of woodlice in a dead tree, 100 woodlice were captured and marked, then re-released into the tree. 4 weeks later, 150 woodlice were captured, of which 15 were found to be marked.

   a) Calculate the number of wood-lice in the population. (2 marks)

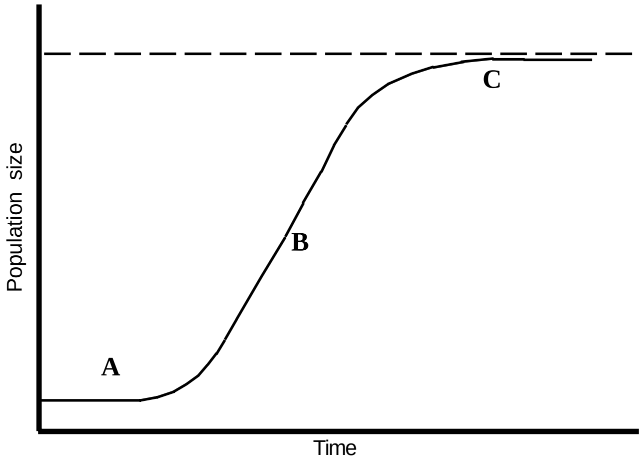
   b) Suggest what effect, if any, the following would have on the population estimate:

      (i) It was later discovered that marking woodlice reduced their ability to find a mate. (2 marks)

      (ii) It was found that the marking exerted a poisonous effect on the woodlice (2 marks)

      (iii) It was discovered that a large number of the marked woodlice had remained near the site of capture. (2 marks)

2. The diagram illustrates a population growth curve



   (a) What is the name given to this type of growth? (1 mark)

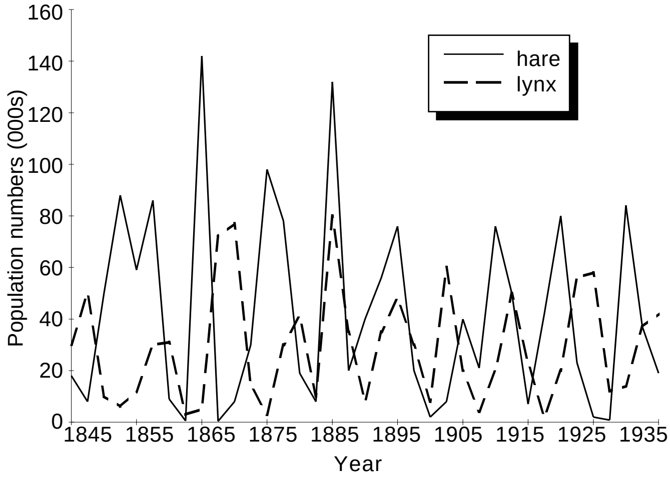
   (b) What does the dotted line represent? (1 mark)

   This growth can be used to model the growth of a yeast population and of a rabbit population.

   (c) For the yeast population, describe and explain the growth rates at points A, B and C (6 marks)

   (d) For the rabbit population, explain the growth rates at points A, B and C (4 marks)

3. The graph illustrates the variation in numbers of hare and lynx populations over the period 1845 -1935.



   a) Explain why you would expect the number of hares to be higher than the number of lynx. (1 mark)

   b) Estimate the cycle length for the hares (1 mark)

   c) Explain why the lynx population peaks after the hare population. (1 marks)

Answers

Semi-colons indicate marking points

1. (a) population = 150 x100/15 = 1000;
   (allow one mark for appropriate method)
   (b) (i) no effect; because this does not affect the spatial distribution/survival chances of woodlice;
   or estimate shold be reduced; woodlice might leave area/ would eventually reduce birth rate
   (ii) estimate should be revised upwards; because a higher proportion of marked woodlice have died, so there would have otherwise been more in the sample;
   (iii) estimate should be revised downwards; because marked woodlice may be over-represented in second sample;

2. (a) sigmoidal/S-curve/logistic;
   (b) the carrying capacity;
   (c) A: slow growth; yeast is synthesizing enzymes
   B: rapid growth; enzymes available/waste products not causing toxicity;
   C: slow growth; yeast being affected by accumulating waste products (alcohol);
   (d) A: Since the increase in numbers depends on no. of rabbits already in population, few births *(do not accept low birth rate)* as numbers small;
   B: High birth rate/high number of births; few deaths since population not high enough for density-dependent effects to be really noticeable;
   C: Increased death rate/decreased growth rate due to intraspecific competition/ shortage of resources;

3. (a) Decreasing numbers going up trophic levels;
   (b) 10 years
   (c) Lynx population cannot increase until young are born;

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