I WANT TO LIVE FOREVER...

2E. EVOLUTION AND AGEING

You are a researcher in the LifeSpan project. Like all of the other students in the class, you are conducting research on ageing. Your specific research is on evolution, natural selection and ageing. Ultimately you will be presenting your results to the rest of the class. The following assignments will help you to study the results, and to prepare your presentation.

Have fun!

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De Praktijk

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Assignment 1. Mortality and survival

Some organisms live for only a few months, others for over 100 years. Why is that? Organisms need to divide their energy between maintenance and reproduction. The more organisms invest in maintenance (i.e. repairing cell damage), the longer they live. However, investing all of one's energy in maintenance makes no sense from an evolutionary perspective: then you don't produce any offspring at all. But what is the optimum balance between maintenance and reproduction? And why is it different for each organism?

1. Watch the following video:

Daryl Shanley 1 – Trade-off between longevity and reproduction

Cells possess a range of repair mechanisms, which operate more or less independently of each other. However, organisms usually invest roughly the same amount of energy into each process (see Figure 1).

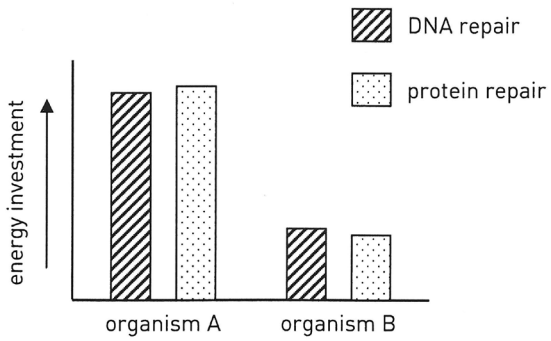

Figure 1. Organisms invest roughly the same amount of energy into all repair processes.

2. Look at Figure 1. Cross out answers that do not apply.

Organism A probably belongs to a long-lived / short-lived *species.*

Organism B probably belongs to a long-lived / short-lived *species.*

3. Why does it not make sense to invest large amounts of energy into one specific repair process (e.g. protein repair) but not in other repair processes (such as DNA repair)?

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Ageing can be regarded as the result of all of the damage suffered by an organism over the course of its life. This damage occurs mainly at the molecular and cellular level. Even under ideal circumstances, every organism will ultimately die of old age. This type of death is caused by *intrinsic factors*. In nature, however, organisms have a much greater chance of dying due to *extrinsic factors*, such as hunger, illness or predation (being eaten).

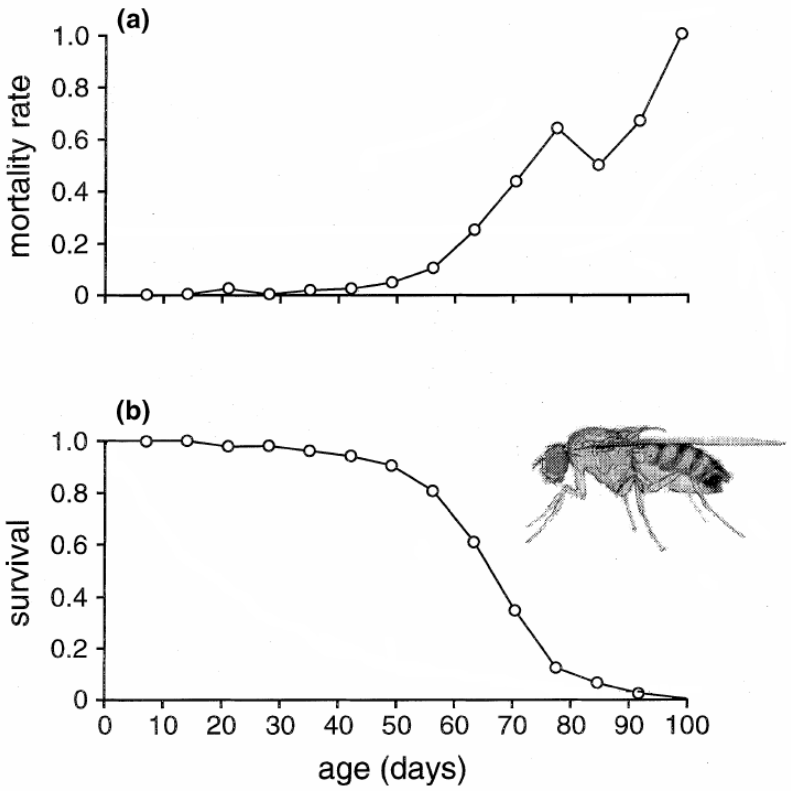

Figure 2. The relationship between age (in days) and survival and mortality rates among fruit flies (Drosophila melanogaster). The fruit flies were kept at a constant temperature of 25°C and were given enough food. Graph a shows the mortality rate. The older the flies get, the higher the mortality rate. Graph b shows the survival curve. This line indicates, as it were, how many fruit flies were still alive after a certain period. There were therefore no flies that lived longer than 100 days. From: B. Zwaan (1999).

4. Look at Figure 2. Did the fruit flies in this experiment die due to intrinsic or extrinsic factors? Explain your answer.

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In the experiment described in Figure 2, the mortality rate increased rapidly as the fruit flies aged. However, this is not always the case. Mortality rates can also remain more or less the same throughout an organism's life (see Figure 3a). Alternatively, the mortality rate can be variable and depend on age (see Figure 3b).

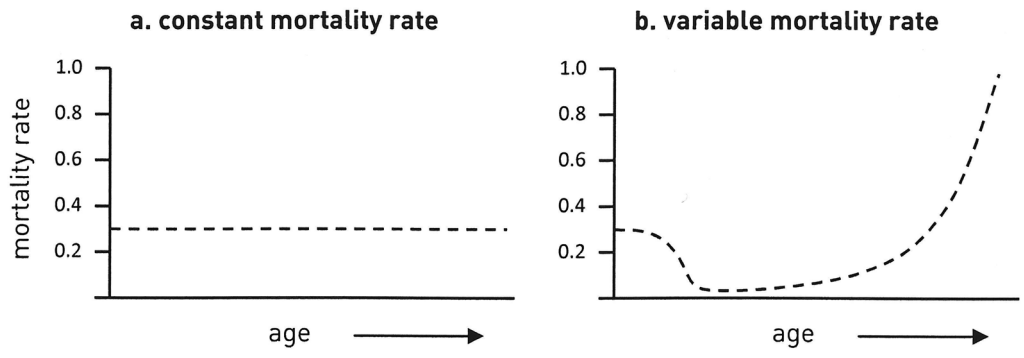

Figure 3. Two models: one with a constant mortality rate (a) and one with a variable mortality rate (b).

5. Two different groups of organisms are described below. Which graph best describes each situation? Cross out answers that do not apply.

Organisms living in an environment in which they are very likely to be eaten by a predator.

corresponds to graph a / graph b

Organisms living in an environment containing many pathogens that primarily affect young individuals.

corresponds to graph a / graph b

6. Use graphs a and b in Figure 3 to derive the survival curves associated with each model. Choose between the six curves in Figure 4 (see following page).

graph a (constant mortality rate) matches survival curve . . . . . .

graph b (variable mortality rate) matches survival curve . . . . . .

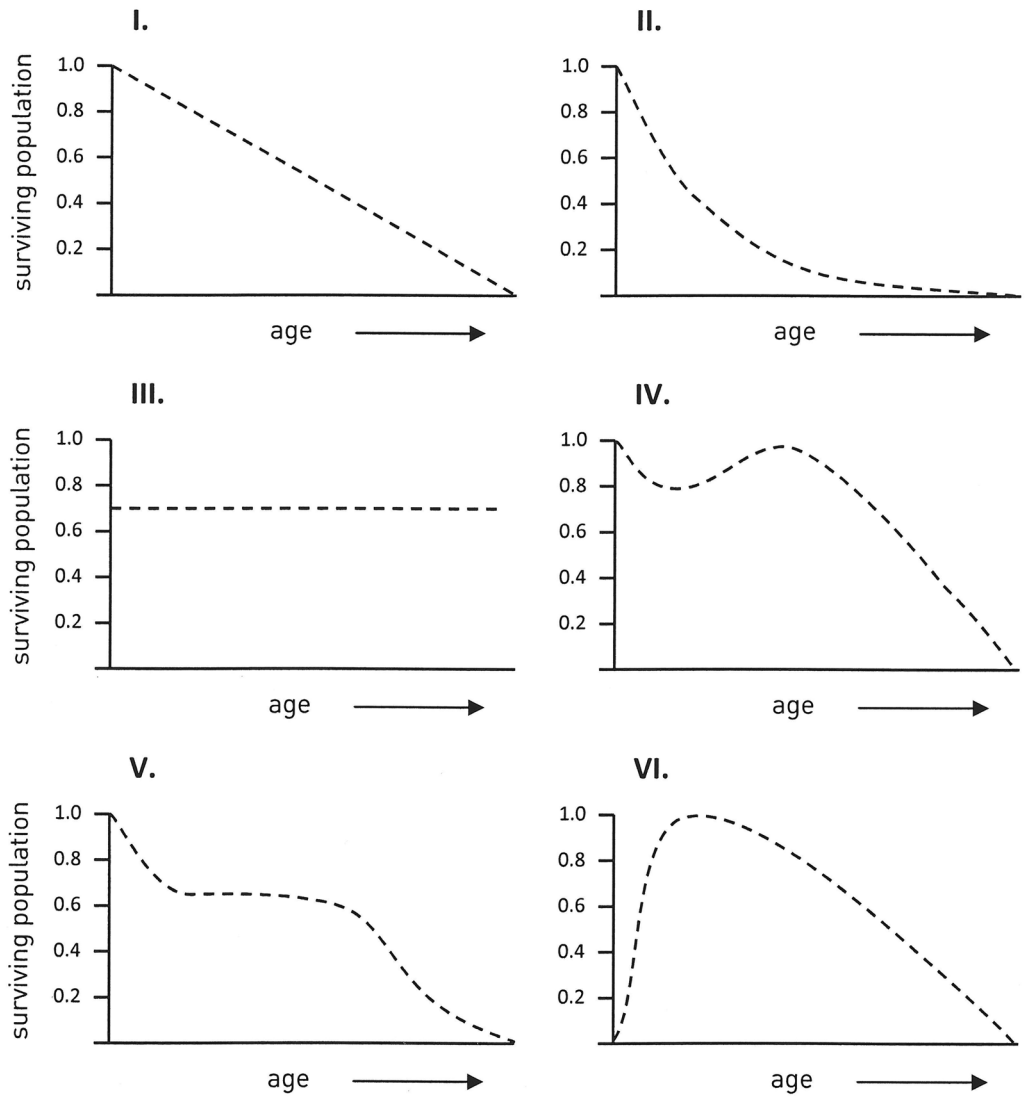

Figure 4. Six survival curves. Two curves match the mortality rate graphs in Figure 3.

7. We will now compare the following two models, in which the mortality rate either remains more or less the same (Figure 3a) or increases with age (Figure 2a). We will leave aside the model with a variable mortality rate (Figure 3b) for the moment. Which model do you think is most applicable to each of the following groups of organisms?

field mice	mortality rate constant / increases with age
fruit flies in nature	mortality rate constant / increases with age
lions in the African savannah	mortality rate constant / increases with age
people in the Netherlands	mortality rate constant / increases with age
penguins in the zoo	mortality rate constant / increases with age

Assignment 2. Natural selection

Even under ideal conditions, organisms eventually die. But why? Various theories exist to explain this. You now know that ageing can be regarded as the result of the accumulated damage to an organism throughout its life. However, evolutionary mechanisms also play a role.

Organisms in nature are constantly affected by *natural selection*. Essentially, natural selection boils down to the following:

- There is variation; organisms possess a range of different characteristics.
- These characteristics are (partially) hereditary.
- Some characteristics are more favourable than others (in certain environments).
- Organisms with favourable characteristics live longer and have more offspring than organisms without those characteristics.
- The next generation contains more individuals with favourable characteristics.

1. Imagine that a mutation in a certain gene produces an individual that lives to be twice as old as others of the same species. However, this individual is less fertile: in its lifetime it can produce only a single healthy baby, whereas others of the same species produce an average of four. Will this characteristic (longer-lived, but less fertile) spread to successive generations? Explain your answer.

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Ultimately, natural selection is not that concerned with 'long life'. The number of offspring is the only thing that counts. Does the age at which you have offspring even matter?

2. In the previous assignment, you learned that the mortality rate of many organisms is more or less constant (see Figure 3a). Given this fact, which of the two (sets of) characteristics below is the most beneficial? The number of offspring is the same in each case. Explain your answer.

characteristic 1: fast sexual maturity – have offspring – die young

characteristic 2: late sexual maturity – have offspring – die old

characteristic 1 / 2 is the most beneficial in terms of evolution, because

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3. Watch the following video:

Laurent Keller 2 – A compromise between reproduction, maintenance and protection

4. Laurent Keller explains that there is a link between lifespan and the degree to which organisms are exposed to predation, illness and starvation. Explain in your own words how it is possible for the queen of an ant colony to live so long.

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5. A connection between lifespan and extrinsic mortality can also be observed if we compare different species. For each pair below, indicate which species will have the highest average life expectancy (circle either a or b).

a. a tarsier, a small monkey measuring around 12 centimetres in length

b. a bonobo, an anthropoid ape closely related to the chimpanzee

And how about this one?

a. a species of bird living on an island without any large predatory mammals

b. a species of bird (of comparable size) living on the mainland

Organisms need to divide their energy between maintenance and reproduction. Investing everything in maintenance produces no offspring; investing everything in reproduction means that you will die before having your first baby. The optimum balance between maintenance and reproduction is different for each species (see Figure 5).

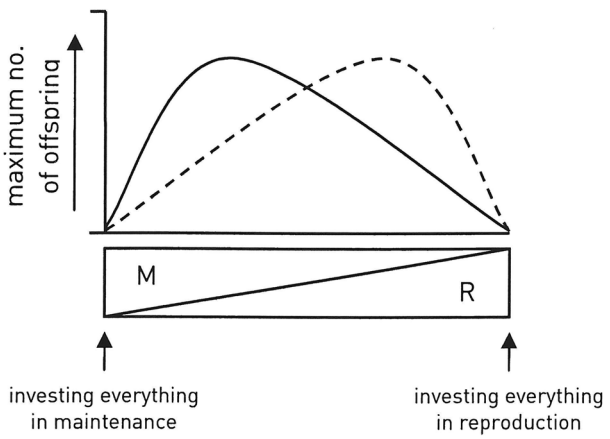

Figure 5. The relationship between the maximum number of offspring (y-axis) and the balance between maintenance and reproduction (x-axis) for two hypothetical species.

6. Look at Figure 5 (see previous page). Which graph belongs to a hippopotamus? Which to a hamster?

The solid line belongs to a hippopotamus / a hamster.

The dotted line belongs to a hippopotamus / a hamster.

7. We can conclude the following: *organisms that are more likely to die of extrinsic factors start reproducing* earlier / later *and live* shorter / longer . *Even under laboratory conditions (without the extrinsic factors), the lifespan of these organisms is* shorter / longer *: they are genetically programmed that way. There is also a link between lifespan and body size:* large / small *organisms usually live longer.*

There is another evolutionary mechanism that plays a part in ageing: the accumulation of adverse *mutations*. Mutations are changes in the nucleotide sequence of DNA. Some mutations reduce the effectiveness of certain proteins (enzymes, hormones, etc.). If an organism is the carrier of such a mutation, it will suffer the effects to a greater or lesser extent.

8. Some mutations occur spontaneously. The game *I want to make babies!* also presented you with a number of external (and other) causes of mutations. Name three.

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Many adverse mutations ultimately disappear due to natural selection: the carriers of an adverse mutation produce, on average, fewer offspring than others in the species without the mutation. However, this is not always the case.

9. The following three mutations occur within a group of organisms:

> *mutation 1:*
> The gene for a certain digestive enzyme has mutated, meaning that certain nutrients in the mother's milk cannot be digested. The mortality rate during the first years of life increases.
>
> mutation 2:
> The gene for a certain signal protein has mutated, reducing the effectiveness of the immune system. Carriers of this mutation are more susceptible to infectious diseases.
>
> *mutation 3:*
> The gene for a certain membrane protein has mutated, causing damage to the nervous system later in life. Brain function will decrease as the carrier of this mutation ages.

Which mutation will NOT be filtered out through natural selection? Explain your answer.

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10. We can conclude the following (cross out answers that do not apply):

Natural selection has no influence on...

> *. . . mutations related to the reproduction of an organism.*
>
> *. . . mutations that become manifest before an organism has reproduced.*
>
> *. . . mutations that become manifest after an organism has reproduced.*

These mutations can simply spread throughout the population.

Assignment 3. Family ties

1. Watch the following video:
Daryl Shanley 2 – From mother to grandmother

Daryl Shanley wonders why natural selection has ensured that women are still able to live for decades even after they become infertile. The video presents two possible explanations. The first explanation – *the mother hypothesis* – deals mainly with the first ten years after menopause: a mother needs to live at least long enough to take care of her last child. The second explanation – *the grandmother hypothesis* – assumes that grandparents are indirectly able to make an important contribution to the survival of their grandchildren.

2. Assisting another member of the same species with raising their children costs energy. Surely it is better to invest this energy in your own offspring? Imagine that there are two genes that cause the following behaviour:

gene 1: an organism assists a family member with the production of offspring

gene 2: an organism assists a random member of the same species with the production of offspring

Which type of behaviour is the most beneficial in terms of evolution (circle either gene 1 or gene 2)? Explain how the gene causing this behaviour can spread amongst the population?

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3. A mother shares half of her genes with each of her children. What proportion of her genes does a grandmother share with a grandchild?

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An extreme example of 'helping others reproduce' can be seen among social insects, such as ants. In an ant colony, there are usually only a few individuals that reproduce: the queen, and one or more males. The (female) workers are infertile, and help the queen to produce more offspring.

4. The workers are usually daughters of the queen. By helping their mother to reproduce, they also (indirectly) pass on their own genes. Does it make a difference to the 'genetic advantage' of a worker whether the queen has one or several males? Explain.

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Assignment 4. The LifeSpan conference

At scientific conferences, researchers from a range of universities come together to share information and discuss research results. You are going to do this too. To conclude this assignment you will hold a kind of scientific conference, in which you will give a short presentation on the subjects you have studied thus far. You will also write a short proposal for further research.

The presentation will consist of three sections:

A. Mortality and survival

Use the diagram on page 12 to explain the following:
- that under laboratory conditions, mortality increases with age,
- that the mortality rates of many organisms in nature stay more or less constant (due to extrinsic factors),
- and that their survival curve therefore also looks different.

B. Natural selection

Use the diagrams on page 13 to explain the following:
- that organisms with a high, constant mortality rate invest more in reproduction and less in maintenance, in comparison with organisms with lower mortality rates,
- and that they therefore often reproduce early and die young.

Also explain why mutations whose (possibly adverse) effects do not appear until later in life can easily spread throughout the population.

C. Proposal for further research

You are participating in a project that examines the relationship between body size and maximum lifespan among mammals. Information on the body weight of 120 different species of mammals (of different sizes) is already available. It is your job to find out what the maximum lifespan of these species is. Briefly describe what you could do to determine the maximum lifespan of a particular species of mammal (and complete the template on page 14).

Preparation
PowerPoint slides have already been made for you, containing the images on pages 12 and 13. Use these copies to make your notes. Write your research proposal using the template on page 14. Make a rough copy first if necessary.

The conference
Using your PowerPoint slides, give a short presentation on what you have learned. You may refer to your notes if you wish. Also present your research proposal to the rest of the class. The teacher will determine whose turn it is.

A. Mortality and survival

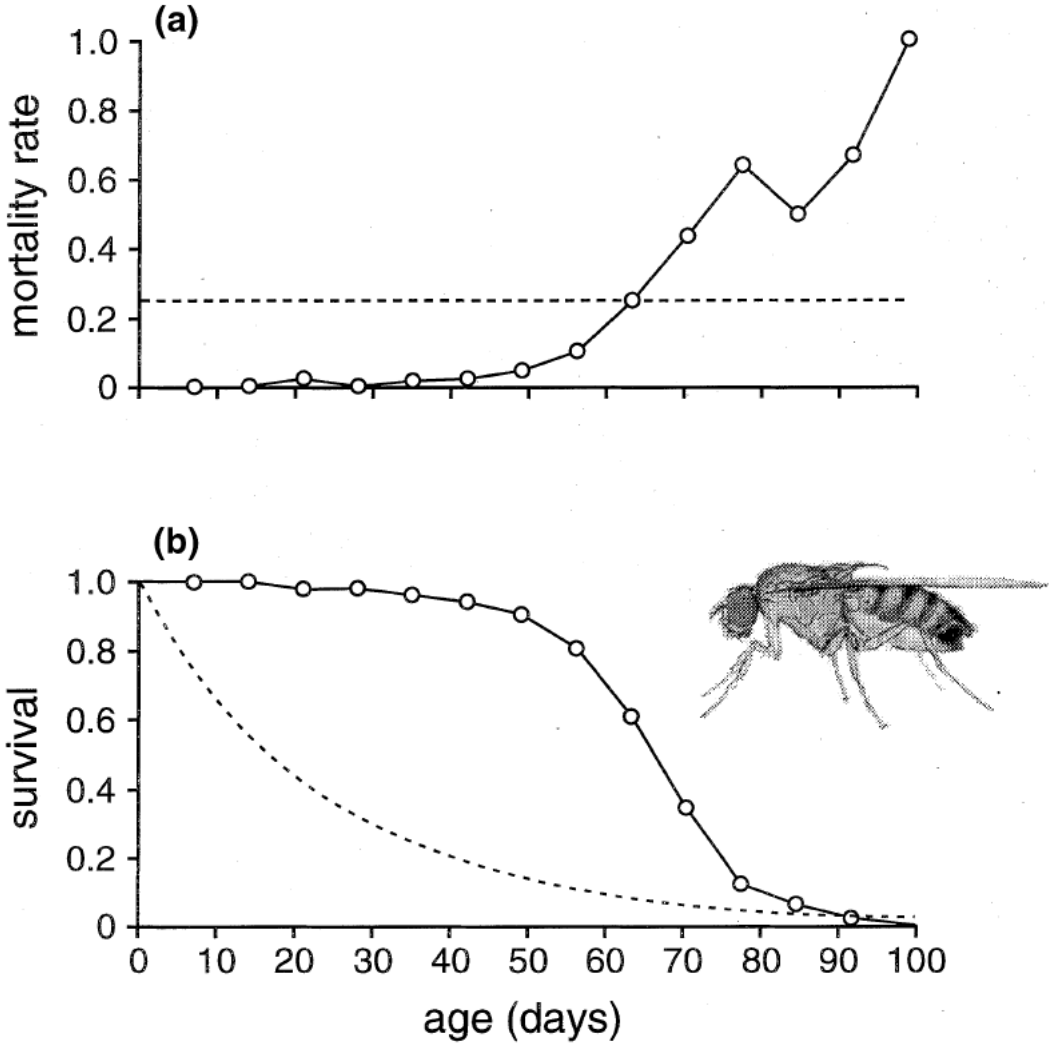
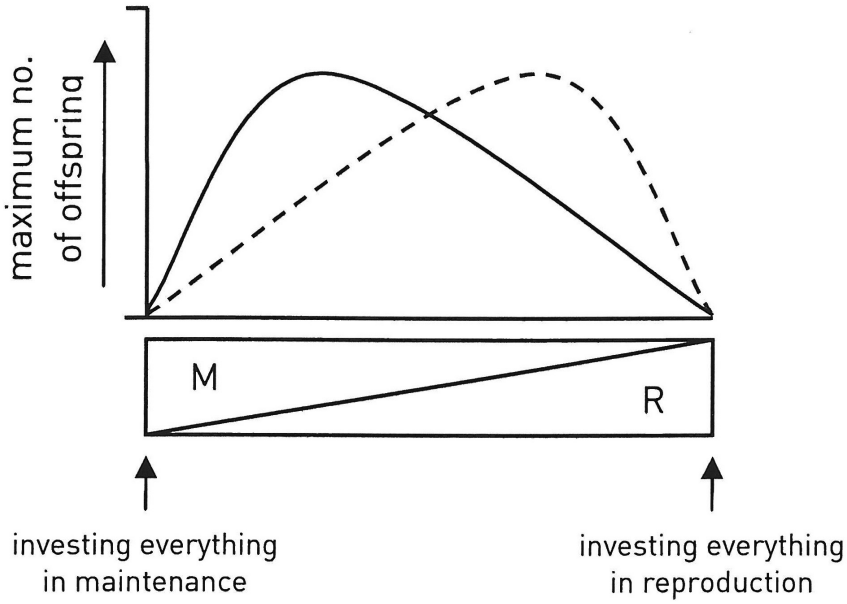


Fig. 1 Relationship between age and mortality rate (A), and between age and survival (B). The solid curve represents a population of *Drosophila melanogaster* males grown and kept at 25°C. The (exponential) increase in mortality rate with age (A) indicates the presence of ageing. For comparison the dashed curves are drawn; these represent a hypothetical non-ageing population (i.e. when the mortality rate is constant with age).

B. Natural selection



C. Research proposal

Title of research project
Introduction (approx. 50 words)
Research question
Hypothesis
Research plan (including materials and methods)