Natural Selection in the Peppered moth

Aim
The aim of this exercise is to see how the concept of Natural Selection works using the example of the Peppered Moth discussed in the talk.

Introduction
In Britain, the Peppered Moth occurs in two forms, a light-coloured **mottled** phenotype and a dark-coloured **melanic** phenotype. Around 1800, the mottled type was dominant but by 1900 the situation had changed and the melanic type was dominant. Biologists argued that this reversal of fortune was due to rising levels of pollution during the Industrial Revolution that covered the trees on which the moths rested with black soot. The dark melanic moths were better camouflaged from predators, whereas the light mottled moths were more vulnerable. Natural selection acted on the moth population to weed out the light individuals in favour of the dark individuals.

Background to Genetics
We know that the colour of the Peppered Moth is controlled by just one gene and the melanic allele (M) is dominant over the mottled allele (m). Hence moths that are MM or Mm are melanic while only those that are mm are mottled. Now imagine if two melanic moths that were genetically Mm bred with one another. The table below shows the probable outcome: the frequency (or proportion) of MM is 0.25 (or 25%) Mm is 0.5 (or 50%), and mm is 0.25 (or 25%). As M is dominant, 75% of the offspring are melanic.

male

female	M	m
M	MM	Mm
m	Mm	mm

Now suppose that the frequency of M alleles in a population is denoted by ‘p’ and the frequency of m alleles is denoted by ‘q’. We could express the same table like this:

male

female	p	q
p	p^2	pq
q	pq	q^2

This tells us that the frequency of the two alleles in the population is equivalent to $p^2 + 2pq + q^2$. This is known as **the Hardy-Weinburg equation**. In the above example, the alleles M and m occur in equal proportions (a frequency of 0.5). Just to prove to that the Hardy-Weinburg equation is correct, we can enter these values into the equation. The result is the same as above: 0.5^2 MM + 2(0.5 x 0.5) Mm + 0.5^2 mm which equals 0.25 MM + 0.5 Mm + 0.25 mm.

The Exercise
Now imagine that you have a population of 100 moths, all of which are genetically Mm. The landscape in which they live is polluted and the melanic moths are better camouflaged than the mottled moths. In fact in each generation, birds only eat 10% of the melanic moths but eat 50% of the mottled moths.

Carefully follow the following instruction to discover how natural selection acts on this moth population to change its genetic make-up.

Step 1. Allow birds to feed on your initial population of 100 moths. Remember all these moths are genetically Mm. How many moths do you have left?

Step 2. Assume that the surviving moths now breed and second generation is twice as big as the one before. Use the Hardy-Weinburg equation to work out the number of moths in your new generation that are MM, Mm and mm.

Step 3. Repeat Steps 1 and 2 until the third generation is reached. Assume that when birds feed on melanic moths they take MM and Mm in proportions equal to their number. Or to put it another way if you have 30 MM and 20 Mm moths and birds eat 10% that means 3 MM and 2 Mm moths will be eaten.

Question. How has natural selection in this polluted environment altered the genetic make-up of the moth population?

Worked answer

Step 1. Allow birds to feed on your initial population of 100 moths. Remember all these moths are genetically Mm. How many moths do you have left?

> As all the moths are Mm, they are all melanic so the birds eat 10% of them. This leaves 90 Mm moths.

Step 2. Assume that the surviving moths now breed and the second generation is twice as big as the one before. Use the Hardy-Weinburg equation to work out the number of moths in the second generation that are MM, Mm and mm.

> The moth population doubles from 90 individuals in the first generation to 180 individuals in the second generation. The frequency of the M allele is 0.5 and the frequency of the m allele is 0.5. If we put these values into the Hardy-Weinburg equation we discover that the second generation is 25% MM, 50% Mm, and 25% mm. As the second generation comprises 180 individuals, 45 will be MM, 90 will be Mm, and 45 will be mm.

Step 3. Repeat Steps 1 and 2 until the third generation is reached. Assume that when birds feed on melanic moths they take MM and Mm in proportions equal to their number. Or to put it another way if you have 30 MM and 20 Mm moths and birds eat 10% that means 3 MM and 2 Mm moths will be eaten.

As we have already calculated, the second generation comprises 45 MM moths, 90 Mm moths and 45 mm moths so there is a total of 135 melanic moths and 45 mottled moths. Birds eat 13.5 melanic moths (10% of 135; rounded up to 14) and 22.5 mottled moths (50% of 45; rounded up to 23). Consequently, a total of 143 moths survive of which there are 40 MM, 81 Mm and 22 mm (assuming that MM and Mm melanic moths are eaten at random).

In this surviving population the number of M alleles is 40 + 40 + 81 = 161 whereas the number of m alleles is 81 + 22 + 22 = 125, and the total number of alleles is 161 + 125 = 286. Therefore the frequency of M alleles is 161/286 = 0.56 and the frequency of m alleles is 125/286 = 0.44.

When these 143 survivors breed, the third generation is twice as big, comprising 286 moths. If we input the new allele frequency values into the Hardy-Weinburg equation we get: 0.56^2 MM + 2(0.56 x 0.44) Mm + 0.44^2 mm. This is equivalent to 31% MM, 50% Mm, and 19% mm, or 89 MM, 143 Mm, and 54 mm in a population of 286 moths.

Question: Pollution has selected against the mottled moth and in favour of the melanic moth. Although 25% of moths were mottled in the second generation, only 19% were mottled in the third generation, and if we were to carry on the experiment, the frequency of mottled moths would continue to decrease.