

## EVOLUTION AND BATESIAN MIMICRY

**Time recommended: 2 hours**

- This exercise aims to improve understanding and development of the following key topics and skills:
  - ⊙ principles of evolution by natural selection
  - ⊙ understanding of the importance of Bates', Wallace's and Darwin's contributions to science
  - ⊙ influence of genetic and environmental factors on variation
  - ⊙ linkage of genes
- Previous knowledge of genetics and the theory of natural selection is assumed.
- Additional background information available from the internet is referred to in Q15, which could be used as an extension activity but is not an essential part of the exercise.
- For notes on the mark scheme see page 8.

### Background information about Henry Walter Bates, 1825 – 1896

The Victorian era was a period of great expansion and development of the British Empire and a golden period of adventure and exploration. Reports and specimens sent back to England from exotic places such as South America, Africa and the Far East fired the enthusiasm of a generation of great young naturalists. In 1844 two young men, aged 19 and 21, who had both read and been inspired by Darwin's book *The Voyage of the Beagle*, met by chance in Leicester Public Library. They became friends and soon decided to set off on a voyage of discovery up the Amazon River in South America. They were Alfred Russel Wallace and Henry Walter Bates.

Bates was born in Leicester, the son of a stocking factory owner. As a boy he became passionately interested in insects and published his first scientific paper (on beetles) at the age of 17! He was trapped in a boring office job in his father's firm. Bates and Wallace planned to fund their expedition by collecting butterflies prized by collectors in Europe. In 1848 they set sail for the city of Pará (now Belém) on the coast of Brazil, where the mighty River Amazon finally meets the Atlantic Ocean.



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Stuck in a boring job, what Bates really wanted to do was collect butterflies

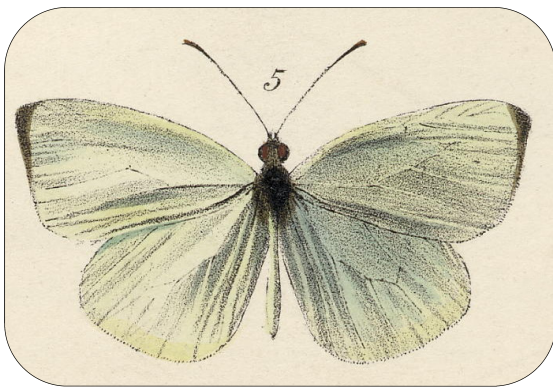
They parted after a year and Wallace returned to England in 1852. Unfortunately, his ship caught fire on the journey and most of his collection was destroyed. Undeterred, Wallace set off in the opposite direction and travelled through the 'East Indies', now known as Indonesia and Malaysia, from 1854 to 1862.

Meanwhile, Bates was to spend a total of eleven years in 'Amazonia', a vast network of largely unexplored major rivers and their tributaries set in the world's largest area of tropical rain forest. By the time he returned in November 1859 he had sent back over 14000 specimens, mainly insects, over half of which were newly recorded species.

The year before Bates' return, Wallace, who was still collecting in the East Indies, sent a paper to Darwin outlining a theory he had developed to try to explain how evolution of living things could occur by a process of natural selection. Darwin had independently arrived at the same theory. It was agreed that they submit a joint paper to the Linnean Society in London in 1858. Darwin's famous book *On The Origin of Species by Natural Selection*, which gave a detailed account of the theory and the evidence for it, was published a year later in June 1859. Five months later, in November 1859, Bates was back in England with his own collection and observations and had already been thinking along similar lines to Darwin and Wallace. As soon as he got back, he read Darwin's book and was immediately struck by how well it could explain some of his own observations. In particular, it seemed to be able to explain a phenomenon he had observed among butterflies which he described as **mimicry**.

### Batesian mimicry

One of the most common types of butterfly that Bates observed in the forests of Amazonia belonged to the family now known as Nymphalidae (we'll refer to it as Family 'N' for short). They have characteristic wide, elongated wings and a slowly flapping flight. They are brightly coloured and patterned (see page 3). However, when Bates examined captured specimens in detail, he discovered that these butterflies were not always what they seemed. Characteristics such as the pattern of 'veins' on the wings showed that a few belonged to a completely different family, the Pieridae ('P' for short). Typically, members of this family are white or yellow and have different-shaped wings (the wings are not elongated), as you can see in the image below.



**Family P** *Dismorphia nehemia*

Family N butterflies produce a foul smell and are avoided by insectivorous birds. Family P butterflies are perfectly edible, but Bates noted that birds couldn't tell the difference between them and members of Family N when the butterflies were in flight. Later research has shown that Family N butterflies contain chemicals which make them distasteful to insectivorous birds - the birds vomit if they make the mistake of eating one! They get the chemicals from their caterpillar stage and the caterpillars get them from the plants they eat.

Bates had discovered what we now refer to as **Batesian mimicry**. In Batesian mimicry a palatable species mimics an unpalatable one. Palatable means it's good to eat. Unpalatable ones are presumably distasteful. This mimicry was one of many examples he discovered among butterflies. He also discovered examples amongst birds and reptiles. We now refer to the unpalatable species as the '**model**' and the species which imitates it as the '**mimic**'.

In 1862, Bates published a famous paper in *The Transactions of the Linnean Society* which described his findings. The diagrams of butterflies in this worksheet are taken from that paper. In 1863 Bates also published what is generally agreed to be one of the finest travel books ever written, *The Naturalist on the River Amazons*.

## WHO'S WHO?

### MODELS Family N

Five different species of the genus *Ithonia* are shown



### MIMICS Family P

Butterflies shown are all the same species: *Dismorphia theonoe*



**Q1** Of the two families, 'N' and 'P', mentioned in the introduction above, which contains the 'model' butterflies and which the 'mimics'?

*Family N contains the models, family P the mimics;* **1**

**Q2 (a)** What is the advantage gained by the mimic?

*insectivorous birds do not eat the mimic/the mimic is protected (from its predator) OWTTE;* **1**

**(b)** Explain how this advantage is gained.

*insectivorous birds cannot distinguish between the mimic and the model; even though the mimic is not distasteful/ if it eats a butterfly with that pattern it is likely to be distasteful;* **2**

**(c)** Suggest a possible disadvantage for the model.

*competition for resources/named resource (e.g. food); if numbers of mimics increase, birds might start trying to eat the models again; any other sensible suggestion;* **1 max**

Bates observed that the mimics were always "very much fewer in individuals" than the models they imitate – "they cannot be more than as 1 to 1000...".

**Q3** Explain why it would be a disadvantage for the mimic to be as common as the model.

*birds will no longer associate the pattern with distastefulness; explanation given; if the mimics were common the birds would take longer to learn to avoid them/might be willing to take the risk of occasional vomiting; birds might become more experienced at distinguishing between the mimics and the models;*

**2 max**

**Q4** State two characteristics of mimics that would have enabled Bates to decide whether a butterfly was a model or a mimic.

*the mimic would show differences from the normal characteristics of its species/genus / mimics are not typical of their species/genus; ORA mimics do not smell foul; ORA Accept: the mimic would be rare;*

**2 max**

## WHO'S WHO?

Page 3 shows examples of family N and family P. The members of family P shown are all the same species, *Dismorphia theonoe*. Page 3 also shows that a species such as *Dismorphia theonoe*, which is a mimic, may have many different forms. The species is described as **polymorphic**. Not surprisingly, it was very difficult for Bates and other naturalists to decide whether the different forms were different species or different varieties of the same species. As Bates said in his paper, "It may be asked, how can we know they are all varieties... of one species?"

- Q5** How could a biologist determine whether two different forms were in fact the same species?  
*find out if they can interbreed;*  
*to produce fertile offspring;* 2
- Q6** (a) Humans can be described as **dimorphic**. Why is this?  
*humans have 2 sexes which show different forms;* 1
- (b) State whether a dimorphic characteristic (phenotype) would be an example of continuous or discontinuous variation.  
*discontinuous variation;* 1
- Q7** Bates believed Darwin's theory of natural selection could explain mimicry. What would Bates have said was the **selective agent** responsible for the evolution of mimicry?  
*predation;*  
*by insectivorous birds;* 2
- Q8** According to the theory of natural selection, the better adapted individuals of a species are more likely to survive. Suggest another possible explanation (other than that given by Bates) for the fact that mimics and models resemble one another.  
*they have become adapted to the same habitat;* 1
- Q9** The caterpillars of mimics do not mimic the caterpillars of models. Suggest two possible reasons why this is the case.  
*the caterpillars of the mimics may be well camouflaged (and therefore not need additional protection);*  
*the caterpillars of the mimics may be distasteful;*  
*birds may not feed on the caterpillars;*  
*accept any other reasonable suggestion* 2 max

Darwin hailed Batesian mimicry as "a most beautiful proof of natural selection". Butterflies in family P tend to live in open grassland. As mentioned in the introduction, they tend to be white or yellow in colour and their wings are not elongated (see picture on page 2). The members of family P that Bates found in the forests of Amazonia were all mimics. However, the more butterflies that Bates collected, the more intermediate forms he discovered, even though these were very rare (only one or very few found). These intermediate forms do not usually imitate any other butterflies. Some of them were shown in his paper of 1862 and are shown on page 5. The top butterfly in Family P (butterfly 6) seems to mimic a member of family N (*Ithonia illinissa*).

- Q10** Explain how Darwin's theory of natural selection can be used to explain the origin of the mimics and the existence of forms that are intermediate between the original members of Family P and the mimics.  
*members of family P have migrated/moved from open grassland to the forest;*  
*all species show variation;*  
*in the forest members of family P were vulnerable to predation by insectivorous birds;*  
*those variants which show some resemblance to model species have a (slight) selective advantage/fitter to survive/greater survival fitness;*

...Continued on next page



## WHO'S WHO?

...Continued from previous page

therefore greater chance of surviving to produce (similar) offspring;  
 predators weed out the poorest mimics (in each generation)/predator is the selective agent;  
 over time/many generations come to resemble model more and more;  
 until predator can't distinguish between mimic and model;  
 Ignore references to mutation as source of variation since not part of Darwin's original theory

5 max

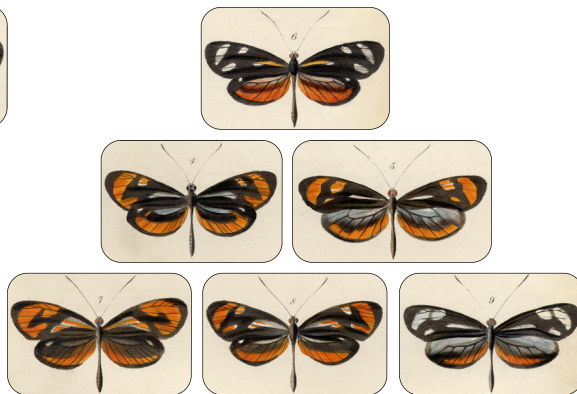
### Family N

A member of family N  
 N (*Ithonia illinissa*)



### Family P

Six members of family P showing rare  
 intermediate forms of *Dismorphia theonoe*



**Q11** Mimics are not **exact** copies of the models (see page 3).  
 Suggest **two** reasons why not.  
*the process of evolution is not yet complete;*  
*the mimic is sufficiently similar to the prey to deceive the predator;*  
*the mimic is sometimes predated but not often enough to lead to its extinction;*  
*perfect mimics might increase to the point where the selective advantage of mimicry is lost;*

2 max

The image below shows the butterfly species *Papilio dardanus*, a swallowtail butterfly which belongs to the family Papilionidae. It mimics three different species of the family Danaidae. In *Papilio* the different morphs (forms) are controlled by a group of tightly linked\* genes (a 'supergene').



© Dave Rogers

*\*note for those who have not studied linkage*

All the genes on a given chromosome are said to be 'linked'. This is because they tend to stay together during the process of meiosis, when whole chromosomes segregate. The closer they are together, i.e. the more tightly they are linked, the more likely they are to stay on the same chromosome during meiosis.

**Q12 (a)** Define the term linkage.

*genes on the same chromosome are said to be linked;*

1

**(b)** Linkage affects the amount of variation shown by the morphs. State what effect linkage has on variation.

*reduces variation;*

1

**(c)** Suggest why it is an advantage for the genes of a given morph to be tightly linked.

*it reduces variation in the offspring;*

*therefore successful pattern is preserved/passed on / increases chances of getting same pattern again;*

2

**(d)** At what stage in the life cycle of a butterfly does meiosis occur?

*adult butterfly/imago (when it produces gametes);*

1

Bates observed that when butterflies mate they seem to be very selective in choosing a partner with a very similar colour pattern.

**Q13 (a)** Explain one possible **advantage** and one possible **disadvantage** of this behaviour.

*Advantage: reduces variation in the offspring;  
(therefore) preserves successful patterns;* **2**

*Disadvantage: possible inbreeding;  
harmful recessive traits may be expressed in offspring;  
less opportunity for generating new patterns;  
which may be better mimics;* **2 max**

**(b)** Define the term speciation.

*The process by which new species are formed;* **1**

**(c)** What effect would selective mating have on speciation? Explain your answer.

*it would tend to favour speciation;  
it is a form of reproductive isolation;  
the different patterned butterflies would form different populations and over time  
they would grow more and more dissimilar as a result of evolution/genetic drift/random  
mutation/separate selection pressures;* **2 max**  
accept similar arguments

Another type of mimicry, known as Müllerian mimicry, was identified by the German biologist Fritz Müller in 1878. In this case, two or more **model** species evolve to resemble each other. The models show warning colouration which deters predators from eating them – they may be unpalatable, poisonous, have a sting, etc. For example, the yellow and black striped warning pattern is common to several different species of stinging wasps. Another example is the butterfly *Heliconius*, found in South and Central America. *Heliconius erato* and *Heliconius melpomene* are both distasteful to birds and they mimic each other. At least eleven different warning patterns are found in different regions, but in any one region the two species share the same pattern.



A butterfly of the genus *Heliconius*

© Chris Perrett www.naturesart.co.uk

**Q14 (a)** Why is it important that, in a given region, the pattern for *H. erato* is the same as that for *H. melpomene*?

*the more common the pattern, the more likely it is that predators/insectivorous birds will learn to avoid them;* **1**

**(b)** Explain the evolutionary advantage gained by two different distasteful species mimicking each other.\*

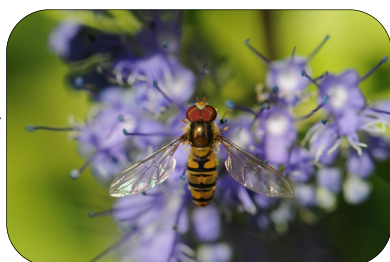
*if the patterns were different they would not reinforce the learning behaviour of the birds/predators / predator/bird only has one pattern to learn before it avoids all species;  
OWTTE* **1**

**(c)** Some harmless insects, such as certain hoverflies, mimic wasps. What type of mimicry is this?

*Batesian;* **1**

## WHO'S WHO?

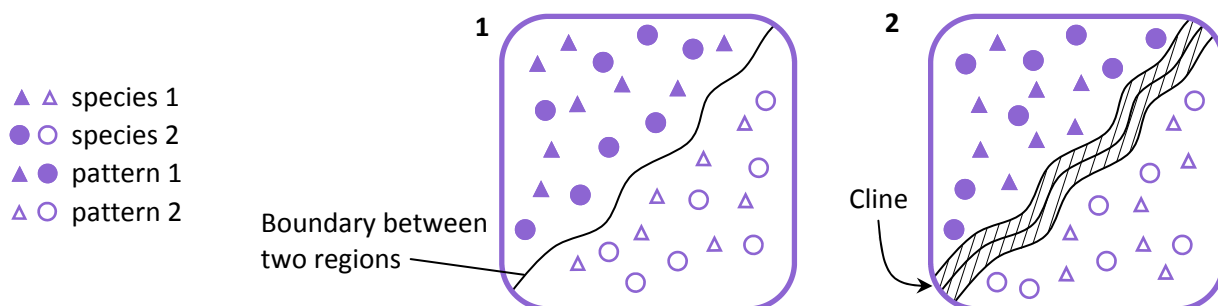
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A hoverfly mimicking a wasp

\* **N.B.** The two species of *Heliconius* can be strikingly similar. They can be compared by looking them up in the Linnaean collection under their original names that Linnaeus used, namely *Papilio erato* and *Papilio melpomene*. Access the website of the Linnean Collections Online using the web address [www.linnean-online.org](http://www.linnean-online.org). Select 'Insects' from the top menu and follow the links to the appropriate specimens.

Diagram 1, below, shows an imaginary situation similar to *Heliconius* in question 15.



There are two species, but only two pattern types. In this imaginary situation two regions with different pattern types meet at a common boundary. In such a situation there is a possibility of interbreeding (hybridisation) between butterflies from the two regions. This results in a zone called a **cline** where hybrid offspring are found (Diagram 2).

**Q15 (a)** Explain what is meant by a hybrid.

*an organism produced by a cross between two parents that are not genetically identical/  
a cross between two very unlike parents/a cross between two different varieties/species;*

1

**(b)** What possible hybridisations are **most** likely to take place in this imaginary example?

*crosses between colour pattern 1 and colour pattern 2 of species 1;*

*crosses between colour pattern 1 and colour pattern 2 of species 2;*

2

*although hybridisation between species 1 and 2 is theoretically possible, it is much less likely to occur.*

**(c)** Suggest two factors which will determine the width of the cline. Explain your answer.

*the rate of spread of the butterflies;*

*the faster the hybrids spread, the wider the zone will be;*

*selection pressure;*

*the greater the selection pressure against the pattern(s) not normally found in the region,  
the narrower the cline;*

4

**(d)** The colour pattern is controlled by three tightly linked genes in *H. erato* and by four tightly linked genes in *H. melpomene*. Each gene has a number of alleles. If the colour pattern in species 1 in the diagram above were controlled by one gene with three alleles, what would be the maximum number of colour patterns that could appear in species 1 in the cline?

6;

1

*with incomplete dominance each genotype would have its own phenotype - compare the 6 possible genotypes obtained with the three alleles in the ABO blood group system.*

**(e)** Distinguish between the terms 'allele' and 'gene'.

*a gene is found at a particular locus/particular place, on a particular chromosome/a gene  
is a unit of recombination/a piece of DNA which codes for a protein/a unit of inheritance;  
alleles are different forms of the same gene;*

2

### Point for discussion:

In a small group, discuss whether you think it would be an advantage if the birds were killed by the toxins contained in the butterflies.

- If each bird has to learn the avoidance for itself, then it may be better for the butterflies if the bird received a lethal dose of toxin. Presumably, the birds would then be in danger of extinction – perhaps this has occurred with some bird species or individual birds of a given species. Natural selection would ensure that the only surviving predators are those which are not killed by the toxin.
- Perhaps the lethal dose (or dose at which a critical percentage are killed) is too high for a caterpillar or butterfly to carry, but it works as a deterrent anyway.
- *If* there is a *gradual* build-up of toxins within the caterpillars and butterflies over evolutionary time, then perhaps the selection pressure only works to the point where it becomes an effective deterrent and doesn't need to continue to the point where it becomes lethal?
- Bates himself didn't know about the chemicals and the vomiting effect (he only knew they smelt foul when he caught and preserved them). That was discovered by separate experiments on birds which had not previously come across these butterflies - were they the same species of bird. So it's just possible the birds in the forest *are* sometimes killed?
- Birds are quite clever, so it seems likely that they learn from the behaviour of others. In which case avoidance of the butterflies would quickly spread through the bird population. This would be a selective advantage for both the birds and the butterflies.
- Do parents teach their offspring what to hunt for?
- Do the offspring only hunt what has been brought to the nest when they are fledglings?

### Notes on mark schemes:

; indicates award of 1 mark  
text in brackets is not required for the mark  
/ means alternative responses  
OWTTE: or words to that effect  
ORA: or reverse argument  
words underlined are essential

**Total 50 marks**

### Educational resources from the Linnean Society of London

For more information contact:

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