BIOZONE

CIE BIOLOGY 2

Cambridge International Examination

A Level Year 2 | **Student Workbook**

Topic 12

Energy and respiration

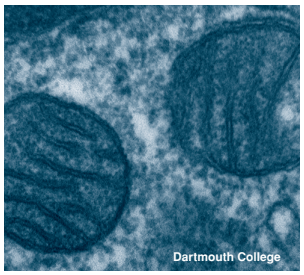
Key terms

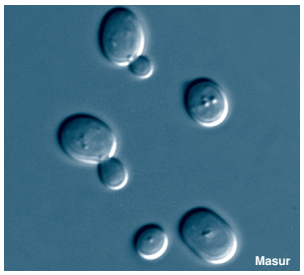
acetyl coA
anaerobic metabolism
ATP
ATP synthase
cellular respiration
chemiosmosis
coenzyme A
cristae
decarboxylation
dehydrogenation
electron transport chain
ethanol
FAD
fermentation
glycolysis
Krebs cycle
lactic acid
link reaction
matrix
mitochondrion
NAD
oxidative phosphorylation
pyruvate
respirometer
respiratory quotient (RQ)
respiratory substrate
substrate level phosphorylation
triose phosphate

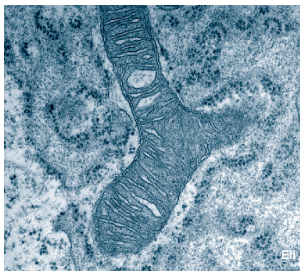
Energy

Learning outcomes

		Activity number
☐	1 Explain why organisms require energy, as illustrated by examples, e.g. anabolic reactions, active transport, movement, and regulation of body temperature.	1
☐	2 Describe how ATP's structure enables it to act as the universal energy currency. Explain ATP generation by substrate-linked phosphorylation.	2
☐	3 Outline the roles of the coenzymes NAD, FAD, and coenzyme A in respiration.	6
☐	4 Explain how the synthesis of ATP is associated with electron transport in the membranes of mitochondria and chloroplasts.	6 7 19
☐	5 Describe and explain the relative energy values of carbohydrates, lipids, and proteins as respiratory substrates. Describe how respiratory quotients (RQ) can be used to determine the respiratory substrate being utilised. Calculate and interpret RQ values for organisms in different conditions.	4
☐	6 **PRAC** Use simple respirometers to determine the RQ of living organisms.	5







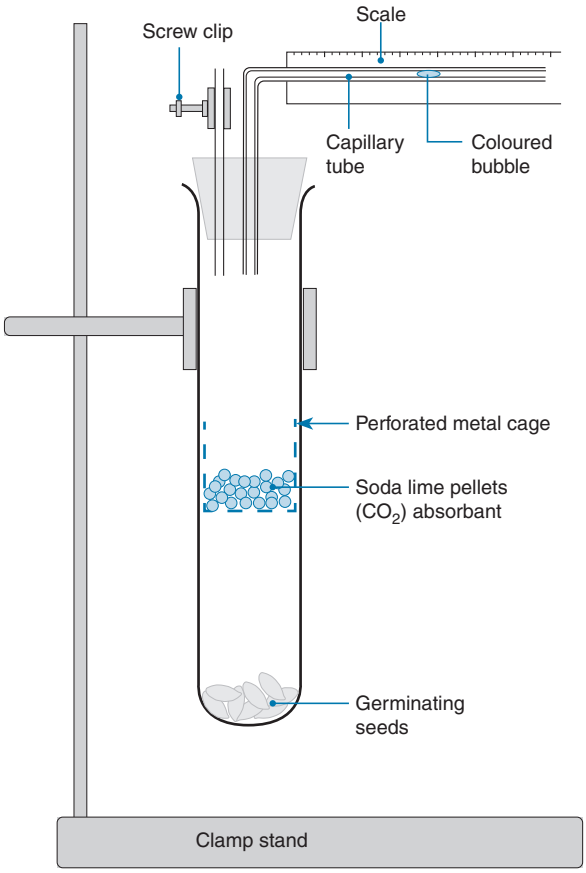
Respiration

Learning outcomes

		Activity number
☐	7 Identify the four stages of aerobic respiration and their location.	3
☐	8 Outline glycolysis and recognise it as the major anaerobic pathway in cells. State the net yield of ATP and $NADH_2$ from glycolysis.	6
☐	9 Describe the link reaction to include decarboxylation of pyruvate, reduction of NAD, and formation of acetyl coenzyme A.	6
☐	10 Outline the Krebs cycle including reference to the stepwise oxidation of intermediates and the importance of decarboxylation, dehydrogenation, reduction of NAD and FAD, and substrate level phosphorylation.	6
☐	11 Explain oxidative phosphorylation in the electron transport chain to include the roles of electron carriers in the mitochondrial cristae and the role of oxygen as the terminal electron acceptor.	6
☐	12 Describe the relationship between structure and function of the mitochondrion using diagrams and electron micrographs.	6
☐	12 Describe chemiosmotic theory as an explanation for ATP generation in oxidative phosphorylation and photophosphorylation (in photosynthesis).	7
☐	13 Compare aerobic and anaerobic pathways for ATP generation in eukaryotes to include alcoholic fermentation in yeast and lactic acid fermentation in mammalian muscle, including the concept of oxygen debt. Compare and explain the differences in ATP yield from aerobic respiration and from fermentation.	8
☐	14 **PRAC** Investigate factors affecting fermentation in yeast using a redox indicator.	9 10
☐	15 Explain how rice is adapted to grow in anaerobic conditions with reference to its tolerance for ethanol and the presence of aerenchyma tissue.	8
☐	16 **PRAC** Use a simple respirometer to investigate the effect of temperature on the respiration rate of germinating seeds or small invertebrates.	11

11 Measuring Respiration

Key Idea: Oxygen consumption and carbon dioxide production in respiring organisms can be measured with a respirometer. A respirometer measures the amount of oxygen consumed and the amount of carbon dioxide produced during cellular respiration. Respirometers are quite simple pieces of apparatus but can give accurate results if set up carefully.



Measuring respiration with a simple respirometer

The diagram on the left shows a **simple respirometer**. It measures the change in gases as respiration occurs.

- Respiring organisms, in this case germinating seeds, are placed into the bottom of the chamber.
- Soda lime or potassium hydroxide is added to absorb any carbon dioxide produced during respiration. Therefore the respirometer measures oxygen consumption.
- Once the organisms have been placed into the chamber the screw clip is closed. The start position of the coloured bubble is measured (this is the time zero reading).
- The coloured bubble in the capillary tube moves in response to the change in oxygen consumption. Measuring the movement of the liquid (e.g. with a ruler) allows the change in volume of gas to be estimated.
- Care needs to be taken when using a simple respirometer because changes in temperature or atmospheric pressure may change the readings and give a false measure of respiration.
- **Differential respirometers** (not shown) use two chambers (a control chamber with no organisms and a test chamber) connected by a U-tube. Changes in temperature or atmospheric pressure act equally on both chambers. Observed changes are only due to the activities of the respiring organism.

1. Why does the bubble in the capillary tube move?

_____

_____

_____

2. A student used a simple respirometer (like the one above) to measure respiration in maggots. Their results are presented in the table (right). The maggots were left to acclimatise for 10 minutes before the experiment was started.

   (a) Calculate the rate of respiration and record this in the table. The first two calculations have been done for you.

   (b) Plot the rate of respiration on the grid, below right.

   (c) Describe the results in your plot: _____

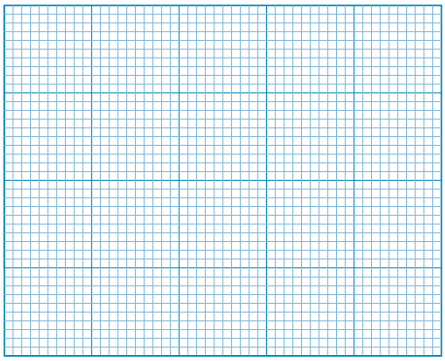
   _____

   _____

   _____

   _____

Time / minutes	Distance bubble moved / mm	Rate/ mm min^{-1}
0	0	0
5	25	5
10	65	
15	95	
20	130	
25	160	



   (d) Why was there an acclimatisation period before the experiment began?

   _____

   _____

3. Why would it have been better to use a differential respirometer? _____

   _____

   _____

   _____

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26 Investigating Photosynthetic Rate

Key Idea: Measuring the production of oxygen provides a simple means of measuring the rate of photosynthesis.

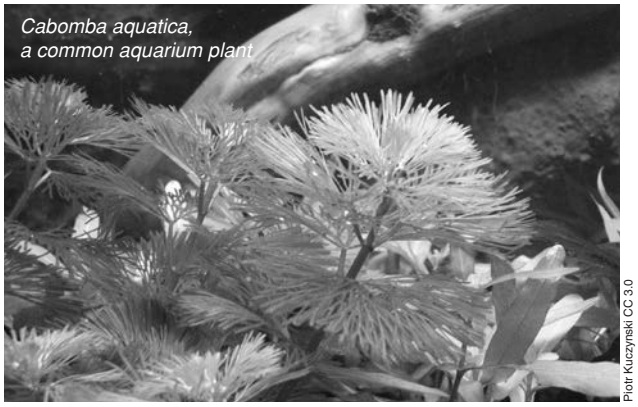
The rate of photosynthesis can be investigated by measuring the substances involved in photosynthesis. These include measuring the uptake of carbon dioxide, the production of oxygen, or the change in biomass over time. Measuring the rate of oxygen production provides a good approximation of the photosynthetic rate and is relatively easy to carry out.

The aim

To investigate the effect of light intensity on the rate of photosynthesis in an aquatic plant, *Cabomba aquatica*.

The method

- 0.8-1.0 grams of *Cabomba* stem were weighed on a balance. The stem was cut and inverted to ensure a free flow of oxygen bubbles.
- The stem was placed into a beaker filled with a solution containing 0.2 $molL^{-1}$ sodium hydrogen carbonate (to supply carbon dioxide). The solution was at approximately 20°C. A funnel was inverted over the *Cabomba* and a test tube filled with the sodium hydrogen carbonate solution was inverted on top to collect any gas produced.
- The beaker was placed at distances (20, 25, 30, 35, 40, 45, 50 cm) from a 60W light source and the light intensity measured with a lux meter at each interval.
- Before recording data, the *Cabomba* stem was left to acclimatise to the new light level for 5 minutes. Because the volumes of oxygen gas produced are very low, bubbles were counted for a period of three minutes at each distance.



Cabomba aquatica, a common aquarium plant

Piotr Kuczynski CC 3.0

The results

Light intensity / lx (distance)	Bubbles counted in three minutes	Bubbles per minute
5 (50 cm)	0	
13 (45 cm)	6	
30 (40 cm)	9	
60 (35 cm)	12	
95 (30 cm)	18	
150 (25 cm)	33	
190 (20 cm)	35	

1. Complete the table by calculating the rate of oxygen production (bubbles of oxygen gas per minute):
2. Use the data to draw a graph of the bubble produced per minute vs light intensity:
3. Although the light source was placed set distances from the *Cabomba* stem, light intensity in lux was recorded at each distance rather than distance *per se*. Explain why this would be more accurate:

_____

_____

_____

4. The sample of gas collected during the experiment was tested with a glowing splint. The splint reignited when placed in the gas. What does this confirm about the gas produced?

_____

5. What could be a more accurate way of measuring the gas produced in the experiment? _____

_____

_____

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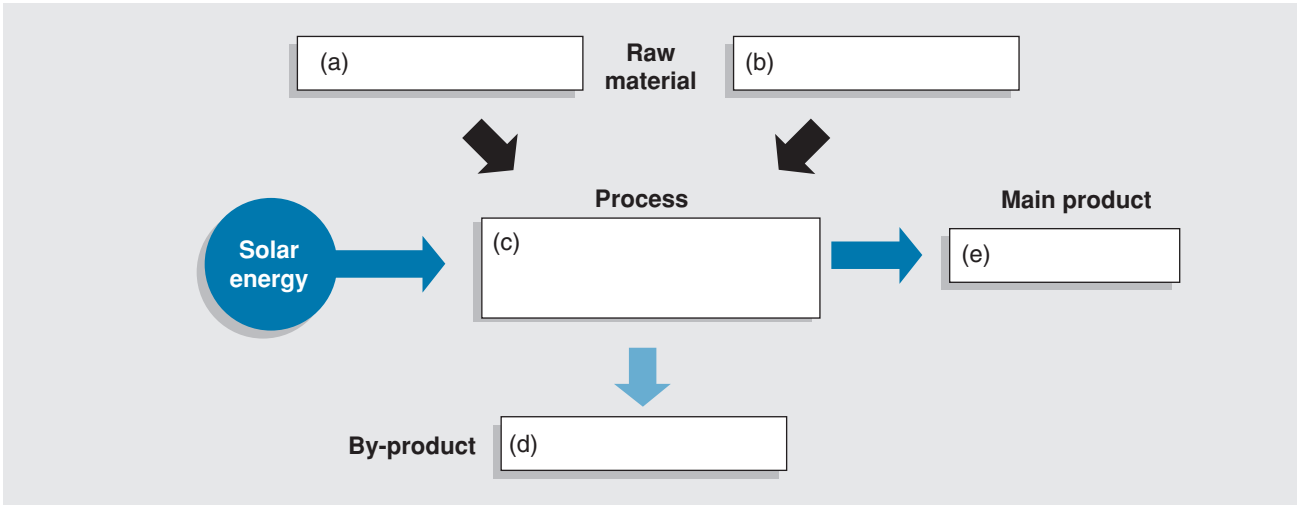
29 KEY TERMS: Did You Get It?

1. Complete the schematic diagram of photosynthesis below:



2. (a) Write the process of photosynthesis as:

   A word equation: _____

   A chemical equation: _____

   (b) Where does photosynthesis occur? _____

3. Test your vocabulary by matching each term to its correct definition, as identified by its preceding letter code.

absorption spectrum .....

accessory pigments .....

action spectrum .....

Calvin cycle .....

chlorophyll .....

grana .....

light dependent phase .....

photosynthesis .....

ribulose bisphosphate .....

stroma .....

thylakoid discs .....

A The biochemical process that uses light energy to convert carbon dioxide and water into glucose molecules and oxygen.

B A 5-carbon molecule which acts as the primary CO_2 acceptor in photosynthesis.

C Membrane-bound compartments in chloroplasts. They are the site of the light dependent reactions of photosynthesis.

D The phase in photosynthesis where chemical energy is used for the synthesis of carbohydrate. Also called the light independent phase.

E The liquid interior of the chloroplast where the light independent phase takes place.

F The phase in photosynthesis when light energy is converted to chemical energy.

G The term to describe the light absorption of a pigment vs the wavelength of light.

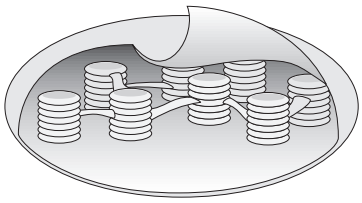
H Plant pigments that absorb wavelengths of light that chlorophyll *a* does not absorb.

I A profile of the effectiveness of different wavelengths of light in fuelling photosynthesis.

J The green, membrane-bound pigment involved in the light dependent reactions of photosynthesis.

K The stacks of thylakoids within the chloroplasts of plants.

4. Label the following features of a chloroplast on the diagram below: granum, stroma, thylakoid disc, stroma lamellae



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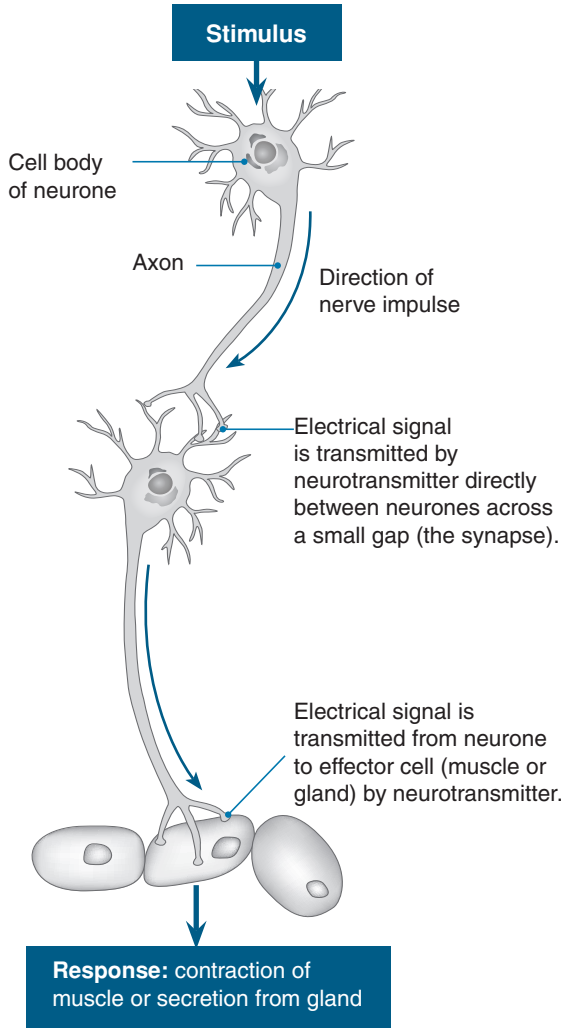
34 Nervous and Endocrine Interactions

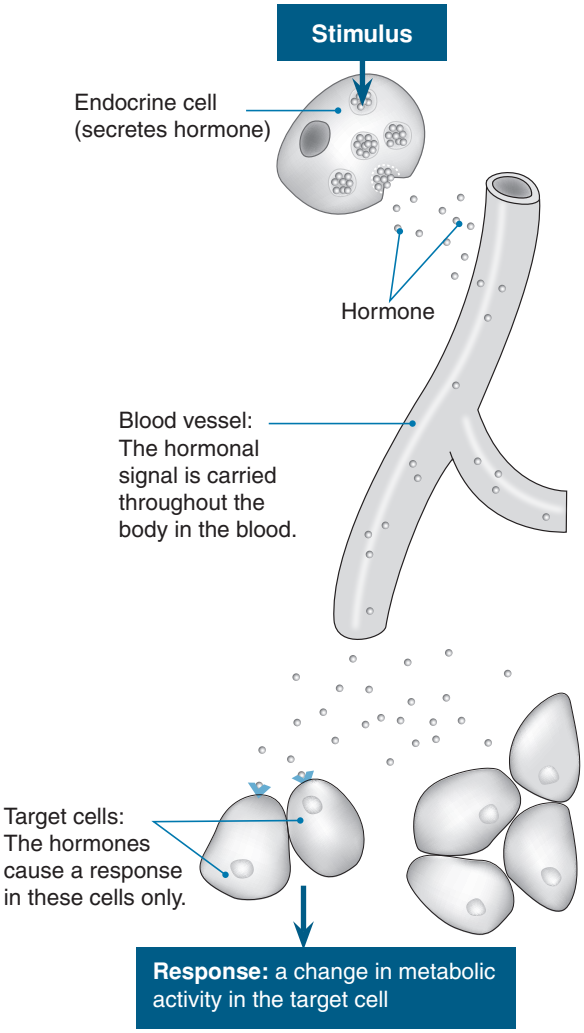
Key Idea: The nervous and endocrine systems work together to maintain homeostasis.

In mammals, the nervous system and endocrine (hormonal) systems act independently and together to maintain homeostasis. The two systems are quite different in their modes of action, the responses they elicit, and the duration of action. The nervous system stimulates rapid, short-lived responses through electrical signals transmitted directly between adjacent cells. The endocrine system produces a slower, more long-lasting response through blood-borne chemicals called hormones. Hormones control many life processes such as reproduction, growth, and development.

Signalling by neurones (nerve cells)



Signalling by hormones



The nervous system transmits electrical impulses directly between cells through electrical junctions or via chemicals called neurotransmitters, which can diffuse across the small gap (synapse) between cells. The response of a cell to nervous stimulation is rapid (milliseconds), short lived, and localised.

Hormones secreted from endocrine cells are carried in the blood throughout the body, where they interact only with target cells carrying the correct receptor to bring about a response. The speed of hormonal signalling is relatively slow, and it exerts its effects over minutes, hours, or days.

1. Complete the table below to show the comparison between nervous and hormonal signalling:

	Nervous control	Hormonal control
Communication	Impulses directly between cells across cell to cell junctions	
Speed		
Duration		
Target pathway		Carried in blood throughout body to target cells
Action		

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LINK 48 LINK 32 KNOW

121 Disruptive Selection in Darwin's Finches

Key Idea: Disruptive selection in the finch *Geospiza fortis* produces a bimodal distribution for beak size.

The Galápagos Islands, 970 km west of Ecuador, are home to the finch species *Geospiza fortis*. A study during a prolonged drought on Santa Cruz Island showed how **disruptive selection** can change the distribution of genotypes in a population. During the drought, large and small seeds were more abundant than the preferred intermediate seed size.

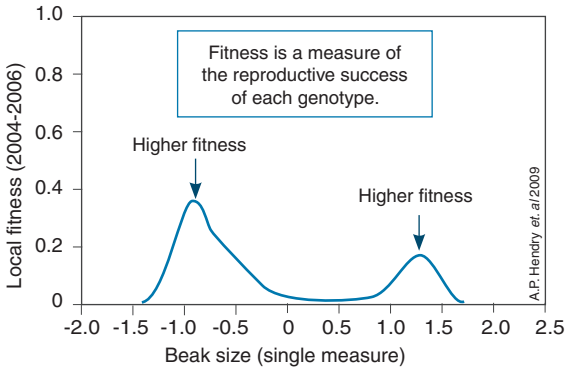
Beak sizes of *G. fortis* were measured over a three year period (2004-2006), at the start and end of each year. At the start of the year, individuals were captured, banded, and their beaks were measured.

The presence or absence of banded individuals was recorded at the end of the year when the birds were recaptured. Recaptured individuals had their beaks measured.

The proportion of banded individuals in the population at the end of the year gave a measure of fitness. Absent individuals were presumed dead (fitness = 0).

Fitness related to beak size showed a bimodal distribution (left) typical of disruptive selection.

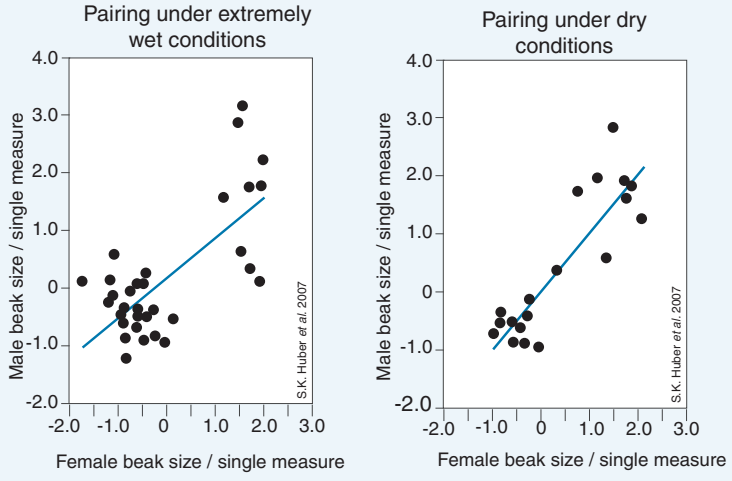
Beak size vs fitness in *Geospiza fortis*

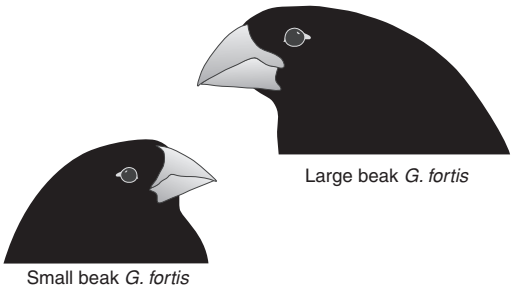


*Fitness showed a **bimodal distribution** (arrowed) being highest for smaller and larger beak sizes.*

Measurements of the beak length, width, and depth were combined into one **single measure**.

Beak size pairing in *Geospiza fortis*





Large beak *G. fortis*

Small beak *G. fortis*

A 2007 study found that breeding pairs of birds had similar beak sizes. Male and females with small beaks tended to breed together, and males and females with large beaks tended to breed together. Mate selection maintained the biomodal distribution in the population during extremely wet conditions. If beak size wasn't a factor in mate selection, the beak size would even out.

1. (a) How did the drought affect seed size on Santa Cruz Island? _____

   _____

   (b) How did the change in seed size during the drought create a selection pressure for changes in beak size?

   _____

   _____

   _____

2. How does beak size relate to fitness (differential reproductive success) in *G. fortis*? _____

   _____

   _____

   _____

3. (a) Is mate selection in *G. fortis* random / non-random? (delete one)

   (b) Give reasons for your answer: _____

   _____

   _____

KNOW WEB 121 LINK 115 LINK 118 LINK 119

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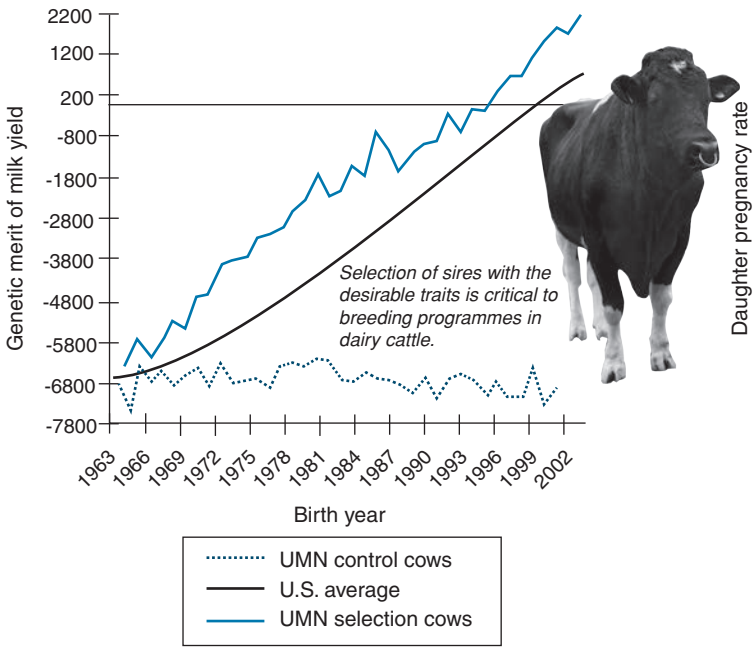
129 Selection in Dairy Cattle

Key Idea: Selective breeding is able to produce rapid change in the phenotypic characteristics of a population.

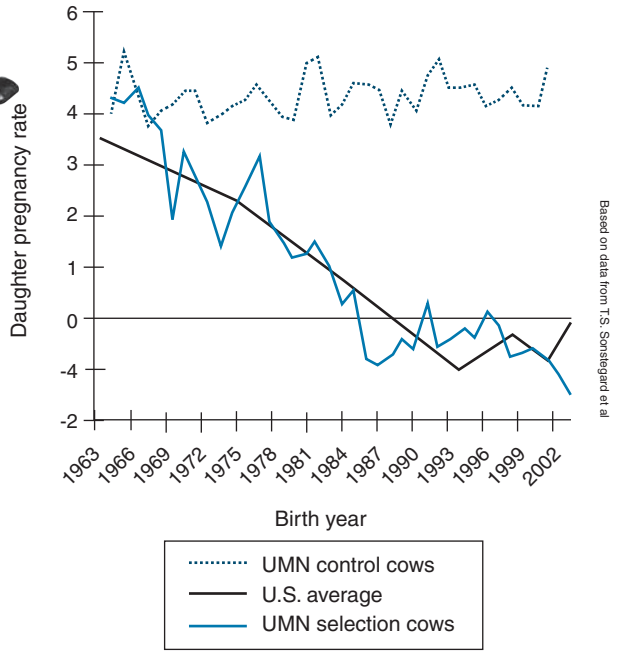
Humans may create the selection pressure for evolutionary change by choosing and breeding together individuals with particular traits. The example of milk yield in Holstein cows (below) illustrates how humans have directly influenced the genetic makeup of Holstein cattle with respect to milk production and fertility. Since the 1960s, the University of Minnesota has maintained a Holstein cattle herd that has not been subjected to any selection. They also maintain a herd that was subjected to selective breeding for increased milk production between 1965 and 1985. They compared the genetic merit of milk yield in these groups to that of the USA Holstein average.

Gain in genetic merit of milk yield



Milk production in the University of Minnesota (UMN) herd subjected to selective breeding increased in line with the U.S. average production. In real terms, milk production per cow per milking season increased by 3740 kg since 1964. The herd with no selection remained effectively constant for milk production.

Fertility in holstein cows



Along with increased milk production there has been a distinct decrease in fertility. The fertility of the University of Minnesota (UMN) herd that was not subjected to selection remained constant while the fertility of the herd selected for milk production decreased with the U.S. fertility average.

1. (a) Describe the relationship between milk yield and fertility on Holstein cows: _____

   _____

   (b) What does this suggest about where the genes for milk production and fertility are carried? _____

   _____

   _____

2. What limits might this place on maximum milk yield? _____

   _____

3. Why is sire selection important in selective breeding, even if the characters involved are expressed only in the female?

   _____

4. Natural selection is the mechanism by which organisms with favourable traits become proportionally more common in the population. How does selective breeding mimic natural selection? How does the example of the Holstein cattle show that reproductive success is a compromise between many competing traits?

   _____

   _____

   _____

   _____

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151 Diversity Indices

Key Idea: Diversity indices quantify the biodiversity in an area and can be used to measure ecosystem health.

The health of an ecosystem can be assessed by measuring both the number and relative abundances of organisms present. A change in species composition over time can therefore indicate changes in that ecosystem's status. Certain **indicator species** are also useful in this respect as they are associated with habitats of a particular status, e.g. unpolluted water. Scientists quantify biodiversity using a diversity index. Diversity indices take account of both the species evenness and species richness and can be used to assess environmental stress (or recovery).

Simpson's index of diversity

Simpson's Index of Diversity (below) produces values ranging between 0 and almost 1. There are other variants of this index, but the more limited range of values provided by this calculation makes it more easily interpreted. No single index offers the "best" measure of diversity; each is chosen on the basis of suitability to different situations.

Simpson's Index of Diversity (D) is easily calculated using the following simple formula. Communities with a wide range of species produce a higher score than communities dominated by larger numbers of only a few species.

$$D = 1-(\sum(n/N)^2)$$

D = Diversity index
N = Total number of individuals (of all species) in the sample
n = Number of individuals of each species in the sample

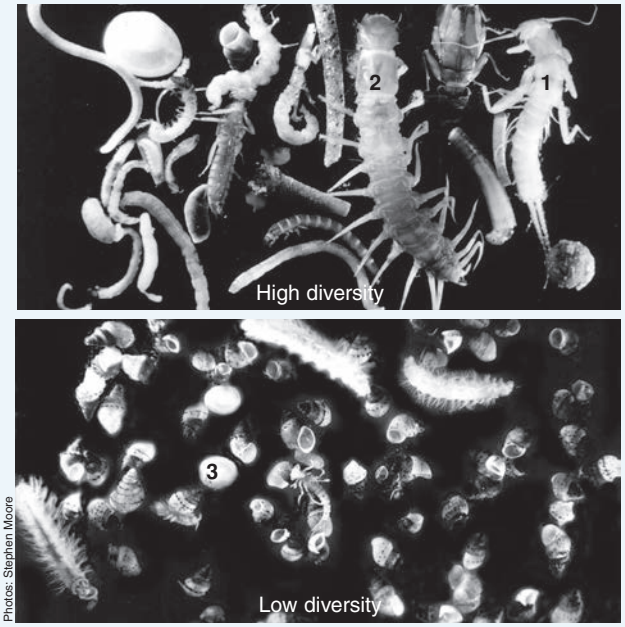
Example of species diversity in a stream

The example below describes the results from a survey of stream invertebrates. It is not necessary to know the species to calculate a diversity index as long as the different species can be distinguished.

For the example below, Simpson's Index of Diversity using $D = 1 - (\sum(n/N)^2)$ is:

Species	n	n/N	$(n/N)^2$
A (backswimmer)	12	0.300	0.090
B (stonefly larva)	7	0.175	0.031
C (silver water beetle)	2	0.050	0.003
D (caddisfly larva)	6	0.150	0.023
E (water spider)	5	0.125	0.016
F (mayfly larva)	8	0.20	0.040
	$\sum n = 40$		$\sum(n/N)^2 = 0.201$

$$D = 1-0.201 = 0.799$$



Photos: Stephen Moore

Using diversity indices and the role of indicator species

To be properly interpreted, indices are usually evaluated with reference to earlier measurement or a standard ecosystem measure. The photographs left show samples from two stream communities, a high diversity community with a large number of macroinverterbate species (top) and a low diversity community (lower photograph) with fewer species in large numbers. These photographs also show indicator species. The top image shows a stonefly (1) and an alderfly larva (2). These species (together with mayfly larvae) are typical of clean, well oxygenated water. The lower image is dominated by snails (3), which are tolerant of a wide range of conditions, included degraded environments.

The aptly named rat-tail maggot is the larva of the drone fly. This species is an indicator of gross pollution. Its prominent feature is a long snorkel-like breathing siphon.

1. Why might it be useful to have baseline data (prior knowledge of a system) before interpreting a diversity index?

2. (a) How might you monitor the recovery of a stream ecosystem following an ecological restoration project?

   (b) What role could indicator species play in the monitoring programme?

LINK
KNOW 152

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