Biology 3.5 (Achievement Standard 91605)

Externally assessed
4 credits

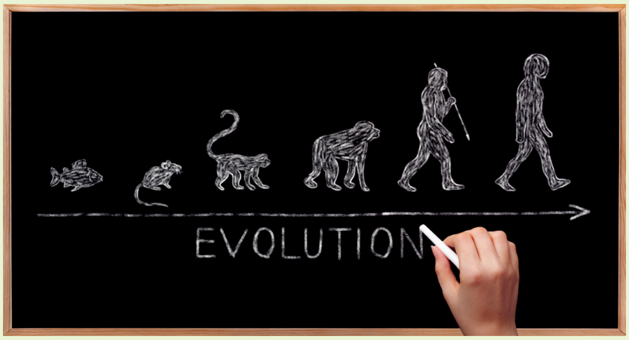
Demonstrate understanding of evolutionary processes leading to speciation

Setting the scene – 'Evolution is the single most important concept in Biology'

Achievement Standard 91605 (Biology 3.5) builds on the content of Achievement Standard 91157 (Biology 2.5) 'Genetic variation and change', extending it to include the *patterns* of evolution and the *processes* that result in *speciation*. Knowledge of these evolutionary concepts is essential for Achievement Standard 91606 (Biology 3.6) 'Demonstrate understanding of trends in human evolution' and is also for candidates entering for Scholarship Biology.

It is recommended that you review your AS 91157 (Biology 2.5) material prior to starting AS 91605 (Biology 3.5), especially the concepts of:

- gene pool and genetic variation
- role of mutation
- natural selection – including selection pressures and selection agents
- migration and gene flow
- genetic drift – including the founder effect and bottleneck effect.



Checkpoints

Throughout AS 91605 (Biology 3.5) you will encounter numbered **Checkpoints**. These are for you to review and check your understanding of the important concepts that have been covered. *Work with a partner (or small group) and take turns to*:

- ☑ define the concept
- ☑ provide as many examples as you can
- ☑ give the adaptive advantages for the concept.

When all in your group have agreed that you are correct, *write in your own words* (this shows understanding – copying from the textbook or workbook does not) a summary of the topic in which you give definitions / examples / explanations. Writing things down will consolidate your learning and provide good study notes for exam purposes (keep the summaries in your work records). It may be an idea to show your summary to your teacher for their feedback on accuracy and completeness, especially for the more difficult topics.

It is recommended that you repeat this exercise prior to your school exams and prior to the end-of-year external exams.

NCEA exemplar questions

Throughout AS 91605 (Biology 3.5) you will encounter **NCEA exemplar questions**. Write your answers to these on your own paper and include them in your work records.

Overview

Biological evolution is the genetic change in a population from one generation to another.

A **species** may be defined as a group of organisms that normally interbreed in nature to produce fertile offspring. Members of a species that live together in the same geographical area are a **population** (e.g. the trout in lake Taupo, the rimu trees in the Kaimai Forest, kokako on Tiritiri Matangi Island) and share a common **gene pool**. The gene pool is the total number of **alleles** that occurs in a population. The **genetic diversity** of a population is determined by the *range of alleles in its gene pool*.

Populations (not individuals) are the units of evolution and any change in the allele frequency of the gene pool indicates evolution is occurring.

$$\text{frequency of an allele in a population} = \frac{\text{occurrence of that allele in a population}}{\text{total number of alleles in that gene pool}}$$

Gene flow is the *movement of alleles* between two populations of the same species and occurs when individuals **migrate** between their original population and subsequently breed with a resident of the destination population. In the conservation of endangered species, researchers often translocate individuals between isolated populations (e.g. kokako translocated between Tiritiri Matangi Island / Hunua ranges / Taranaki forests) so that genetic diversity is maintained or increased.

Kokako

The *processes* that contribute to changes in the allele frequency in the gene pool and therefore evolution include:

- **mutation**
- **natural selection**
- **gene flow**.

Evolution over many generations may result in **speciation** – the *formation of a new species* as a result of *reproductive isolation.* Speciation may be:

- **allopatric**
- **sympatric**.

Reproductive isolating mechanisms (**RIMs**) that contribute to speciation include geographical barriers, ecological barriers, behavioural barriers, temporal barriers, structural barriers, and polyploidy.

The *patterns* of evolution that may be seen in speciation include:

- **gradualism** and **punctuated equilibrium**
- **divergent evolution** and **convergent evolution**
- **adaptive radiation**
- **co-evolution**.

Similarities (biochemical and structural) between species indicate the presence of a **common ancestor** from which those species have evolved and diverged.

Evolutionary concepts

Answers p. 272

1. Use your knowledge from Level 2 Biology and any necessary research to answer the following questions.
   a. Define the following terms:
      i. species ______________________
      ____
      ii. population ______________________
      ____
      iii. gene pool ______________________
      ____
      iv. gene flow ______________________
      ____
      v. genetic diversity ______________________
      ____
      vi. evolution ______________________
      ____
      vii. speciation ______________________
      ____
      viii. gene mutation ______________________
      ____
      ix. natural selection ______________________
      ____
      x. genetic drift ______________________
      ____

xi. founder effect

xii. bottleneck effect.

b. Explain why maintaining and/or increasing the genetic diversity of members of a population helps the population.

2. Continue doing some research so that you can define and are able to clearly distinguish between the following terms:

a. allopatric and sympatric speciation

b. divergent evolution and convergent evolution

c. divergent evolution and adaptive radiation.

3. Reproductive isolating mechanisms (RIMs) act to prevent breeding between species. They result in the members of a species being reproductively isolated from the members of all other species. Find out and then describe how the following mechanisms act as RIMs; where possible, include an example with each answer.

   a. Geographical barriers: ______

   b. Structural barriers: ______

   c. Ecological barriers: ______

   d. Temporal barriers: ______

   e. Behavioural barriers: ______

4. 'Evolution is the single most important concept in biology'. Discuss this statement in class and come up with ideas as to why this is so. From your discussion, write 1–3 paragraphs presenting your ideas. Hand this to your teacher for their feedback.
   Write your answer on your own paper.

Evidence for evolution

Planet Earth came into existence about 4.6 billion years ago (bya). The earliest life forms discovered are microscopic structures found in rocks in Western Australia and dated to 3.4 bya. Photosynthetic organisms first appeared about 3–2.5 bya, the first eukaryotes about 1.8 bya, multicellular organisms date to about 1 bya.

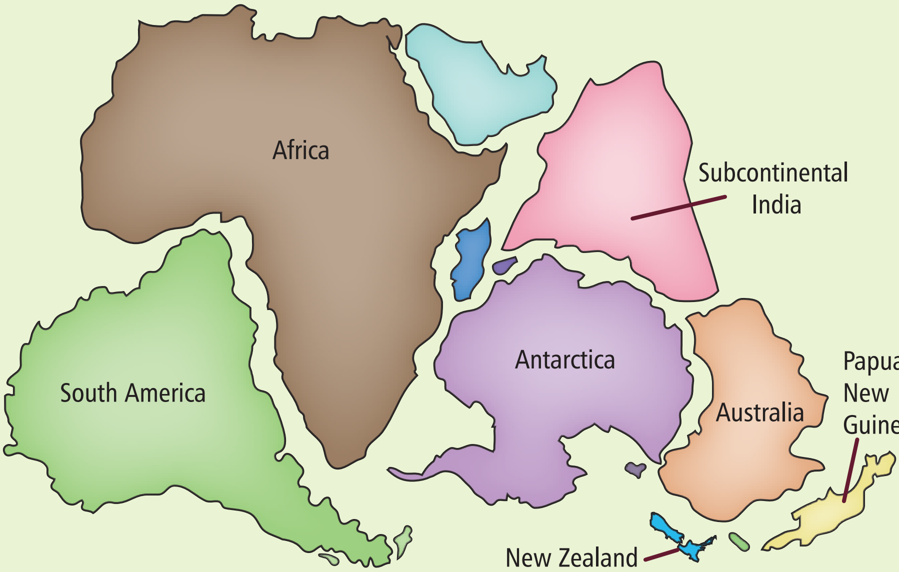
The first animals appeared somewhere between 1 bya to 600 million years ago (mya); the origins of most animal groups living today date back to about 550 mya (known as the 'Cambrian explosion'). Mammals came into existence about 200 mya, while our genus *Homo* appeared about 2.5 mya.

It is analysis of the **fossil record** that has produced our knowledge of early life forms; recently, **molecular biology** (including evidence from **proteins** and from **DNA** / **genome analysis**) has added significantly to this knowledge. The geographic distribution of fossils and living forms throughout the continents (**biogeography**) further provides evidence of divergence from a common ancestor/ancestral group.

Biogeography

Biogeography is the study of the geographic distribution of species; the natural geographic distribution of *related* species provides evidence of evolution.

The origins and dispersal of present-day life forms can be explained by the *movement of the continents* that sit upon the tectonic plates that make up the Earth's crust. **Gondwana** was the southern supercontinent which about 180–150 mya began splitting up into the land masses which we now call New Zealand, Antarctica, Australia, South America, Africa, India.



Gondwana is shown with gaps between the fragments to indicate present-day land masses.
The southern super-continent of Gondwana

The land masses separated and moved apart, carrying their cargo of organisms with them; the sea/ocean barriers that formed prevented gene flow – therefore the plants and animals became genetically isolated from ancestral populations and evolved in isolation. Sea/ocean barriers also prevented gene flow as islands formed

Biology 3.6 (Achievement Standard 91606)

Externally assessed
4 credits

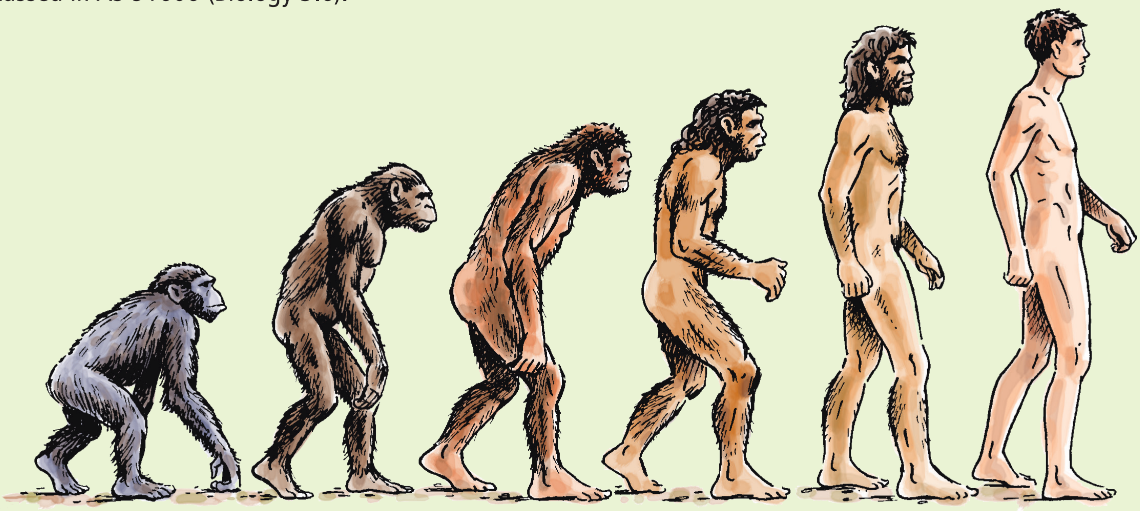
Demonstrate understanding of trends in human evolution

Setting the scene

Sitting at my desk working on this chapter using my laptop computer caused me to pause and reflect on the progress in our *biological evolution* over the last 2 million years; we have come from making and using stone tools to making and using computers – a very big step in a very short time. Our brains are now sufficiently large and complex that we can visualise and design computers (however, no computer can yet match our brains in complexity of function), our hands are now sufficiently flexible that we can make and manipulate the tools that make the computers and then operate their associated keyboards.

In preparing this material on AS 91606 (Biology 3.6), I am processing and passing on knowledge learnt about our origins based on the analysis of data collected from the fossil record and from DNA samples – this is *cultural evolution* in action; again we have made some very big steps in a very short time from our hunter-gatherer ancestors passing on oral knowledge around the hearth to present-day mass dissemination of knowledge over the internet.

It is the key steps in our biological and cultural evolution from our early hominin ancestors that are covered and discussed in AS 91606 (Biology 3.6).



Introduction

Trends in human evolution refer to *changes over a period of time* in relation to:

- **biological evolution**
- **cultural evolution**
- **dispersal patterns of hominins.**

Knowledge of the content of AS 91905 (Biology 3.5) 'Demonstrate understanding of evolutionary processes leading to speciation' is essential background for AS 91906 (Biology 3.6) as the processes (e.g. mutation, natural selection) and patterns (e.g. divergence) of evolution also apply to the biological evolution of humans.

The important trends in the **biological evolution** of humans include:

- skeletal changes linked to **bipedalism**
- changes in the **skull** and **endocranial** features (endocranial refers to the *volume of the cranium* – an indicator of the size of the brain)
- changes in the **manipulative ability of the hand** (relates to manufacture and use of tools).

The important trends in the **cultural evolution** of humans include:

- manufacture and use of **tools** – stone / wood / bone
- (controlled) use of **fire**
- *clothing*
- abstract thought – **communication** / *language* / *art*
- food gathering – **hunter-gathering**; **domestication** and **farming** of animals and plants
- shelter – caves; temporary and permanent settlements.

Interpretation of the trends in human evolution needs to be based on *current scientific evidence* which is *widely accepted* and presented in *peer-reviewed scientific publications*.

Research into the origins and evolution of humans is ongoing with new findings continually being published (e.g. announcement of a new *Homo* – *H. naledi* – in 2015). Be aware of newly published and accepted findings since the time of writing of this book and how they fit into the trends in human evolution – i.e. keep up to date with the latest research findings.

H. naledi fossils

Biological evolution results from the *transmission of genetic material* (DNA / genes / alleles / chromosomes) from parents to offspring / from generation to generation. New alleles result from gene mutations and those alleles that enter the gene pool are subject to natural selection (as well as genetic drift). Aspects of human biology determined by biological evolution include bipedalism, the manipulative hand and brain development. Biological evolution is random, and tends to be slow, with the rate determined by mutation, natural selection and environmental changes. As modern-day humans now have considerable control over the natural environment (we no longer adapt to the environment but adapt the environment to us), selection pressures / natural selection have largely been removed, and biological evolution is currently not a major aspect of our biology.

Cultural evolution results from the *transmission of learning/knowledge* between and within generations. Knowledge results from higher-level thinking and is stored as memory as well as in written form and is transmitted by language (both spoken and written). Knowledge includes ideas, beliefs, customs and values (both of individuals and societies) and can be individual and collective. Aspects of human lifestyle resulting from cultural evolution include tool technology, controlled use of fire, food-gathering techniques, settlements and farming, language and communication, politics, spirituality, art, music, science and maths. Cultural evolution is directional and tends to be rapid. Its speed has increased (and continues to do so) with information technology becoming a huge influence in recent years. So rapid has been our cultural evolution that it has outstripped the capacity for biological evolution of most of our predator/prey/competitor species.

Cultural evolution accelerates with the development of a complex brain and an ability to communicate – these are the result of biological evolution. *Biological and cultural evolution have interacted together in the evolution of modern humans*.

The primate *Homo sapiens*

Checkpoints

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Work with a partner (or small group) and take turns to:

- ☑ define the concept
- ☑ provide as many examples as you can
- ☑ give the significance of the concept in human evolution (as applicable).

When all in your group have agreed that you are correct, *write in your own words* (this shows understanding – copying from the textbook or workbook does not) a summary of the topic in which you give definitions / examples / explanations. Writing things down will consolidate your learning and provide good study notes for exam purposes (keep the summaries in your work records). It may be an idea to show your summary to your teacher for their feedback on accuracy and completeness, especially for the more difficult topics.

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NCEA exemplar questions

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Introduction to human evolution

Answers p. 282

You may need to do some research to answer some of the following questions.

1. Write a definition for:
   a. bipedalism
   b. endocranial
   c. hunter-gatherer
2. Describe how the hand of modern-day humans allows us to make and use refined tools while that of a chimpanzee does not.
3. Discuss with your partner or have a class discussion to suggest reasons why 'interpretation of the trends in human evolution needs to be based on *current scientific evidence* which is *widely accepted* and presented in *peer-reviewed scientific publications*'. Then write one or two paragraphs summarising your findings.
4. a. Distinguish between biological and cultural evolution.
   b. Give examples for humans of:
      i. biological evolution
      ii. cultural evolution

Answers

Achievement Standard 91603 (Biology 3.3)

Ecological niche (page 3)

1. a. The fundamental niche of *Chthamalus* occupies all the intertidal zone from high tide to low tide, while the realised niche is restricted to the upper $\frac{1}{3}$ of the intertidal shore (from high tide).
   b. As the tide recedes, the barnacle is no longer submerged in water and needs to be able to tolerate the lack of water and increased summer temperatures, which will dehydrate/desiccate it over time. Therefore, the upper limit to the niche is set by the barnacle's physiological tolerance to dehydration.
   c. i. The lower limit to the fundamental niche is set by the barnacle's physiological tolerance to constant submergence in (sea) water and/or effect of competition for space on rocks by seaweeds and/or effects of predation by starfish and fish.
   ii. The lower limit to the realised niche is set by competition for living space on the rock by the (bigger) *Balanus* barnacle.
   d. Realised niche is the same as fundamental niche for *Balanus* as it is likely that the limits are set by physiological tolerances to submergence by water (lower) and exposure to air (upper). Biotic factors (e.g. competition from seaweed for living space on rocks, predation by fish) may be acting to set the lower limit to the niche.
   e. i. The upper limit to the niche is set by the barnacle's physiological tolerance to dehydration when exposed to the air by the receding tide.
   ii. The lower limit is set by any of or a combination of:
      - the barnacle's physiological tolerance to continuous submergence under water
      - competition by seaweeds for living space on the rocks
      - predation by starfish and/or fish.
   f. *Chthamalus* has the wider range of tolerance as it is able to live throughout the intertidal shore from low tide to high tide, whereas *Balanus* is only able to occupy the lower $\frac{2}{3}$ of the shore.
   g. *Balanus* is out-competing *Chthamalus* for living space on the shore and is restricting *Chthamalus* to the upper $\frac{1}{3}$ of the shore.
2. Stewart Island – abiotic factor – island is in southern latitudes that give a (comparatively) short night during the summer months which means reduced foraging time. Diurnal foraging behaviour may be required to provide needed amounts of food.
   Ponui island – biotic factor – island is small and large number of kiwi produces high level of intraspecfic competition for food; diurnal behaviour may reduce intraspecific competition for food. No diurnal predators.
3. Both species of clover germinate and growth is nearly equal for the first 20 days. After this, Clover A increases greatly in dry weight, which indicates a rapid increase in growth and/or numbers of plants. The weight of Clover B increases slightly to Day 40, then abruptly decreases to almost zero by Day 60, i.e. it is being eliminated. As there are no other factors operating, this strongly suggests that Clover B is being out-competed for resources by Clover A (e.g. Clover A is larger and grows more vigorously so prevents Clover B from getting adequate light). The root system and growth of Clover A may also be more vigorous, preventing Clover B from getting adequate supplies of water and nutrients or Clover A may be releasing a chemical that inhibits the growth of Clover B (allelopathy). The elimination of Clover B supports Gause's Principle – it has been outcompeted by Clover A.
4. a. i. When grown separately, the population of each species grows steadily to reach large numbers at the end of 8 weeks (species A from about 50 to about 420 mg biomass and species B from about 75 to 600 mg biomass). When grown together, species A still grows steadily (from about 30 to about 350 mg biomass, though the rate is lower than when grown separately); however, species B grows only slightly then declines, so that after 8 weeks there is only about 30 mg biomass.
   ii. When grown together, species A outcompetes species B. This could be as a result of species B having inadequate light to photosynthesise; it is likely that species A has bigger air sacs in its leaves which enable the leaves to float higher above the water and so cover and block out the light for species B.
   b. Gause's principle states that 'if two species have identical or sufficiently similar niches, one species will outcompete and eliminate the other'. The two species of *Lemna* have sufficiently similar niches that they compete. In the particular experimental conditions, species A outcompetes species B, although species B is not completely eliminated. Thus the experiment only partially supports Gause's principle – the experiment should have been run for a longer time.
5. *Answer – teacher feedback*. Discussion should refer to:
   - both herbivores, but have different foods (*described*) and adaptations (*described*) to feeding
   - different habitats (*described*)
   - warning colouration described and explained in terms of toxic compounds / unpalatable / predator avoidance
   - advantages related to reduction in intraspecific competition (*explained*), hence increased survival of individuals and survival of species.

Timing responses (1) (page 9)

1. a. Biotic factors are *living* environmental factors (e.g. other plants and animals); abiotic factors are *non-living* (physical) environmental factors (e.g. water, oxygen, substrate).
   b. Exogenous refers to *external* factors or external control; endogenous refers to *internal* factors or internal control.
   c. Nocturnal refers to *night*-active organisms; diurnal refers to *day*-active organisms.
   d. Circadian refers to an activity that displays a free-running period of about a *day/24 hours*; circannual refers to an activity that displays a free-running period of about a *year/365 days*.
   e. Circatidal refers to an activity that displays a free-running period of about a *tidal cycle/12.4 hours*; circalunar refers to an activity that displays a free-running period of about a *lunar cycle/29.5 days.*
2. a. Circa means 'about' and is used to refer to activities which have a free-running period of about 24 hours ('circadian'), 365 days ('circannual'), and so on.

b. Zeitgeber is the name for an environmental cue that sets the internal clock; the most common zeitgeber is the day/night cycle.
c. Phase shift refers to movement of the onset of activity as a zeitgeber changes; if the zeitgeber change is large then the onset of activity changes each period until synchronised (entrained) to the zeitgeber.
d. Entrained refers to the onset of an activity becoming synchronised with a zeitgeber; entrainment occurs when a zeitgeber changes such a lot that the onset of activity takes a while to become synchronised with the zeitgeber.
e. The free-running period is the period of an activity under constant conditions, i.e. when there are no environmental cues to set the internal clock and hence set the onset of activity.

3. a. The period of testicular growth is about a year / 365 days.
b. Cockle feeding activity occurs with a period of about 12.5 hours / a tide.
c. Weta are night active; butterflies are day active; New Zealand bats are active at dusk.
d. Moths are active at night. They have a free-running activity period of about a day / 24 hours.
e. The sleep/wake internal clock cycle is reset by onset of light or onset of darkness.
f. Light is the environmental cue that resets the internal clock to determine onset of activity for grasshoppers.

4. The time of nightfall changes throughout the year as night length varies from season to season. The onset of activity of nocturnal animals will change correspondingly throughout the year as it is entrained by the onset of nightfall. After the midwinter solstice (June 21/22), the nights begin to get shorter than daylength so activity onset gets later until the summer solstice (Dec 21/22). After this, nights begin to get longer than daylength so activity will begin to start earlier again.

5. a. The period of the activity in the absence of environmental cues / in a constant environment.
b. 1500 hours (3 p.m.).
c. Set up a light/dark regime with a 24-hour cycle such that the dark phase encompassed 3 p.m. (e.g. set the timer so that the lights went off sometime / shortly before 3 p.m.).
d. Entrainment.

6. a. Circadian.
b. The activity has a free-running period of less than 24 hours, as onset of activity gets earlier each day from Day 5 onwards.
c. Activity remains rhythmic in the absence of environmental cues / zeitgeber / in constant conditions.
d. To ensure all environmental conditions remained constant / temperature could act as an environmental cue.
e. The activity pattern is likely to lose rhythm / become arrhythmic in the prolonged absence of a zeitgeber to reset the clock.

7. a. 0700 hours (+/– 30 min) and 1900 hours (+/– 30 min).
b. Circadian – the activity displays a period of about a day in constant conditions (Day 4 onwards).
c. Ants are crepuscular – active at dawn and dusk.
d. Light or light/dark cycle, as the onset of activity changes when the light is turned off. If temperature was the key factor, the time of onset of activity would be maintained.
e. Endogenous – the rhythmic pattern of the activity continues when the light is turned off and ants are in constant darkness / no zeitgeber.

Internal ('biological') clocks (page 13)

1. a. Allows the animal to **prepare for migration** – e.g. by moulting and replacing feathers so that the feathers are in top condition for the upcoming long hours of flying; laying down of fat layers to provide energy to fuel the long distances flown / swum / walked during migration.
b. Allows the animal to **prepare for winter** – e.g. moulting hair and replacing with longer/denser hair for increased insulation during colder months; laying down of fat layers to insulate and provide energy for hibernating animals (e.g. bears).
c. Acts to **synchronise reproductive behaviour** between males and females of the same species – e.g. maturing/ripening of the reproductive organs; arriving at breeding grounds for mating; development of breeding colours for courtship. These activities are essential if successful breeding is to occur.

2. Melatonin is the 'sleep' hormone and prepares the body for sleep – e.g. lowers metabolic rate and temperature; its release into the bloodstream (from the pineal gland) is stimulated by darkness.

3. Jet lag occurs when a person rapidly passes through different time zones. It results from the body's activity patterns being no longer synchronised with the new time of nightfall/daybreak. It takes several days (during which the body phase shifts) before activity patterns are again entrained/synchronised to the new onset of daybreak/nightfall.

Timing responses (2) (page 15)

1. a. Two.
b. Tidal movement / ebb and flow. The period between the tides is 12.5 hours / slightly more than 12 hours, so the tide (high and/or low) gets later each day.
c. i. Activity is controlled by an internal clock.
ii. 12.5 to 14 hours.
iii. Circatidal – as the activity occurs about every 12 hours / twice in 24 hours.
iv. The crab benefits by being to anticipate/predict the state of the tide so is able maximise feeding time between tides.

2. a. As onset of darkness changes seasonally, onset of weta activity changes with it. The onset of darkness acts as a zeitgeber to entrain the internal clock.
b. Being night active, the weta reduces its chances of suffering predation as most native predators are diurnal (e.g. birds such as saddleback). Apart from tuatara, there are few nocturnal native predators. Also, weta's colour camouflages it better in the dark. Temperatures lower at night, so reduced chance of dehydration. However, lower temperatures reduce weta's activity levels as it is a poikilotherm (cold blooded), which may reduce its chances of finding food/prey, especially on cold nights. In summer, nights are short so provide less time to feed / find mate. For the weta to be nocturnal and survive over a long period of time, benefits must outweigh disadvantages.

3. The squirrels display a *daily* (i.e. 24 hours) *activity* pattern. They start to become active just before or at nightfall – in the LHS actogram the start of the squirrel's activity is *synchronised* (*entrained*) with the start of the dark phase in the 24 hour (L12 : D12) regime it is exposed to. Light acts as the *zeitgeber* (environmental cue) to set the clock and thus the onset of activity. Activity ceases just before or after the end of the dark phase/ night. This activity pattern is *endogenous* (i.e. under the influence of an *internal clock*) – shown by the RHS actogram. When the squirrels are exposed to constant darkness (no zeitgeber) the activity free runs with a *free-running period* of more than 24 hours (about $24^1/_4$ hours from the actogram).

The experiment lasted 25 days. Under constant darkness (24D) the onset of activity increased from onset approx. 18 hr to onset approx. 1 hr – a time difference of 7 hours; $\frac{7}{25}$ is approx. $\frac{1}{4}$.

The adaptive advantage of the endogenously controlled nocturnal activity is that the squirrels can *predict the onset of nightfall* so do not have to continually leave their burrows to determine onset of darkness. The squirrels therefore reduce the risk of *diurnal predation*.