17.1 Variation

1. *explain, with examples, that phenotypic variation is due to genetic factors or environmental factors or a combination of genetic and environmental factors.*
2. *explain what is meant by discontinuous variation and continuous variation.*
3. *explain the genetic basis of discontinuous variation and continuous variation.*
4. *use the t-test to compare the means of two different samples (the formula for the t-test will be provided).*

Explain why the variation in a particular characteristic can be described as discontinuous.

- Discrete / distinct categories / phenotypes / morphs / groups.
- No range of phenotypes / no intermediates / no normal distribution.
- Only one gene involved.
- Not affected by the environment.

Explain why the variation in a particular characteristic can be described as continuous.

- Not discrete / categorical / with only a few values.
- Has a normal / bell(-shaped) distribution / curve.
- Polygenic / many genes / multiple loci involved.
- Environment has large effect.

17.2 Natural and Artificial Selection

Natural Selection

1. *explain that natural selection occurs because populations have the capacity to produce many offspring that compete for resources; in the 'struggle for existence', individuals that are best adapted are most likely to survive to reproduce and pass on their alleles to the next generation.*
2. *explain how environmental factors can act as stabilising, disruptive and directional forces of natural selection.*
3. *explain how selection, the founder effect and genetic drift, including the bottleneck effect, may affect allele frequencies in populations.*
4. *outline how bacteria become resistant to antibiotics as an example of natural selection.*
5. *use the Hardy–Weinberg principle to calculate allele and genotype frequencies in populations and state the conditions when this principle can be applied (the two equations for the Hardy–Weinberg principle will be provided).*

The stickleback fish, *Gasterosteus aculeatus*, has two distinct forms, the saltwater form and the freshwater form. The larger, freshwater form is thought to have evolved from the smaller, saltwater form. Both forms have armour plating on each side of the body. The plates are made of bone and contain a high proportion of calcium.

The ectodysplasin gene, *EDA*, codes for a protein involved in the development of armour plates. The *EDA* gene has two alleles, low armour and high armour.

Three main morphs of armour plating have been described.

Complete morph armour plating:

- is found mainly in the saltwater form
- has many plates from head to tail to cover most of the body
- provides defence against large, predatory fish
- limits the growth of the fish.

Partial morph armour plating:

- is found mainly in the freshwater form
- has a reduced number of plates to cover only part of the body.

Low morph armour plating:

- is found mainly in the freshwater form
- has very few, undeveloped plates and no body cover.

In 1982, at Loberg Lake in Southern Alaska, the entire freshwater stickleback fish population was accidentally destroyed by humans. In 1990, a new population of stickleback fish was found in the lake. Most of these fish had armour plates from head to tail on each side. Suggest why these new stickleback fish have armour plates from head to tail on each side, despite living in freshwater.

- saltwater / ocean fish had colonised the lake.
- saltwater sticklebacks have full armour plates for protection from predators.
- mutation/allele for full armour present in founders.

From 1990, annual sampling took place in the lake. Each year showed a reduction in the number of individuals with complete morph armour plating (from head to tail on each side). This change took place in a relatively short period of time.

- **In 1990, 96% of the stickleback fish population had complete morph armour plating.**
- **In 1993, 39% of the stickleback fish population had complete morph armour plating.**

Explain how natural selection has occurred in this new stickleback fish population.

- genetic variation in population.
- environmental changes: low calcium supply, reduction in numbers of predatory fish.
- selective advantage / selection for fewer armour plates.

- so fish can grow larger / lay more eggs / shed more sperm OR less energy wasted making armour.
- they survive / reproduce.
- they pass on advantageous / low armour alleles to offspring.
- allele frequency of low armour increased.
- this is directional selection towards reduced armour.

Two subspecies of reindeer live in North America. Members of the different subspecies belong to the same species but have some morphological differences and are found in different geographical locations.

feature	woodland subspecies, *R. tarandus caribou*	barren ground subspecies, *R. tarandus groenlandicus*
habitat	southern woodland (warmer)	northern tundra (colder)
type of food	tree leaves, grass	lichens, moss
summer and winter feeding grounds overlap	yes	no
carry out long migrations	no	yes
body size	large	small
colour of fur	dark	light

Assess the relative importance of natural selection and genetic drift in producing:

a. **the different colours of fur of the two subspecies of reindeer**
    - natural selection.
    - dark colour fur is adaptive: absorbs more heat so good in woods / shade.
    - camouflage / right colour protects against predators.

b. **the different body sizes of the two subspecies of reindeer.**
    - genetic drift / not natural selection.
    - small size in north is not adaptive.
    - small body size loses heat faster / harder to keep warm.
    - smaller fat reserves are not good with unstable food supply.
    - less food in north reduces growth / size.

Hybridisation has occurred between individuals of the two subspecies. Comment on how the hybrid populations compare to the pure subspecies in terms of genetic variation and potential to adapt to climate change.

- hybrid populations have more genetic variation / alleles.
- they have genes / mutations / alleles from both subspecies.
- they have more potential to adapt / can adapt better in the future.
- genes / alleles linked to migration may help some find new habitats.

- they have genes / alleles suited to both warm and cold / different temperatures.

A 28-year study of Magellanic penguins, *Spheniscus magellanicus*, found in Argentina, provides evidence of natural selection.
Magellanic penguins lay their eggs in nests. They use their bills (beaks) to catch prey and feed their chicks (offspring) in the nest. Each breeding pair of penguins uses the same nest each year.

A Magellanic penguin is shown in Fig. 4.1.

Fig. 4.1

- Data were collected for bill size every year from 1983 to 2010.
- Bill size was calculated using the length and depth of the bill.
- Bill size showed variation between the individuals.
- In 1983 all the penguins in one area were tagged.
- All tagged penguins were measured each year and their new chicks were tagged and measured.
- For each year of the study, an estimate of food availability was made.
- A statistical analysis was conducted to quantify whether selection had taken place.

Statistical analysis of the data showed that selection was not significant in most years of the study. However, a significant increase in bill size occurred in four years Name the type of selection that occurred in these four years.

- Directional

In these same four years, food availability was low. Explain how the data for bill size and food availability supports the idea of the 'struggle for existence' seen in natural selection.

- adults / penguins compete for food.
- large bill size is a selective advantage OR those with large bills get more food / get food more easily / survive.
- food availability is a selection pressure.

Further investigation showed that, in some years, larger bill sizes of adult males correlated with higher reproductive success.

Reproductive success was measured by the number of chicks that survived per adult each year. Suggest why larger bill size of adult males correlated with higher reproductive success.

Males with bigger bills:

- get more food for offspring / chicks.
- can better defend chicks / offspring.
- more chance of getting / attracting a mate / female.

Researchers investigated the extent to which the founder effect and natural selection affected evolutionary change.

Fig. 5.1 shows the brown anole lizard, *Anolis sagrei*. These lizards live on a number of Caribbean islands and feed on a variety of invertebrates and other small animals.

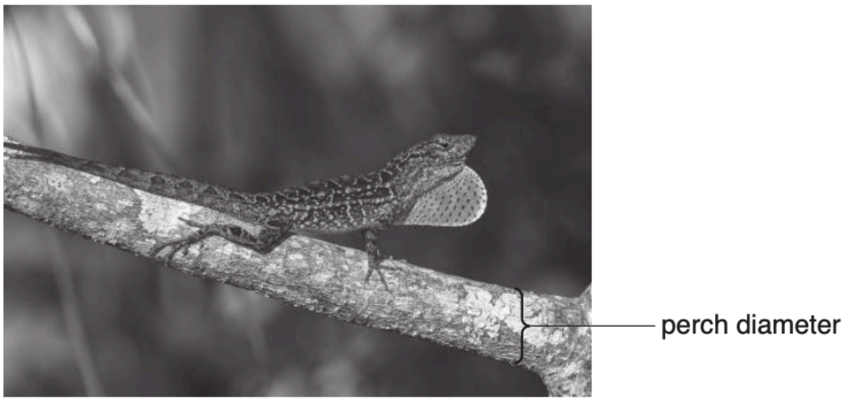

Fig. 5.1

A. sagrei spends a lot of time perching (resting) on, or moving along, branches of shrubs and trees. The width of the branch that *A. sagrei* perches on is known as the perch diameter, as labelled in Fig. 5.1.

There is a positive correlation between perch diameter and hind limb length of *A. sagrei*.

- Longer hind limbs allow *A. sagrei* to run faster on vegetation with a larger diameter.
- Shorter hind limbs are needed to provide stability on vegetation of a smaller diameter.

In 2004, a hurricane caused the death of all the *A. sagrei* lizards on seven islands.

In 2005, the researchers randomly collected seven male and seven female lizards from a source population on a nearby island. For each of the seven islands affected by the hurricane, a male and female lizard were mated and placed on each island. These islands formed the experimental founder islands where new populations of *A. sagrei* were successfully established from each founding pair.

Fig. 5.2 shows the difference in vegetation between the source island and the seven experimental founder islands.

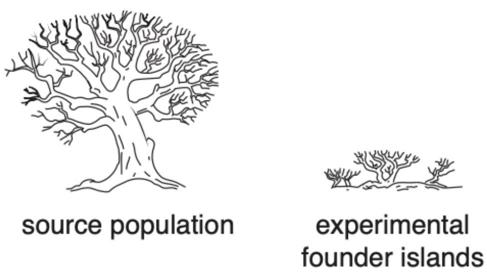

Fig. 5.2

Predict the effect of natural selection on mean hind limb length of A. sagrei on the seven experimental founder islands.

- (mean hind limb length) should decrease / legs get shorter

Predict how collecting individuals at random for the seven founding pairs affects the mean hind limb length of A. sagrei on the different islands.

- (mean hind limb length) will vary

Many generations of *A. sagrei* were produced over the four years after the introduction of the founding pairs.

Fig. 5.3 shows how the mean hind limb length of *A. sagrei* changed on the seven experimental islands and on the source island.

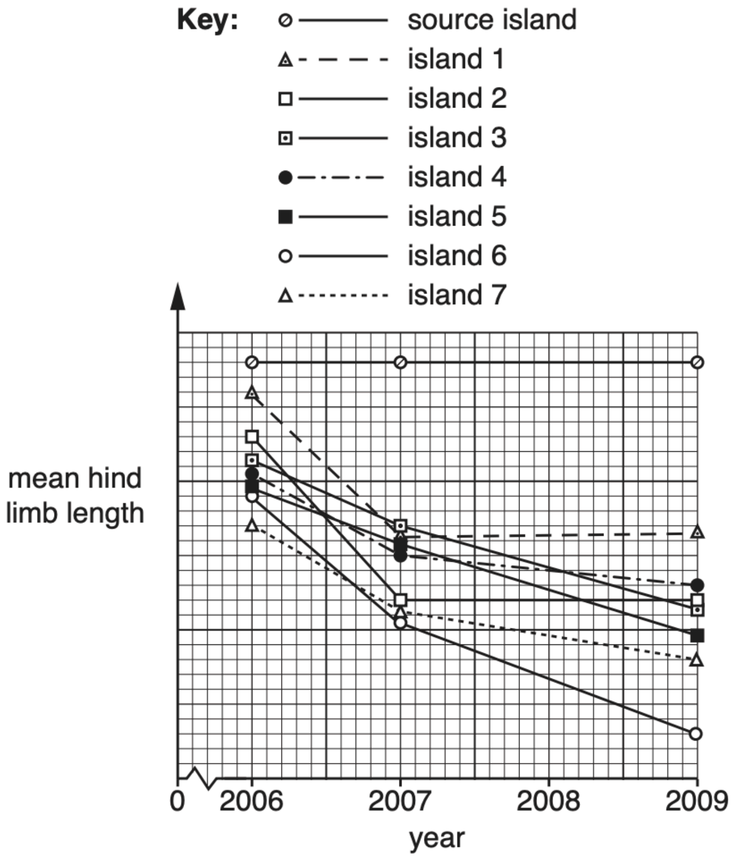

Fig. 5.3

With reference to Fig. 5.2 and Fig. 5.3, describe and suggest explanations for the results for the islands.

descriptions (D), suggestions (S), explanations (E):

- D1 on all / seven / the experimental / founder islands hind limb length decreased.
- S1 directional selection.
- D2 on source island hind limb length stayed the same.
- S2 stabilising selection.
  explanation in context of experimental islands:
- E1 selection pressure is (reduced / thinner) perch / branch (diameter).

- E2 short (hind) limbs are a selective advantage / selected for on experimental islands / founder islands / thin branches.
- E3 (short hind limbs) allow / increase stability / survival.
- E4 (survivors) reproduce / breed / pass on allele(s) (for short hind limbs).
- E5 allele(s) for short (hind) limbs increases in frequency.

In the investigation, one population of A. sagrei was established on each experimental founder island. Outline how speciation may occur on the seven experimental founder islands.

- allopatric
- populations / lizards / A. sagrei on different islands are geographically / geologically isolated / separated.
- have different selection pressures / environmental conditions.
- different mutations occur.
- genetic drift.
- no gene flow / reproductive isolation between lizards on different islands / populations / (new) species.
- genetic differences accumulate over time leading to speciation.

Speciation is one possible outcome for the experimental founder populations, but there is also a high risk that they may become extinct. Explain why the experimental founder populations are at high risk of extinction.

- each island has a small population
- with low genetic diversity / small gene pool.
- low heterozygosity / high homozygosity – inbreeding depression.
- environmental change / natural disaster may kill them all / make (whole / each) population extinct.

Artificial Selection

6. *describe the principles of selective breeding (artificial selection).*
7. *outline the following examples of selective breeding:*
    - *the introduction of disease resistance to varieties of wheat and rice.*
    - *inbreeding and hybridisation to produce vigorous, uniform varieties of maize.*
    - *improving the milk yield of dairy cattle.*

17.3 Evolution

1. *outline the theory of evolution as a process leading to the formation of new species from pre-existing species over time, as a result of changes to gene pools from generation to generation.*

2. *discuss how DNA sequence data can show evolutionary relationships between species.*
3. *explain how speciation may occur as a result of genetic isolation by:*
    - *geographical separation (allopatric speciation)*
    - *ecological and behavioural separation (sympatric speciation)*

State the general theory of evolution.

- organisms have changed over time.

Two subspecies of reindeer live in North America. Members of the different subspecies belong to the same species but have some morphological differences and are found in different geographical locations.
During the ice age, an ice sheet separated southern and northern populations of a species of reindeer. Explain how this ice sheet affected the evolution of that species to result in two different subspecies.

- geographical isolation / allopatric speciation.
- little / no interbreeding / gene flow between populations.
- different selection / selective pressures on each population.
- different mutations in each population.
- each population adapts to its environment / habitat / climate / food / vegetation over time.
- this gives morphological / ecological / behavioural differences, producing two distinct subspecies.

The genus *Heliconius* contains more than 40 species of brightly patterned butterflies.

Researchers have investigated in the laboratory how one species, *Heliconius heurippa*, could have developed as a separate species. The phenotype of *H. heurippa* is intermediate between that of two other species, *H. cydno* and *H. melpomene*.

Laboratory breeding experiments showed that:

- matings between *H. cydno* and *H. melpomene* (parent species) produce fertile hybrid offspring
- controlled matings of the hybrids produces individuals identical in appearance to *H. heurippa* within three generations
- hybrid butterflies prefer to mate with each other, rather than with individuals of either of the parent species.

The researchers concluded that the *H. heurippa* species could contain DNA from the two parent species as a result of hybridisation.

Suggest, with reasons, predictions that can be made about the chromosome numbers of H. cydno and H. melpomene.

- Chromosome numbers are the same.
  Reasons:

- Hybrids are fertile.
- Meiosis occurs in hybrid offspring.
- Two identical sets of chromosomes pair up / homologous chromosomes pair up / bivalents form during meiosis.

Because the hybrid butterflies preferred to mate with each other, this could make speciation more likely to occur. Give reasons why this made speciation more likely.

- Behavioural isolation occurs (hybrids prefer each other, not parent species)
- This leads to reproductive isolation between hybrids and parent species.
- No gene flow with parent species / populations.
- So hybrid gene pool maintained/ stays separate.
- Different mutations occur in hybrid population to parent populations.
- Natural selection acts differently on hybrids vs parents.
- Isolation occurs before fertilisation – pre-zygotic isolating mechanism.
- This separation leads to sympatric speciation (new species in same area).

Heliconius butterflies taste unpleasant to predators such as birds. The bright colours on the wings of the butterflies act as warnings so that birds avoid eating them.

Individual birds have to learn which patterns to avoid. If one *Heliconius* species is abundant, or if it has a pattern shared with another similar species, predators learn to avoid this pattern faster. Therefore this pattern provides a selective advantage.

In the wild, *Heliconius* hybrids occur in small numbers and have patterns that do not resemble the established warning pattern of either parent species. These hybrids have a selective disadvantage.

This is an example of a post-zygotic isolating mechanism.

Explain how selection against hybrids can act as a post-zygotic isolating mechanism.

- Hybrids are eaten / die / fail to reproduce.
- Hybrid gene pool not maintained.
- Parents better adapted, so survive and reproduce more.
- Leads to disruptive selection favouring the 2 parent species.

Mimulus is a plant genus containing a diverse range of species that have colourful flowers to attract pollinators, such as bees and hummingbirds. Pollinators transfer pollen between flowers for plant sexual reproduction.

Table 5.1 compares some features of two closely-related species of *Mimulus* that both grow in the same region of North America.

The features in which they differ are:

- the altitude at which the two species grow
- their flower characteristics, including petal colour and the distance from the opening of the flower to the nectar on which the pollinators feed
- the percentages of pollinator visits that they receive from bees or from hummingbirds.

Table 5.1

species of *Mimulus*	altitude / m	petal colour	distance to nectar / mm	percentage of visits from pollinator type	
				bee	hummingbird
M. lewisii	1600 – 3000	pink	14	100	0
M. cardinalis	0 – 2000	red	27	3	97

With reference to the data in the table, explain the isolating mechanisms that prevent gene flow between M. lewisii and M. cardinalis populations.

- Cannot exchange pollen / cross-pollinate / cross-breed / interbreed,
- Reproductively isolated,
- Because they live too far apart / not near enough / at different altitudes.
- Geographical barrier / separation / isolation,
- Because they have different pollinators.
- Leads to ccological isolation / different niches / adaptation / specialisation.
- Flower traits reinforce isolation:
    - Petal colour: bees prefer pink; hummingbirds prefer red.
    - Distance to nectar: 14 mm suited to bee tongue length; 27 mm suited to hummingbird beak.
- All are pre-zygotic isolating mechanisms (prevent pollination/fertilisation before it happens).

Breeding experiments in the laboratory show that M. lewisii and M. cardinalis can breed together and produce offspring. The F1 hybrid offspring are fertile. The F1 hybrids produce 50% fewer seeds than either of the two parent species. Explain how the reduced production of seeds by the inter-species (F1) hybrids can act as a post-zygotic isolating mechanism.

- F1 / hybrids have fewer F2 offspring / reduced (reproductive) fitness.
- Hybrid breakdown / hybrid line not sustained long-term.

- They become outcompeted by parent species / non-hybrids.
- Parent species / phenotypes are better adapted / more successful.
- Leads to disruptive selection favouring the 2 parent species.

Steelhead trout, *Oncorhynchus mykiss*, are fish that live in streams in North America.

To increase the number of steelhead trout, captive breeding has occurred since 1992. Fish eggs and sperm are mixed and the young fish grow in large tanks of aerated water for the first year of their lives. Most are then released into the wild, however a few male and female fish are kept to become the parents of the next generation of captive-bred fish.

Each tank may hold up to 50 000 fish. The young captive fish are fed processed food. Some young fish are unable to survive these conditions and a proportion die. Death is usually the result of poor wound-healing after accidents due to overcrowding and due to the spread of diseases.

Name the expected pattern of variation in wound-healing ability in a population of fish

- Continuous variation // normal distribution

Name the process that results in improved survival of captive fish in second, third and subsequent generations of captive-bred fish.

- evolution / natural selection / artificial selection / directional selection / adaptation / selective breeding

Suggest and explain ways in which the tank environment may make the phenotype of a captive fish different from a wild fish.

- controlled conditions so phenotype less varied.
- more oxygen so larger.
- less space / overcrowding so smaller.
- less space / overcrowding so (signs of) disease / wounds.
- food abundant / high quality so bigger / more muscle / more fat.
- no predators so increase in size.
- artificial lighting may change skin colour.
- different temperature affects growth rate / size.

Different types of organism have evolved different structures containing light receptors. Eyes are organs containing light receptors.

Fig. 6.1 describes the light receptors of several types of organism.

Euglena (a single-celled eukaryote) has a simple eyespot that can only detect the intensity and direction of light.

Turbellarian flatworms have cup-shaped eyes, each with a layer of light receptor cells. They can detect the intensity and direction of light better than *Euglena*. They also detect movement.

The mollusc *Nautilus* has eyes with deeper cups and narrower openings for light to enter. They can form a rough image, see shapes and detect the direction of light better than turbellarian flatworms.

The mollusc *Nucella* has eyes with lenses made of jelly. They can form a more detailed image than the eyes of *Nautilus* and can focus light to a small degree.

Mammals have eyes that are more complex than *Nucella*. They have a fixed lens (the cornea) that bends light and a lens that can change shape to focus on objects at different distances. The lenses focus light onto a deeply cup-shaped layer of light receptor cells. The eyes form a very detailed image.

Fig. 6.1

Using the information in Fig. 6.1, suggest how a complex eye such as that of mammals could have evolved in successive stages.

- Mutation occurs.
- Mutation results in a change in eye structure.
- Natural selection / selective advantage: better light detection.
- Light receptor cells develop.
- Light receptor layer becomes cup-shaped.
- Entry for light becomes narrower.
- Lens forms
- Fixed lens / cornea forms.

Octopuses are molluscs that have eyes very similar to those of mammals.

Octopuses and mammals are not closely related.

Octopuses and mammals have lenses that can change shape to focus on objects at different distances.

Suggest reasons why octopuses and mammals have evolved similar eye structures.

- They had similar selection pressures / light conditions.
- This eye structure allows organisms to escape predators.
- This eye structure allows organisms to find food.
- This is an example of convergent evolution: unrelated groups evolve similar adaptations due to similar ecological demands.

Molecular evidence is used to investigate evolution. One study involved a marine worm, *Platynereis dumerilii*, that still has characteristics similar to its ancestors from 600 million years ago.

Researchers sequenced all the proteins in light receptor cells of *P. dumerilii* and humans. The results showed that there are many similarities between the protein sequences of *P. dumerilii* and humans, particularly in the light-detecting protein opsin.

State what this molecular evidence indicates about the evolutionary origins of P. dumerilii and humans.

- shared origin / common ancestor / same ancestor

Explain how amino acid sequences indicate how close the relationship is between two species.

- compare amino acid sequences of two species.
- more similar amino acid sequence, more closely related the species are.
- more similar amino acid sequence, more recent common ancestor / less time has elapsed since a common ancestor.
- based on the molecular clock principle, amino acid differences accumulate at a roughly constant rate over time.

Regressive evolution is a change in a population over time that involves the **loss** of certain phenotypic characteristics. It is thought to be caused by either genetic drift or natural selection.

An example of regressive evolution is the loss of eyes in one form of the Mexican cavefish, *Astyanax mexicanus*. These eyeless cavefish live in caves that are in total darkness.

There are three theories to explain how the loss of eyes in the cavefish has occurred.

Theory A
There is no advantage to having eyes in a cave that is in total darkness, where energy sources are scarce. Having eyes is a disadvantage as there may be an energy cost.

Theory B
A mutation has occurred in a single gene. This mutation has two effects:

- a lack of eye development
- an increase in the number of chemoreceptors on the skin.

Theory C
Various mutations occurred in the genes responsible for eye development over a period of time. By chance, these mutations increased in frequency in small isolated populations. Eventually this produced a population of eyeless cavefish.

State one theory, A, B or C, which describes genetic drift as the cause of loss of eyes.

- Theory C

State and explain which theory or theories are based on natural selection as the cause of loss of eyes.

- Theories A and B.
- 2 (A) energy acts as a selection pressure / having eyes is a selective disadvantage ; ora
- 3 detail of mp2 ; e.g. less energy used means lower need for food
- 4 (B) selection for more chemoreceptors / more chemoreceptors is a selective advantage ;
- 5 detail of mp4 ; e.g. more chemoreceptors allows detection of more food
- 6 no eyes / more chemoreceptors, allows individuals to, survive / reproduce ; AW
- 7 pass on advantageous, mutation / alleles, to offspring / increase in allele frequency ; ora