LEVEL 2 BIOLOGY

GENETIC VARIATION AND CHANGE

NCEA Workbook Answers

Part One

The Foundations

1. Evolution and Gene Pools

a. Evolution is the large scale changes in the genetic make-up of populations over generations. It is due to gradual and cumulative changes in allele frequencies amongst the members of the population

b. A gene is a sequence of bases (in DNA) that codes for a particular trait (e.g. green eyes). An allele is an alternative form of a gene (e.g. blue eyes, green eyes, brown eyes).

c. A biological population is all the members of one species that live in a defined area.

d. A gene pool describes the frequency and nature of all the alleles available in an interbreeding population.

e. Allele frequency refers to the number of each allele within a population.

f. It is unlikely that the allele frequency would be the same in each town as they are both different populations.

2. Variation

a. Sexual reproduction involves one gamete (sex cell) from each of two individuals combining to form a new individual. The new individual is therefore not identical to either parent. Asexual reproduction involves one parent passing all of their DNA on to the next generation. The new individual is therefore identical to the parent.

b. Sexual reproduction increases genetic variation through two processes. Meiosis increases genetic variation as gametes are genetically unique due to crossing over, independent assortment and segregation. Sexual reproduction then also increases genetic variation as when an egg and sperm come together, new combinations of alleles in an individual are formed.

i. FALSE. A gamete is a sex cell and contains only half a set of chromosomes.

ii. FALSE. The offspring produced by asexual reproduction are identical to each other and the parent.

iii. TRUE.

iv. FALSE. Half a set of chromosomes is called haploid.

v. FALSE. A full set of chromosomes is called diploid.

vi. FALSE. Gametes are made by a process called meiosis.

c. Mitosis is a form of cell division where a cell divides to create two identical copies of itself. The purpose of mitosis is to help with the growth and repair of an organism. Meiosis is a form of cell division where a cell creates four daughter cells which are genetically unique cells. Each of the four cells is a gamete so only has half a set of chromosomes. The purpose of meiosis is to produce gametes.

d. The DNA in the cell replicates so there are two identical copies of every chromosome.

e. Two identical copies of a chromosome, created by DNA replication. The sister chromatids are stuck together by a cellular 'glue' until they separate during meiosis or mitosis.

f. Pairs of maternal and paternal chromosomes which carry the same genes at the same location.

g. Crossing over, independent assortment and segregation.

h. At the start of meiosis, the chromosomes line up along the centre (also referred to as the equator) of the cell. The two copies of the maternal chromosome line up side-by-side with the two copies of the paternal chromosome. The two copies of the maternal chromosome may swap some sections of DNA with the two copies of the paternal chromosome. This process is known as crossing over. After this, the homologous chromosomes are pulled to opposite poles of the cell.

i. Crossing over mixes the maternal and paternal alleles, so that the chromosomes end up with different combinations of alleles to what they had before. This means the sister chromatids are no longer identical because they now have different combinations of maternal and paternal alleles. New allele combinations in the gametes are not found in either parent, increasing the genetic diversity of gametes, which in turn increases the genetic diversity in a population.

j. When the chromosomes line up at the start of meiosis, they do so randomly. The way each pair of maternal and paternal chromosomes orient itself does not have an effect on how the next pair arranges. This means when the homologous chromosomes are pulled to opposite poles of the cell, all the chromosomes on the left go to the left and vice versa. This means it is down to chance how many paternal or maternal chromosomes go to which end. This creates a large number of possibilities regarding the inheritance of maternal and paternal DNA combinations.

k. The first cells splits down the middle, so non-identical cells are created.

l. Segregation occurs when the chromosomes line up in the middle of the non-identical daughter cells from the first cell division. The two sister chromatids from each chromosome are pulled to opposite ends of the cell, creating a second split, and resulting in four daughter cells. This means each of the four cells gets only one allele for each gene and the combination of alleles of different genes will be different in every cell.

m. No. Crossing over, independent assortment, and segregation result in different allele combinations and, does not change the genetic information itself.

3. Mutations

a. A mutation is a permanent change in the base sequencing of DNA.

b. Mutations can have positive, negative, or no effects on an organism. Often a mutation can result in the wrong protein being made from DNA. This new protein can often lead to disease and cause harm. However, this new protein may be beneficial and give the individual a survival advantage. Lastly, a neutral mutation may arise which does not affect the organisms likelihood of survival positively or negatively.

c. A somatic cell is a non-sex cell, i.e. a cell in your body. A mutation only affects cells in that area. A somatic cell is never used to pass DNA onto a baby, therefore somatic cell mutations cannot be passed on.

d. A gametic cell, also known as a sex cell, is referred to as the egg or the sperm. As gametic cells create offspring, a mutation in a gametic cell will be passed on. Additionally, since the offspring begins as a single cell, all of the cells in the offspring will have the same genetics and DNA and, therefore, the mutation will be present in every single somatic cell in the offspring as well.

e. Mutations are the only way to make new alleles. Mutations in a gametic cell can create a new allele if an individual with the mutation can reproduce. This adds variation to the gene pool because there are more alleles that could potentially be passed on.

4. Monohybrid Inheritance

a. The genotype is the combination of alleles that determines the expression of a particular characteristic or trait.

b. The phenotype is the set of observable characteristics of an individual resulting from the interaction of the genotype and the environment.

c. A dominant allele is an alternative version of the gene that will always be expressed when it is present in the genotype, as it masks the recessive allele.

d. A recessive allele is an alternative version of the gene that will only be expressed if both alleles are recessive, as there are no dominant alleles to mask the recessive alleles.

e.

i. Aa. An individual with two different alleles for a single trait.

ii. AA. An individual that has two dominant alleles for a single trait.

iii. aa. An individual that has two recessive alleles for a single trait.

f. A monohybrid cross is a theoretical genetic cross using a Punnett square, investigating a single trait with two alleles. The monohybrid cross gives us the probability of the offspring having a certain trait or characteristic, and whether the offspring will be heterozygous, homozygous dominant or homozygous recessive for that trait.

g.

i.

	B	B
B	BB	BB
b	Bb	Bb

ii. 2BB : 2Bb : 1BB : 0bb

iii. 4 Black fur

h. A form of inheritance in which an individual who is heterozygous for a trait will express the phenotypes associated with both alleles as the alleles are equally dominant.

i. A form of inheritance in which an individual who is heterozygous for a trait will express a combination of both dominant and recessive alleles as neither allele has the ability to mask the other allele, hence, a blended phenotype is expressed.

j.

i.

	R	R
W	RW	RW
W	RW	RW

ii. All of the offspring are heterozygous with the genotype RW. As the alleles responsible for the colour of cattle fur exhibits co-dominance, you would expect the cattle to have roan coloured fur, which is expressed as both red-brown and white spots.

k.

i.

	R	R
r	Rr	Rr
r	Rr	Rr

ii. All the offspring are heterozygous. As the alleles responsible for the colour of snapdragon flowers show incomplete dominance, you would expect the colour of the heterozygous flowers to be pink, as pink is a blend of both red and white.

l. Lethal alleles are alleles that cause an organism to die when present in homozygous conditions.

m. Complete dominance, incomplete dominance and recessive.

n.

i.

	M^L	m
M^L	M^LM^L	M^Lm
m	M^Lm	mm

ii. The offspring is expressing the homozygous dominant phenotype, which is lethal. Therefore, it is unlikely the offspring will survive past birth.

iii. 1 tailed cat : 2 Manx cats (tailless).

o. Multiple alleles are when there are three or more alternative versions of a gene. Only two of these alleles can be present in an organism.

5. Dihybrid Inheritance

a. Dihybrid inheritance is the simultaneous inheritance of alleles for two different genes. This is the likelihood that alleles on different genes are being inherited together.

b. You would use a dihybrid cross to predict the phenotypes of offspring when the inheritance of two genes are being studied.

c.

i.

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

ii. 9 tall, purple-flowered : 3 short, purple-flowered : 3 tall, white-flowered : 1 short, white-flowered.

d. Linked genes are genes that are inherited together with other genes as they are located close together on the same chromosome (and are therefore unlikely to be separated by crossing over).

e. In a dihybrid cross between two heterozygous organisms, we expect a 9:3:3:1 phenotypic ratio, however, when genes are linked and this dihybrid cross is carried out, we see a phenotypic ratio that is different from the expected one. This is because the genes that control the traits being examined are linked and are likely to be inherited together.

f. Linked genes decrease variation within a population, as the genes are likely to be inherited together.

g. Linked genes are found on the same chromosome and are close together. Therefore, the genes are less likely to be separated during meiosis. Hence, the linked genes are likely to be inherited together.

h. A test cross is a cross between an organism whose genotype for a particular trait is unknown and an organism that is homozygous recessive for the trait.

i. Someone might want to perform a test cross so they can determine whether an organism with the dominant phenotype is purebred for that characteristic. This is useful to breeders because it means the purebred organism has no hidden genetic characteristics that may be undesirable in offspring.

j. A test cross is carried out by mating the organism whose genotype is unknown, with an individual who is homozygous recessive for that trait. If the recessive phenotype appears in the offspring, then the organism whose genotype was unknown must be heterozygous. If the recessive phenotype does not appear in the offspring, then it is likely that the organism whose genotype was unknown is homozygous dominant. However, as each fertilisation is an independent event, a homozygous dominant organism cannot be conclusively decided through test crosses (but we can say it's pretty likely).

6. Factors that Cause Changes in a Genepool

a. Natural selection, genetic drift, migration, or mutations.

b. Genetic diversity describes the variety of alleles within a population. The more genetically diverse a population is, the greater the number of different alleles that are present, and the more differences a population has within it.

c. Genetic diversity is important as a population with low genetic diversity is less likely to survive a sudden change in the environment, while a population with high genetic diversity is much more likely to survive. This is because greater genetic diversity will increase the likelihood of there being an allele in the population which can cope with the new selection pressures.

d. Natural selection refers to the tendency of individuals with more environmentally favourable alleles to survive. This makes them more likely to pass their alleles on to the next generation, resulting in a greater frequency of these alleles in the gene pool.

e. Individuals with an advantageous allele are likely to survive to produce offspring, thereby passing on that advantageous allele to the next generation. Individuals with a less advantageous allele are less likely to survive to produce offspring, therefore their allele is less likely to get passed on. As a result, the more advantageous allele increases in frequency within the gene pool, while the less advantageous allele decreases in frequency.

f. Genetic drift refers to the natural fluctuations of allele frequency within a population due to chance.

g. Migration is the movement of individuals from one population to another. Emigration and immigration are types of migration. Emigration is leaving one's population to go to another, whereas immigration is entering a foreign population to live.

h. When individuals move into a new population, their alleles are added to the population's gene pool. The allele frequencies in the new population might be different, therefore, changing the allele frequency. Similarly, when individuals leave a population, they take their alleles with them, out of the previously occupied gene pool. If most of the individuals that leave have a particular allele, their migration results in a change in the allele frequencies of the population left behind.

i. The differences in gene pools between an original population, and a new population created by its former members. The founder effect results in a reduced genetic diversity occurring when a population is descended from a small number of colonising ancestors.

j. The most likely change to occur is the small population having a different gene pool to the larger population. This is because the smaller population is just a small sample of the original population and means that the ratio of alleles will be different.

k. A reduction in the size of a population due to environmental events which causes a change in the gene pool.

l. Due to population loss, there will be fewer alleles present, which can rapidly and randomly alter relative allele frequencies as each individual now makes up a greater percentage of the population.

7. Developing Skills

a. A deadly virus is an example of the bottleneck effect; a change in the gene pool after an event causes a large population loss, in this case, the deadly virus. This affects the gene pool as allele frequencies will change as there will be fewer alleles present. 5,000 people leaving New Zealand for an empty island is an example of founder effect; the differences in gene pools between an original population, and a new population created by its former members. The small population is likely to have a different gene pool to the larger population as it is just a small sample of the original population and means that the ratio of alleles will be different.

b. This is an example of bottleneck effect; a reduction in the size of a population due to environmental events which causes a change in the gene pool. Here, the northern elephant seals had a drastic reduction in population size due to being hunted and killed, this reduces the gene pool as allele frequency, the number of each allele within a population is reduced. Genetic diversity, the differences within a population, is reduced. Hence, the elephant seals will be less likely to survive another sudden change in the environment.

c. Incomplete dominance occurs when one allele is not completely dominant over the other. This results in heterozygous individuals exhibiting a blend of both phenotypes. Snapdragon flowers exhibit incomplete dominance as the red allele is incompletely dominant to the white allele, therefore, flowers that are heterozygous for both alleles will have a blended phenotype resulting in pink flowers.

Co-dominance occurs when both alleles are equally dominant and are fully expressed in the offspring. This results in heterozygous individuals exhibiting both phenotypes. Shorthorn cattle exhibit co-dominance as the red allele and white allele are equally dominant, therefore, heterozygous individuals will have a mixture of red and white hairs.

Section Two - Exam Skills & Mixed Practice

Question one:

Multiple alleles occur when there are three or more alternative versions of a gene. Multiple alleles are responsible for human blood groups as there are three different alleles which determine blood type. These multiple alleles exhibit both co-dominance and complete dominance. The alleles I^A and I^B exhibit co-dominance, and the allele i is completely recessive to both I^A and I^B.

Co-dominance is a form of inheritance in which an individual who is heterozygous for a trait will express the phenotypes associated with both alleles. This is seen in blood type, as the alleles I^A and I^B exhibit co-dominance, therefore, when both alleles are present the blood type is AB as both alleles are expressed.

Sophie's genotype is I^AI^A, therefore, she has A-type blood as she is homozygous for the allele I^A. The first potential father has the same genotype as Sophie, I^AI^A, therefore, he has A-type blood. The second potential father has the genotype I^Bi, therefore, he has B-type blood due to the I^B allele being completely dominant over the i allele. The third potential father has the genotype I^AI^B, therefore, he has AB-type blood as the alleles I^A and I^B are co-dominant, hence both alleles are expressed. One of Sophie's children has the genotype I^AI^B, therefore has AB-type blood which is the same as the third potential father. Sophie's other child has the genotype I^AI^A, therefore has A-type blood, the same as Sophie and the first potential father.

A Punnett square is used to make predictions about how possible offspring may inherit the alleles of their parents. The Punnett squares below show the possible offspring of Sophie, her children and their potential fathers.

Punnett Square 1:
Sophie (I^AI^A) X Potential Father 1 (I^AI^A)

	I^A	I^A
I^A	I^AI^A	I^AI^A
I^A	I^AI^A	I^AI^A

Punnett square 1 above shows that all the possible offspring of Sophie and the first potential father would all have the genotype I^AI^A.

Punnett Square 2:
Sophie (I^AI^A) X Potential Father 2 (I^Bi)

	I^A	I^A
I^B	I^AI^B	I^AI^B
i	I^Ai	I^Ai

Punnett square 2 above shows that all the possible offspring of Sophie and the second potential father would either have the genotype I^AI^B or I^Ai.

Punnett Square 3:
Sophie (I^AI^A) X Potential Father 3 (I^AI^B)

	I^A	I^A
I^A	I^AI^A	I^AI^A
I^B	I^AI^B	I^AI^B

Punnett square 3 above shows that all the possible offspring of Sophie and the third potential father would either have the genotype I^AI^A or I^AI^B.

Potential Father 1 cannot be the actual father. The possible offspring between himself and Sophie would all have the genotype I^AI^A, and while one of Sophie's children has this genotype, her other child has the genotype I^AI^B.

Potential Father 2 cannot be the actual father. The possible offspring between himself and Sophie would either have the genotype I^AI^B or I^Ai. While these genotypes would result in the actual phenotypes of Sophie's children, the genotypes do not match.

Potential Father 3 must be the actual father. The possible offspring between himself and Sophie would either have the genotypes I^AI^A or I^AI^B. These genotypes match the genotypes of Sophie's children, indicating that Father 3 is the actual father.

b. Meiosis is a form of cell division where a cell creates four daughter cells which are genetically unique from each other. Each of the four cells is a gamete therefore, it only has half a set of chromosomes.

Genetic variation is the variability amongst individuals in a population caused by genetic differences (genotypic variation) or by effects of the environment (phenotypic variation). Genetic variation increases genetic diversity.

Genetic diversity describes the differences within a population. Genetic diversity is important, as a population with low genetic diversity is less likely to survive a sudden change in the environment, while a population with high genetic diversity is much more likely to survive.

Independent assortment is a process that produces genetic variation during meiosis, resulting in two genetically unique daughter cells after the first cell division. Independent assortment is when the homologous chromosomes line up at the start of meiosis randomly. The way each pair of maternal and paternal chromosomes orient itself does not have an effect on how the next pair of chromosomes are arranged. This means when the homologous chromosomes are pulled to opposite poles of the cell, all the chromosomes on the left go to the left and vice versa. Therefore, it is down to chance how many maternal or paternal chromosomes go to which end. This creates a large number of possibilities, regarding the inheritance of maternal and paternal DNA. Therefore independent assortment ultimately results in genetically unique daughters cells.

Crossing over is another process that produces genetic variation during meiosis. This also happens at the start of meiosis when the chromosomes line up along the equator of the cell. The two copies of the maternal chromosome line up side-by-side with the two copies of the paternal chromosome. The two copies of the maternal chromosome can randomly swap some sections of DNA with the two copies of the paternal chromosome. This process is known as crossing over. After this, the homologous chromosomes (pairs of maternal and paternal chromosomes which carry the same genes at the same location) are pulled to opposite poles of the cell. Crossing over mixes the maternal and paternal alleles, so that the chromosomes end up with different combinations of alleles to what they had before. This means the sister chromatids (two identical copies of a chromosome, created by DNA replication) are no longer identical because they now have different combinations of maternal and paternal alleles. New allele combinations in the gametes are now found in either parent, increasing the genetic diversity of gametes, which in turn increases the genetic diversity in a population.

Segregation is another process that produces genetic variation during meiosis. During segregation, the non-identical daughter cells from the first cell division have their chromosomes lined up in the middle of the cell again. The two sister chromatids from each chromosome are pulled to opposite ends of the cell, creating a second split, and resulting in four daughter cells. This means each of the four daughter cells gets only one allele for each gene and the combination of alleles for each gene will be different in every cell.

These three processes result in gametes with chromosomes that have different combinations of alleles from each other. This results in genetic variation, which at a population level causes genetic diversity which increases the survival of a population. These three processes also mean that despite Sophie's children having the same parents their DNA is not identical, hence making them unique.

Question two:

Dihybrid inheritance is the simultaneous inheritance of alleles for two different genes. It is the likelihood that alleles on different genes are inherited together.
The F_1 generation would result from a cross between a rough, yellow petaled flower, ppYY, and a smooth, red petalled flower, PPyy. All of the offspring would have the genotype PpYy and would have smooth, yellow petalled flowers as their phenotypes.

Dihybrid cross between two F_1 generation flowers. PpYy X PpYy

	PY	Py	pY	py
PY	PPYY	PPYy	PpYY	PpYy
Py	PPYy	PPyy	PpYy	Ppyy
pY	PpYY	PpYy	ppYY	ppYy
py	PpYy	Ppyy	ppYy	ppyy

The genotypic ratio of the offspring is 1 PPYY : 2 PPYy : 2 PpYY : 4 PpYy : 1 PPyy : 2 Ppyy : 1 ppYY : 2 ppYy : 1 ppyy.

The phenotypic ratio of the offspring is 9 smooth, yellow petalled flowers : 3 smooth, red petalled flowers : 3 rough, yellow petalled flowers : 1 rough, red petalled flower.

The phenotype is the observable characteristics of an organism, while the genotype is the genetic makeup of the organism. A flower can have the same dominant phenotype but a different genotype to another flower due to the recessive traits that may be in the genotype being masked. For example, a flower with smooth, yellow petalled flowers may be homozygous (PPYY), or heterozygous for one characteristic (PPYy), or heterozygous for the other characteristic (PpYY), or heterozygous for both characteristics (PpYy). This shows how four different genotypes can lead to the same phenotype being expressed.

A purebred individual is one that is homozygous for both characteristics, for example, PPYY or ppyy. If flowers have both dominant phenotypes, it can be hard to determine their genotypes. This is because there is a variety of different allele combinations which would express the dominant traits. If the flower was heterozygous for one or both characteristics, then there is a chance that any offspring produced could show the recessive traits which may not be desired by a breeder.

A test cross is a cross between an organism whose genotype for particular traits is unknown and an organism that is homozygous recessive for the traits. A test cross can be used to determine whether an individual with the dominant phenotypes is purebred for the characteristics. This is useful for breeders as they are able to ensure that their organisms showing dominant traits are purebred and not masking any recessive genetic characteristics.

A test cross is carried out by cross-pollinating the flower whose genotype is unknown, with a flower that has rough, red petalled flowers (homozygous recessive for both traits). If the recessive phenotype is present in any offspring, then the genotype of the unknown flower must be heterozygous for one or both characteristics. If the recessive phenotype is not present in the offspring then the genotype of the unknown flower must be homozygous dominant. When carrying out a test cross, it is important to observe as many offspring as possible to ensure that the parent flowers are highly likely to be purebred.

Question Three:

The founder's effect is the difference in gene pools between an original population, and a new population created by its former members. The founder's effect could have influenced the Enderby Island rabbits' allele frequency and evolution. This is because the original rabbits were 12 English Silver Grey rabbits which came from an original population elsewhere, and then formed the population on the island. This would have changed the allele frequency (the number of each allele within a population) between the original population of rabbits and the new population of rabbits, as the 12 English Silver Grey rabbits are only a small sample of their original population.

Natural selection refers to the tendency of individuals with more environmentally favourable alleles to survive. This makes these individuals more likely to pass their alleles on to the next generation, resulting in a greater frequency of these alleles in the gene pool. Natural selection could have influenced the Enderby Island rabbits' evolution as the rabbits with the most favourable alleles suited to living on Enderby Island would have been more likely to survive. Therefore, they are more likely to reproduce and pass the more advantageous alleles on. This would affect the allele frequency as the more advantageous allele would increase in frequency within the gene pool, while the less advantageous allele would decrease in frequency.

Genetic drift is the changes in the allele frequencies of a population due to chance. Since 1865, it is likely that the Enderby Island rabbits' would have experienced random changes in allele frequencies, which would have changed the gene pool.

The bottleneck effect is a reduction in the size of a population due to environmental events which causes a change in the gene pool. It is likely that over 180 years the rabbits would have faced an environmental event such as disease, or famine. An event like this would have resulted in the death of rabbits and hence a reduction in the size of the population. This population loss would have resulted in fewer alleles present which could randomly alter allele frequencies.

Founder's effect, natural selection, genetic drift and bottleneck effect will all contribute to the allele frequency being different between the current Enderby rabbits and the original English Silver Grey rabbits. Evolution is the large-scale changes in the genetic make-up of populations over generations due to gradual and cumulative changes in allele frequencies amongst the members of the population. There will have been numerous generations of rabbit populations since 1865 and the changes in allele frequencies would have resulted in changes in the genetic makeup of the population. This is shown though Enderby rabbits being approximately half the size of English Silver Greys rabbits.

Practice Exam

Question One

a. Genotype of the F_1 generation: PpTt
Phenotype of the F_1 generation: Tall with purple flowers.

b.

	PT	Pt	pT	pt
PT	PPTT	PPTt	PpTT	PpTt
Pt	PPTt	PPtt	PpTt	Pptt
pT	PpTT	PpTt	ppTT	ppTt
pt	PpTt	Pptt	ppTt	pptt

c. 9 Tall pea plants with purple flowers : 3 Tall pea plants with white flowers : 3 Dwarf pea plants with purple flowers : 1 Dwarf pea plant with white flowers.

d. Linked genes are when two genes are located on the same chromosome and are close together. Therefore, unless the genes are split up by crossing over, which is unlikely, the two alleles for the genes will be inherited together.

Linked genes can alter the inheritance pattern, as the distance between the linked genes determines whether they are likely to be separated during crossing over. The further apart the linked genes are, the more likely they are to be separated, producing recombined chromosomes.

Independent assortment is when homologous pairs of chromosomes orient themselves along the centre of the cell, independently of the other pairs. This results in each new gamete created during meiosis having a unique combination of alleles. Crossing over is when sections of DNA are swapped between homologous pairs of chromosomes, allowing new combinations of alleles to form.

When genes are not linked, independent assortment assures that the genes are sorted independently of each other into gametes, and crossing over increases the genetic diversity of the gametes. Therefore, when genes are not linked, gametes can inherit any combination of alleles from their parent cell.

For linked genes, independent assortment does not lead to recombined alleles, as the two genes are on the same chromosome. This means the two genes must be inherited together as independent assortment does not apply. Crossing over is less likely to separate linked genes, as they are located close together of the same chromosome. Therefore, when genes are linked, it is highly likely the alleles will end up in the same gamete meaning they are inherited together.

When the genes are not linked, there is an increase in genetic variation in the offspring as unlinked genes can be assorted independently and are recombined due to crossing over. This is not possible for linked genes because they are inherited together and are not likely to be affected by crossing over, decreasing the genetic variation amongst offspring.

The 3:1 phenotypic ratio when the genes are linked shows how the genes are located on the same chromosomes. For one pea plant, the two dominant alleles are linked on the same chromosome and for the other pea plant, the two recessive alleles are linked on the same chromosome as well. This means that the offspring cannot inherit both a dominant allele for flower colour and a recessive allele for pea plant height, and they also cannot inherit both a recessive allele for flower colour and a dominant allele for pea plant height. Therefore, the phenotypes, tall pea plants with white flowers and dwarf pea plants with purple flowers cannot exist.

As the number of possible genotypes and phenotypes has decreased when the genes are linked as opposed to when they aren't linked, they are more likely to have the same genotypes and phenotypes as their siblings.

Question Two

a. A mutation is a change in the base sequence of DNA. Mutations can have positive and negative effects on an organism. Often a mutation can result in the wrong protein being made from DNA. This new protein can often lead to disease and cause harm. However, this new protein may be beneficial and give the individual a survival advantage.

b.

i. The mutation in the PON1 gene in marine mammals makes the gene inactive. This means that the protein which protects marine mammals from organophosphates is not made. This is disadvantageous as it results in marine mammals not being able to break down organophosphates. This increases the risk of marine mammals being harmed by the organophosphates in pesticides, therefore, decreasing their survival chances.

Natural selection refers to the tendency of individuals with more environmentally favourable alleles to survive. This makes them more likely to pass on their alleles to the next generation, resulting in a greater frequency of these alleles in the gene pool.

Marine mammals without the mutation would be more likely to survive and produce offspring, thereby passing on a functioning allele to the next generation. Individuals with the mutated allele are less likely to survive to produce offspring, meaning the mutated allele is less likely to get passed on. As a result, the more advantageous unmutated allele increases in frequency within the gene pool, while the less advantageous mutated allele decreases in frequency.

ii. Meiosis is a form of cell division where a cell creates four daughter cells which are genetically unique cells. Each of the four cells is a gamete so only has half a set of chromosomes. The purpose of meiosis is to produce gametes.

Independent assortment is a process that produces genetic variation during meiosis, resulting in two genetically unique daughter cells after the first cell division. Independent assortment is when the homologous chromosomes line up along the equator of the cell randomly at the beginning of meiosis. The way each pair of maternal and paternal chromosomes orient itself does not have an effect on how the next pair of chromosomes is arranged. This means each gamete resulting from meiosis is genetically unique.

Crossing over is another process that produces genetic variation during meiosis. This also happens at the start of meiosis when the chromosomes line up along the equator of the cell. The two copies of the maternal chromosomes line up side-by-side with the two copies of the paternal chromosome. The two copies of the maternal chromosome can randomly swap some sections of DNA with the two copies of the paternal chromosome. This process is known as crossing over. After this, the homologous chromosomes (pairs of maternal and paternal chromosomes which carry the same genes at the same location) are pulled to opposite poles of the cell. Crossing over mixes the maternal and paternal alleles, so that the chromosomes end up with different combinations of alleles to what they had before. This means the sister chromatids (two identical copies of a chromosome, created by DNA replication) are no longer identical because they now have different combinations of maternal and paternal alleles. New allele combinations in the gametes are now found in either parent, increasing the genetic diversity of the gametes, meaning that a marine mammal is able to produce offspring with different alleles and phenotypes, as each gamete is unique.

Segregation is the final process during meiosis which contributes to increased genetic variation. Segregation refers to the random alignment of sister chromatids at the equator of the cell during the second phase of meiosis. The arrangement of these sister chromatids are independent of each other and therefore creates more variation when the chromatids are separated into their respective gametic cells.

Crossing over, independent assortment, and segregation which occurs during meiosis, increases the genetic diversity within the gametes as new combinations of alleles are formed, therefore, a marine mammal can have offspring with different combinations of alleles and thus, different phenotypes.

Question Three

a. A gene pool describes the number and nature of all the alleles available in an interbreeding population.

b. Due to the significant reduction in the size of the population, it is likely that a population bottleneck occurred. A population bottleneck reduces both the population size and the amount of genetic diversity within a species. This is because a number of Chatham Islands black robins died, removing a variety of alleles present in the gene pool. Therefore, the small remaining population had low genetic diversity as its gene pool also reduced in size and variety.

Amongst the five remaining individuals, there was only one breeding pair, meaning that the entire population of Chatham Islands black robins are descendants of that one remaining breeding pair. As a result of this, the genetic diversity in the population is low.

c. As the population of the Chatham Islands black robins has increased substantially, you would expect their species to no longer be classified as endangered. However, due to the low genetic diversity of the population, it is less likely that the species will survive. For example, if there was a change in the environmental conditions, such as a new disease being introduced and affecting the black robins, it could potentially kill all of the black robins. This is due to low genetic diversity as they all descended from the same breeding pair. Therefore, it is very unlikely that there would be individuals with alternative alleles that may cause a resistance to the disease, decreasing the chance of the species surviving.

d. New mutations could be introduced into the gene pool, therefore, increasing the genetic diversity of the species, however, this is very unlikely. Mutations are a permanent change in the base sequence of DNA, and can bring about new alleles, and new phenotypes. Mutations are rare events and can either be beneficial, neutral (silent) or harmful. It is more likely that a mutation will have a silent or harmful effect on the individual, as opposed to a beneficial effect. Therefore, it is not likely that a beneficial mutation will occur and be introduced into the population, which would increase genetic diversity.

New alleles can also be introduced into a population by migration, specifically immigration. Generally, species have more than one population, and therefore, by moving from one population to another, the genetic diversity of the population that an individual immigrated to, increases. However, the Chatham Islands black robin species have originated from a single breeding pair, and there are no new alleles that can be introduced. Therefore, migration is also unlikely to increase the genetic diversity of the gene pool.

