SBI3U-C

Lesson

4

Speciation

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Introduction

The origin of species was a mystery until Darwin solved it. But many questions remained about how the process actually occurred. This lesson provides an overview of speciation, a usually gradual process in which one population separates from another and builds up enough genetic differences to become a new species. You will examine how these initial separations come about, and the importance of geography in creating new species. Finally, you will learn how human-caused changes in the environment are actually changing the way species evolve.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (hours)	
Species and Speciation	¼
Reproductive Isolating Mechanisms	1
Modes of Speciation	1
Types of Selection	½
Human Impact on Evolution: Polar Bears	½
Key Questions	1

What You Will Learn

After completing this lesson, you will be able to

- use appropriate terminology related to evolution
- evaluate the impact of environmental changes on natural selection and endangered species
- investigate evolutionary processes and analyze scientific evidence that supports the theory of evolution
- define the concept of speciation, and explain the process by which new species are formed

Species and Speciation

The giant panda is the rarest member of the bear family and among the world's most threatened animals. The giant panda has become a victim of environmental changes caused by humans that threaten its survival as a species.

Unfortunately, the giant panda is not alone. All of the earth's biodiversity is being threatened. In order to understand how we can preserve what's left, we must understand how this biodiversity evolved. Not only are we trying to protect the species already in existence, in some cases we also need to stop the evolution of new species. For example, the evolution of drug-resistant bacteria, herbicide-resistant superweeds, and new strains of the influenza (flu) virus are all urgent problems we have to face.

A species is defined as one or more populations of individuals that can interbreed under natural conditions and produce fertile offspring that are reproductively isolated from other such populations. For example, panda bears are called a species because they can only produce fertile offspring with other pandas under natural conditions. But defining a species is not always so easy in nature. The appearance of a new species—the greatest step in evolution—is usually a gradual process and, before a new species branches off from an existing one, there is a period where they are still capable of interbreeding.

Speciation happens when changes in allele frequencies occur that are significant enough to mark the formation of a new species, distinct from the parental species. This divergence in allele frequencies can happen because of selection, mutation or genetic drift. The process starts when there are barriers to reproduction that prevent interbreeding between two closely-related populations. As long as there is interbreeding, new species cannot form. But once a barrier is in place to prevent interbreeding, the process of speciation can begin. You will investigate the different ways speciation can occur later in this lesson.

Once the speciation process starts, there is strong evolutionary pressure for members of the new species to avoid mating with members of the old. Because of the way genetics works, the hybrid offspring produced from any mating between different species are often less successful—they may die earlier, or produce fewer (or no) offspring. Natural selection punishes those individuals that accidentally mate outside their own species because they will leave fewer successful offspring in the next generation. Producing unsuccessful offspring is a wasted effort, so there will be strong selection pressures on individuals to make sure they are only mating with members of their own species. As a result, reproductive barriers to prevent interbreeding are common in almost all species.

There are many types of reproductive barriers that prevent breeding between populations or species. Geographical barriers such as mountains, rivers or other bodies of water prevent interbreeding because the species are physically separated. For example, if two species of squirrels are separated by a large river they can't cross, they will not be able to interbreed. In addition to geographical barriers, biological barriers also exist. For example, if the genomes of two species are too different, they either cannot produce offspring, or the ones they produce will be sterile. So even if the two species of squirrel were on the same side of the river, they still might not interbreed successfully. You will examine some of these reproductive barriers in more detail in the next section.

Reproductive Isolating Mechanisms

A reproductive isolating can be anything that prevents successful reproduction from occurring. This is an important concept in the process of speciation because it allows one species to diverge into two separate species. There are two main types of reproductive isolating mechanisms: pre-zygotic and post-zygotic.

Pre-zygotic Isolating Mechanisms

A zygote is a fertilized egg. Pre-zygotic isolating mechanisms are barriers to reproduction that occur before a zygote can form, usually before mating. If two populations can't get together to mate, their genes will not mix and they will diverge genetically even more from each other over time. Pre-zygotic isolating mechanisms are favoured in evolution because they are more efficient: this way, resources are not wasted producing offspring that will not succeed.

There are several ways pre-zygotic isolation can occur through differences in space, time, behaviour or breeding mechanics.

Geographic Isolation

Geographic isolation occurs when populations first become isolated because of some physical barrier. It usually occurs very gradually, in stages. Once speciation has occurred, even if the barrier is removed, the two populations will no longer be able to interbreed.

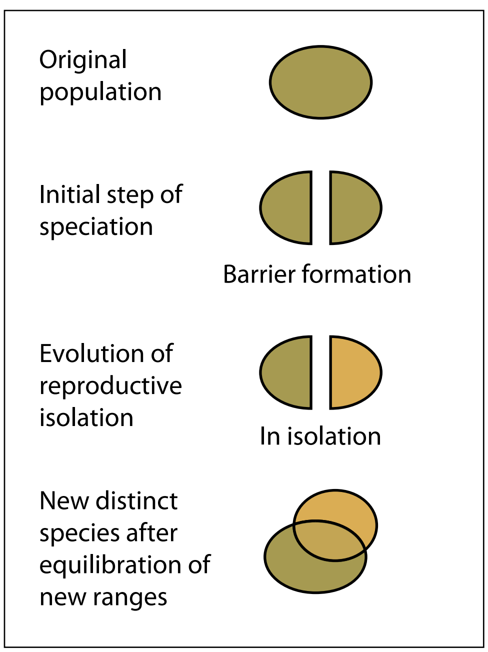


Figure 4.1: Diagram showing geographic isolation

Source: Wikipedia

Habitat Isolation

When two populations occupy different habitats or ecological niches, they are less likely to meet and attempt to reproduce. This type of isolation is commonly experienced by organisms that don't move, like plants. For example, the scarlet oak (*Quercus coccinea*) and the black oak (*Q. velutina*) are closely related tree species that evolved from a common ancestor. They occur in the same ecosystem but occupy different habitats within it. They rarely cross-pollinate because the scarlet oak prefers moist, low-lying areas and the black oak grows best in higher, drier areas. Their speciation could have happened because two populations of the ancestral species began to occupy slightly different habitats. Over time, each became adapted to its own environment, wet or dry. Because they were physically separated from each other, there was less chance that their gametes would meet. Eventually, enough genetic changes built up within each population that they became separate species.

Temporal Isolation

Two populations (or species) may share an ecosystem, but may reproduce at a different time of year. This also prevents interbreeding. Temporal isolation is commonly seen in varieties of angiosperms (plants that flower) that bloom at different times of the day. This prevents them from cross-pollinating with each other. An example in animals is seen in two species of termites (*Reticulitermes hageni* and *R. virginicus*) that have different mating seasons, one in the spring and one in fall. The two species of termites are reproductively isolated because they are not mating at the same time of the year.

Behavioural Isolation

Even if two populations or species of animals occur in the same place at the same time, they may still be isolated by behaviour. Many animals have characteristic behaviours that allow males and females to recognize each other and trigger mating. If there is enough difference in the behaviours between the populations or species, they will not mate. For example, male fireflies emit characteristic patterns of flashes to attract female partners. If the female does not recognize the pattern of flashes, she will not mate with that male. A similar story is seen in another insect, the cricket. Male crickets emit characteristic chirps to attract females. The pattern of chirps is unique to each species, which helps prevent mating between members of two different species. Behavioural isolation in courtship displays is common in animals. The songs of birds, courtship rituals in some species of elk, and the chemical signals given off by insects are all examples of behavioural barriers to reproduction.

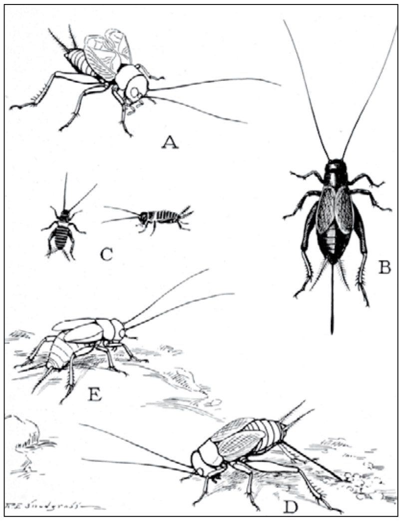


Figure 4.2: Image showing different species of crickets
Source: Wikipedia

Mechanical Isolation

When animal or plant reproductive structures are not compatible, mating cannot occur. For example, male dragonflies have claspers that are suitable for holding on to the female during mating. But if a male grabs a female of the wrong species he will be in the wrong position and sperm transfer cannot occur. This means that these dragonflies can only successfully mate with members of their own species. Many other insects have genitals that operate as a lock and key. This trait evolved to ensure reproductive isolation.

Gametic Isolation

Even if the gametes (sperm and egg) meet, they may not form a viable zygote. For example, in animals, the sperm of one species may not be able to survive in the reproductive tract of another species. As well, the egg may have chemical barriers that prevent the sperm of another species from entering it.

Post-zygotic Isolating Mechanisms

Sometimes, individuals mistakenly mate with a member of the wrong species and transfer gametes. However, there are still many mechanisms that prevent interbreeding from occurring. These are called post-zygotic isolating mechanisms because they happen at, or after, the point where a zygote is being formed. Post-zygotic isolating mechanisms prevent hybrid offspring from developing or being able to breed later on. Post-zygotic isolating mechanisms include ways to prevent the zygote from developing. Even if the zygote successfully forms and develops into an adult, there are still potential barriers to prevent interbreeding. The hybrid could be sterile, or the offspring of the hybrid (called the F_2 generation) could have a high mortality rate.

Zygote Mortality, Hybrid Sterility, and F_2 Fitness

Zygote mortality is a common isolating mechanism. For example, there are several species of frog in the genus *Rana* that sometimes interbreed; however, when they mate, the zygote fails to develop fully. In other cases, the hybrid offspring are sterile; for example, if a donkey and a horse interbreed, the offspring is called a mule, but it cannot reproduce. This ensures that the genetics of the two species do not permanently mix. Even if the hybrid offspring (F_2) are not sterile, they may be less fit than their purebred competitors. The reproductive isolating mechanisms are summarized in Table 4.1 below.

Isolating Mechanism	Example
Pre-zygotic	
Geographic	Populations become separated by a physical barrier.
Habitat	Species in the same ecosystem occupy different habitats.
Temporal	Species reproduce during different seasons or different times of the day.
Behavioural	Courtship behaviour differs, or species respond to different calls, pheromones, or other signals.
Mechanical	Reproductive structures are incompatible.
Gametic mortality	Sperm cannot reach the fertilized egg.
Post-zygotic	
Zygote mortality	Hybrid dies before maturity.
Hybrid sterility	Hybrid survives, but is sterile.
F_2 fitness	Hybrid is fertile, but offspring of hybrid (F_2) has lower fitness.

Table 4.1: Reproductive Isolating Mechanisms

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided.

21. The most common definition of species states that members of the same species can interbreed and produce fertile offspring in nature. A mule is a sterile offspring of a horse and a donkey. According to the above definition, do a horse and a donkey belong to the same species? Explain. Suggested answer

22. Why are pre-zygotic isolating mechanisms favoured by evolution over post-zygotic isolating mechanisms? Suggested answer

23. Where populations of two related species of frogs overlap geographically, their mating calls are different. Where the species don't overlap, their calls are identical. What type of isolating mechanism is in operation? Suggested answer

Examples of Speciation

Speciation occurs when enough genetic differences build up between two populations so that they can no longer interbreed successfully. The easiest way we can imagine this happening is if the two populations are physically separated from each other. For a long time, biologists wondered whether speciation could still happen if the two populations were in the same place at the same time. How could it occur?

Grasses

Stage I: Geographic Isolation

Imagine a grassland ecosystem containing several varieties of grasses. Animals overgraze a central portion until it becomes a desert. The desert gap prevents the grasses in one area from reproducing with grasses in the other area.

Stage II: Reproductive Isolation

Perhaps the grasses on one side are exposed to an oil spill. These grasses evolve a higher frequency of genes that are tolerant to the oil and other harsh chemicals. Now imagine that the desert barrier separating the populations disappears. This allows some interbreeding to start occurring, but the two populations have diverged enough genetically so that hybrid offspring are not successful. There is now strong selection pressure to evolve reproductive isolating mechanisms so that individuals don't waste their reproductive efforts producing hybrids. This creates a barrier to gene flow that is strong enough to keep the populations distinct, even though the physical barrier separating them has disappeared. Each grass is now its own species.

Darwin's Finches

Speciation occurs more rapidly in small populations than in large ones. The evolution of Darwin's Galapagos finches is a textbook example of this. Only a few finches from the mainland arrived at these islands many thousands of years ago, and the birds became geographically isolated on their separate islands. Because of founder effects and genetic drift, the birds on each island rapidly developed different genetic makeups. The birds also began to evolve in response to the different selection pressures on their particular islands. Some birds developed long slender beaks to catch insects hiding in the cracks of rocks, while others developed shorter stubby beaks to eat flower blossoms, seeds, and fruit.

Two distinct lineages of birds evolved. One lineage was more adapted to eating plant material in the trees, while the other was more adapted to eating insects on the ground. After many generations, their genetic differences became so great that even if they were brought together again, they would be unable to reproduce successfully.

Polyploidy in Plants

Some plants experience random mutations where their chromosome number doubles in the gametes. This is called polyploidy (having many copies of chromosomes). These mutated polyploid gametes are generally unable to fertilize with normal gametes. However, if by chance they meet another polyploid gamete, they can produce fertile offspring that has double or triple the chromosome number of the normal plants.

These polyploid individuals are instantly reproductively isolated from the rest of the members of their population. But if enough of them can be produced, they can create their own breeding population alongside the normal plants. This is the first step towards creating a new species, and it was accomplished using a genetic barrier rather than a physical barrier to separate the two populations.

Hybrids

Speciation can also happen through hybrids. If two species interbreed and create a sterile hybrid, the hybrid may still be able to reproduce asexually (for example, by sending up shoots or through cloning). If the hybrids produce enough copies of themselves, they may be able to create a small breeding population. They would be reproductively isolated from their parents but able to breed amongst themselves. Gradually, through mutation, genetic drift, and selection, the sterile hybrids may be transformed into fertile polyploids. In this way a new species could form.

Evidence that this has actually happened is found in wheat. Chromosome analysis of wheat shows that it was formed from the hybridization of two types of wild grasses followed by two mutations. Eventually they evolved into the modern wheat species that we use in breads and other baked goods.

In some cases of speciation in animals, certain animals begin to use resources (like food) that are not used by the parent population. The ones eating the same food tend to mate together, creating sub-groups in the population and eventual speciation. A famous example of this is found in Lake Victoria, in eastern Africa. It is home to a remarkable diversity of fish in the cichlid family. The hundreds of different species of cichlid were thought to have evolved from one ancestor in the lake. Initial divergence occurred when different sub-populations began specializing on different food sources in the lake. Eventually, the groups became reproductively isolated and speciation occurred. This pattern repeated itself several hundred times in the lake over hundreds of thousands of years, producing the incredible diversity of species seen today.

Figure 4.3: Six species in the cichlid family of fishes. Note the diversity of shapes in the body, head, mouth, and fins. (A. Amphilophus trimaculatus, B. Labidochromis caeruleus, C. Lamprologus meleagris, D. Benthochromis tricoti (male), E. Astronotus ocellatus, F. Symphysodon spp)

Source: Wikipedia

Support Questions

24. For each example below that was discussed in this lesson, state which isolation mechanism was used to create the species.

a) grasses

b) finches

c) polyploidy in plants

d) wheat

Suggested answer

Types of Selection

So far, you have examined how large-scale speciation events happen. Genetic differences between populations build up to the point where they become different species. But exactly how does this genetic divergence come about? In this section, you will examine how natural selection creates either a divergence or a convergence of traits, leading to a change in the population and, perhaps eventually, speciation.

In natural populations, traits are usually distributed in a normal bell-shaped curve. Most individuals are close to the average for the trait (in the peak of the curve) while a few are either very low or very high for that trait (in the lower and upper tails of the curve). For example, in humans, the distribution of adult heights in any population follows a bell-shaped curve (Figure 4.4). You can see that most people are of average height, but a few are shorter or taller than average. Only a very few are extremely short or extremely tall. Height, like most traits, shows some variation, and it is this variation that natural selection can act upon.

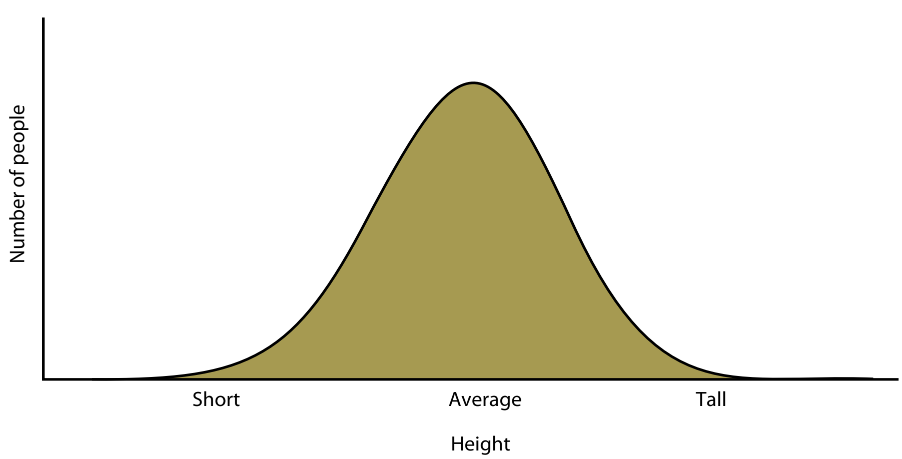


Figure 4.4: Graph showing the distribution of height in the human adult population

Selection changes the shape of the bell curve for traits over time. There are three kinds of selection: stabilizing, disruptive and directional (Figure 4.5).

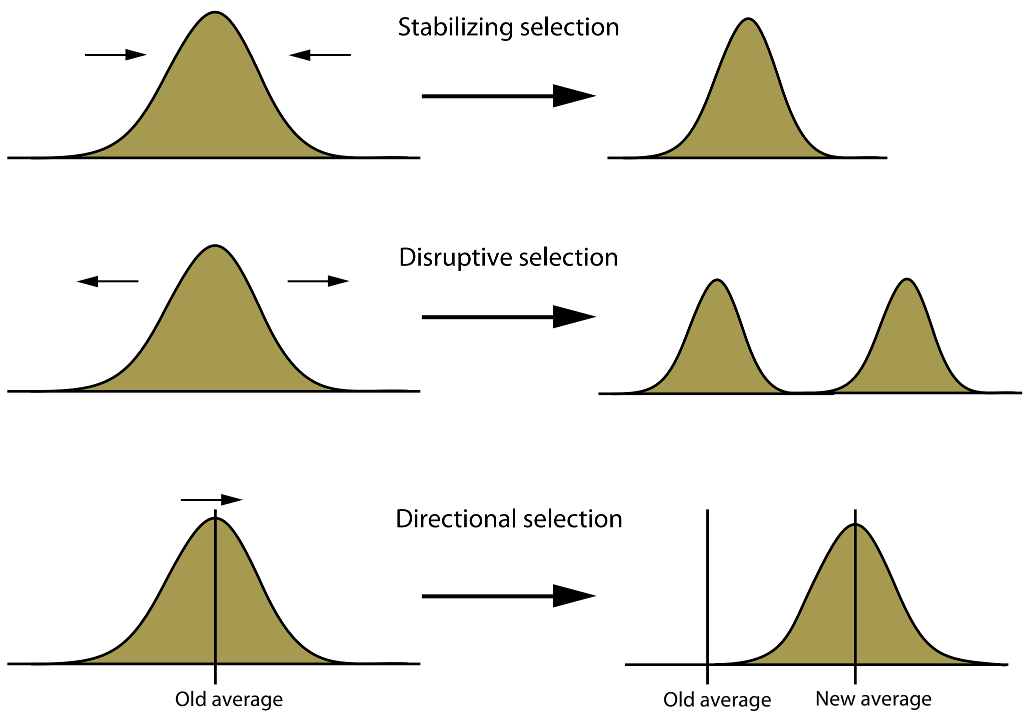


Figure 4.5: Diagrams showing how three types of selection result in different distributions for a trait

Stabilizing Selection

When selection favours the middle values of a trait and is against the two extreme values, the population experiences stabilizing selection. For example, height in most plants experiences stabilizing selection. A plant that is too short may not be able to compete with other plants for sunlight. It gets over-shadowed by its taller neighbours. However, extremely tall plants may be damaged more by wind. Combined, these two selection pressures act to lower the fitness of short or tall plants and reward plants of medium height. The number of plants of medium height will increase, while the numbers of short and tall plants will decrease. This results in a narrowing of the bell-shaped curve (Figure 4.6).

There are many examples of stabilizing selection in nature. Stabilizing selection appears to be acting on the birth weight of human babies to keep them at an intermediate weight. Birth records show that babies that are too heavy or too light have a lesser chance of being born healthy.

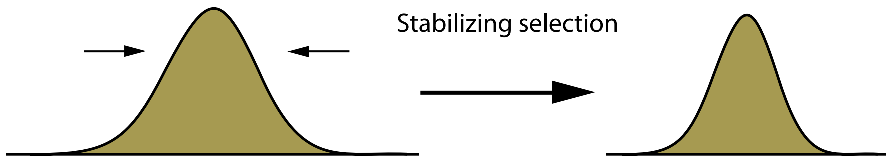


Figure 4.6: Diagram showing stabilizing selection, the type of selection working on plant height and human birth weight

Disruptive Selection

In disruptive selection, selection pressures act against individuals that possess the average trait. The result is a bimodal, or two-peaked, curve in which the two extremes of the curve create their own smaller curves (Figure 4.7). For example, imagine a species of plant whose population shows a variation in height. It is also pollinated by three different species of bees. One species of bee was attracted only to the shorter plants, another preferred plants of medium height and the third visited only the tallest plants. If the bee species that preferred plants of medium height disappeared, then the medium-height plants would not be able to reproduce. The population would tend toward both short and tall, but not medium-height plants, creating a divergence in the population and a reproductive isolating mechanism (since short plants can't exchange pollen with tall plants). Eventually, the two populations could diverge enough on other traits to lead to speciation.

This type of selection probably happened with Darwin's finches. For example, on the Galapagos Islands, plants produce either large or small seeds. A population of birds that starts out with a medium-sized beak would not be as efficient at gathering seeds. Those birds with slightly smaller beaks would do better eating smaller seeds, and birds with larger than average beaks would do better eating larger seeds. But birds with the medium-sized beak would not be very efficient at gathering either type of seed. Over many generations, two beak sizes are selected for in the population, small and large, and the birds with medium-sized beaks die out.

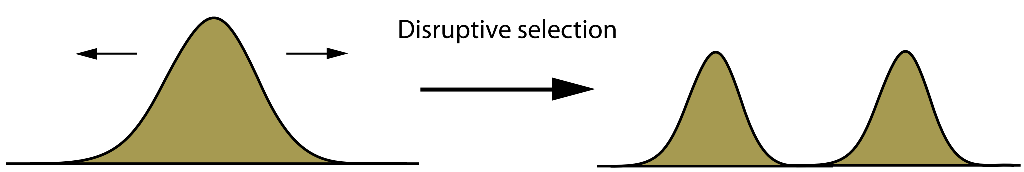


Figure 4.7: Diagram showing disruptive selection, the type of selection working on Darwin's Finches

Directional Selection

In directional selection, individuals that are either above or below the average do better, depending on where natural selection was pushing them. The result is that, over time, the population's trait distribution shifts toward the favoured type. The mean of the population graph shifts to the left or the right (Figure 4.8). Using the example of giraffe necks, there was directional selection for neck length. Short necks were selected against since individuals with short necks could not reach as many leaves on which to feed. As a result, the distribution of neck length shifted to favour individuals with long necks. This led to a higher percentage of giraffes having long necks, which eventually dominated the gene pool. Today, only long-necked giraffes are present.

The evolution of the horse also demonstrates directional selection. Early horses were very small and slow runners who were adapted to living in a forest environment. The modern horse is large and fast and adapted to life on grasslands. As their environment changed and the forests were replaced by grasslands, larger individuals did better because they had the strength and speed to outrun predators faster. With each generation, the average size of the horses in the population increased.

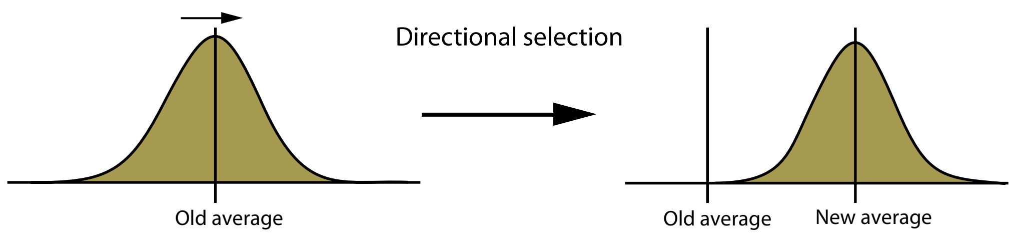


Figure 4.8: Diagram showing directional selection, the type of selection working on giraffe neck length

Support Questions

25. Identify and explain the type of natural selection that accounts for the evolution of the giraffe's long neck.

Suggested answer

Human Impact on Evolution: Polar Bears

The polar bear (*Ursus maritimus*) is considered at risk of becoming endangered because of global warming. Polar bears are related to grizzly bears (*Ursus arctos horribilis*) and live in the high Arctic; they eat seals and small whales that they catch while hunting out on the frozen Arctic Ocean during the long winter months. It is estimated that there are between 22 000 and 40 000 polar bears in the world. Close to half of the polar bear population lives in Canada.

Polar bears are one of the world's largest carnivores; adult males can weigh over 700 kilograms and be three metres long. Polar bears are well adapted to their Arctic environment. They have strong neck muscles and sharp teeth to tear meat from their prey (Figure 4.9). Their dense fur coat keeps them warm and helps them stay afloat as they swim between patches of ice. Large feet covered in thick fur and short, sharp claws provide good traction on the ice.

Figure 4.9: Photograph of a polar bear, whose long muzzle and neck help it to search in deep holes for seals, while powerful hindquarters enable it to drag massive prey like large seals, walrus, and beluga whales out of the water.

Source: Wikipedia

Polar bears need to eat seals to live, and they can only hunt seals while out on the ice. If the ice melts, the bears cannot hunt seals, and they will starve. Fortunately for the bears, the Arctic ice pack has remained stable for thousands of years. But that is rapidly changing.

Impact of Global Climate Change

The earth's climate is changing rapidly now, in large part because humans have been burning fossil fuels for hundreds of years and releasing carbon dioxide and other greenhouse gases into the atmosphere. These gases trap heat against the earth's surface, causing a gradual warming. As the earth slowly warms up, the effects are felt most dramatically in the polar regions. Even though the average global temperature increase so far is only about 1°C, the heating in the polar regions has been more dramatic. This is causing the Arctic Sea ice to form later every fall and melt earlier every spring. As the amount of ice shrinks and the ice-free periods get longer every year, the polar bears are forced onto the shore earlier, where they slowly starve until the ice forms again.

The effect on polar bears in the southern Arctic around Hudson's Bay in Canada has been especially dramatic. Bears are dying younger and producing fewer offspring as their sea ice gradually disappears. The warming weather has also brought grizzly bears into polar bear territory in Canada, since the Arctic becomes a more favourable habitat for grizzly bears as it warms up.

Hybridization

Grizzly bears are close relatives of the polar bear (Figure 4.10); in fact, they are so closely related that the two species can produce fertile offspring (but we still consider them separate species for other reasons). Genetic evidence indicates that the two species separated about 150 000 years ago, and were kept separated by isolation in different habitats.

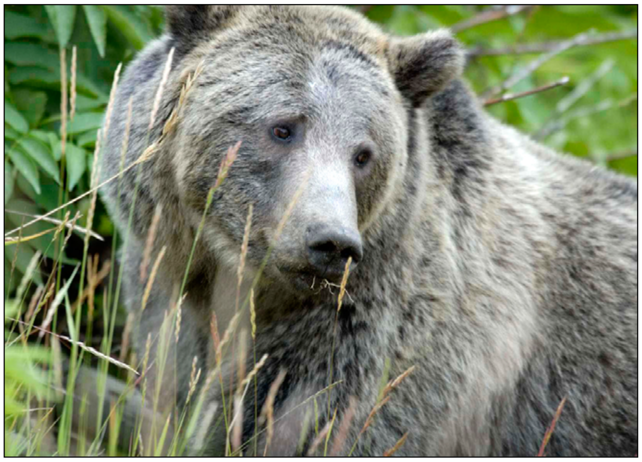


Figure 4.10: Photograph of a female grizzly bear (*Ursus arctos horribilis*)
Source: Wikipedia

The polar bear lives mostly on the ice, feeding on seals, while the grizzly bear lives on the land, feeding on vegetation and prey. For thousands of years, these two species have maintained reproductive isolation because of geographic and behavioural mechanisms. Today, however, climate change is altering bear habitats and movement patterns throughout the Arctic; it is taking grizzly bears farther north into habitats where they never were before, bringing them into direct contact with polar bears.

One concern is that the more aggressive grizzly bear will out-compete or attack the polar bears. Another concern is that grizzly bears and polar bears are now interbreeding and forming hybrids (Figure 4.11); this could lead to less fit individuals that are not well adapted to life on the land or on the ice. Thus, human-caused climate change could be leading to new directions in evolution for the polar bear.

Figure 4.11: Photograph comparing the polar/grizzly bear hybrid and a purebred grizzly bear
Source: Wikipedia

Support Questions

26. Describe the threats to polar bear survival and reproduction that are caused by climate change. Suggested answer

27. Explain how the grizzly bear moving into polar bear territory may cause a change in the evolution of the polar bear. Suggested answer

Key Questions

Now work on your Key Questions in the online submission tool. You may continue to work at this task over several sessions, but be sure to save your work each time. When you have answered all the unit's Key Questions, submit your work to the ILC.

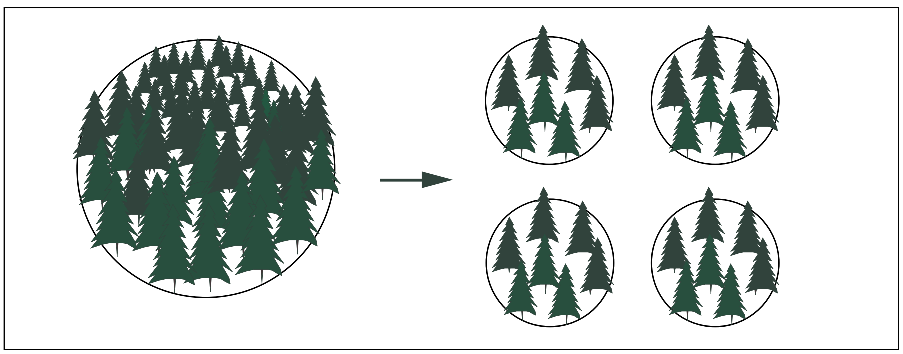
(18 marks)

12. Name the reproductive isolating mechanism operating in each situation below. **(5 marks: 1 mark for each)**

- **a)** One species of frog mates in April, but another mates in May.
- **b)** Two fruit flies of different species produce sterile offspring.
- **c)** The sperm of a marine worm penetrates eggs of the same species only.
- **d)** One species of flower grows in forested areas, another in meadows.
- **e)** Two species of pheasant perform different courtship dances.

13. Describe the steps necessary for geographic isolation to lead to speciation. **(4 marks)**

14. As a result of human activity (such as logging), large forests are becoming fragmented into several smaller forests.



- **a)** How might the increasing isolation of populations in these forests influence their evolution? **(3 marks)**
- **b)** How might the fragmentation affect the evolution of a large mammal, like a moose, compared to a small invertebrate, like a worm? **(2 marks)**

15. Identify and explain the type of natural selection that accounts for the evolution of the hollow bones of birds, which make flight possible. **(4 marks)**

This is the last lesson in Unit 1. When you have completed all the Key Questions, submit your work to the ILC. A teacher will mark it and you will receive your results online.