Name: ____________________________

Bodensee Nature Museum Evolution Worksheets: Selection and Adaptation

Helpful Definitions:

Evolution: descent with modification from a common ancestor.

Gene: a locus (or region) of DNA that encodes a functional RNA or protein product, and is the molecular unit of heredity.

Allele: one of a number of alternate forms of the same gene or same genetic locus.

Selection: any natural or artificial process that results in differential reproduction among members of a population so that the heritable traits of only certain individuals are passed on, or are passed on in a greater proportion, to subsequent generations.

Natural Selection: the process by which organisms that are better suited to their environment than other members of their species produce more offspring. As a result of natural selection, the proportion of organisms in a species with characteristics that are adapted to a given environment increases with each generation. Therefore, natural selection modifies the originally random variation of genetic traits in a species so that alleles that are beneficial for survival predominate, while alleles that are not beneficial decrease. Originally proposed by Charles Darwin, natural selection forms the basis of the process of evolution.

Sexual Selection: selection arising through preference by one sex for certain characteristics in individuals of the other sex. Sexual selection can be *intrasexual*, between individuals of the same sex (ex. elephant seals fighting), that is male–male competition, or *intersexual*, where one gender chooses mates (ex. peacocks). Traits that are favorable under sexual selection may be unfavorable under natural selection.

Sexual Dimorphism: the condition where the two sexes of the same species exhibit different characteristics beyond the differences in their sexual organs. Sexual dimorphism often occurs in organisms with sexes that have different ecological and/or reproductive roles.

Artificial Selection: the process by which humans use selective breeding to develop particular traits (characteristics) in animals and plants by choosing which males and females will sexually reproduce.

Kin Selection: because relatives share some proportion of the same genetic material, they will help individuals that are closely related even when there is a cost to their own survival. Helping relatives increases your own 'inclusive fitness'. An organism's inclusive fitness includes its own offspring ('fitness') plus the genes reproduced in other closely related offspring.

Adaptation: any alteration to the behavior, physiology, or structure of an organism or any of its parts that results from natural selection and by which the organism becomes better fitted to survive and multiply in its environment.

Species: a group of closely related organisms that are very similar to each other and are usually capable of interbreeding and producing fertile offspring.

Population: a summation of all the organisms of the same group or species, which live in a particular geographical area, and have the capability of interbreeding.

Common Ancestor: the most recent individual from which all organisms in a group are directly descended.

Niche: the role and position a species has in its environment including how it meets its needs for food and shelter, how it survives, and how it reproduces. This includes all of its interactions with the biotic and abiotic factors of its environment.

Matching. *On the line provided, write the letter of the definition that best matches each term on the left.*

______d.__________ **1.** allele

______i.__________ **2.** gene

______f.__________ **3.** evolution

______a.__________ **4.** natural selection

______b.__________ **5.** vestigial organ

______e.__________ **6.** adaptation

______h.__________ **7.** sexual selection

______c.__________ **8.** population

______j.__________ **9.** species

______g.________**10.** common ancestor

______k.__________**11.** fitness

a. the process by which organisms that are better suited to their environment than other members of their species produce more offspring

b. organ with little or no function

c. a summation of all the organisms of the same group or species, which live in a particular geographical area, and have the capability of interbreeding

d. one of the possible forms of a gene

e. any alteration to the behavior, physiology, or structure of an organism or any of its parts that results from natural selection and by which the organism becomes better fitted to survive and multiply in its environment

f. descent with modification

g. an organism which is the shared ancestor of two or more different descendant groups of organisms

h. selection arising through preference by one sex for certain characteristics in individuals of the other sex

i. basic unit of heredity

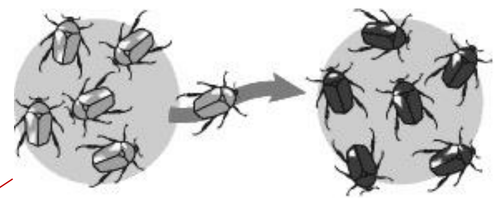
j. a group of closely related organisms that are very similar to each other and are usually capable of interbreeding and producing fertile offspring

k. the average contribution to the gene pool of the next generation that is made by an average individual of the specified genotype or phenotype

Matching. *There are 4 processes that can lead to evolution. Match each with their correct diagram.*

1. Natural Selection: the process where organisms with favorable traits are more likely to reproduce.

2. Mutation: a permanent, heritable change in the nucleotide sequence in a gene or a chromosome. Such a change may result in the creation of a new character or trait.



3. Migration: the movement of populations, groups or individuals. In genetic terms, migration enables gene flow: the movement of genes from one population into another.

4. Genetic Drift: the process of change in the genetic composition of a population due to chance or random events rather than by natural selection, resulting in changes in allele frequencies over time.

* Image Credit: The University of California Museum of Paleontology's Understanding Evolution (http://evolution.berkeley.edu)

Natural Selection

Bodensee Example: Three-spine Stickleback (*Gasterosteus aculeatus*). Three-spine Sticklebacks are small fish that inhabit lakes, rivers, and oceans in the northern hemisphere. They were introduced to the Lake Constance region around 150 years ago. These fish provide a rare example of natural selection and evolution over short timescales. The sticklebacks that live in freshwater lakes, like Lake Constance, are very different from the sticklebacks living in rivers, like the Rhine. One of the starkest differences is in the number of armored plates along the side of the fish, which serve as a protective covering. Due to their recent introduction to this region, it is likely that sticklebacks have rapidly evolved different numbers of armor plates along their sides. Sticklebacks living in rivers like the Rhine have very few armor plates. This allows them to swim faster and rapidly escape from large insect predators (like dragonflies) that are not very mobile but can eat the sticklebacks. The sticklebacks that live in the center of the lake often have extensive numbers of plates that protect them from predatory fishes that might eat them. However, these plates have the disadvantage of slowing the sticklebacks down, which makes it difficult for them to escape from stationary predators in the rivers. But, these heavy plates help to defend against fast swimming predators in open water that the sticklebacks could never outswim, whether they had plates or not. Because these changes in plate number happen so rapidly, it is likely that the river environments are selecting for low-armored gene variants that are already present at a low frequency (~1%) in both ocean and lake populations of sticklebacks. A single gene, Ectodysplasin receptor (*Edar*), has been found to be responsible for changes in plate number in most stickleback populations. Individuals with two high plate Edar alleles have the most plates and the ones with two low plate alleles have the least. The heterozygous individuals, one low and one high plate allele, have an intermediate number of plates.

Adult marine (top) and freshwater (bottom) threespine sticklebacks. The freshwater fish rapidly lost its armor after moving from the ocean. Photo: Nicholas Ellis and Craig Miller, UC Berkeley

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a) In Lake Konstanz, what stickleback (low armor or high armor) is natural selection selecting AGAINST? ______low____________ FOR? ______high___________

b) In the Rhine River, what stickleback (low armor or high armor) is natural selection selecting AGAINST? _____high_____________ FOR? _____low____________

Darwin's Theory of Natural Selection has 5 key points. Identify the 5 key points using the freshwater sticklebacks as an example.

1) There is heritable variation in traits within a population. What is the heritable difference between sticklebacks?

_____armor plate number____

2) In a population, more offspring are produced each generation than can survive. If two parents have intermediate numbers of plates and produce offspring that have low, intermediate, and high plate number in the Rhine, which offspring will most likely survive.

_____offspring with fewer plates____

3) Some individuals have adaptive charecteristics that enable them to survive and reproduce better than other individuals. Which individuals should survive in the middle of the lake? Are they more likely to have high, low, or a mixture of Edar alleles.

____high armor individuals, high number of Edar alleles______________________

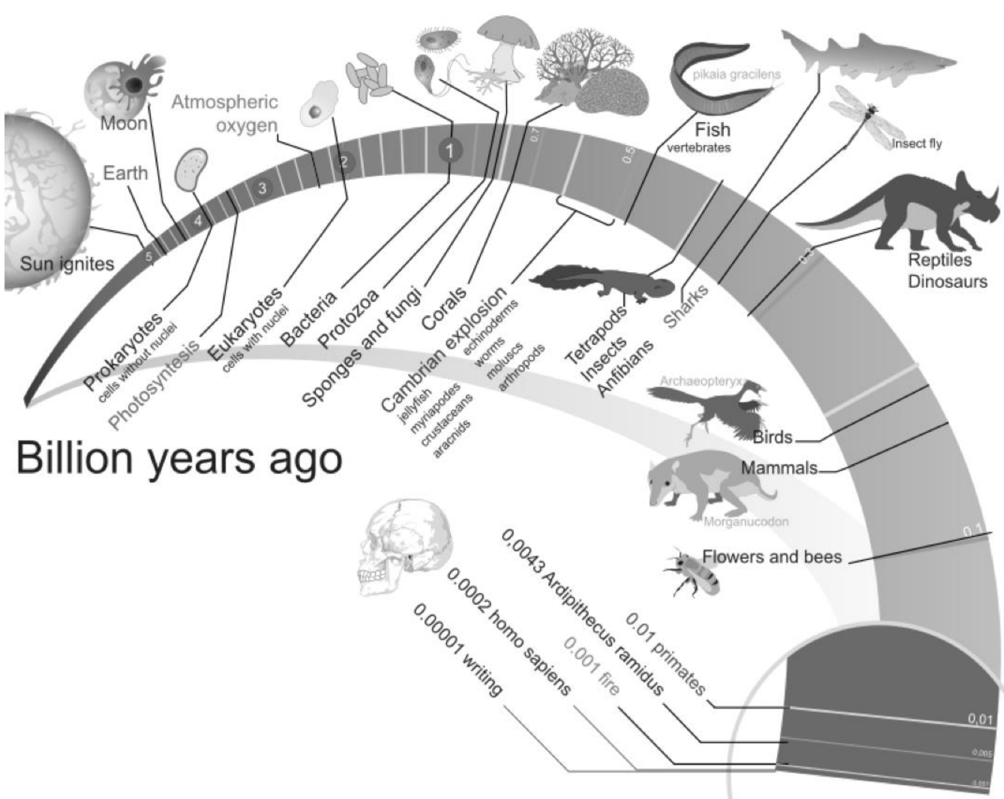
4) An increasing proportion of individuals in succeeding generations have adaptive characteristics due to the genetic inheritance of traits. Which stickleback variant is the most common in the Rhine? The Bodensee?

___Rhine: low armor variant, Bodensee: high armor variant___________________

5) A population will change over time. What will happen to the Edar alleles if there was a dam put on the Rhine?

Because the dam would cause the part of the Rhine behind it to become more like a lake, over time there would be a higher percentage of high armor alleles.

The Threespine stickleback example is unique as these changes have occurred over very short timescales (~150 years). Recent studies have suggested that for evolutionary changes to accumulate and persist, it takes about one million years. With evolution generally being such a slow process, what evidence do we have of evolutionary change?
Fossils



Example: This famous *Archaeopteryx* fossil was found not far from here, in Eichstätt, Germany. This incredibly important discovery led to the consensus that birds and dinosaurs were closely related. This ancient bird has long been extinct, but all of the birds we see today evolved from the group that includes this prehistoric species. You can see this particular specimen on display at the Museum für Naturkunde in Berlin.

By H. Raab (User: Vesta) - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=8066320

Check around the museum for other fossils found in this region. Don’t miss the giant salamander *Andrias scheuchzeri* or the skeleton of *Hippotherium primigenium*.

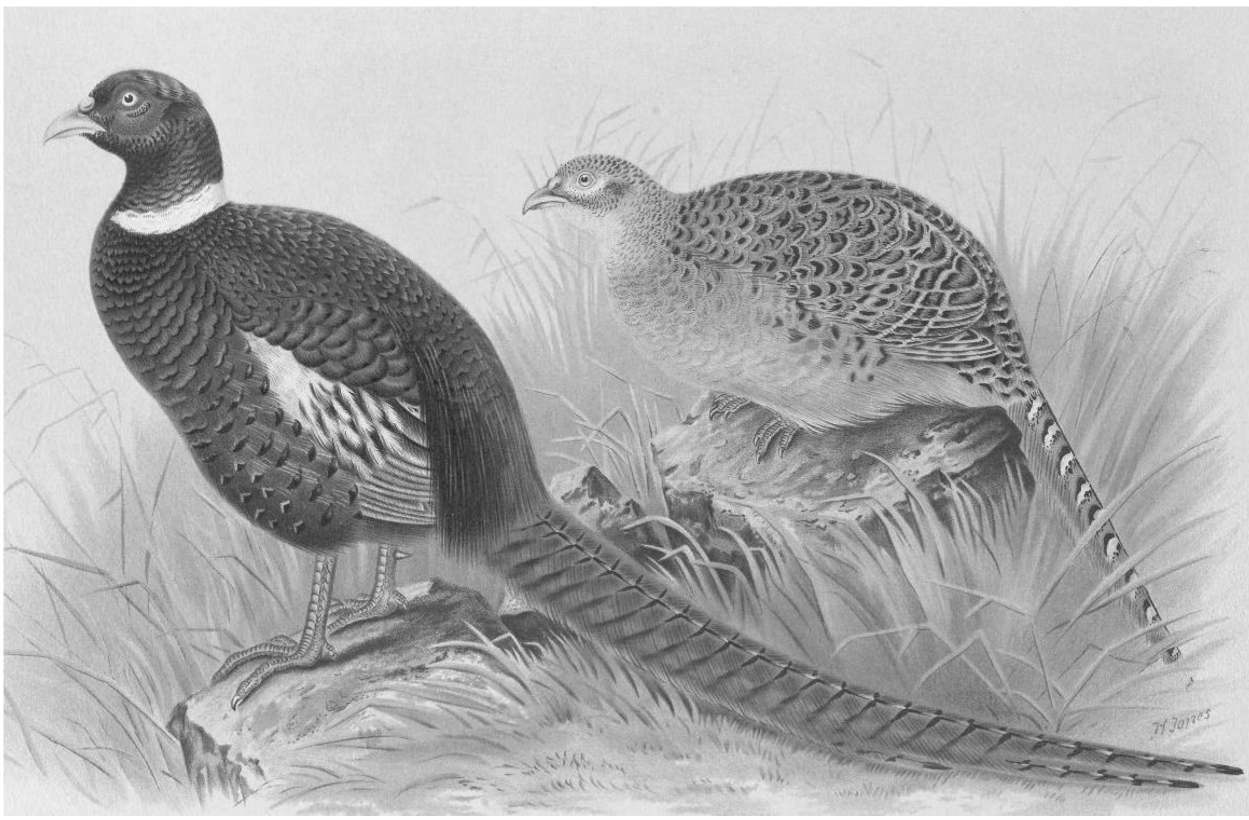
Sexual Selection

Sexual selection is a special case of natural selection that arises through preference by one sex for certain characteristics in individuals of the other sex. Sexual selection acts on an organism's ability to obtain a mate, and often produces extreme features that may be harmful to an organism's long-term survival. Therefore, traits that are favorable under sexual selection may be unfavorable under natural selection. Sexual selection can be *intrasexual*, between individuals of the same sex (ex. elephant seals fighting), or *intersexual*, where one gender chooses mates (ex. peacocks).

Famous Example: Peacock (*Pavo cristatus*). The showy feathers of the male peacock are a classic example of intersexual selection. These large, bright feathers can be easily seen by predators, and are an impediment to mobility. This would lead us to believe that these showy tails are maladaptive, or more harmful than helpful, and that they should have been lost through natural selection. However, the existence of these extravagant tails can be explained by sexual selection. Peahens, female peacocks, prefer male peacocks with large and colorful tails. Therefore, the peacocks with the largest and brightest tail feathers get to mate more often and have more offspring. The male peachicks will then inherit the genes for similar tail feathers. Since the males with the most extravagant tails have more offspring, the resulting next generation will have showier tails on average.

By Thimindu Goonatillake from Colombo, Sri Lanka - Peacock Dance, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=19395087

Bodensee Example: Ring-Necked Pheasant (*Phasianus colchicus*). This species is a classic example of both intrasexual and intersexual selection. The spurs on the back of the legs serve both as an ornament to attract females, and also as an armament (weapon) for battling with rival males.



By H. Jones - A Monograph of the Pheasants, volume 3 by William Beebe, Public Domain, https://commons.wikimedia.org/w/index.php?curid=32115204

Fill in the blanks: Sexual selection occurs when certain traits increase mating success. ___intrasexual_____ selection involves fighting (competition) among males for a female, whereas ____intersexual_____ selection involves males displaying traits to impress females.

A common result of sexual selection is **sexual dimorphism**. Sexual dimorphism is the condition where the two sexes of the same species exhibit different characteristics beyond the differences in their sexual organs. Sexual dimorphism often occurs in organisms with sexes that have different ecological and/or reproductive roles.

Famous Example: African lions (*Panthera leo*). Lions are the only cats that exhibit distinct sexual dimorphism. African lion males are known for their impressive manes, while the females lack this feature. The males are also much larger than females, weighing in at 150-220 kg, while females weigh between 120-180 kg. Male and female lions also differ in their behavior. They live in groups called prides that usually consist of several related females, their offspring, and a small number of males. The female members usually remain members of the pride for life, while the males must continually fight other males for leadership of the pride. Females are primarily responsible for hunting and caring for cubs, while males are responsible for protecting the pride from rival males and mating with the females.

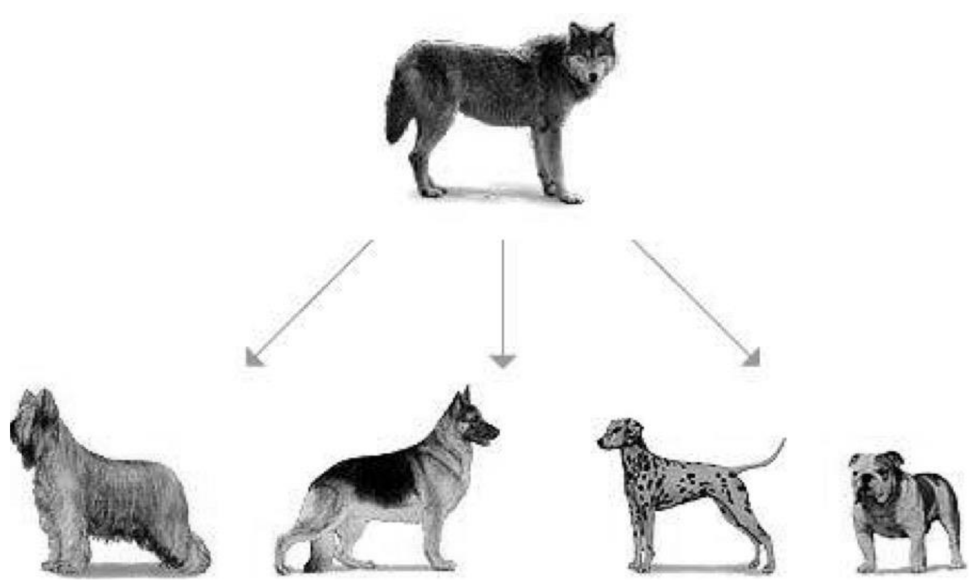
Bodensee Example: European Roe Deer (*Capreolus capreolus*). The European Roe deer is a clear example of sexual dimorphism. The males have antlers, while the females do not. Additionally, the males are larger than the females.

Drawing. *Find and draw an example of sexual dimorphism in the museum. Hypothesize about the functions of the differences between the males and females you drew.*

- Most birds
- Roe Deer

Artificial Selection

Bodensee Example: Wolf (*Canis lupis*). All of the dog breeds that exist today were derived through the selective breeding of one species, the gray wolf. In less than 10,000 years, humans have altered the traits of dogs to result in nearly 400 morphologically distinct breeds. Unlike natural selection, the traits favored by humans may not be directly beneficial to the animal. For example, artificial selection for increasingly large heads in bulldogs has resulted in natural birth no longer being a possibility for these animals. All bulldog puppies born must be delivered by Caesarian section.



Questions.

1) Can you think of other examples of artificial selection? (Hint: think about your food.) Farm animals, produce (corn, bananas, wild mustard, tomatoes, etc)

2) Are there any plants or animals that you eat that have traits that would cause them to have a difficult time living in the wild without help from humans? bananas (sterile), cows (oversized utters and too much milk production)

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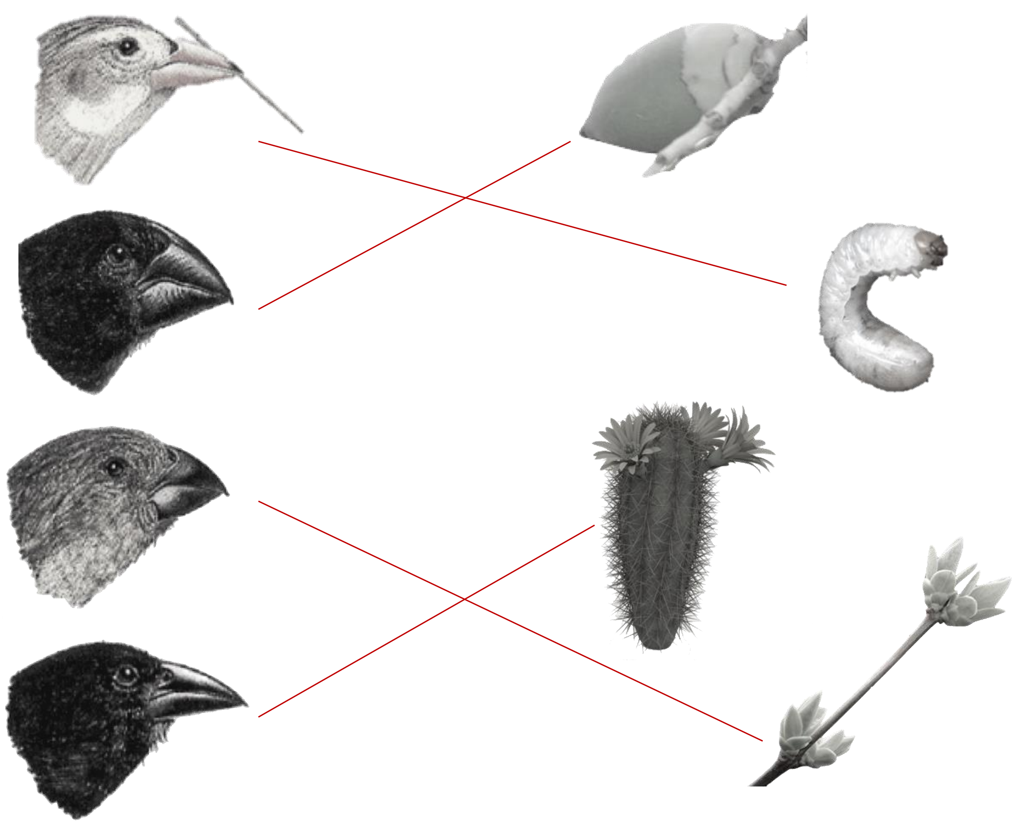
Adaptation

Adaptations are characteristics that have evolved via natural selection.

Famous Examples: Darwin’s Finches. The South American ancestors of these birds were likely blown off course and ended up in the Galapagos, a chain of islands that are 1000 km off the coast of Ecuador. Populations of birds on different islands became isolated from each other and a gradual accumulation of small adaptations to the particular environment led to each population's characteristics drifting apart. The main adaptation was in the shape and type of beak, as the birds adapted to the local food sources on each island.

Matching. *Match each finch with which food source you think it eats.*



Bodensee Example: Eisfuchs (*Alopex lagopus*)**.** These mammals are able to survive in some of the coldest places on earth due to a number of anatomical, physiological, and behavioral adaptations. Compared to other species of fox, these animals have a relatively low surface area to volume ratio. This means that they have smaller ears, shorter necks, and shorter extremities compared to other fox species. Having a low surface area to volume ratio means that they have less surface area from which to lose heat. The Eisfuchs also has a thick layer of fur covering its entire body and a thick layer of fat under the skin to help it preserve body heat. Additionally, the Eisfuchs has an important physiological adaptation to help it survive in these icy habitats—countercurrent heat exchange in the circulation of its paws. Countercurrent heat exchange is a mechanism in which there is a crossover of some property, usually heat, between two flowing bodies moving in opposite directions to each other. For the Eisfuchs, this means that blood entering the paws is used to heat up blood that is leaving the paws. This adaptation prevents the core of the Eisfuchs from being cooled by heat loss at the extremities.

Can you identify any similar adaptations to artic life in the Musk Ox (*Ovibos moschatus)* and/or the Wolverine (*Gulo gulo*)?

long, thick hair; low surface area to volume ratio, short legs, small ears, thick layer of body fat

Pick two adaptations and describe how they help the musk ox to survive in the artic.

1.) Long, thick hair: protects the musk ox from extreme weather conditions.

2.) Low surface area to volume ratio: less surface area to lose heat from, which helps the musk ox to stay warm in the winter.

Sometimes organisms diversify rapidly from an ancestral species into a multitude of new forms with different adaptations, particularly when a change in the environment makes new resources available, creates new challenges, or opens new environmental niches. What is this process called?

__________adaptive radiation____

Adaptive Radiation

Famous Example: The Hawaiian Silversword alliance (*Argyroxiphium*, *Dubatia, Wilkesia;* Asteraceae). The Hawaiian Silverswords are the best-known example of adaptive radiation in plants. Around 5-6 million years ago, an ancestor of a weedy plant called tarweed made it from the coast of California to the Hawaiian island chain, either by floating or catching a ride on a migrating bird. This single species subsequently gave rise to about 30 species in three genera that are endemic to Hawaii. This group of species exhibits tremendous phenotypic and ecological diversity and includes trees, shrubs, mats, and vines. Additionally, these species occur in a broad range of environments, from rainforests to desert-like habitats. Despite the great morphological differences between these species, they are incredibly similar genetically. Electrophoretic studies have shown that the genetic similarities among these island species are comparable to the genetic distances between populations of a single continental plant species.

Dubautia scabra — By Forest & Kim Starr, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=6110811

Dubautia arborea — By Forest & Kim Starr, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=6129341

Argyroxiphium sandwicense — Laurascudder, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=435901

What kind of conditions might favor adaptive radiations? (Hint: what are some peculiar characteristics of Hawaii?) environmental change, newly formed niches, isolation, mass extinction

Can you think of other groups of organisms that might represent adaptive radiations? What about in this region? Hawaiian honeycreepers, Darwin's finches, African rift lake cichlids, European whitefish.

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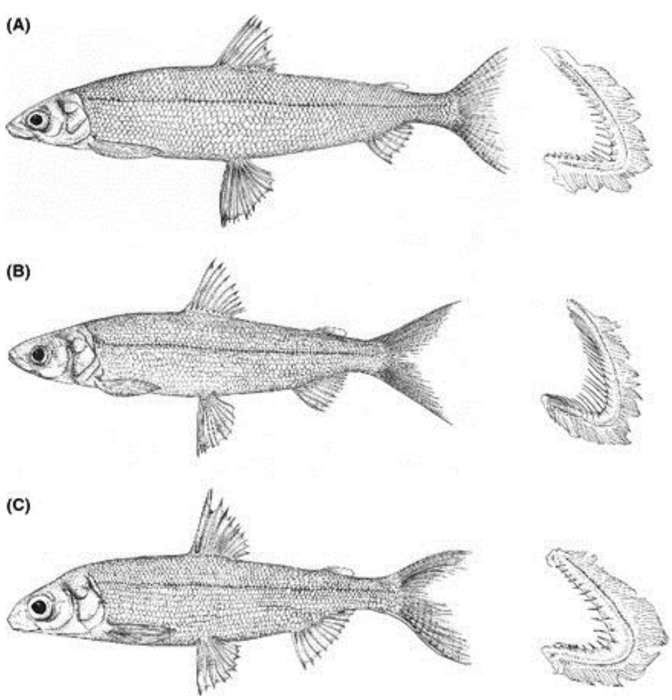
Bodensee Example: European whitefish (*Coregonus lavaretus*). European whitefish is a highly polymorphic species, with more than 200 intraspecific morphs described from postglacial lakes in Europe. These morphs are highly variable in their morphology, ecology, life history, and spawning preferences. The number of gill-rakers most easily differentiates these fishes. Gill-rakers are bony or cartilaginous projections that point forward and inward from the gill arches and aid in fish feeding. Gill-raker number is an important trait for whitefish identification as it is highly heritable, temporally stable, and due to its role in foraging, exposed to selection. Studies show that the morphological difference in gill-raker number between species can be attributed to the utilization of different trophic niches and reproductive isolation within and among lakes that likely arose only since the last glaciation.



Three morphs of European whitefish (Coregonus lavaretus L.) from northern Norway.

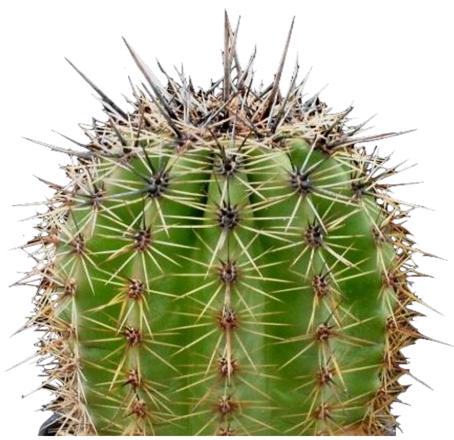
Præbel K, et al. Ecological speciation in postglacial European whitefish: rapid adaptive radiations into the littoral, pelagic, and profundal lake habitats. Ecol Evol 3: 4970-4986 - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/259879861_fig6_Figure-1-Three-morphs-of-European-whitefish-Coregonus-lavaretus-L-from-northern [accessed 15 Jun, 2016]

Convergent Evolution

In an adaptive radiation, closely related species evolve many different forms and functions. Sometimes, the opposite happens and completely unrelated species independently evolve very similar structures. This process is called **convergent evolution.**

Famous Example: Cacti (*Cactaceae*) and Euphorbs (*Euphorbiaceae*). Members of the plant family *Cactaceae* are spiny succulents found only in desert-like habitats of the Americas. Because these species live in extremely dry environments, they have evolved several adaptations to help them survive. For example, most cacti have lost their true leaves in favor of leaves that are modified into spines used for protection and water loss prevention. Additionally, many cacti have ribbed stems that allow them to significantly expand in response to rapid water absorption during rare rainfall events, and contract during dry periods. Certain South African euphorbs look almost identical to cacti, with similar spines and ribbed stems. However, these species are not closely related. The South African euphorbs have evolved similar structures to the American cacti because they evolved in similar dry environments.

Euphorbia columnaris



Carnegiea giganteana

Bodensee Example: Wings. You can see another classic example of convergent evolution here in the museum, wings. Several types of animals have evolved wings, including mammals (bats), birds, and insects. These animals are not closely related, but have all evolved similar structures as a solution to a common problem—flight. You can see all three of these examples around Lake Constance.

Bodensee Example: European Hedgehog (*Erinaceus europaeus*). The spiny projections exhibited by the European hedgehog are another example of convergent evolution. These structures are used for protection. Similar structures can be seen in tenrecs (a small mammal found in mainland Africa and Madagascar), porcupines, and echidnas, even though these animals are highly divergent genetically.

Questions.

1) Which of the following generates the formation of adaptations?

a. Diffusion   b. Genetic Drift   c. Migration   d. Natural Selection

2) Which of the following is an example of an adaptive radiation?

a. Domestic Dogs   b. Musk Ox   c. Galápagos' finches   d. Elephants

3) In Australia there are gliding squirrels called sugar gliders. They look almost exactly like the flying squirrel found in North America, but they are not closely related. This is an example of:
Convergent evolution

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4) Convergent evolution occurs when:

a. Multiple species merge to become one   b. Unrelated organisms evolve similar structures

c. Related organisms develop novel adaptations   d. None of these

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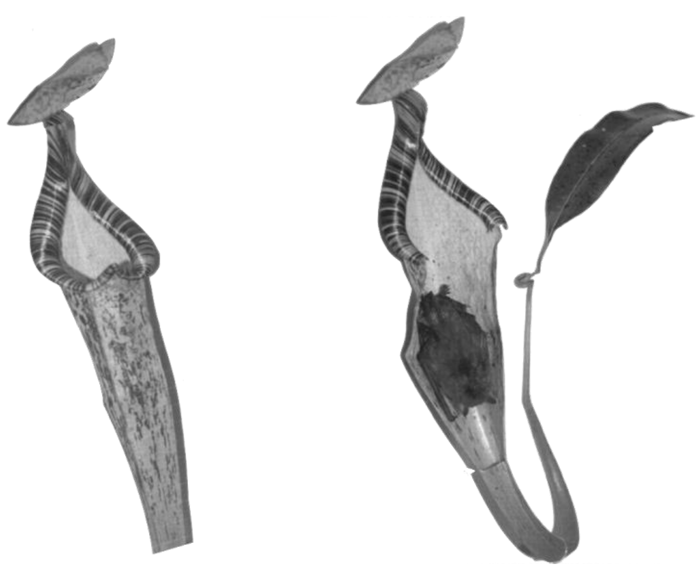
Coevolution

When changes in at least two species' genetic compositions reciprocally affect each other's evolution it is called **coevolution**.

Famous Example: Hardwicke's Woolly Bat (*Kerivoula hardwickii*) and Pitcher Plant (*Nepenthes rafflesiana*). These two species, which are native to Borneo, have developed a particularly interesting coevolutionary relationship. *Nepenthes* is a genus of tropical pitcher plants. The species in this genus are carnivorous, and have leaves that are modified into pitcher shaped traps that are filled with digestive fluid. These pitchers are used for catching prey such as insects and occasionally small vertebrates like rodents, birds, and lizards. Similar to other carnivorous plants, these species evolved in nitrogen poor environments, and acquire nitrogen by digesting trapped animals instead of obtaining nitrogen from the soil like most plants. The largest pitcher plant, *Nepenthes rafflesiana*, has developed a unique coevolutionary relationship with the Harwicke's Woolly Bat, *Kerivoula hardwickii*. The bats roost in the plant's pitchers, which have less digestive fluid than other *Nepenthes* species and also exhibit a protective girdle that prevents the bats from slipping down into the fluid. The plant takes in nitrogen from the bat's droppings and in return, the bats are provided with a safe place to sleep.



Adapted from: Grafe et al. 2011: http://rsbl.royalsocietypublishing.org/content/early/2011/01/21/rsbl.2010.1141

Bodensee Example: Bee Orchid (*Ophyrus apifera*). Members of the orchid genus *Ophyrus* are classic examples of coevolution. In fact, Charles Darwin studied these orchids and their close relationships with their pollinators and used his findings to develop his theory of coevolution. These orchid species are unique in that they have developed exclusive relationships with their pollinators. The flowers mimic female bees, wasps, or beetles, depending on the species of pollinator. Additionally, they emit pheromones that attract the males of these pollinator species. The male pollinators often attempt to copulate with the flowers, thinking they are females, and during this process packets of pollen from the flowers are transferred to their bodies. The males will frequently be tricked into copulating with several individual flowers, therefore cross-pollinating the orchids. In return, the pollinators receive fragrance compounds that they use during courtship displays. One species, *Ophyrus apifera,* is widespread through Europe and can be seen here in the museum. This species has flowers that resemble a female bee, giving it its common name, the bee orchid.

Questions.

1) Can you think of any other examples of coevolution?

Hummingbirds and flowers, Acacia ant and Acacia tree, hosts and parasites.

2) What do you think would happen to the bee orchid if the pollinators disappeared?

The bee orchid would either go extinct or develop an alternate pollination strategy (asexual reproduction, self fertilization).

3) What do you think would happen to the Hardwicke's woolly bat if there were no longer pitcher plants?

The bat would either go extinct or find a new place to roost.

Extinction

Extinction is a natural phenomenon that is defined as the end of an organism or of a group of organisms (taxon), normally a species. There are several causes for extinctions, both natural and those that are caused by human activities. These causes include: climate change, changing sea levels, asteroids/cosmic events, disease, invasive species, habitat destruction or fragmentation, pollution, and over harvesting.

Famous Example: Dinosaurs. The most famous example of extinction is that of the dinosaurs 65 million years ago. What is less well appreciated, is that along with the dinosaurs, 50% of other life forms on the planet also disappeared at this same time. Over the years there have been several hypotheses regarding the cause of this mass extinction event. The most likely explanation is that a gigantic meteor or asteroid, around 6 miles in diameter, caused the extinction. In 1991, a meteor crater that is 110 miles in diameter (now called the Chicxulub Crater) was discovered in the Yucatán Peninsula in southeastern Mexico. It is hypothesized that this is the impact site of the meteor that ended the dinosaurs. Scientists believe that the meteor crashed into the earth at 40,000 miles per hour. A crash of this magnitude would have released energy 2 million times more powerful than the most powerful nuclear bomb ever detonated, and put the earth into a “nuclear winter”. Immediately after the crash, the heat released would have scorched the surface of the earth and ignited massive wildfires. The ash and dust would have then clouded the earth’s atmosphere and blocked the sun’s rays, resulting in plummeting temperatures worldwide. The resulting cold and darkness would have lasted for months, or possibly years. Plants would be the first to die off due to the freezing temperatures, followed by herbivores, and then carnivores, resulting in the tremendous loss of biodiversity that has been observed in the fossil record.

Bodensee Examples: Lake Constance Whitefish (*Coregonus gutturosus*) and Deepwater Char (*Salvelinus profundus*). The Lake Constance whitefish and Deepwater char are extinct species of fish in the salmon family. These species were historically found in the deepest areas of the lake, and were highly vulnerable to environmental changes. It is hypothesized that the pollution and resulting eutrophication of Lake Constance in the 1960’s and 1970’s caused the extinction of these species.

Can you think of any other species that have gone extinct, or that are in danger of going extinct?

Extinct:

- dodo
- passenger pigeon
- woolly mammoth
- sabre-toothed tiger
- Tasmanian tiger
- black rhinoceros

At Risk:

- Rhinoceros
- Mountain gorilla
- Red tuna
- Tiger
- Snow leopard
- Giant panda
- Blue whale
- Asian elephant
- Orangutan