<u>ADAPTIVE RADIATION</u>

ADAPTIVE RADIATION

Hello Friends! Very warm greetings to all in this special session of Evolutionary Biology! In this particular lecture, today we will learn about very significant component of evolution in terms of 'Adaptive Radiation'.

Introductory Background

Dear Students, if we look around, we will find vast diversity of Living organisms in the forms of many different species of bacteria, viruses, insects, plants and animals surrounding us. Obviously, questions may arise in your minds that how did all these species get here and how did the organisms evolve gradually on this earth? The answers to these questions lie in one of the most reflected pathway of evolutionary mechanism called 'Adaptive Radiation'.

Dear Learners! Let us try to understand first the scientific meaning of adaptive radiation.

In evolutionary biology, adaptive radiation is the phenomenon of rapid divergence of multiple species from a single ancestral lineage. The term 'adaptive radiation' has been coined by H. F. Osborn in 1902 for explaining the evolution from a single ancestor of a number of descendants, with a great variety of adaptations to different niches. In other words, adaptive radiation is the process of evolution of different species starting from a point in a geographical area and finally radiating to other areas of geography. Adaptive radiation involves the diversification of dominant evolutionary group into large number of subsidiary types which are adapted to more restricted modes of life. i.e. different adaptive zones. This divergence generally happens in a relatively short interval of geological time. Hence, scientifically, we can say that adaptive radiation is an evolutionary process in which organisms diversify rapidly from a single ancestral species into a multitude of new related forms. Usually, the adaptive forms differ in their use of resources or habitats. Hence, more precisely, we can say that "Adaptive radiation is an evolutionary pattern of divergence of members of a single lineage into a variety of different adaptive forms".

According to George Gaylord Simpson, adaptive radiation is the rapid proliferation of new taxa from a single ancestral group. As per this concept, the different descendant taxa are similar, but each is adapted for a particular environmental niche. In short, this phenomenon involves the tendency of a group of animals to evolve in response to selective pressure and adapt to their environments in different ways. One of the very common ways for adaptive radiation to happen is the migration of animals into a new area that has lots of new ecological opportunities. Adaptive radiation happens particularly, when a change in the environment makes new resources available; creates new challenges or opens up new environmental niches.

Initiating with a recent single ancestor; adaptive radiation results in the speciation and phenotypic adaptation of an array of species exhibiting different morphological and physiological traits. Luria *et. al.* in 1981 held that adaptive radiation has led to the presence of over 250,000 different species of beetles, 14 different species of Darwin's finches on the Galapagos Islands, over 25,000 types of teleost fishes and different marsupials in Australia.

Identification of Adaptive Radiation

Friends! There are four salient features of adaptive radiation which can be utilized to identify it.

1. ***A Common Ancestry of Component Species:*** It involves specifically a recent ancestry.

2. ***A Phenotype-Environment Correlation:*** i.e. A significant association between environment and the morphological as well as physiological traits used to exploit varieties of environment.

3. ***Trait Utility:*** i.e. The performance or fitness advantages of trait values in their corresponding environments and

4. ***Rapid Speciation:*** i.e. Presence of one or more bursts in the emergence of new species around the time during which ecological and phenotypic divergence is underway.

Causes of Adaptive Radiation

Dear Students! Let us know three principal reasons responsible for adaptive radiation to occur.

a) Innovation - The evolution of a novel feature may permit a clade to diversify by making new areas of morpho-space accessible. One of the classic examples is the evolution of a fourth cusp in the mammalian tooth. This trait permits an enormous increase in the range of foodstuffs which can be fed on. Evolution of this character has thus increased the number of ecological niches available to mammals. This trait arose for number of times in different groups during the Cenozoic, and in each instance was immediately followed by an adaptive radiation. In birds the evolution of flight opened new avenues for evolution to explore, initiating an adaptive radiation. Other examples include placental gestation for eutherian mammals and bipedal locomotion in hominins.

b) ***Opportunity -*** Isolated ecosystems, such as archipelagos and mountain areas, can be colonized by a species which, upon establishing itself, undergoes rapid divergent evolution. Monotremes and marsupials are considered to be examples of geographic isolation. Monotremes evolved before the evolution of placental mammals, and they are found today only in Australia, which has been isolated from the other continents for 50 million years. Marsupials, which also evolved before the appearance of placental mammals, are also common in Australia. It is held that in Australia, marsupials evolved to fill many ecological niches that placental mammals fill on other continents. In context to this, Richard Leakey (in 1994) wrote that "Biologists who have studied the fossil record, know that when a new species evolves with a novel adaptation, there is often a burgeoning of descendant species over the next few million years, expressing various themes on that initial adaptation and this burgeoning is known as adaptive radiation."

c) ***Extinction -*** Adaptive radiation may also occur after mass extinctions. One of the nice examples of this is the fossil records showing that biodiversity increased massively in the Triassic after the Permian-Triassic extinction event. End of the Ediacaran and the beginnings of multicellular life lead to adaptive radiations and the genesis of new phyla during the Cambrian period.

Examples of Adaptive Radiation

Adaptive radiations are best exemplified in closely related groups that have evolved in a relatively short period of time. Let us have a glimpse of some of the striking examples of adaptive radiation one by one.

1. Adaptive Radiation in Darwin's Finches: One of the classical examples of speciation involving the interplay of complex forces like isolation, competition, adaptation, etc. which lead to adaptive radiation at the species level, is provided by Darwin's finches. Darwin's finches are the small Sparrow-like dark birds belonging to family *Fringillidae*. In the archipelago, there are 5 large islands in the group; with 19 smaller ones and 47 rocks. The ancestors of Darwin's finches were early migrants to the Galapagos Islands in the Pacific Ocean and probably the first land birds to reach the islands. The present-day assemblages of Darwin's finches descended from these birds that once inhabited the mainland of South America, the Galapagos Islands which lie on the equator about 600 miles west of South America i.e., Ecuador. These early colonists have given rise to 14 distinct species, each well adapted to a specific niche. 13 of these species of Darwin's finches occur in the Galapagos and one is found in the small isolated Cocos Island, northeast of Galapagos. Not all 13 species are found on each island. These islands are of volcanic origin. They were never connected with the mainland of South America. The tugged shoreline cliffs are of grey lava and the coastal lowlands are parched, covered with cacti and thorn bushes. In the humid uplands, trees flourish in the rich black soil. Due to this geographical segregation, the finches on different islands could not interbreed, so the populations on the different island tended to become distinct. Significantly, the study of these birds in their native habitat gave Darwin his first insight into evolutionary processes. Darwin's finches were utilized as evidence for his theory of evolution.

David Lack (1969) has evaluated the phenomenon of adaptive radiation of Darwin's finches very carefully. Darwin's finches occupy the fragmented landscape of the Galapagos Islands and are diversified into many varieties of species which differ in ecology, song pattern and morphology. The most conspicuous differences among these species are in the size and shape of their beaks, which are correlated with marked differences in their feeding habits (As per Wells, 2000). Six of these species are '**Ground finches**', with heavy beaks specialized for crushing of seeds. Some of the ground finches live mainly on a diet of seeds found on the ground. For example, there are 3 seed-eater ground finches: (i) small-beaked (*Geospiza fuliginosa*), (ii) medium-beaked (*Geospiza fortis*) and (iii) large-beaked (*Geosptiza magnirostris*) which occur together in the coastal lowlands of several islands. Each species, however, is specialized in feeding on a seed of a certain size. The small-beaked finch feeds on small grass seeds, whereas large-beaked finch eats large, hard fruit. Other ground finches feed primarily on the flowers of prickly pear cacti. The cactus eaters possess decurved, flower-probing beaks. Their beaks are thicker than those of typical flower-eating birds.

All other species are '**Tree finches**', the majority of which feed on insects in the moist forests. One of the most remarkable of these tree dwellers is the 'woodpecker finch'. It possesses a stout, straight beak, but lacks the long tongue characteristic of the woodpecker. Like a woodpecker, it bores into wood in search of insect larvae, but then it uses a cactus spine or twig to probe out its insect prey from the excavated crevice.

Equally extraordinary is the '**Warbler finch**' which resembles in form and habit the true warbler. Its slender, warbler-like beak is adapted for picking small insects of bushes. Occasionally, like a warbler, it can capture an insect in flight.

Thus, the original ancestral stock of finches on the Galapagos diverged along several different paths. All the finches are related to one another, but the various species of ground finches evidently are more related by descent to one another than to the members of the tree-finch assemblage. As a measure of evolutionary affinities, the ground finches are grouped together in one genus (*Geospiza*) and the warbler finches are clustered in another genus (*Camarhynchus*). The diagram portrays different lineages of finches.

As per Stanley, 1969, Darwin's finches like adaptive radiations, within ecologic islands of any sort are called '**eco-insular radiations**'. Darwin's finches provide circumstantial evidence for the origin of a new species by means of geographical isolation.

2. Adaptive Radiation in Penguins: G. G. Simpson in the year 1953 has cited evidence that when a group of organisms enters a new adaptive zone previously unoccupied by the group, there may be rapid bursts of speciation and adaptive divergence into a variety of ecological niches. The diagram here depicts Simpson's visualization of such adaptive radiation for penguins in which three different zones for penguins include: (l) aerial flight, (2) aerial and submarine flight and (3) submarine flight. These zones were sequentially invaded by penguins during their evolution and they are now extinct in the aerial flight zone or subzone.

3. Adaptive Radiation in Reptiles: The class Reptile first appeared in the fossil record in Pennsylvanian times around 250 million years ago. The ancestral reptilians initiated one of the most spectacular adaptive radiations in the history of life. Adaptive radiation of the reptiles occurred between Permian and Cretaceous times. The living reptiles are derived from Cretaceous ancestors. The Mesozoic era, during which the reptiles thrived, is often termed as the “Age of Reptiles”. The initial success of the reptiles stem resulted into a mega-evolutionary shift from aquatic to completely terrestrial development. i. e. the cleidoic or amniotic eggs of reptiles, like bird eggs, do not need to be immersed in water to survive. The basic stock of reptiles included the Cotylosauria from which a variety of reptiles were blossomed.

The most inspiring and famous dinosaurs ruled over the lands until the close of the Mesozoic era before they suffered extinction. Dinosaurs were remarkably diverse in terms of their size, body forms as well as habits. Some of the dinosaurs were carnivorous, such as the gigantic Tyrannosaurus; whereas others were vegetarians, such as the feeble-toothed but elephantine Brontosaurus. The bulky body of Brontosaurus weighed approximately 30 tons and measured nearly 70 feet in length. Not all dinosaurs were huge; some were no bigger than chickens also. Some dinosaurs strode on two feet, while others had reverted to four. The exceedingly long necks of certain dinosaurs were adaptations for feeding on the foliage of tall coniferous trees.

The dinosaurs were descended from the thecodonts which were slender, fast-running lizard-like creatures. The thecodonts gave rise also to bizarre reptiles that took to the air, the pterosaurs. These so called ‘dragons of the air’ possessed highly expansive wings and dis-proportionately short bodies. The winged pterosaurs became extinct before the end of Mesozoic era. Another independent branch of the thecodonts led to exceptionally more successful flyers, the birds. The origin of birds from reptiles is revealed by the celebrated *Archaeopteryx*, a Jurassic form. The feathered creatures possessed a slender lizard-like tail and scaly head equipped with reptilian teeth. Certain mesozoic reptiles returned to water also. The streamlined, dolphin like ichthyosaurs and long necked, short-bodied plesiosaurs were marine, fish-eating reptiles. The ichthyosaurs were expert swimmers. Their limbs were fin-like and tails were forked. The plesiosaurs were efficient predators and capable of swinging their heads 40 feet from side to side and seizing fish in their long, sharp teeth. These aquatic reptiles breathed by means of lungs. They did not redevelop the gills of their very descendant fish ancestors. Indeed, it is axiomatic that "*A structure once lost in the long course of evolution cannot be regained"*. This forms the basis for the doctrine of "Irreversibility of Evolution or Dollo's Law" which was proposed by eminent Belgian paleontologist Louis Dollo (1895).

Further, among the early reptiles present before Mesozoic days (i.e. Permian of Palaezoic era), were the pelycosaurs (For e. g. *Dimetrodon*), notable for their peculiar sail like extensions of the back. It appears that the sail of pelycosaurs was a functional device to achieve some degree of heat regulation. Pelycosaurs gave rise to an important group of reptiles, the therapsids. These mammal-like forms bridged the structural gap between the reptiles and the mammals.

The history of the reptiles attests to the ultimate fate to many groups of organisms-extinction. Of the vast host of Mesozoic reptiles, relatively few have survived to modern times; the ones that include the lizards, snakes, crocodiles and turtles.

4. Adaptive Radiation in Eutherian Mammals: The eutherian (i.e. placental) mammals form another classical example of the process of adaptive radiation. It is believed that, all the present day types of mammals have evolved from a primitive, insectivorous, short-legged, rat-like terrestrial creature that walked with the soles of its feet flat on the ground. Among eutherian mammals, with respect to limb structure, adaptive radiation has occurred in five different lines:

(i) Arboreal - One evolutionary line radiates to form arboreal forms which have adapted limbs for living in trees. The legs which are adapted for climbing are termed as scansorial. For e.g. squirrels, sloth, monkeys, etc. are arboreal organisms.

(ii) Volant or Aerial - Second line radiates to aerial or volant, which represents mammals adapted for flight. For e.g. Bats. Along this line, we can also place the gliding mammals such as 'flying squirrel'. The arboreal forms not arose independently from the terrestrial forms, but perhaps through semi-arboreal or climbing ancestor.

(iii) Cursorial - Third line of radiation gives rise to cursorial forms such as horses and antelopes. They have developed limbs suitable for rapid movement of running. The cursorial mammals have three different types of adaptations in their foot-postures, which include (l) Plantigrade, i.e. walking with whole sole of the foot touching the ground. e.g., bears and primates including human beings; (2) Digitigrade, i.e., digits touch the ground and are provided with pads on their ventral side which absorb the shock and help in making stealthy approach towards the prey. For e. g. lion, tiger, leopard, wolf, cat and dog; and (3) Unguligrade, i.e., animals walk and run on the tips of their fingers and toes which are shielded by hoofs. e.g., double-hoofed animals or artiodactyls like cattle, sheep and buffaloes as well as single-hoofed animals or perissodactyls such as asses, horses and zebras.

(iv) Fossorial - Fourth line of radiation formed the fossorial mammals which are burrowing organisms. Certain fossorial mammals like moles have modified their forelimbs for digging purpose but they are poorly adapted for locomotion on the ground, while other fossorials such as pocket gophers and badgers are expert diggers and can also move readily on the surface of ground.

(v) Aquatic - Fifth line of radiation leads to the aquatic mammals. Whales and porpoises having limbs strongly adapted for aquatic life, but they cannot move about on land. While seals and sea lions have also strongly modified limbs for aquatic life but they are also able to move about on land. The third group in this category includes accomplished swimmers such as otters and polar bears which are equally at home in water or on land.

Lastly, animal's legs modified for walking are called 'ambulatory' and those that are adapted for jumping are called 'saltatory'. Among eutherial mammals, adaptive radiation is also applied to teeth development. i.e. For different mode of feeding.

5. Adaptive Radiation in Marsupial (or Meta-Therian) Mammals: A remarkable example of adaptive radiation in animals is the tremendous diversity of marsupials (i.e. pouched mammals) in Australia. In many ways they parallel the adaptations of placental mammals in the rest of the world. Thus, in the absence of placental mammals, marsupials developed grazing forms (like some kangaroos); burrowing forms (such as marsupial moles); forms resembling tree and flying squirrels (such as flying phalangers and pygmy gliders); forms resembling arboreal eutherians (like teddy bear or koala and tree kangaroo); forms containing rodent-like dentition (such as wombats and marsupial mouse); rabbit-like forms (like hare wallabies); wolf-like carnivores (like Tasmania wolves); badger-like carnivores (like Tasmania devil) and ant-eating carnivores (such as banded anteater).

6. Adaptive Radiation in Cichlid Fish: Another excellent example of adaptive radiation is of cichlid fishes in lakes of the East African Rift. The lakes in this area are believed to support and sustain about 2,000 different species of these fishes, each with different ecological and morphological characteristics such as different body size. Like the Galapagos Islands, these lakes form fragmented landscape, that isolates the cichlid fishes from one another, allowing them to evolve separately. Another striking feature that has created the interest in scientists about the Cichlid fish is the possibility of convergent evolution or the evolution of analogous structures independently, driven under the influence of environmental selection pressures.

7. Adaptive Radiation in Hawaiian Honeycreepers: Another nice example of an adaptive radiation can be an endemic, very large and highly diverse avian species of the Hawaiian Islands called ‘Hawaiian honeycreepers’. Via natural selection, honeycreeper species adapted themselves rapidly and converged based on the different environments of the Hawaiian Islands. The mechanism by which this adaptive radiation occurred can be described as allopatric speciation. Each time a new island formed, a dispersal event would occur, which would result in new community structures on each island. New selection pressures forced the adaptive radiation of the Hawaiian honeycreepers, as they needed to exploit new resources from the different environments of each island. It has been determined that many of the similar morphological and behavioral features of the Hawaiian honeycreepers, located on distant islands, are due to convergence of analogous traits caused by similar environments.

8. Adaptive Radiation in Hawaiian Silverswords: Just like the famous adaptive radiation of Darwin's finches or the Cichlid fish, which occurred in animals, it might be observed in plant species as well. The most famous example of adaptive radiation in plants is of the Hawaiian silverswords. Its alliance consists of 28 species of Hawaiian plants, which range from trees to shrubs to vines. These radiations occurred millions of years ago. This is an exceptional diversification as can be identified through the significant morphological differences between each species of the Hawaiian silverswords. Studies over the past few decades suggested that the rate of speciation and diversification was extremely high in these areas. These high rates, as well as the fragmented landscape of the Hawaiian Islands, can be considered as the key characteristics which point directly to adaptive radiation.

9. Adaptive Radiation in Anolis Lizards: Another best example of adaptive radiation comprises of anolis lizards. Anolis lizards have been radiating widely in many different environments, including Central and South America, as well as West Indies and exhibited great diversity of species. They have clearly evolved differently to the environments they inhabit. The environmental pressures on the Anolis lizards are not the same on the mainland as they are on the islands. There are significantly more predators preying on the Anolis lizards on the mainland. Among the Caribbean islands, a larger perch diameter correlates with longer forelimbs, larger body mass, longer tails and longer hind limbs. However, on the mainland, a larger perch diameter correlates with shorter tails. This suggests that anolis lizards adapted differently to their environment depending on whether they were located on the mainland or the islands. These differing characteristics reconfirm that most of the adaptive radiation between the mainland and the islands occurred independently. On the islands specifically, species have adapted to certain ‘microhabitats’ in which they require different morphological traits to survive. Irschick (in 1997) divided these microhabitats into six different groups as: ‘trunk–ground, trunk–crown, grass-bush, crown-giant, twig and trunk’. Different groups of lizards would acquire traits for one of these particular areas that made them more specialized for survival in that particular microhabitat and not so much in others. Hence, it can be concluded that adaptive radiation allows species to acquire the traits they need to survive in their microhabitats and reduce the competition to allow the survival of a greater number of organisms.

Simpson’s Adaptive Grid and Macro-evolution

Dear Students! At last, let’s also get an overview of Simpson’s adaptive grid and macro-evolution concept in brief.

G. G. Simpson (1953) has developed a very handy conceptual framework for describing major evolutionary patterns. It is well known that, at any moment in time, the interaction of organisms and their environment define a series of broad or narrow adaptive zones. All members of the major group share one major adaptive zone because of their common possession of complex general adaptations. For e.g. Within the broad zone, each species of crustacean occupies a distinct but narrow field of its own because of the species’ peculiar combination of special and general adaptations. Each kind of organism is an adaptive type, discontinuous from other adaptive types. For example, a crab is distinct from a barnacle though both are crustaceans and a snake is definitely distinct from a man or a sunflower. Simpson has suggested that the adaptive types or zones may be represented diagrammatically as bands or pathways on an adaptive grid. The discontinuities between the major zones (A, B, C, D) are ecologic discontinuities or unstable ecologic zones. The adaptive zone itself represents an ecologic role or characteristic relationship between organism and its environment. Thus, when a new major zone is occupied, the first zone entered is usually the widest and requires the least special adaptation. This initial breakthrough to the new zone is observed due to general adaptations of the organisms. Later on, more special zones will be occupied by the organisms. The subsequent evolution leads to specialization. This pattern also fits the macro-evolutionary speciation. i.e. adaptive radiation of Darwin’s finches.

Hence, it can be interpreted that adaptive radiation can be considered as one of the significant product of evolution as evidenced by citation of numerous examples that we have described in our today’s lecture that can play noteworthy role in increasing biodiversity of the planet.

SUMMARY

Dear Friends! Let’s have a quick overview of the topics that we have learnt in our today’s session on evolutionary biology.

In this particular lecture, initially, we have started with the understanding of scientific meaning of term ‘adaptive radiation’. During this lecture, we have also studied identification criteria for adaptive radiation along with the chief causes responsible for it. The principal focus of today’s session was to impart detail knowledge regarding adaptive radiation phenomenon with appropriate citation of the examples and illustrations. In this lecture, we have studied adaptive radiation phenomenon in most famous Darwin’s finches, Penguins, Reptiles, Eutherian Mammals, Marsupial Mammals, Cichlid Fish, Hawaiian Honeycreepers, Hawaiian Silverswords and Anolis Lizards. Not only these, at last, we have also taken a glimpse of Simpson’s adaptive grid and macroevolution concept in brief.

Dear Learners! Hope today’s lecture on adaptive radiation will definitely assist you to strengthen your knowledge regarding evolutionary phenomenon and provide hint to understand the concept of biodiversity creation in the nature.

Dear Friends! This is all for today’s session. Thank you!