Fundamentals of Evolutionary Genetics

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By

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PREFACE

Fundamentals of Evolutionary Genetics tells the role of genetics in the evolution of organisms, their phenotypic characters, and adaptations. Genetics is essential in our daily lives as well as in the lives of other organisms. Bacteria, viruses, plants, yeast, fungi- none of them can spare themselves from the involvement of genetics in their daily body functions, reproduction, interactions with the environment, and evolution. Genetics significantly extends its role to agriculture, livestock, and biotechnology. Though the way of working and the mechanisms may vary in these sectors, fundamentally, they play a pivotal role in the development and progress of these sectors. The same is the case with evolution, which can only occur with genetics's involvement. Recent technological advances have expanded and increased the resolution of studies in genetics and genetic-related disciplines, provide a clear, up-to-date, and enjoyable introduction to evolutionary biology and genetics that explains fundamental evolutionary concepts, illustrates recent exciting findings, and offers hands-on experience in analyzing and interpreting genomic data. Hence, this book is a valuable resource for undergraduate courses that blend evolution and genetics.

Indeed, evolution cannot occur without genetic manipulation. Irrespective of nature, a form of animals and its habitat terrestrial, marine, and other aquatic ecosystems, evolution happened, and genetics provided the raw material for it. Climatic changes have always stressed the life of an organism, no matter what it is. To cope with such a hostile environment, organisms strive to build mechanisms to survive these changes. Suppose these environmental changes prevail sustainably and organisms do not modify their internal mechanisms with inheritable changes. In that case, they will perish immediately, possibly due to natural selection or other natural phenomenon. Genetics intrigue the body to modify its organs and immune system following the transfer of these alterations in developmental and demographic mechanisms. Understanding such phenomenon is a fundamental requirement of any undergraduate and graduate student in the field of Zoology. Keeping in mind the requirements of Zoology students, it strived to compose such a comprehensive compendium that blends genetics and evolution and provides fundamental information on both subjects separately and when amalgamated in a blend. This book is a

comprehensive compendium on evolution with detailed illustrations of the role of genetics in evolutionary processes and their mechanisms. This book will be equally helpful to undergraduate and graduate students in general and those majoring in specific fields.

This book contains 8 chapters. Chapter 1 asks the following question: What is evolutionary genetics? It defines and tells some basic details of evolutionary genetics. Chapter 2 describes the structure of genetics, specifically implied in evolutionary processes. Chapter 3 is “Causes and Mechanisms of Evolution.” This chapter is self-explanatory; it explains what causes evolution and the different mechanisms that control the evolutionary processes. Chapter 4 is Darwin and Mendel's Evolution and Genetics. This chapter correlates with Darwin's concepts about evolution and the role of Mendel's genetics in fine-tuning and further intriguing evolutionary processes. Chapter 5 is on the “Genetics and Morphological Evolution.” The genetics is the basis of morphology. This chapter further elaborates on how genetics manipulates the morphological expressions in organisms. Chapter 6 is on “Mutation Theory and Phenotypic Evolution.” As the mutations cause changes in the genetic makeup and subsequently in the phenotypic characters of an organism, this chapter is all about types of mutations and how they play a role in the modifications of the genetic makeup and how they manipulate the phenotypic expressions of an organism. Chapter 10 is on “Behavioral Genetics”. As the name implies, behavior and genetics are very closely related. Whatever behavior an animal adapts to survive in the changing and hostile environment becomes part of its genetics, which is then transferred to its offspring. Chapter 7 is on “Genetics manipulates Convergent evolution.” Though the first look appears something different, it stresses that genetics controls and manipulates every step of evolution irrespective of its nature. Hence, convergent evolution also owes to genetics and cannot work and operate without genetics. Chapter 8, the last chapter of this book, is on “Origin of New Genes and their Evolutionary and Phenotypic Impact.” it is well established that gene flows among individuals and populations. Genes also inherit character from parents to offspring. So, genes are the fundamental unit of heredity; hence, they are also a basic unit in evolutionary processes and phenotypic expressions. Therefore, the origin of new genes means the origin of new characters and modifications in the existing ones, which serve as a raw material for evolution; this last chapter is all about these notions and ideas.

The present book aims to give an up-to-date overview of the studies on evolutionary genetics. The purpose was to understand the fundamentals of

the relationships between genetics and evolution irrespective of organisms' environment. Therefore, this book would be an ideal source of scientific information for advanced students, junior researchers, faculty, and scientists involved in ecology, agriculture, plant and animal sciences, environmental microbiology, molecular biology, biochemistry, biotechnology, and other areas affecting the study of evolutionary genetics. We are thankful to all the contributors for their interests, significant contributions, and cooperation that made this humble endeavor possible because, without their unending support, motivation, and encouragement during the accomplishment of this grueling task, this would never have succeeded.

Masroor Elahi Babar

Muhammad Ashraf

FOREWORD

Evolutionary genetics deals with genetic variation and its consequences on evolution. Recently, there has been an explosion of genome sequence data, which has made a lot of contributions to the study of evolutionary genetics. Day by day, vast quantities of genetic data are generated at an ever-increasing pace. A thorough understanding of evolutionary principles is essential to make sense of this data. This up-to-date textbook covers all the significant components of evolutionary genetics. It carefully explains the fundamental processes such as mutation, natural selection, genetic drift, and Speciation. This book also discusses the role of these concepts in evolution and the consequences of overacting and depressive behavior. The book takes full advantage of the authors' experience working in post-genomic revolutions in the world with an introduction to the molecular, genetic, and evolutionary methods for studying these concepts currently used at a mass scale. Throughout the reading of this book, readers will learn how the study of genetics and evolution is beneficial for the continuation of life as we know it.

This book titled, “Fundamentals of Evolutionary Genetics,” presented here, is of paramount importance because it will help to educate the next generation of students about the role of genetics in evolution and its processes, serving as a good resource book for all the stakeholders involved in this profession. In genetics and evolution, various ideas and issues infiltrate from different biological resources and the depth of biological sciences to the physical and social sciences, including politics.

Hence, the efforts to produce a text that covers evolution and genetics following their amalgamation into single and unitary subjects with in-depth facets must come from a comprehensive group of specialists, as is the case here. This book allows each field of study to bring its unique perspective and shed light on a very complex and vital subject that could otherwise be intractable. This book might be unusual for an academic text, but it comprehensively covers academic and applied aspects of evolution and genetics. It is worth mentioning that environmental problems exist, and ecological changes are occurring persistently. Animals must cope with these changes and modify themselves physically and psychologically for survival and fitness. This compendium is both time-sensitive and evolving,

and complete understanding does not exist and may never exist, but we have to address all of them for timely remedial measures. But such an issue still has to be addressed in good faith, promptly, with the best science on hand.

I hope this work, when shared freely and widely, will be an educational milestone as humanity struggles to understand and solve the enormous problems regarding genetics and its various aspects and where it serves basic uplift, be it an evolution or any other aspect. Further, this text, “Fundamentals of Evolutionary Genetics,” is a comprehensive text on Evolution and Genetics and will provide an intellectual foundation that will allow students to become the engines that move and use genetics for a variety of applications of evolution is one. Therefore, this compendium can help provide long-lasting guidelines in studying genetics and its related disciplines and fields if used and applied in its actual letter and spirit.

CHAPTER 1

WHAT IS EVOLUTIONARY GENETICS?

Summary:

This chapter briefly discusses the concept of evolutionary genetics, evolutionary research, challenges, and opportunities. Further, it briefly overviews evolutionary history, evolutionary mechanisms, and developmental genetics. It further discusses agriculture and biological resources, their manipulation, management, and conservation. This chapter ends with the concepts.

1.1. Introduction

What is evolution?

Evolution describes the mechanism and development of diversified life on Earth from common ancestors over time. Even there is variation in the hereditary traits within a population of organisms, which results from the changes in the genetic code of individual organisms. Changes in the genetic code transmit and induce variations in hereditary traits within a population of organisms. These changes can occur when genetic material shuffles during sexual reproduction and by random mutation. One mechanism that causes changes in populations or results in evolution is natural selection. Evolution occurs in the population, which ultimately changes sets of traits in each individual, affecting their ability to survive and reproduce. For example, some individuals can find food, hide from predators, and attract mates much better than others. Better traits with successful survival and reproduction pass the genes responsible for these traits to the next generation through natural selection. With time, there are changes in the characteristics of the population, and these changes reflect the changes in the genetic makeup of the population. This process helps us to record the differences we can see in microevolution (within species) and macroevolution (emergence of new species).

1.2. Evolutionary Research: Challenges and Opportunities

A. Elementary /or Basic Research

Research is in progress on many aspects of evolution, but still, a lot is unknown. Suppose research on evolution gets sufficient support from the well-trained researchers involved in this field. In that case, we can expect extraordinary progress in basic evolutionary biology in the next decade or two. Several questions are still unanswered and demand progress, while many evolutionary biologists would like to add high-priority questions and challenges that are variably categorized, though they are equal in importance and priority.

1. Formulation of Theory and Development of a Technique

The theory, which is mainly mathematical, provides the required guidelines for evolutionary research. This theory helps the evolutionary research in the following easy steps. It starts with framing the hypothesis, providing precise predictions or expectations, and speculating the data required to test the hypotheses. The availability of trained theoreticians is essential for completing all these steps. In evolution, several areas require further theoretical explorations. The first is the development of combination or accumulation theory, which uses gene trees to acquire the necessary conclusions on the evolutionary processes. Following this is the development of theory. This theory explains the relationship between phylogenies of genes and phylogenies of species and populations. This theoretical work is further extended to phylogenetic trees, specifically comparison and, finally, evaluation of these phylogenetic trees. Then, population genetic theory is applied to topics that need better exploration. Essential topics that still need to be fully explored are the nature and evolutionary consequences of gene interactions and gene-environment interactions, ultimately dealing with the evolution of polygenic traits with different genetic architectures and morphologies. Development and extension in these research areas help us develop optimization models. These models are then used to analyze the evolution of behavior, life histories, and other phenotypic traits. Evolutionary change models are conveniently used for studying different developmental phases and pathways during evolution; nonetheless, we use predictive models to study and understand the coevolution of interacting species (Fig. 1.1, and 1.2).

Research is based on the advancements in techniques. Molecular and other experimental methods heavily impact evolutionary research. Accordingly, evolutionary biology depends on analytical, statistical, and numerical (computational) methods. DNA sequences, improvement of methods for the analysis of population genetic data (e.g., molecular markers of mating systems), methods for the alignment of different DNA sequences, improvement in the methods of phylogenetic analysis, and improvements in the methods for fine-scale mapping of quantitative trait loci, is a massive amount of data and until and unless methods for its search and further manipulation are not sought and gathered its further progress is hard to predict.

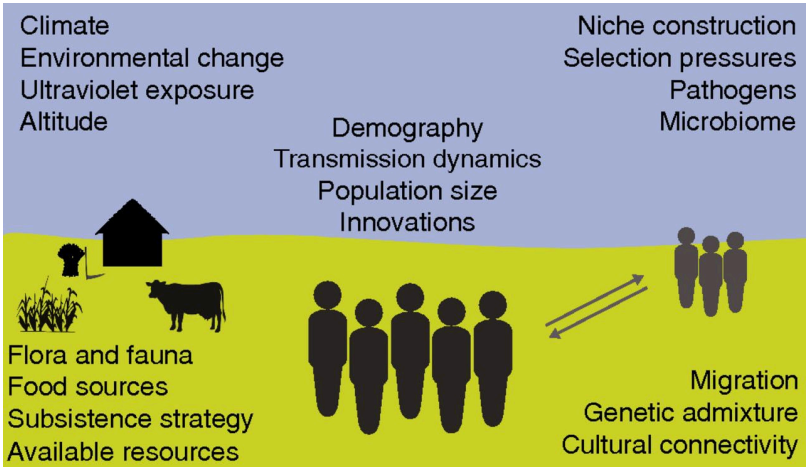

Fig. 1.1. Cultural evolutionary theory (Source: Evolution-institute.org)

Fig. 1.2. Systems theory (Source: Audo and Oudshoorn 2020)

2. Evolutionary history

Among its other goals, evolutionary biology also describes and explains the history of evolution. Phylogenetic methods and paleo-biological studies can demonstrate the achievement of the history of evolution. A complete history of the diversity of life through time, especially of bacteria and other forms of life, can be explored by applying Paleobiology. Paleo-biology further improves the level of data and methods used. Further data and methods are also used to attest to the hypotheses formulated to

determine the possible reasons for variability in the rates of diversification, speciation, and extinction. Paleo-biology can act as a facilitator to understand comprehensively the constraints and mechanisms of adaptation during unique historical events, for example, sudden outbreak and explosive origin of life and its diversity following occupation and colonization of land by plants and arthropods. Paleo-biology can explain the difference between various organisms in their susceptibility to extinctions and their way of recovering from such lethal activities, highlighting and making the principle of common sequences that favor one taxon and expose others to extinction activities more understandable. This discipline also provides us with necessary information on the mechanism of expansion of weedy species and characteristic time scales of ecosystem recovery. Both of these parameters deal with the modern biodiversity crisis and trace the history of characters, how and when they appeared during evolution, and whether these characters are mutually related. This relevancy and relationship of characters can be observed and is more prominent in evolving lineages. This data type is required to test many hypotheses, such as “punctuated equilibrium” (Fig. 1.3, and Fig. 1.4).

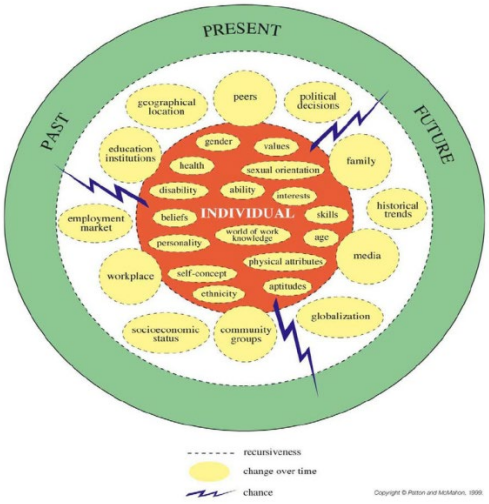

Fig. 1.3. Systems theory(Courtesy of Smith et al., 2009)

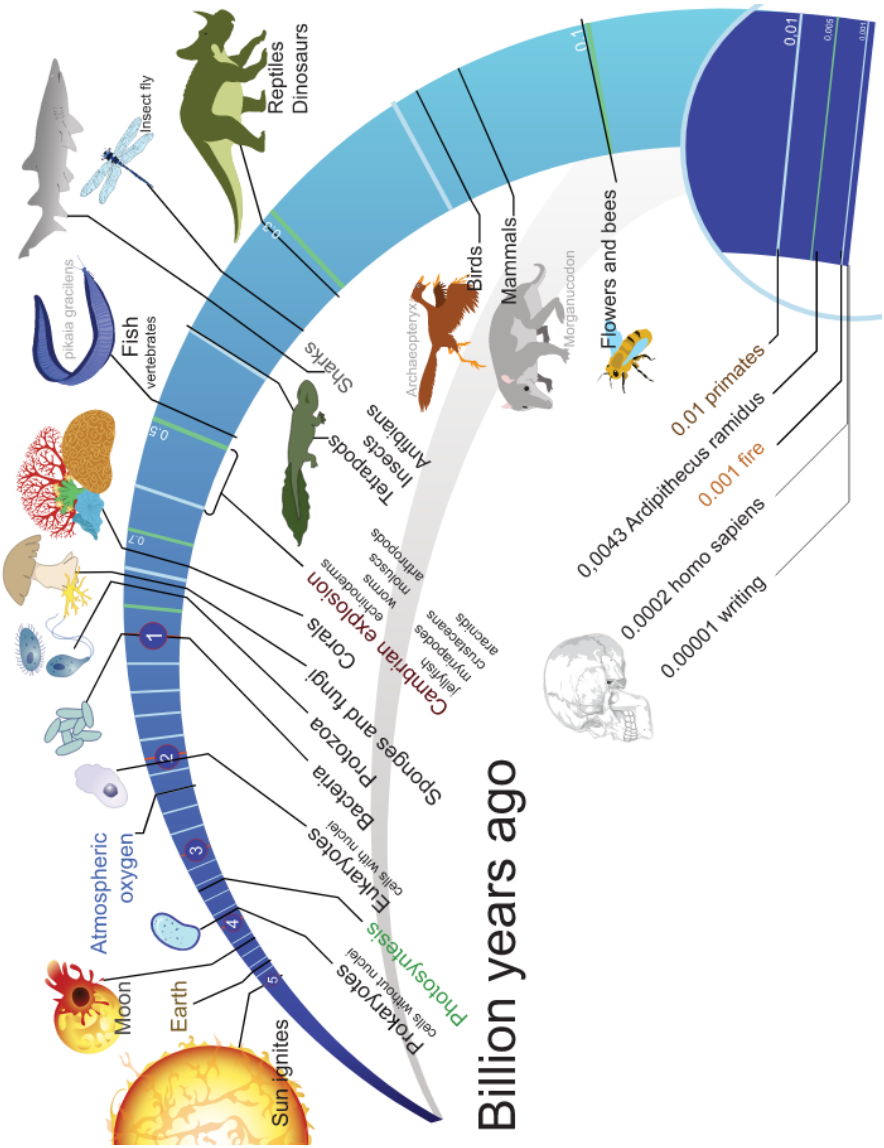

Fig. 1.3. Deep dive into evolutionary history (Source: medium.com)

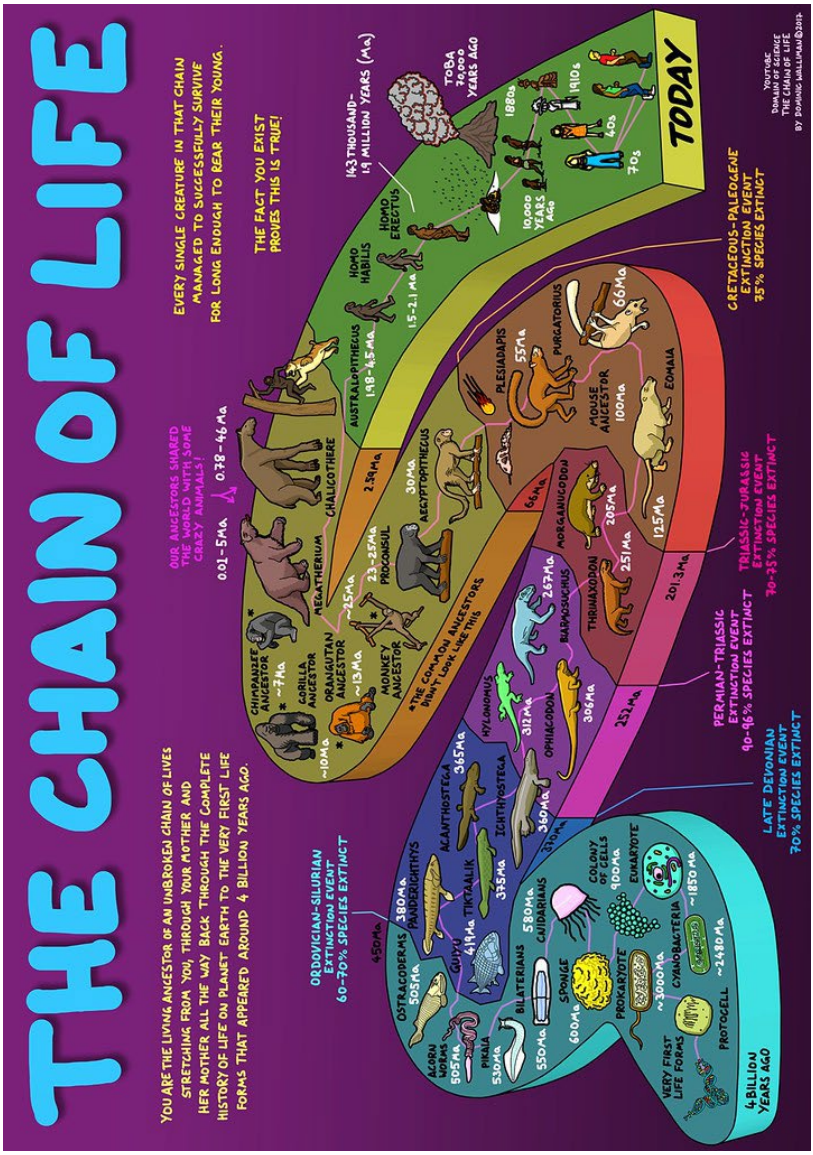

Fig. 1.4. Chain of life (Source: flicker.com)

3. Systematics

In evolutionary history, systematics contribute much to our knowledge of this study area. Systematics can also help. To confirm evolutionary processes, we need to test hypotheses by getting information from the sequences and time when lineages of organisms divided into branches when changes occurred in sequences and what the rate of change in characteristics in all these activities systematics can act as a facilitator to achieve all these processes. With the improvements in analytical methods and data, systematics has become a more vibrant and rigorous field than before. Despite all these efforts, there is still a lot to do. Among the critical challenges which need immediate and necessary attention are;

The first one is documentation of the diversity of living organisms, which means that living organisms vary and diversify significantly. For example, in invertebrates, several species need description and proper identification; important among them are bacteria, protists, fungi, nematodes, mites, and many groups of insects. Nonetheless, these groups of organisms play a pivotal role in ecosystems in their various forms, impinging directly on human welfare. Suppose all the existing organisms are fully known, and their record with peculiar characteristics is current. In that case, the majority of branches of biology like ecology, evolutionary biology, and other biological sciences can base and depend on that data for their further development, similar to the different data sets obtained from geologic surveys that support earth science and the extractive industries for their further development and promotion (Fig. 1.5, 1.6, and 1.7).

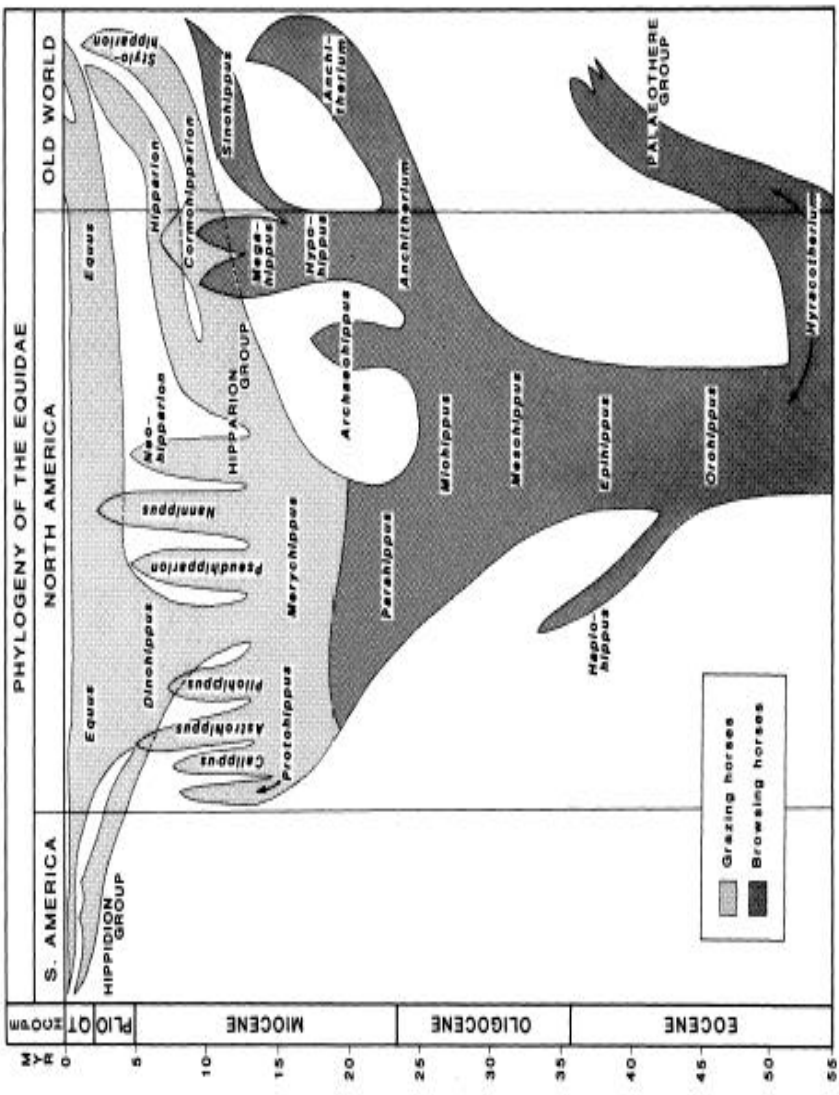

FIGURE 1. Current phylogeny of the Equidae, with particular emphasis on the North American taxa.

Fig. 1.5. Evolutionary systematics (Source: palaeos.com)

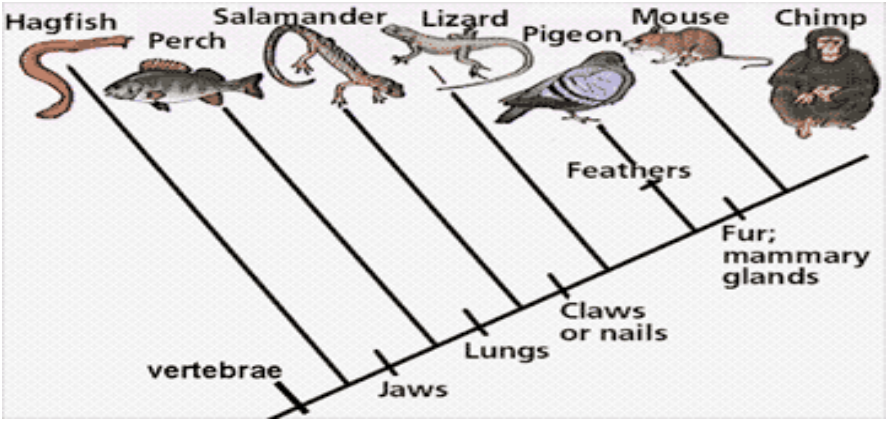

Fig. 1.6. Phylogeny and systematics (Source: quia.com)

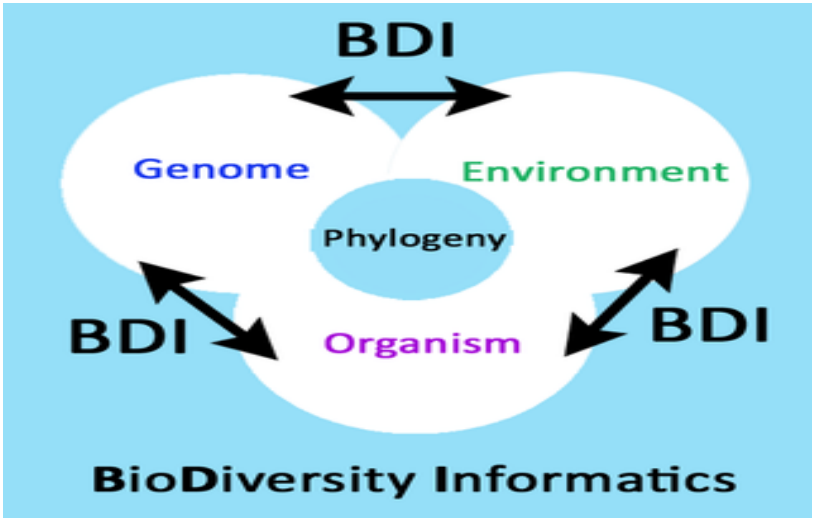

Fig. 1.7. Evolutionary genetics for 21st century (Source: journals.plos.org)

The development of the Tree of Life tells the development of estimates of Phylogeny for a small minority of taxa. Despite their limited applicability, these few estimates have already been widely used to verify various hypotheses in many ecology and evolutionary biology areas. Evolutionary systematics should promote more phylogenetic trees that display living and extinct organisms, which is always a focus of evolutionary systematics.

If these trees of life join together, they can facilitate the building and development of the Phylogeny of all life. Perfect development of the Tree of Life helps to organize a framework for biological data of all kinds, serving as a basis for testing numerous hypotheses.

Only when and unless the methods used for phylogenies, evaluation, and finally inferring their outcomes are well-improved testing of hypotheses is hard to achieve. Further, methods still need to be developed to determine the differences among groups in diversification rates from each other by using tree structure. Further, this establishment of theoretical and empirical bases that facilitate the integration of phylogenetic history with evolutionary processes is still a challenge for evolutionary biologists. Suppose researchers want to create a fully integrated theory of evolutionary biology. In that case, they must find ways to bridge the gap between theory and data on evolutionary processes and the procedures of phylogenetic inference.

4. Formation of Species

Speciation is a controversial and challenging topic in evolutionary biology. This topic proceeds too fast and needs to be revised fossil record fully. In another way, it is round too slowly, so it is hard to observe during the lifespan of the researcher. In this scenario, to answer some major questions about this process, we need to develop new approaches that still need to be developed. Speciation requires some essential criteria for its complete comprehension and apprehension. It requires genetic and mathematical characterization of characters that differentiate between newly formed species that cannot exchange genes between them. During the formation of new species, along with several genes and their location, we also need to know the biochemical and developmental effects on the reproductive isolation of the species due to these gene differences. What causes Speciation has yet to be fully explored. Speciation is still a central, unresolved question despite knowing that natural selection and genetic drift are two significant factors that cause Speciation. If Speciation occurs due to natural selection, then the agents for this selection must be appropriately identified. As we do not know whether isolated populations inevitably become different species, there is also a need to determine the rapidity and predictability of Speciation. Not enough is known about the rate of Speciation, and also still, it needs to be clarified what factors control the rate of Speciation, whether it depends on environmental conditions or taxa. Moreover, we also need information on the level of

involvement and requirement of the geographic isolation for the process of Speciation (Fig. 1.8, 1.9, 1.10, 1.11, and 1.12).

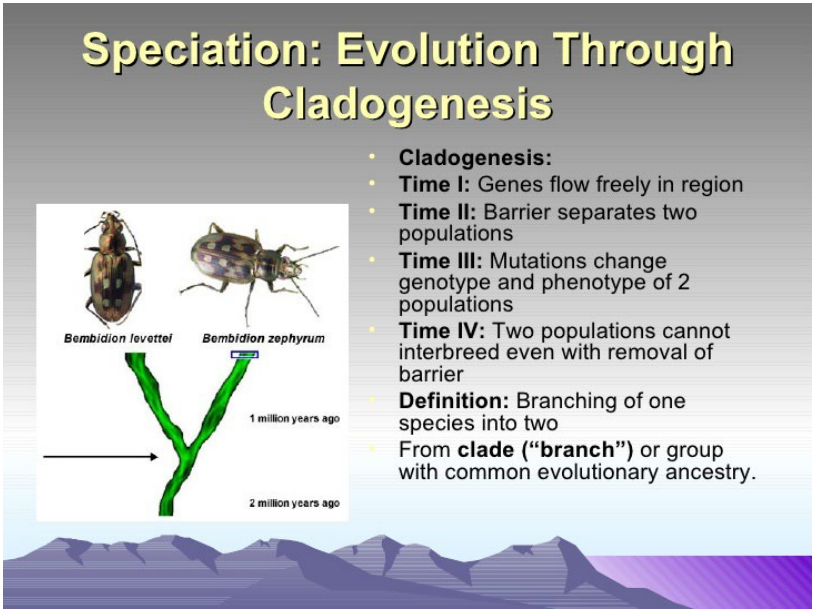

Fig. 1.8. Speciation and evolution (Source: slideshare.net)

G11.4B 5 – Evolution – Speciation

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Speciation occurs when populations of the same species evolve to become so different that they can't breed with one another to produce fertile offspring.

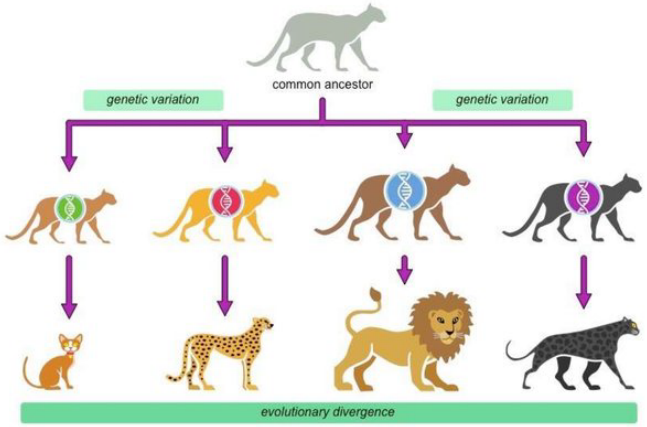

Fig. 1.9. Speciation-evolution (Source: ppt-online.org)

Extra help

Bozeman Speciation
http://www.bozemanscience.com/speciation

Understanding Evolution Website
https://evolution.berkeley.edu/evolibrary/article/evo_14

Learning Objectives

11.2.6.5 11.2.6.5 classify the main mechanisms of speciation

Success Criteria

1. Define species, speciation and hybrid.
2. State and explain the two parts of speciation with examples.
3. Explain, identify, and give examples of the 4 main mechanisms of speciation

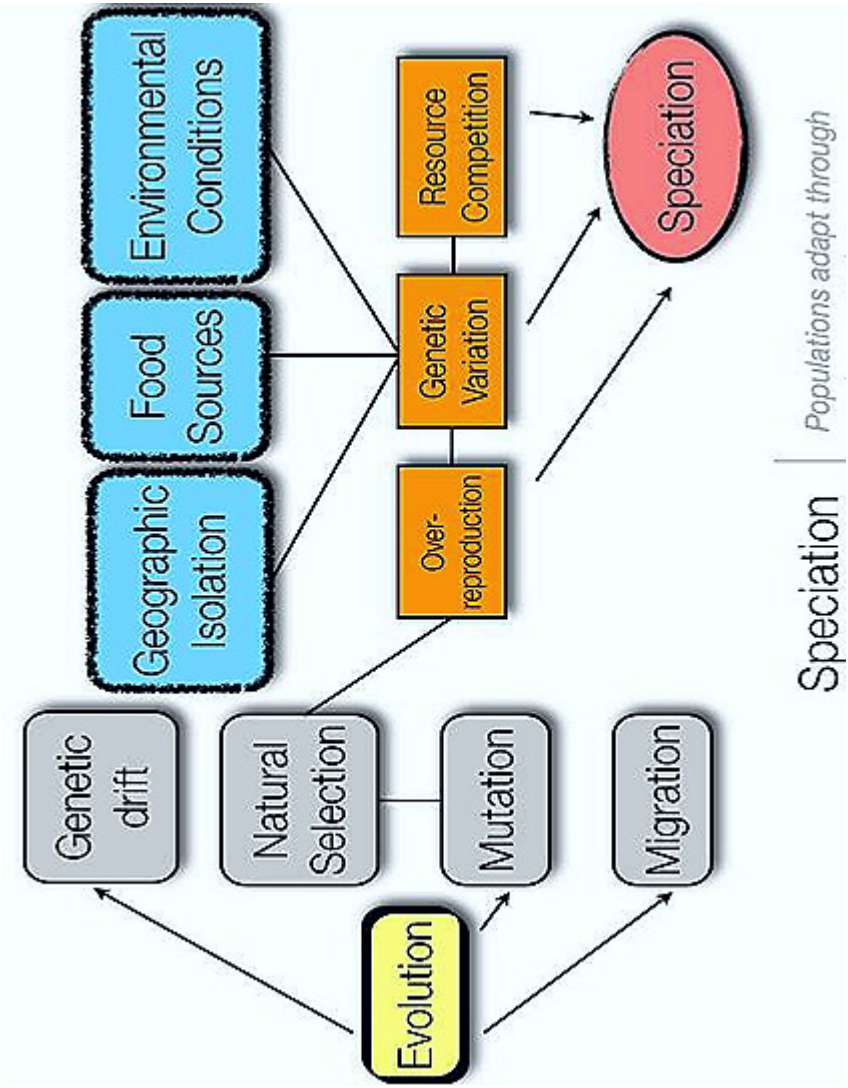

Fig. 1.10. Speciation in organic evolution (Source: biozoomer.com)

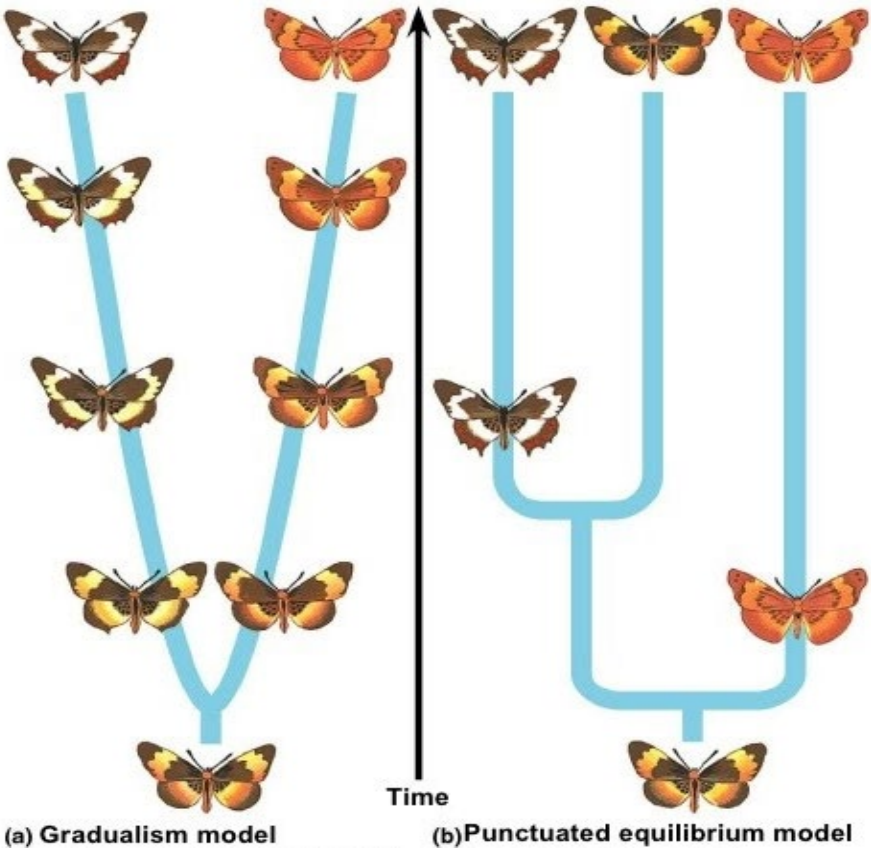

Fig. 1.11. Rate of Speciation (Source: sites.google.com)

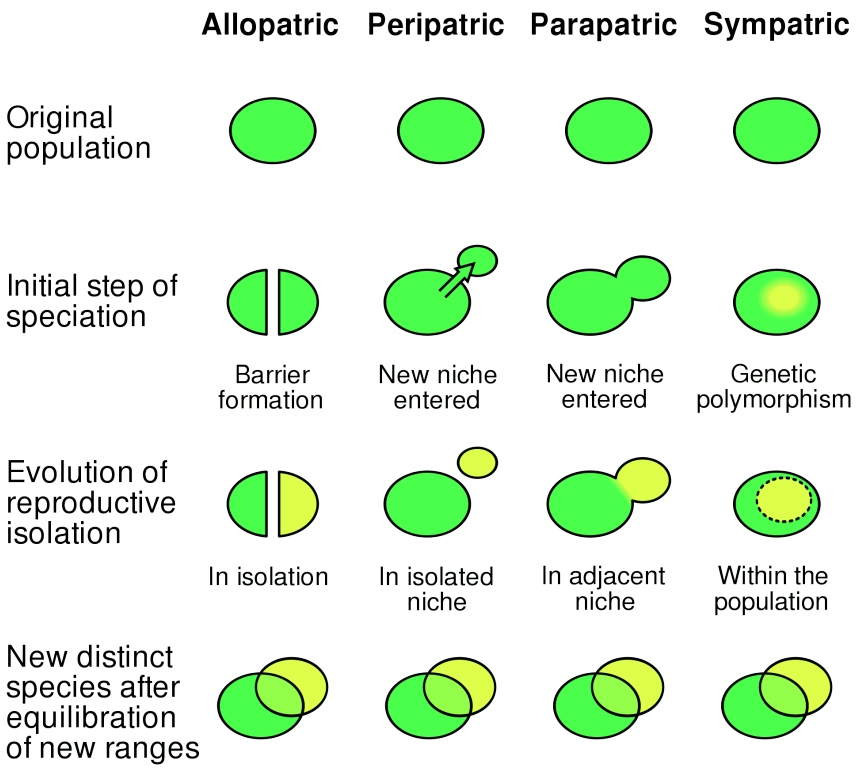

Fig. 1.12. Types of Speciation (Source: nationalgeographic.org)

5. Evolutionary genetics

Evolutionary and population genetics play a significant role in the theory of evolution and Speciation following their characteristic analysis. Currently, evolutionary genetics is facing several challenges. The foremost and the major one is to develop a new theory on those topics of this field of study that need to be adequately explored. Such issues are like epistasis, also called the nature of gene interactions, and what are the consequences of these interactions in evolution? In addition to these, some other topics are included under this category. These are clusters of local populations susceptible to recolonization of genetic processes in meta-populations and extinction. Finally, these genetic processes lead to Speciation. New methods developed so far are giving us much better and more precise

information and helping us explain the genetic variation in natural populations. Out of these methods, analysis of DNA sequence variation is essential. Understanding of the evolutionary processes can be further facilitated if DNA sequence variation studies are integrated into population-level studies. If we talk about variations in species and populations that arise through mutations, then several questions come to mind. These questions are: are there any prohibited states of various characters that never come up? The next question is whether the occurrence of mutations is synergistic, and if they happen synergistically, then what might their pleiotropic effects be? The next challenge is characterizing the genetic basis responsible for the variation of characters in species and populations.

Nonetheless, improvement in the mapping methods (quantitative trait loci) eases the identification of the loci responsible for character variation. In addition, it will also help explore and observe the mechanical effects of those loci on the development, morphology, and physiology of developing organisms. Studies on the developmental function of genes and their variation and evolution can be integrated with the identification of candidate genes. The next challenge comes in developing such a theory that can predict the Level of adaptability of living organisms to environmental change when it occurs. We must thoroughly understand when and where populations succeed and fail in adapting the organisms to global warming and linked environmental change (Fig. 1.13, 1.14, 1.15, 1.16, and 1.17). This phenomenon ultimately requires that we fully understand what factors and forces govern the rate of evolution. With the comprehension and understanding of other basics, we also need to understand population genetics of extinction of species. From a comparative perspective, there is insufficient knowledge about the mechanism by which these factors halt the flow of genes and promote inbreeding depression in a population that is already in the process of decline or shrinkage. This type of knowledge, for the preservation of biodiversity and designing of the refugia for endangered species, will be necessary.

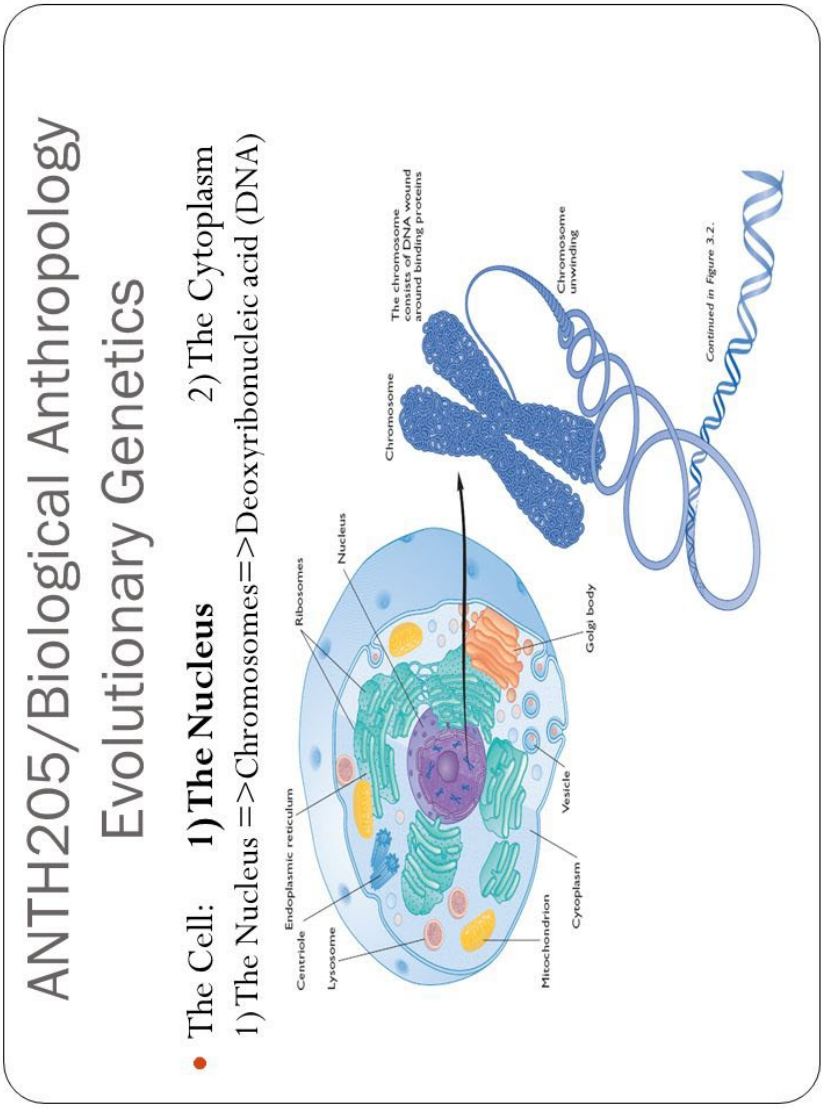

Fig. 1.13. Cell structure and evolutionary genetics (Source: slideplayer.com)

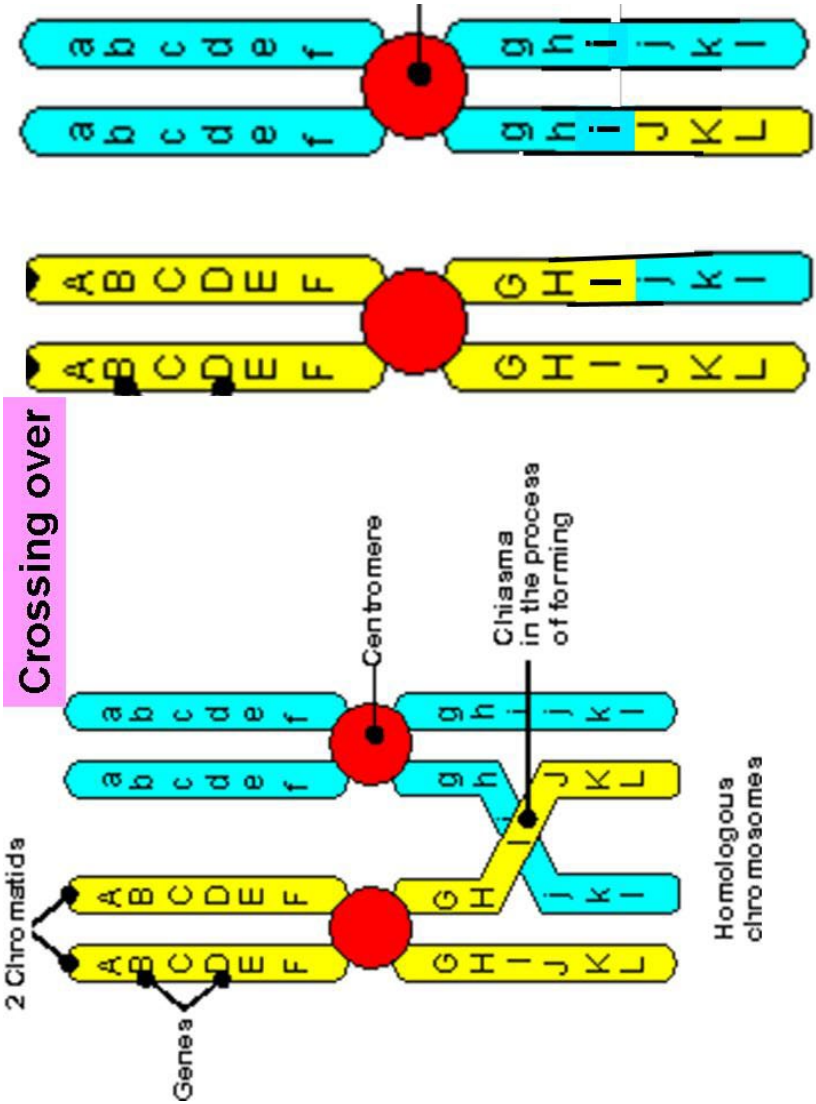

Fig. 1.14. Crossing over and evolutionary genetics (Source: scienceoveracuppa.com)

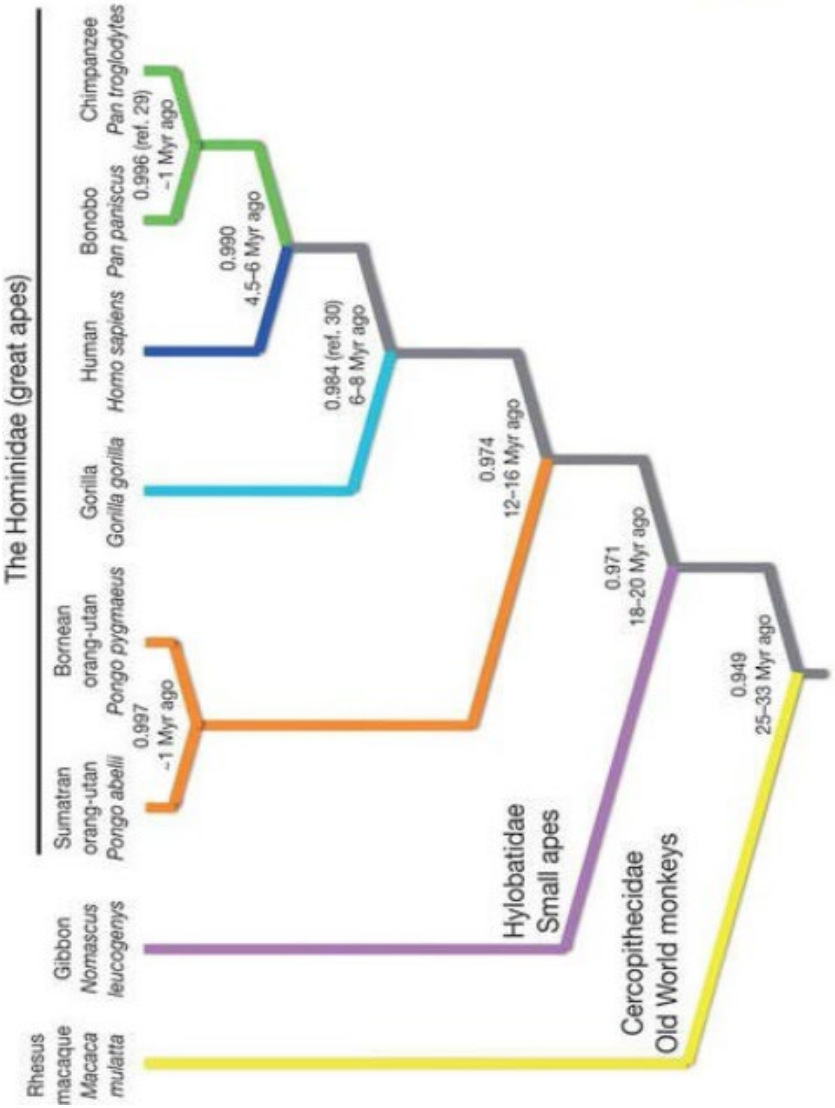

Fig. 1.15. Evolutionary genetics (Source: slideshare.net)