Beyond Origins: Evolution and Extinction of humans Unraveling the Remarkable Story of Life's Evolution from Single-Celled Organisms to Modern Humans

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Abstract:

The discussion about the evolution of life on Earth has always been an interesting and debatable topic that has been studied for many years. This review article aims to thoroughly examine the evolution of life on Earth, from the origin of single-celled organisms to the development of contemporary humans. It focuses on the variables that have affected the process of evolution of life on Earth. It highlights the events that have led to the evolution of humans. The study of evolution covers various stages, starting from the early Earth and the origin of life to the emergence of prokaryotes. This study includes the analysis of competing theories of abiogenesis and panspermia. It also examines significant milestones such as the oxygenation of the atmosphere, the evolution of photosynthesis, and the transition of eukaryotes. Furthermore, it explores the evolutionary transitions that occurred during the colonization of land, which involved the adaptations of plants and fungi, the evolution of various terrestrial animals such as insects, amphibians, reptiles, and mammals, and the formation of diverse ecosystems. This review also discusses the contemporary challenges and future directions in the field. It encompasses the implications of human-induced changes on ecosystems, the importance of conservation efforts in preserving biodiversity, the role of technological advancements in advancing our understanding of evolution, and the promising avenues for future research. Finally, it reflects on the future of evolution and its potential implications.

Keywords: Evolution, Life on Earth, Abiogenesis, Panspermia, Eukaryotes, Biodiversity

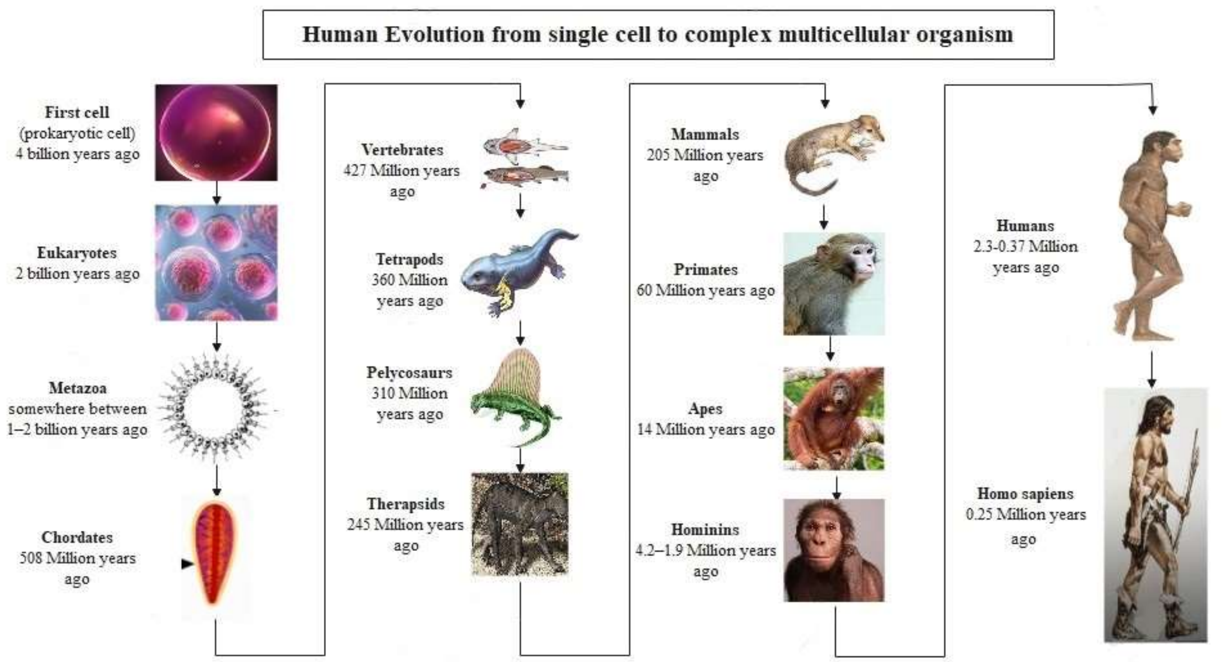

Figure 1: Phylogenetic tree of Human Evolution

1. Introduction

Evolution is defined as a process that results from the genetic modifications of a species over a period of time. It is termed as adaptations of the population of species in their changing environment that can result in the alternation of genes or physical traits. The evolution of life on Earth has been the subject of interest to scientists for billions of years. Scientists believed that approximately 3.8 billion years ago life evolved from single-celled organisms. (Erwin, 2015; Fortey, 2011; Lane, 2015). With the passage of time in order to adapt to the changes in environment several other life forms got evolved from these primitive creatures which are exist today such as single-celled organisms including bacteria, fungi, and viruses, and more complex multicellular organisms such as plants and animals (Doolittle, 2000; Tirichine & Bowler, 2011). This process of evolution from a single-celled organism to the development of complex multicellular modern humans consists of a time period of billions of years which also includes a plethora of biological and environmental changes. While the exact time period that the whole process of evolution took is still a topic of debate among the scientific community, this paper is an attempt to present the summary of key milestones and crucial events during this whole process. A general overview of significant stages and events in this whole process of human evolution will be discussed below.

The development of the first living forms, possibly in the form of single-celled creatures like bacteria, is thought to have occurred between 3.8 and 3.5 billion years ago, marking the beginning of life on Earth. The beginning of life as we know it now occurred within this time frame. (Davies, 2001). Prokaryotic cells, which lack a nucleus, predominated in the Earth's biosphere between 3.5 and 2 billion years ago. During this time, cyanobacteria underwent an evolution and acquired the capacity for photosynthesis, which allowed them to release oxygen into the atmosphere. (Shevela *et al.*, 2013). The evolution of eukaryotic cells, which have a nucleus and other organelles, marked a crucial turning point some 2 billion years ago. This signaled the eukaryotic revolution and opened the door for the emergence of sophisticated cellular structures through endosymbiosis, including mitochondria and chloroplasts. (O'Malley, 2010). With the evolution of basic multicellular organisms like algae and sponges, multicellular life first appeared between 1.2 billion and 600 million years ago. During this time, differentiated cell types and cell specialization also began to form (Makuch *et al.*, 2017). A dramatic diversification of life known as the Cambrian Explosion occurred between 541 and 485 million years ago. Various animal phyla emerged, leading to the appearance of complex organisms including arthropods, mollusks, and chordates (Peng *et al.*, 2020). In the subsequent period of vertebrate evolution, which occurred around 500 to 360 million years ago, the first vertebrates, jawless fish, arose in the oceans. This period also saw the evolution of fish with jaws and cartilaginous skeletons, such as sharks (Pandey, 2005). Around 385 to 360 million years ago, the tetrapod transition occurred as fish transitioned to land, giving rise too early tetrapods like Tiktaalik, which possessed features of both fish and amphibians (Clack, 2009). Reptiles became dominant around 310 to 66 million years ago, with the appearance and diversification of dinosaurs. Interestingly, birds evolved from tetrapod dinosaurs during this time (Griffin *et al.*, 2022). Approximately 225 to 66 million years ago, mammals emerged and diversified, occupying various ecological niches. Primates, including early primates resembling modern prosimians, also appeared during this period (Strier, 2015). The hominin evolution, which took place around 6 to 2 million years ago, marked the emergence of early hominins such as Australopithecus in Africa. Hominins began to walk upright, adapting to life on the ground (Pontzer, 2017). The genus Homo, spanning from approximately 2 million years ago to the present, saw the evolution of species like *Homo Habilis* and *Homo Erectus*. Important developmental milestones include the use of tools, the emergence of language, and a rise in brain size occurred during this time. Around 300,000 years ago, *Homo Sapiens*, or modern humans, first appeared. Subsequent human migration and spread over the globe led to the rich range of cultures and civilizations we see today. (Broadhurst *et al.*, 1998; Carroll, 2003; Wood & Collard, 1999a, 1999b).

1. Over time, these organisms have undergone evolution resulting in the emergence of new species that occupy diverse ecological niches (Loxdale *et al.,* 2011; Polechová & Storch, 2008). The emergence of photosynthesis was a crucial turning point in the evolution of life on Earth. It allowed plants to harness the energy of the sun and produce oxygen as a byproduct. This momentous event is well-documented in scientific literature (Janssen *et al.,* 2014; Souza & Eguiarte, 2018). This led to an increase in atmospheric oxygen levels, which allowed for the evolution of oxygen-dependent species. (Cole *et al.,* 2020; Reinhard, *et al.,* 2016; Taverne *et al.,* 2018).

2. Importance of Studying the Evolution of Life on Earth:

The study of the evolution of life on Earth is essential in comprehending the origin of the diverse species that inhabit our planet today (Hu *et al.,* 2019). Scientists can gain insights into how different animals interacted with their environment by examining the historical development of life on Earth, including the environmental factors that impacted their evolution (Schell *et al.,* 2020). Evolutionary biology also has significant implications for fields such as medicine and agriculture, as it helps us understand the mechanisms that support the development and adaptability of living creatures (Holmes *et al.,* 2016).

Recent studies have provided fascinating insights into the evolution of life on Earth, shedding new light on the origin and development of many types of creatures (Bukh, 2016). For example, new evidence suggests that microbial life existed on Earth over 3.7 billion years ago, earlier than previously believed (Pearce *et al.,* 2018). Additionally, other studies have identified new information about the development of early creatures, such as the discovery of the oldest known fossilized animal embryo, dating back over 550 million years (Cunningham *et al.,* 2017).

Understanding the evolution of life on Earth is crucial in predicting and mitigating the impact of environmental changes on biodiversity (Urban *et al.,* 2016). With growing concerns about climate change and other human-made environmental changes, the study of the evolution of life on Earth is more important than ever (Daz *et al.,* 2019). By analyzing the past reactions of living organisms to environmental change, scientists can better understand how present and future environmental changes will affect current and future species (Cavicchioli *et al.*, 2019).

3. Evolutionary Milestones: Humans Unleashed

A series of significant evolutionary milestones, such as the development of bilateral symmetry and the emergence of vertebrates, have defined the animal kingdom's history (Holland, 1998; Xu *et al.*, 2019). Eventually, humans evolved as a distinct species, with the ability to think, reason, and build advanced civilizations. (Carballo *et al.*, 2014; Kissel & Kim, 2019; Richerson & Boyd, 2001; Tainter, 1988; Tomlinson, 2015). Modern humans are thought to have evolved some 200,000 years ago, and we have continued to change and adapt to our environment since then (Almecija, 2021; Binford, 1989; Campbell & Tishkoff, 2010; Klein, 2009; Lewin, 1987). Table 1 & 2 indicating the major evolutionary milestones in the history of life.

Event	Approximate Time	References
Emergence of single-celled organisms	Around 3.8 billion years ago	Erwin, 2015; Fortey, 2011; Lane, 2015
Development of photosynthesis	Around 3 billion years ago	Janssen et al., 2014; Souza & Eguiarte, 2018
Great Oxygenation Event	Around 2.4 billion years ago	(Ligrone & Ligrone, 2019)
Emergence of bilateral animals	Around 555 million years ago	(Bottjer, 2005; Butterfield, 2015)
Emergence of vertebrates	Around 530 million years ago	(Feinberg & Mallatt, 2013)
Emergence of anatomically modern humans	Around 200,000 years ago	Binford, 1989; Campbell & Tishkoff, 2010; Klein, 2009; Lewin, 1987
Neolithic Revolution	Between 10,000 and 5,000 years ago	(Cao et al., 2006; Weisdorf, 2005)
Publication of "On the Origin of Species"	1859	(Darwin's, 1859)

Table 1: *A timeline of life on earth, from single-celled organisms to modern humans and beyond.*

The study of the evolution of life on Earth is a complicated and ongoing field of study, with new discoveries and insights being discovered on a regular basis. Scientists may piece together the amazing tale of how life on Earth developed over time by researching the fossils, DNA, and ecological interactions of different species.

4. Life Evolution:

The evolution of life on Earth is a captivating and intricate subject that delves into the transformations of living beings' diversity and complexity over billions of years. From its origins about 4.5 billion years ago, life on Earth has undergone countless remarkable changes, giving rise to the wide range of life forms we see today. This multidisciplinary field of study involves biology, geology, paleontology, and genetics. As illustrated in table 2, the evolution of life over time is a fascinating journey that continues to unfold.

Event	**Approximate Date**	**References**
Formation of Earth	4.6 billion years ago	(Svensmark, 2006)
Origin of Life	4.5 billion years ago	(Wald, 1964)
Photosynthesis	3.5 billion years ago	(Olson & Pierson, 1986)
First Eukaryotic Cells	2 billion years ago	(Vidal, 1984)
Cambrian Explosion	541 million years ago	(Briggs, 2015; Smith & Harper, 2013)
Colonization of Land	500 million years ago	(Graham *et al.*, 2014)
Dinosaurs	230 million to 66 million years ago	(Benton, 2022)
Mass Extinction Events	Throughout Earth's history	(Raup, 1986)
Rise of Mammals	200 million years ago to present	(Falkowski *et al.*, 2005)
Human Evolution	Over the past few million years	(Owen *et al.*, 2018)

Table 2: *Timeline of Life Journey through Billions of Years*

5. Early Earth and the Origin of Life:

The question of how life originated on Earth is still a subject of debate and speculation among scientists. It is believed that life began to emerge around 3.8 to 4 billion years ago (Morowitz, 1993; Rauchfuss, 2008), during a period when the Earth's ecology was drastically different from what it is today. The atmosphere was much more volatile, and there was frequent volcanic activity (Prinn & Fegley Jr, 1987; Sigurdsson, 1990). Despite our understanding of the conditions present at that time, the exact requirements for life to emerge remain unknown. Some hypotheses believe that the first living species arose in underwater hydrothermal vents, while others propose that life began on land as self-replicating RNA molecules (Hazen, 2001; Horgan, 1991; Orgel, 1998). Whatever its roots, the origins of life on Earth were a complicated and spectacular process that has enthralled scientists and the general public for ages (Bada & Lazcano, 2003).

5.1. Conditions of early Earth:

The early Earth, 4.6 billion years ago, was a radically different world than it is today (McCarthy, 2013; Zalasiewicz *et al.,* 2010). The surface was hot and molten, and asteroids and comets were continually bombarding it (Cockell, 2006). The atmosphere was mostly constituted of carbon dioxide, nitrogen, and water vapour, but it was devoid of oxygen (Liss, 1973; Ryle & Hesketh, 1969; Yamamoto, 1962). The oceans were only starting to form and were likely acidic due to high carbon dioxide levels (Beniash *et al.,* 2010; Hartmann *et al.,* 2013; Heuer & Grosell, 2014). The early Earth was also exposed to high levels of UV light from the sun, which could have harmed living species (Bryce *et al.*, 2015; *Cockell et al.*,2011).

5.2. Hypotheses on the origin of life:

There are several hypotheses on the origin of life, including:

Abiogenesis: According to this theory, life evolved spontaneously from non-living substances through a sequence of chemical interactions. Some scientists believe that the first living species sprang from hydrothermal vents on the ocean floor or from shallow pools of water on land (Marshall, 2020).

Panspermia: This theory posits that life on Earth evolved from microscopic life forms brought to Earth on comets or asteroids from other planets or solar systems (De Mol, & M. L. 2023).

Directed panspermia: Lovelock, J. (2016) contends that life on Earth was purposefully seeded by a sophisticated extraterrestrial culture.

5.3. Evidence supporting the origin of life:

There is no definitive evidence that proves the origin of life, but there are several lines of evidence that support the various hypotheses:

- Miller-Urey experiment: In 1952, Stanley Miller and Harold Urey conducted an experiment to recreate early Earth conditions. They generated a gas mixture of methane, ammonia, and hydrogen and exposed it to electrical sparks to simulate lightning. The experiment produced amino acids, which are the building blocks of proteins, implying that the early Earth's circumstances may have produced the building blocks for life Cleaves II, H. J. (2022).
- Fossil record: The fossil record contains evidence of the earliest known life forms, dating back around 3.5 billion years. These organisms were primitive, single-celled organisms capable of photosynthesis, such as cyanobacteria (Roos *et al.*, 2019).
- The RNA world hypothesis contends that RNA, rather than DNA, was the first self-replicating molecule on Earth. Because RNA can store genetic information as well as operate as an enzyme, it may have been able to catalyst its own reproduction and evolve into more complex organisms (Kun *et al.*, 2015).
- Organic molecules in space: Organic molecules such as amino acids and sugars have been discovered in meteorites and comets, implying that they were delivered to Earth via panspermia (Yamagishi *et al.*, 2021).
- In figure 5 some major milestones in the Journey Life Origin is presented.

Evidence Supporting the Origin of Life	**Date/Year**	**References**
Miller-Urey experiment	1952	(Cleaves II, H. J. 2022)
Fossil record	Approximately 3.5 billion years ago	(Roos *et al.*, 2019)
RNA world hypothesis	1960s	(Kun *et al.*, 2015)
Organic molecules in space	Ongoing discoveries over the past few decades	(Yamagishi *et al*., 2021)
Ancient microbial fossils	Various periods, dating back to approximately 3.5 billion years ago	(Noffke *et al.*, 2013)
Hydrothermal vents	Late 1970s	(Oreskes, 2003)

Early genetic material	Approximately 4 billion years ago	(Eigen *et al.*, 1981)
Astrobiology missions	Ongoing, with notable missions including Viking missions (1976), Mars rovers, and Mars 2020 Perseverance rover	(Farley *et al.*, 2020)
Alternative biochemistries	Ongoing scientific investigations	(Wilson, 1990)

Table 3: *Key Milestones in the Origin of Life Journey*

6. Prokaryotes and the Rise of Oxygen

An important factor in the increase of oxygen in the Earth's atmosphere was played by prokaryotes. A study that was published in Nature Microbiology claims that the ability to manufacture oxygen through photosynthesis first appeared in cyanobacteria about 2.5 billion years ago (Soo *et al.*, 2017). As a result of this process, oxygen accumulated in the atmosphere, opening the door for the development of more complex eukaryotic species. Many prokaryotes, on the other hand, found it difficult to adjust to the surge in oxygen since they were used to living in an oxygen-free environment (Scilipoti *et al.*, 2021). As a result, many anaerobic prokaryotes have to change to survive in the presence of oxygen. Through processes like nitrogen fixation and carbon cycling, prokaryotes still play a significant part in controlling the Earth's oxygen levels today. (Rucker, *et al.*, 2023).

6.1.Characteristics of prokaryotes:

Prokaryotes are unicellular creatures without a nucleus or organelles that are bound to membranes. With an estimated 5 x 1030 unique prokaryotic cells in existence, they are the oldest and most numerous forms of life on Earth (Mushegian, 2020). Based on their genetic and metabolic properties, prokaryotes can be classified into the Archaea and Bacteria domains (Czech *et al.*, 2018). Figure 8 shows how organisms are categorized hierarchically, from domains to species. They display a variety of metabolic processes, such as fermentation, chemosynthesis, and photosynthesis. Prokaryotes are essential for the global cycling of nutrients, and the biosphere of the planet is significantly impacted by their metabolic activities (Chen *et al.*, 2023). A summary of the genetic and molecular data proving evolutionary relationships can be found in figure 10.

6.2. Cyanobacteria and the Great Oxygenation Event:

According to Sciuto, K., & Moro (2015), cyanobacterria are a class of photosynthetic prokaryotes that were essential to the evolution of life on Earth. Cyanobacteria acquired the capacity for oxygenic photosynthesis, which entails using water as an electron source to produce oxygen gas as a byproduct, about 2.4 billion years ago (Shih *et al.*, 2017). The emergence of eukaryotic species was made possible by this process, which also significantly increased the amount of oxygen in the atmosphere (Cole *et al.*, 2020). The time between 2.4 and 2.3 billion years ago, when atmospheric oxygen levels sharply increased, is known as the Great Oxygenation Event (GOE) (Wogan *et al.*, 2022). It is most likely that cyanobacteria's broad evolution and proliferation is what caused the increase in oxygen levels. The GOE had significant effects on the biology of the planet, leading to the demise of several anaerobic creatures that could not tolerate oxygen. (Judson, 2017). The emergence of complex multicellular organisms, such as plants and animals, was also facilitated by the increase in atmospheric oxygen (Reinhard *et al.*, 2016).

6.3. Impact of oxygen on Earth's atmosphere and life:

The Earth's biosphere was significantly impacted by the increase of atmospheric oxygen. As a result, many anaerobic organisms went extinct and new, oxygen-tolerant species developed (Ward *et al.*, 2019). Additionally, oxygen was essential in the formation of the ozone layer, which shields the surface of atmospheric the Earth from dangerous UV radiation. Plants and animals were able to colonize the land thanks to this protection (Bornman *et al.*, 2015; Haidri et al., 2023; Hussain et al., 2024). The global carbon cycle was significantly impacted by the increase in oxygen as well (Schimel *et al.*, 2015). When oxygen and organic material interact, carbon is oxidized, which releases carbon dioxide into the environment. Over geological eras, this activity, known as respiration, has assisted in regulating the Earth's climate. It is important to the global carbon cycle. In 2020, Hilton, R. G., and West, A. J. Figure 6 Shows the timeline for the evolution of life on Earth.

7. Eukaryotes and the Emergence of Multicellularity

A crucial evolutionary event that enabled the diversification and complexity of life on Earth was the development of multicellularity in eukaryotes (Mukherjee *et al.*, 2018). A 2020 study that appeared in Nature Communications suggests that a combination of genetic modifications, such as the evolution of cell adhesion and signaling mechanisms, and environmental pressures, such as predation and competition for resources, were likely responsible for the evolution of multicellularity. Additionally, the formation of tissues and organs as a result of the specialization of cells made possible by multicellularity allowed for the emergence of more advanced animals. It is obvious that the development of multicellularity was a crucial stage in the evolution of life on Earth, even though the precise mechanisms underpinning this process are still under investigation. (Luisi, 2015).

7.1. Characteristics of eukaryotes:

Organisms known as eukaryotes contain a separate nucleus and membrane-bound organelles that are in charge of performing certain tasks (Volland *et al.*, 2022). They stand out for their size, intricate cellular makeup, and high level of cellular specialization. Eukaryotes also have a cytoskeleton, which aids in cell mobility and division as well as structural support (Harding *et al.*, 2020). The ability of eukaryotes to reproduce sexually, which involves the fusing of gametes and the exchange of genetic material between people, is one of their most distinctive characteristics. As a result, more genetically diverse offspring can be produced, which may improve their capacity to adjust to changing surroundings (Xavier et al., 2019; Ummer et al., 2023; Waseem et al., 2023).

7.2. Evolution of multicellular organisms:

A significant turning point in the history of life on Earth is the evolution of multicellularity. Animals, plants, and fungi are all lineages of eukaryotes, and multicellularity independently emerged in each of these lineages. (Jindrich *et al.*, 2016). The formation of specialized cell types, the ability to communicate and coordinate behavior amongst cells, and the capacity to control cell division and differentiation were all crucial developments required for the evolution of multicellularity. (Niklas *et al.*, 2020). Red algae, which first emerged in the fossil record about 1.2 billion years ago, is one of the first examples of multicellularity (Demoulin *et al.*, 2019). Important fossils to demonstrate significant evolutionary events or remarkable species are shown in figure 7. These creatures develop intricate, branching structures that can reach lengths of several meters. The brown algae, which create kelp forests in the ocean, and the green algae, which contain a variety of creatures ranging from single-celled plankton to giant seaweeds, are two further examples of multicellular eukaryotes. (Jayasankar, 2022; Fatima et al., 2024; Haidri et al., 2024). Animals are believed to have evolved multicellularity some 600 million years ago, during the Ediacaran era (Stockey, 2018). Small, tube-shaped animals that lived on the ocean floor left the first animal remains. Animals developed a variety of specialized tissues and organs over time, including muscles, nerves, and sensory systems, which enabled them to move and react to their surroundings in more intricate ways (Jékely *et al.*, 2021; Ullah et al., 2024)).

7.3. <u>Diversification of eukaryotes:</u>

The group of organisms known as eukaryotes is extraordinarily diverse, with a huge variety of morphological, physiological, and ecological traits. Environmental change, interspecies competition, and genetic innovation are some of the causes that are hypothesized to have contributed to eukaryote diversification (Knoll *et al.,* 2017). The endosymbiotic theory proposes that mitochondria and chloroplasts were once free-living bacteria that were consumed by ancient eukaryotic cells. This theory allowed eukaryotes to diversify by creating new metabolic pathways and allowing the use of new energy sources, which could have led to the evolution of more complex animals (Taverne *et al.*, 2018). Sexual reproduction also played a significant role in the diversification of eukaryotes by producing offspring with greater genetic variation. This variation improved an organism's ability to adapt to its environment, which may have been crucial to the rapid diversification of eukaryotes during the Cambrian explosion about 540 million years ago (Wood *et al.,* 2019).

In summary, the origin of eukaryotes and the development of multicellularity have had a profound impact on the history of life on Earth. They have resulted in the formation of a diverse range of complex organisms with various ecological roles and adaptive mechanisms. (Huang *et al.*, 2022).

8. Evolution of Animals

The evolution of animals is a fascinating and complex topic that has been extensively researched by experts. According to recent studies, creatures first emerged on Earth during the Neoproterozoic era, which occurred roughly 800 million years ago (Cole *et al.,* 2020). Over time, these early animals evolved and diversified, resulting in the creation of several phyla and species. The Cambrian explosion, which happened approximately 541 million years ago and led to the rapid diversification of living organisms, is considered one of the most significant events in the history of mammals. Since then, animals have continued to adapt and change in response to their environments, leading to the vast array of species that exist today. The interesting tale of animal evolution continues to be illuminated by developments in genetics and evolutionary biology (Ernst *et al.*, 2021).

8.1. The Cambrian Explosion:

Approximately 541 million years ago, during the Cambrian period, there was a tremendous diversity of animal life known as the Cambrian explosion. Most significant animal phyla, or groups, emerged at this time, and many of them are still around now. Most of the diversity appeared within 10–20 million years, indicating that the explosion took place over a geologically brief time span (Scotese *et al.,* 2021).

There is still substantial disagreement among scientists regarding the reason behind the Cambrian explosion. According to one explanation, it was caused by an increase in atmospheric oxygen concentrations, which would have given metabolism more energy and aided in the evolution of complex species. Another idea contends that the development of genetic regulatory networks enabled the emergence of more complicated body designs (Harrison, 2017). According to recent study, a number of environmental conditions may have helped to facilitate the Cambrian explosion. For instance, it's possible that the dissolution of the supercontinent Rodinia led to the creation of new habitats that facilitated diversification (Yang *et al.*, 2021). In the field of evolutionary biology, it is believed that the development of defensive adaptations and novel body designs might have been shaped by predation, according to (Lüddecke *et al.* 2022).

8.2. Evolution of vertebrates

The group of animals known as vertebrates includes fish, amphibians, reptiles, birds, and mammals. They can be identified by the vertebral column in their backbone, which provides support and protection to the spinal cord. Over the course of 500 million years of evolutionary history, vertebrates have undergone significant changes. The appearance of jawed fish during the Silurian epoch, around 420 million years ago, was one of the most significant turning points in the evolution of vertebrates, as noted by Andreev *et al.,* in 2022). Jawed fish, such as placoderms, had a more effective feeding strategy that allowed them to take advantage of new food sources and occupy new ecological niches. This led to rapid diversification of fish, with various body types emerging. Another major development in vertebrate evolution is the evolution of limbs. The earliest vertebrates, such as ostracoderms, were primarily bottom-dwellers and lacked limbs. Fish, on the other hand, were able to move through the water more efficiently thanks to the evolution of their fins, while vertebrates were able to move onto land thanks to the evolution of their limbs. This paved the way for the emergence of mammals, birds, reptiles, and amphibians, among others, that had adapted to life on land, as highlighted by Bennett *et al.*, in 2018).

8.3. Adaptive Radiation of Mammals:

Over 5,400 different species of mammals, ranging in size from tiny shrews to massive elephants, make up the diverse group of animals known as mammals. They are distinguished by having three middle ear bones, hair, and mammary glands. According to Lacher *et al.*, (2019), the evolution of mammals is characterized by a sequence of adaptive radiations that resulted in the emergence of a diverse range of body plans and ecological roles. Approximately 66 million years ago, at the conclusion of the Cretaceous epoch, one of the most dramatic adaptive radiations in the development of mammals took place. As a result of this occurrence, mammals were able to diversify and fill new ecological niches. As a result, numerous novel body plans emerged, including those of rats, whales, bats, and primates (Brocklehurst *et al.*, 2021). The Eocene period, which lasted roughly 56-34 million years ago, saw the occurrence of another significant adaptive radiation in the evolution of mammals. Modern orders of mammals, such as primates, carnivores, ungulates, and rodents, emerged as a result of this occurrence. According to Grossnickle *et al.*, (2019), these groups swiftly underwent diversification as they adapted to a variety of ecological roles and environmental factors. Recent studies have also demonstrated how interactions with other creatures have affected the evolution of mammals. For instance, interactions with nocturnal insects may have fueled the evolution of bats, whereas interactions with fruits and seeds may have affected the evolution of primates. (Nevo and Ayasse, 2020).

9. Evolution of Humans

The difficult and interesting process of human evolution has been thoroughly investigated by academics and scholars. Genetic study and empirical data support the theory that humans descended from apes and had a common ancestor with chimpanzees and bonobos (Prang *et al.*, 2021). Humans have evolved distinctive physical and mental traits over time, including an upright posture, larger brains, and intricate social structures. These changes and adaptations have taken many forms. Insight into the evolution of humans, particularly the origin of Homo sapiens in Africa and their migration to other continents, has been gained through the finding of ancient fossils and archaeological evidence (Groucutt *et al.*, 2015). The complexity of human evolution and the elements that have contributed to our current biological and cultural variety are still being clarified by ongoing research (Foley *et al.*, 2016). The genesis and development of people are considered in a distinctive way in Islamic theology. Islamic scholars have argued over the role of evolution in the creation of people, despite the Quran's assertion that all humans are the creation of Allah. While some claim that Allah created mankind directly, others maintain that they were produced gradually. The creation of humanity was a wondrous event, and according to Islamic thinkers, we have a unique place in the cosmos (Guessoum, 2016). Many Islamic scholars also contend that scientific advancements are compatible with Islamic principles and that knowledge of evolution can enhance our respect for Allah's creation. Overall, scholars and scientists are still delving into the rich and complicated Islamic view of human evolution, according to Jamali, & Karam, (2018).

9.1. Overview of human evolution:

The process of genetic and physical changes that have taken place in the human lineage over millions of years is known as human evolution. About 65 million years ago, the first monkeys appeared, and over time, many other kinds of primates evolved and diverged. (Kaas, 2019). Around 7 million years ago, the human lineage, or hominins, started to separate from other primates. Hominin species including Australopithecus, Paranthropus, and Homo all evolved over time. Around 300,000 years ago, Homo sapiens, or modern humans, first appeared. Physical, cognitive, and behavioral changes are hallmarks of human evolution. (Klein, 2019).

9.2. Hominin evolution:

About 7 million years ago, in Africa, the hominin lineage first appeared. The earliest hominins were bipedal apes with a mix of human and ape characteristics that lived in woods. Hominins evolved new physical characteristics and learned to adapt to new settings over time (Almécija *et al.*, 2021). The most well-known genus of early hominins is Australopithecus, which existed between 4 and 2 million years ago. According to Masao *et al.*, (2016), Australopithecus species possessed prominent faces and lengthy limbs in addition to being bipedal and having small brains.

The earliest members of the genus Homo originally arose about 2 million years ago. In comparison to Australopithecus, Homo species had larger brains and was able to create more sophisticated tools (Herries *et al.*, 2020). *Homo Habilis*, the ancestor of all modern humans, had a 600–700 cc brain and was capable of forging stone tools. The first human to leave Africa and colonize other areas of the world was Homo erectus, who lived between 1.8 million and 300,000 years ago. Homo erectus had a brain that was roughly 900 cc in size

(Oxfordand & Geary 2019).

9.3. Emergence of Homo sapiens:

About 300,000 years ago, *Homo Sapiens* began to appear. *Homo Sapiens* fossils dating back to roughly 300,000 years ago are found in Morocco. Although the brains of these early Homo sapiens were comparable in size to those of modern humans, their skulls differed in important ways, such as having a more pronounced brow ridge. Over time, Neanderthals and Denisovans were displaced by Homo sapiens, who evolved and colonized the entire planet (Klein, 2019). Homo sapiens' genetic and physical progress resulted in the creation of highly developed cognitive and behavioral capabilities. Modern humans can utilize language, produce art, and build sophisticated societies, for instance. A significant turning point in human evolution, the appearance of *Homo Sapiens* had a dramatic effect on the entire planet (MacDonald *et al.*, 2021).

10. Implications and Applications

10.1. Importance of understanding the evolution of life on Earth

Understanding the origins and diversity of life as well as foreseeing future patterns in evolution, studying the development of life on Earth is essential. The evolutionary history of various species and groups, including humans, can be reconstructed through the study of fossils, genetics, and comparative anatomy. Many other sectors, such as medicine, conservation, agriculture, and biotechnology, can benefit from this knowledge (Munshi and Johnson, 2017). For instance, knowing how infectious illnesses have changed through time can aid researchers in creating new drugs and vaccines. Scientists can determine which virus strains are most likely to produce outbreaks by charting their evolution. They can then create tailored therapies to stop or slow the spread of disease. Additionally, understanding evolutionary processes can aid scientists in creating novel medications and treatments that are suited to certain genetic differences found in various populations (Mulder *et al.*, 2018).

10.2. Medical and technological applications

The study of evolution has significant implications for both technology and medicine. For instance, scientists have incorporated evolutionary theory into the production of more potent medications and vaccinations. Scientists can create novel medicines that are less likely to be made ineffective by genetic mutations by knowing how bacteria and viruses generate medication resistance (Andersson *et al.,* 2020). As with biomimetic materials and robots, new technologies have been created using evolutionary principles. Researchers can create robots and other gadgets that imitate the performance and functioning of natural systems by researching the adaptations and behaviors of various species. These technologies have uses in a variety of industries, including agriculture, defense, and the aerospace industry (Javaid *et al.,* 2021).

10.3. Conservation and environmental management

Finally, maintaining biodiversity and managing ecosystems depend on our ability to comprehend how life evolved on Earth. Scientists can create more effective plans for preserving endangered species and preserving the health of ecosystems by comprehending the evolutionary links between various species and the ecological roles they perform (Isabel *et al.,* 2020). For instance, scientists have utilized evolutionary ideas to create conservation plans that place a high priority on safeguarding imperiled species' genetically unique populations. Researchers can contribute to preventing the loss of genetic variety and ensuring the long-term survival of species by locating and protecting these distinctive genetic lineages (Hoban *et al.,* 2022). Additionally, knowing the evolutionary background of various ecosystems can assist guide management tactics like restoring damaged habitats and eradicating invasive species. In general, the study of evolution has numerous significant applications in industries including technology, medicine, conservation, and environmental management. Researchers can uncover fresh insights and solutions to some of the most important problems confronting humanity now by continuing to look into the origins and diversity of life on Earth (Rodrguez *et al.,* 2017).

11. Conclusions:

The complicated and intriguing process of life's evolution on Earth has been influenced by a number of variables, including the environment, genetic mutations, natural selection, and genetic drift. Single-celled organisms were the first living forms to emerge on Earth, and they progressively developed into more sophisticated species like plants, animals, and people (Stern, 2016). Scientists continue to research and learn more about the mechanisms that propel evolution as it takes place. The area of evolutionary biology still has a lot of open research topics and directions. The function of epigenetics in evolution, the evolution of social behavior, and the effects of climate change on species adaptation and evolution are some of the topics that scientists are now focusing (Neve *et al.,* 2020). Additionally, technological developments like DNA sequencing and bioinformatics are shedding new light on the processes of evolution and the connections between various species. Life on Earth has showcased remarkable resilience and adaptability throughout its evolution. The planet has undergone numerous transformative events and influences, including meteorite impacts, volcanic eruptions, and varying sea levels. Despite these obstacles, life has persisted and flourished into an extraordinary spectrum of species. As humans, it is our duty to comprehend and value the diversity of life on our planet and to safeguard its ongoing existence and progression (Samways *et al.,* 2020).

Tables of Different Data:

Era	Period	Epoch	Dates (approx.)	Major Evolutionary Events	Sources and References
Precambrian			4.6 billion - 541 million years ago	Formation of Earth, origin of life, emergence of eukaryotes	(Hewaidy, 2023)
	Paleozoic	Cambrian	541 - 485.4 million years ago	Explosion of complex life forms, appearance of most major animal phyla	(Ogg, & Gradstein, 2016)
		Ordovician	485.4 - 443.8 million years ago	Diversification of marine life, colonization of land by plants and arthropods	(Blankenheim, 2021)

		Silurian	443.8 - 419.2 million years ago	First jawed fish, diversification of early vascular plants	(Spicer, 2021; Valette, 2021)
		Devonian	419.2 - 358.9 million years ago	Age of fish, first tetrapods, forests	(Valette, 2021)
		Carboniferous	358.9 - 298.9 million years ago	Origin of reptiles, vast coal swamps	(Blankenheim, 2021)
		Permian	298.9 - 252.2 million years ago	Dominance of reptiles, mass extinction at the end	(Glaeser *et al.*, 2017; Kurbel, 2014)
Mesozoic	Triassic		252.2 - 201.3 million years ago	Age of reptiles, first dinosaurs, origin of mammals	(Sookias, *et al.*, 2012)

	Jurassic		201.3 - 145 million years ago	Dominance of dinosaurs, first birds	(Slater *et al.*, 2018)
	Cretaceous		145 - 66 million years ago	Flowering plants, diversification of dinosaurs, mass extinction (including non-avian dinosaurs)	(Hunter, 2020)
Cenozoic	Paleogene	Paleocene	66 - 56 million years ago	Radiation of mammals, first primates	(Upham *et al.*, 2021)
		Eocene	56 - 33.9 million years ago	Diversification of mammals, origin of many modern groups	(Siqueira *et al.*, 2023)

		Oligocene	33.9 - 23 million years ago	Further diversification of mammals	[2], [26], [27]
	Neogene	Miocene	23 - 5.3 million years ago	Emergence of apes, early hominins	(Kaya *et al.*, 2018)
		Pliocene	5.3 - 2.6 million years ago	Hominins diversify, climate cooling	(Timmermann *et al.*, 2022)

Table 4: *Geological time scale: A table displaying geological eras, periods, epochs, their corresponding time frames and significant evolutionary events.*

This data can help provide a timeline for the evolution of life on Earth.

Milestone	**Description**	**Reference**
Emergence of photosynthesis	The evolution of organisms capable of harnessing light energy for photosynthesis, leading to the production of oxygen.	(Chávez, *et al.*, 2020)
Development of multicellular organisms	The transition from single-celled organisms to complex multicellular organisms, enabling increased specialization and complexity.	(Knoll, 2011)
Colonization of land	The movement of life from aquatic environments to terrestrial habitats, leading	(Peterson *et al.*, 2004)

	to the diversification of plants and animals on land.	
Evolution of mammals	The emergence and diversification of mammals, including the development of unique mammalian features such as mammary glands and hair.	(Benton, 2014)
Emergence of Homo sapiens	The appearance and evolution of modern humans, characterized by advanced cognitive abilities, language, and culture.	(Stringer, 2012)

Table 5: *Key evolutionary milestones: A table highlighting key evolutionary milestones, including the emergence of photosynthesis, the development of multicellular organisms, the colonization of land, the evolution of mammals, and the emergence of Homo sapiens.*

This data can help illustrate the major transitions in the history of life.

Species Name	**Geological Age**	**Location of Discovery**	**Notable Characteristics**	**Reference**
Archaeopteryx lithographica	Late Jurassic (150 million years ago)	Solnhofen Limestone, Germany	Feathered dinosaur with bird-like features	(Wang & Zhou, 2017)
Tiktaalik roseae	Late Devonian (375 million years ago)	Ellesmere Island, Canada	Transitional fossil between fish and land-dwelling tetrapods	(Lundborg & Lundborg, 2014)
Australopithecus afarensis	Pliocene (3.7 - 2.9 million years ago)	Hadar, Ethiopia	Early hominin with a combination of ape-like and human-like traits	(Selassie *et al.*, 2016)
Homo erectus	Pleistocene (1.9 million - 143,000 years ago)	Java, Indonesia	Early human ancestor with larger brain size and advanced tool use	(Naskar, 2017)

Mammut americanum	Pleistocene (5.3 million - 11,700 years ago)	North America	Extinct relative of elephants with long, curved tusks	(Noss & Noss, 2013)
Tyrannosaurus rex	Late Cretaceous (68 - 66 million years ago)	Western North America	Large carnivorous dinosaur with sharp teeth and small forelimbs	(Fiffer, 2001)

Table 6: *Fossil record: A table presenting key fossils representing major evolutionary transitions and notable species, including their species name, geological age, location of discovery, and notable characteristics.*

This table provides concrete examples of evolutionary changes over time.

Taxonomic Group	**Examples of Organisms**	**Reference**
Domain	Bacteria, Archaea, Eukarya	(Woese *et al.*, 1990)
Kingdom	Animalia, Plantae, Fungi, Protista, Archaeaebacteria, Eubacteria	(Margulis & Chapman, 2009)
Phylum	Chordata, Arthropoda, Mollusca, Annelida, Echinodermata, Cnidaria, Porifera	(Hickman *et al.*, 2016)
Class	Mammalia, Aves, Reptilia, Amphibia, Actinopterygii, Insecta, Arachnida	(Benton, 2014)
Order	Primates, Carnivora, Rodentia, Squamata, Coleoptera, Diptera, Hymenoptera	(Simpson, 2010)

Table 7: *Taxonomic classification: Table of organism classification, including domains, kingdoms, phyla, classes, and orders, along with examples of each group.*

This will help readers understand life diversity and evolution.

Organism Group	Limb Structure	Skeletal Features	Reproductive System	Sensory Organs	Reference
Fish	Fins	Cartilaginous or bony skeleton	External fertilization	Lateral line system for detecting vibrations	(Morgan, 2004)
Amphibians	Short limbs, webbed feet	Bony skeleton	External fertilization (in most species)	Simple eyes, with some species having a third eyelid called a nictitating membrane	(Khanna, 2008; Miller, 2005)
Reptiles	Legs or no legs, depending on the species	Bony skeleton	Internal fertilization, some species lay eggs	Well-developed eyes, some species have specialized organs like the Jacobson's organ	(Alexander, 2013; O'Shea & Halliday, 2010)
Birds	Wings and legs	Bony skeleton	Internal fertilization, eggs laid with hard shells	Well-developed eyes, some species have excellent color vision	(Heilmann, 1927; Sakas, 2002)
Mammals	Legs and specialized limbs (e.g., hands, wings)	Bony skeleton	Internal fertilization, live birth or egg-laying depending on the species	Varied sensory organs, including well-developed eyes, ears, and olfactory organs	(Allaby, 2003; Gonçalves, 2018)

Table 8: *Comparative anatomy: A table comparing anatomical features across different organisms, such as limb structure, skeletal features, reproductive systems, and sensory organs.*

This table can demonstrate evolutionary changes.

Species	**DNA Sequences**	**Protein Structures**	**Molecular Markers**	**Reference**
Homo sapiens	Complete genome sequence	Hemoglobin structure	Mitochondrial DNA (mtDNA)	(Bharti *et al.*, 2014)
Pan troglodytes	Complete genome sequence	Cytochrome c oxidase structure	Microsatellites	(Xu *et al.*, 2018)
Canis lupus	Partial genome sequence	Alpha-amylase structure	Single nucleotide polymorphisms	(Torrecilha, 2018)
Felis catus	Partial genome sequence	Rhodopsin structure	Short tandem repeats (STRs)	(Zhao *et al.*, 2012)
Equus ferus	Mitochondrial DNA (mtDNA)	Myoglobin structure	Insertion/deletion polymorphisms	(Gonçalves, 2011)
Gallus gallus	Partial genome sequence	Beta-actin structure	Restriction fragment length polymorphisms (RFLPs)	(Chaves *et al.*, 2005)

Table 9: *Genetic and molecular data: A table summarizing genetic or molecular evidence supporting evolutionary relationships, such as DNA sequences, protein structures, or molecular markers used in phylogenetic analyses.*

This can showcase the genetic basis for evolutionary changes and relationships between different species.

Ethics Approval

This study followed the ethical rules established by the "Origins of Life and Evolution of Biospheres" Institutional Review Board (IRB), ensuring the protection of human participants and their privacy throughout the research process.

This review article's study included a thorough investigation and synthesis of current scientific material. Because no direct engagement with human or animal participants was required, the project was free from ethical assessment.

-Conflict of Interest

Conflict of Interest Statement: The authors declare that they have no conflicts of interest in relation to the review article "Beyond Origins: Unraveling the Remarkable Story of Life's Evolution from Single-Celled Organisms to Modern Humans".

Potential Conflict of Interest Disclosure: We confirm that there are no conflicts of interest that could jeopardise the objectivity or integrity of the review article "Beyond Origins: Unraveling the Remarkable Story of Life's Evolution from Single-Celled Organisms to Modern Humans".

-Data Availability

This paper offers a thorough examination of the astonishing story of life's evolution, from single-celled organisms to modern humans, delving into the subtle mechanisms and transformative events that influenced the trajectory of biological history.

This review article presents a thorough analysis of the evolutionary journey, offering new insights and perspectives on the origins and development of life forms, drawing on an extensive range of scientific literature, including peer-reviewed research articles, seminal studies, and cutting-edge discoveries.

-Funding

The funding for our review article, "Beyond Origins: Unravelling the Remarkable Story of Life's Evolution from Single-Celled Organisms to Modern Humans," is unfortunately not available to us as students. Due to our limited funding, we hope to publish it in a closed access format in the prestigious journal Origins of Life and Evolution of Biospheres published by the venerable publisher "Springer Nature."

Consent to publish

The review article "Beyond Origins: Unravelling the Remarkable Story of Life's Evolution from Single-Celled Organisms to Modern Humans" will be published with our permission in the journal "Origins of Life and Evolution of Biospheres" under the publisher "Springer Nature." We have worked tirelessly day and night to create this article, which is a representation of our committed efforts and passion to investigate the complexities of life's origins.

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