A brief note about the origin, evolution and future of life in the marine environment

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Abstract. This paper is a brief retrospective of the evolution of life in the marine environment and a presentation of the prospects for marine conservation. The paper presents synthetically the hypotheses of the appearance of life on Earth, the stages of the evolution of life in the marine environment, future threats to the marine environment, and the perspectives of the conservation of the marine environment in the context of changes that are climatic, geological or anthropic in nature.
Key Words: future, origin of life, perspectives, planetary ocean, threats.

Introduction. Water is the cradle of life, the place from which all life forms emerged. The planetary ocean is currently home to an immense biodiversity that must be preserved from future threats (Petrescu-Mag 2007; Petrescu-Mag & Bud 2017). This paper is a brief retrospective of the evolution of life in the marine environment and a presentation of the threats and prospects for the conservation of the marine environment in the context of many and alarming environmental changes (Bellard et al 2022).

Origin(s) of Life. The origin of life from non-living matter is a complex and debated topic in scientific research (Petrescu-Mag et al 2011; Bose et al 2022; Petrescu-Mag & Proorocu 2022). While there is no universally accepted theory, several hypotheses have been proposed, each highlighting different aspects of the complex processes that might have led to the emergence of living organisms. Here are some of the prominent theories or hypotheses in recent literature.

These hypotheses are not mutually exclusive, and it is possible that multiple processes and environmental conditions contributed to the origin of life. Research in this field continues, incorporating insights from diverse scientific disciplines such as chemistry, biology, geology, and astrobiology.

RNA world hypothesis. This hypothesis suggests that life on Earth may have started with self-replicating ribonucleic acid (RNA) molecules. RNA is capable of both storing genetic information and catalyzing chemical reactions. It is proposed that early RNA molecules played a crucial role in the development of more complex biological molecules, eventually leading to the emergence of cellular life (Higgs & Lehman 2015).

Prebiotic chemistry and Miller-Urey experiment. The Miller-Urey experiment, conducted in the 1950s, demonstrated that simple organic molecules, such as amino acids, could be produced from a mixture of gases thought to resemble Earth's early atmosphere. While the experiment has faced criticism, it sparked interest in the study of prebiotic chemistry, suggesting that the building blocks of life could have formed under early Earth conditions (McCollom 2013; Shaw 2016).

Iron-sulfur world hypothesis. This hypothesis proposes that life originated at hydrothermal vents on the ocean floor, where iron and nickel sulfide minerals could have played a role in catalyzing the formation of complex organic molecules. These environments provide a rich source of chemical energy that could support the synthesis of essential biomolecules (Ross 2008).

Hydrothermal vent hypothesis. Some scientists suggest that life may have originated in the high-temperature, high-pressure environments of hydrothermal vents on the ocean floor. These vents release mineral-laden fluids that could provide the necessary chemical components for life, and the temperature gradient at these vents could drive chemical reactions (Martin et al 2008).

Clay hypothesis. This hypothesis proposes that complex organic molecules essential for life may have formed on the surfaces of clay minerals. The minerals could have provided a structured environment that facilitated the concentration and organization of biomolecules (Brack 2006).

Panspermia. Panspermia suggests that life may not have originated on Earth at all but could have come from elsewhere in the universe. Microorganisms or organic molecules may have reached Earth on comets, meteoroids, or interstellar dust, providing the seeds for life to develop (Kawaguchi 2019).

Protocell and lipid world hypotheses. These hypotheses focus on the formation of protocells, rudimentary cell-like structures, as a key step in the transition from non-life to life. The lipid world hypothesis suggests that simple lipid molecules could have formed membranous structures, creating a boundary between the internal and external environments of a protocell (Damer & Deamer 2020).

Evolution of Life in the Marine Environment. The evolution of life in marine environments spans billions of years and involves numerous significant steps. Here is a broad overview of some key milestones, roughly chronologically, in terms of millions of years. These timeframes are approximate, and the evolution of life is a complex and ongoing process with many interrelated factors. Additionally, the history of life on Earth is not confined to marine environments, as organisms have also adapted to various terrestrial habitats over time.

Origin of life (3.5-3.8 billion years ago). The exact timeline of the origin of life is still uncertain, but most evidences suggest that simple, single-celled organisms emerged in a primordial soup rich in organic compounds (Bada & Lazcano 2003; Longo & Damer 2020; Stüeken et al 2020).

Prokaryotes (3.5-3.2 billion years ago). Prokaryotes, such as bacteria and archaea, were among the earliest life forms (Martin et al 2003; Battistuzzi et al 2004; Bertrand et al 2015; Poole 2021). They are unicellular and lack a nucleus and other membrane-bound organelles.

Photosynthesis (3.5-2.7 billion years ago). Cyanobacteria evolved the ability to perform photosynthesis, releasing oxygen as a byproduct (Olson & Pierson 1986; Altermann et al 2006; Drews 2011; Pathak et al 2022; Murphy & Cardona 2022). This event contributed to the oxygenation of Earth's atmosphere (Hamilton 2019).

Eukaryotes (2.7-1.5 billion years ago). Eukaryotic cells, which have a distinct nucleus and organelles, emerged through a process called endosymbiosis (Martin et al 2003; Edgar 2019; Poole 2021; Mills et al 2022; Fakhraee et al 2023). This allowed for increased cellular complexity.

Multicellular life (1.2-1 billion years ago). The transition from single-celled to multicellular organisms marked a significant step in the evolution of complexity (Edgar 2019; Strother et al 2021). Algae and simple multicellular organisms appeared.

Ediacaran fauna (635-541 million years ago). During the Ediacaran period, some of the earliest complex multicellular organisms, though not clearly related to modern forms, appeared in marine environments (Yin 2017; Dunn & Liu 2017).

Cambrian explosion (541-485 million years ago). A rapid diversification of life occurred during the Cambrian period, leading to the emergence of a wide variety of marine invertebrates, including arthropods and mollusks (Cutting 2021).

Fish/vertebrates (500-360 million years ago). Fish, the first vertebrates, appeared in the oceans. Jawed fish and, later, bony fish, became dominant marine organisms (Carter et al 2021; Lamanna et al 2023).

Amphibians (360-320 million years ago). Some fish evolved the ability to live in both aquatic and terrestrial environments, marking the transition to amphibians (Sues 2019; Carter et al 2021).

Reptiles/dinosaurs (320-66 million years ago). Reptiles, including marine reptiles, became dominant (Sues 2019). Marine reptiles like ichthyosaurs and plesiosaurs inhabited the oceans.

Mass extinctions (e.g., Permian-Triassic, Triassic-Jurassic, Cretaceous-Paleogene). Several mass extinction events throughout history significantly impacted marine life and led to the rise of new species (Song et al 2021).

Mammals/whales (50-35 million years ago). Marine mammals, including early whales, evolved from land-dwelling ancestors and adapted to life in the oceans (Sénégas 2020; Marino 2020).

Evolution of modern marine life (from 2 million years ago to present). Modern marine ecosystems with a wide variety of fish, mammals, invertebrates, and other life forms have continued to evolve and diversify (Kolomyts 2023) (Figure 1).

Figure 1. The wonderful underwater marine environment; shoal of diagonal butterflyfish (*Chaetodon fasciatus*) in the Red Sea (original picture).

The Future of the Planetary Ocean. Predicting the future of life in the planetary ocean involves considering a range of factors, including climate change, human activities, technological advancements, and ecological dynamics. While it is challenging to make precise predictions, especially given the complexity of these interactions, scientists and researchers can offer insights based on current trends and potential scenarios. Here are some considerations for the future of life in the planetary ocean.

The future of life in the planetary ocean is interconnected with broader global issues. Mitigating climate change, promoting sustainable practices, and fostering international cooperation are key components of ensuring a healthy and resilient marine environment for future generations.

Climate change impact. The planetary ocean is greatly influenced by climate change, including rising sea temperatures, ocean acidification, and changes in circulation patterns. These factors can affect the distribution and abundance of marine species, with potential impacts on ecosystems, fisheries, and biodiversity.

Rising sea levels. As global temperatures rise, polar ice caps and glaciers are melting, contributing to rising sea levels (Griggs 2021). This can lead to changes in coastal habitats, affecting both marine and terrestrial ecosystems. Coastal regions, where a significant portion of marine life thrives, may face increased vulnerability.

Ocean acidification. The absorption of excess carbon dioxide by oceans leads to ocean acidification. Some scientists say that this phenomenon can negatively impact marine organisms with calcium carbonate shells or skeletons, such as corals and mollusks, potentially affecting entire ecosystems. The results of Leung et al (2022) suggest that the impacts of ocean acidification on calcifiers are less deleterious than initially thought, because their adaptability has been underestimated. Therefore, they underlined that in the forthcoming era of ocean acidification investigation, it is advocated that studying how marine organisms persist is as important as studying how they perish, and that future hypotheses and experimental designs are not constrained within the paradigm of negative effects (Leung et al 2022).

Overfishing and depletion of resources. Overfishing and the depletion of marine resources are ongoing concerns. Unsustainable fishing practices can lead to the decline of fish stocks and disrupt marine food webs. Implementing effective fisheries management and conservation measures is crucial for the future sustainability of marine life (Ionescu & Petrescu-Mag 2022).

Pollution and plastic accumulation. Marine pollution, including plastic waste, oil spills, and other contaminants, poses a significant threat to marine life. Efforts to reduce pollution and develop technologies for cleaning up existing waste are essential for the health of the planetary ocean (Adji et al 2022).

Emerging Technologies and Exploration. Advances in technology, such as autonomous underwater vehicles, remote sensing, and genetic tools, enable scientists to explore and study the ocean in unprecedented ways. Continued technological advancements may lead to new discoveries and a better understanding of marine ecosystems.

Conservation and protected areas. The establishment and effective management of marine protected areas play a crucial role in preserving biodiversity and providing refuge for marine species. Ongoing efforts to expand and enforce protected areas contribute to the conservation of marine life.

Global collaboration and governance. Addressing the challenges facing the planetary ocean requires international collaboration and effective governance. Agreements and initiatives that promote sustainable practices, combat illegal fishing, and mitigate climate change are vital for the future of marine ecosystems.

Conclusions. The origin of life from non-living matter is a complex and debated topic in scientific research. While there is no universally accepted theory, several hypotheses have been proposed, each highlighting different aspects of the complex processes that might have led to the emergence of living organisms. The hypotheses about origin of life are not mutually exclusive, and it is possible that multiple processes and environmental conditions contributed to the origin of life. Research in this field continues, incorporating insights from diverse scientific disciplines such as chemistry, biology, geology, and astrobiology. The evolution of life in marine environments spans billions of years and involves numerous significant steps. Predicting the future of life in the planetary ocean involves considering a range of factors, including climate change, human activities, technological advancements, and ecological dynamics. The future of life in the planetary ocean is interconnected with broader global issues. Mitigating climate change, promoting sustainable practices, and fostering international cooperation are key components of ensuring a healthy and resilient marine environment for future generations.

Conflict of Interest. The author declares that there is no conflict of interest.

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