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Marine Algae (*Braarudospharea bigelowii*): First Known Eukaryote to Pull Nitrogen from Air

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Abstract

A group of scientists from various countries has unveiled the discovery of the first nitrogen-fixing organelle within a eukaryotic cell. This organelle marks the fourth instance in the evolutionary phenomenon known as primary endosymbiosis, where a prokaryotic cell merges with a eukaryotic one, eventually transforming into an organelle. Tyler Coale, a postdoctoral scholar at UC Santa Cruz and lead author of one of the recent studies, highlighted the rarity of such organelle emergence. He drew parallels to past occurrences, such as the genesis of mitochondria, which catalyzed the emergence of complex life forms. Similarly, the advent of chloroplasts led to the proliferation of plants. The third instance involved a microbe akin to a chloroplast. This latest discovery introduces the groundbreaking concept of a nitrogen-fixing organelle, termed a nitroplast by the researchers. It represents a significant milestone in our understanding of cellular evolution.

Keywords: Marine Algae, *Braarudospharea bigelowii*, nitroplast, nitrogen-fixing organelle

Introduction

Marine algae, often referred to as seaweeds, are diverse and ubiquitous organisms that play crucial roles in marine ecosystems worldwide. These remarkable organisms encompass a wide range of forms, from microscopic single-celled phytoplankton to large, multicellular seaweeds that can form extensive underwater forests. As primary producers, marine algae harness sunlight through photosynthesis, converting carbon dioxide into organic matter and releasing oxygen into the environment. This fundamental process not only sustains marine life but also influences global climate patterns. Marine algae exhibit extraordinary adaptability, thriving in various marine habitats, from shallow coastal waters to the deep sea, and from polar regions to the tropics. They come in an array of colors, shapes, and sizes, reflecting their evolutionary diversity and ecological niches. Some algae species are prized for their nutritional value and are consumed by humans directly or indirectly through seafood consumption, while others are used in biotechnological applications, such as biofuel production and pharmaceuticals.

Understanding marine algae is essential for comprehending marine ecosystems' dynamics, biodiversity, and ecological relationships. Moreover, they serve as indicators of environmental health and can be sensitive to changes in water quality, temperature, and nutrient availability. Consequently, studying marine algae is crucial for monitoring and managing marine environments and addressing challenges such as climate change, pollution, and habitat degradation. This article explores their taxonomy, morphology, ecological significance, economic importance, and current research trends. By delving into the fascinating world of marine algae, this article gains valuable insights into the intricate web of life that sustains our oceans and influences the health of our planet.

A Decades - Long Mystery

For the past decade, marine scientists have been intrigued by a captivating mystery surrounding marine algae, one that has puzzled researchers and captured the imagination of the scientific community worldwide. At the heart of this enigma lies a perplexing phenomenon observed in certain species of marine algae, which exhibit unprecedented behavior or characteristics previously unseen in their counterparts. From mysterious blooms of algae in unexpected locations to peculiar adaptations enabling survival in extreme environments, these anomalies have challenged conventional understanding and prompted a flurry of research activity. One aspect of this mystery revolves around the dynamic interactions between marine algae and their environment. Scientists have observed perplexing shifts in algae distribution patterns, with some species appearing in regions where they were previously unknown, while others vanish inexplicably from their traditional habitats. These shifts raise questions about the underlying drivers, whether they stem from natural fluctuations, environmental changes, or human activities, and their implications for marine ecosystems.

Furthermore, researchers have uncovered surprising biochemical properties and ecological roles of certain algae species, shedding light on their potential applications in biotechnology, medicine, and environmental remediation. These discoveries underscore the untapped potential of marine algae and the importance of further exploration to unlock their secrets. The mystery of marine algae also extends to their evolutionary history and genetic diversity. By studying their genomes and tracing their evolutionary trajectories, scientists aim to unravel the intricate relationships between different algae species and understand the mechanisms driving their adaptation and speciation over millions of years. As scientists continue to delve into this decade-long mystery, they are driven by a sense of curiosity and a desire to unravel the mysteries of the ocean's depths. With each new discovery, they inch closer to unraveling the secrets of marine algae, revealing the hidden wonders of the underwater world and enhancing our understanding of life on Earth.

Organelle Origins

The origin of marine algae is a captivating tale that spans billions of years and intertwines with the evolution of life on Earth. These remarkable organisms have deep roots in our planet's history and have played pivotal roles in shaping marine ecosystems over millennia. The story begins around 3.5 billion years ago when life first emerged in Earth's ancient oceans. Early microorganisms, such as cyanobacteria, were among the first photosynthetic organisms, harnessing sunlight to convert carbon dioxide into organic matter and releasing oxygen as a byproduct. This primitive photosynthesizes laid the groundwork for the proliferation of life forms that would follow. As Earth's oceans evolved and diversified, so too did the algae inhabit them. Over millions of years, algae adapted to a myriad of marine environments, ranging from shallow coastal waters to deep ocean trenches, and from polar regions to tropical seas. This remarkable adaptability allowed algae to colonize diverse habitats and contribute to the formation of complex marine ecosystems.

The evolutionary history of marine algae is characterized by key milestones, including the emergence of multicellular forms from single-celled ancestors, the development of specialized structures for reproduction and survival, and the co-evolutionary relationships with other marine organisms. These evolutionary innovations have shaped the diversity and ecological significance of marine algae, influencing processes such as nutrient cycling, habitat formation, and food webs. Today, marine algae encompass a vast array of taxa, from microscopic phytoplankton to macroscopic seaweeds, encompassing diverse lineages such as green algae, red algae, brown algae, and diatoms, among others. Each group exhibits unique adaptations and ecological roles, contributing to the richness and complexity of marine ecosystems. Understanding the origin of marine algae is not only a journey through evolutionary history but also a window into the dynamic interplay between life and the environment. By unraveling the mysteries of algae's origins, scientists gain insights into the origins of biodiversity, the mechanisms of adaptation, and the resilience of life in Earth's oceans, a story that continues to unfold with each new discovery.

Nitroplast: The first nitrogen-fixing organelle

A ground-breaking scientific revelation has emerged from an international coalition of researchers, unveiling the "nitroplast" - the first nitrogen-fixing organelle identified within a eukaryotic cell. This discovery disrupts the longstanding notion that only bacteria possess the capacity to convert atmospheric nitrogen into a biologically viable form. It also marks the fourth documented case of primary endosymbiosis in evolutionary history, where a prokaryotic cell is assimilated by a eukaryotic cell, leading to the evolution of an organelle (Figure 1).

Spearheaded by Tyler Coale and Jonathan Zehr from UC Santa Cruz, this collaborative effort underscores the significance of the nitroplast's revelation, as highlighted in recent publications. Coale emphasizes the rarity of organelle emergence, noting its pivotal role in the evolution of complex life forms, such as mitochondria and chloroplasts. The journey towards uncovering the nitroplast was extensive, spanning decades of meticulous research. In 1998, Zehr stumbled upon a brief DNA sequence resembling a nitrogen-fixing cyanobacterium in Pacific Ocean seawater, leading to the focus on UCYN-A, which was later revealed to be associated with a marine alga by Kyoko Hagino. UCYN-A's evolution from a mere endosymbiont to an organelle is supported by recent studies, indicating consistent size ratios between UCYN-A and its algal hosts across various species. Further evidence, including protein importation from host cells and DNA shedding, solidifies UCYN-A's classification as an organelle. The discovery of the nitroplast provides valuable insights into oceanic ecosystems, where UCYN-A's nitrogen-fixing abilities play a crucial role globally. Additionally, the potential of the nitroplast to revolutionize agricultural practices by offering a natural alternative to synthetic fertilizers is highlighted. Understanding the role of nitroplasts in the nitrogen cycle is crucial for maintaining the delicate balance of ecosystems and ensuring the welfare of all life forms (Figure 1).

Figure 1. The single-celled algae *Braarudosphaerea bigelowii*, magnified at 1000x in this image, stands out as the pioneer eukaryote capable of nitrogen fixation, all credit to its nitroplast organelle, indicated by the arrow.

Stages of the Nitrogen Cycle

a) **Nitrogen Fixation:** Conversion of atmospheric nitrogen (N_2) into biologically usable forms, such as ammonia (NH_3) and nitrates (NO_3^-). Natural processes like lightning and certain bacteria, along with human activities like the Haber-Bosch process, contribute to nitrogen fixation.

b) **Assimilation:** Plants assimilate biologically usable forms of nitrogen from the soil, incorporating them into essential biomolecules like amino acids and proteins. Animals obtain nitrogen by consuming plants or other organisms.

c) **Ammonification**: Decomposers break down dead organic matter, releasing nitrogen in the form of ammonium (NH_4^+) into the soil.

d) **Nitrification:** Nitrifying bacteria convert ammonium into nitrites (NO_2^-) and then nitrates (NO_3^-), which plants absorb from the soil.

e) **Denitrification**: Denitrifying bacteria convert nitrates back into atmospheric nitrogen gas (N2), completing the nitrogen cycle.

Changing Perspectives

The perspective on marine algae has undergone a significant transformation over time, evolving from mere curiosities of the sea to pivotal players in the functioning of marine ecosystems and valuable resources with diverse applications. Historically, marine algae were often regarded as nuisances or inconsequential components of marine environments. Consequently, efforts were made to control or eradicate algae blooms through mechanical, chemical, or biological means, often without fully understanding their ecological roles or long-term consequences. However, as scientific understanding of marine ecosystems deepened, so too did appreciation for the ecological importance of marine algae. It became evident that algae serve as primary producers, harnessing sunlight to fuel photosynthesis and form the base of marine food webs. They play crucial roles in nutrient cycling, oxygen production, and habitat provision, influencing the abundance and distribution of marine life from microscopic plankton to large marine mammals. Furthermore, marine algae have emerged as valuable resources with diverse applications in various fields. Certain algae species are cultivated for food, providing nutritious ingredients for human consumption and contributing to sustainable aquaculture practices. Others are utilized in pharmaceuticals, cosmetics, bioremediation, and renewable energy production, highlighting their potential in addressing global challenges such as food security, healthcare, environmental pollution, and climate change.

Conclusion

Today, the perspective on marine algae has shifted from one of indifference or disdain to one of appreciation and recognition for their ecological, economic, and societal value. Scientists, policymakers, and industry stakeholders increasingly recognize the importance of conserving and sustainably managing marine algae ecosystems to safeguard biodiversity, support livelihoods, and promote the sustainable use of marine resources. As our understanding of marine algae continues to evolve, so too will our appreciation for their myriad contributions to the health and well-being of our planet. From humble beginnings as overlooked organisms of the sea, marine algae have risen to prominence as essential components of marine ecosystems and invaluable assets for humanity's future.

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