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The Role of GenBank in Sustainable Utilization of Algal Genetic Resources

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Abstract:

This study explores the application of GenBank, an extensive genetic sequence database, for preserving the genetic diversity of beneficial algae. By utilizing GenBank's comprehensive molecular archive, researchers can track genetic variations and safeguard rare or endangered algal species. This approach not only enhances our understanding of algal biodiversity but also supports conservation initiatives and encourages sustainable applications in biotechnology, agriculture, and environmental management. Integrating genetic data into conservation strategies establishes a robust framework for protecting both the ecological and economic significance of beneficial algae.

Key words: Beneficial effects of algae, blue green algae, prokaryotes, reproductive traits, Kingdom Protista,

Introduction:

The taxonomic classification of algae was initially based on morphological criteria derived from terrestrial plant taxonomy. However, from the 1960s onwards, advances in research methodologies, particularly electron microscopy, revealed previously unrecognized ultra structural features of cellular organelles, flagella apparatus, and mitotic processes. These technological developments led to the identification of fundamental biochemical and structural differences between algae, fungi, and protozoa, prompting substantial revisions to existing taxonomic frameworks and the establishment of new phylogenetic relationships based on cellular ultra structure rather than gross morphology alone. A gene bank supported by machine learning is a crucial tool for analyzing biosamples, enabling the identification of all bacterial, viral, fungal, and plant species, including algae (Ali et al. 2025; Yan et al., 2024).

As time progresses, these modifications due to mixing, genetic engineering or supplementation or different waste continues (Odoi-Yorke et al., 2025). Furthermore, molecular methods such as gene sequencing have facilitated a range of advancements. Algae are a polyphyletic grouping that encompasses species from several distinct clades. This classification is used to describe organisms that do not share a common ancestor and should not be placed within the same taxon. It is important to note that prokaryotes are generally excluded from the discussion of algae, following the consensus of numerous scholars (Negi, B. B., & Das, C., 2025; Teke et al., 2024). . Algae are becoming key element of meat replacement (Espinosa et al. 2023), biofuels production due to fast growth and high lipid content being a base for biofuel (Sravan et al. 2026). Their cultivation efforts are promoted due to efficient carbon dioxide capture (the highest known in plants, much higher than firs) (Yu et al, 2023; Alami et al., 2025) , and after growth they can be a resource for drugs (Chuechomsuk et al., 2025) and as feed for fermentation for becoming source of biopolymers and hydrogen (Gunasena et al., 2025). Phycology is the study of algae. It should be noted that there isn't a single, widely recognized definition of algae. To give a quick summary of the term, eukaryotic organisms that are photosynthetic and belong to the Kingdom Protista are collectively referred to as algae. Algal studies encompass a wide range of organisms, including giant kelp and multicellular brown algae, as well as unicellular microalgae like diatoms. The plastids of algae are referred to as a polyphyletic group due to the various manner in which they were acquired, even though they appear to share a common ancestor, cyanobacteria (also known as "blue-green algae"). Algae also display a variety of reproductive traits, from sexual reproduction to asexual reproduction, or cell division. The algal body can be either siphonaceous or flat parenchymatous, with filaments that are branching or unbranched and may be unicellular or multicellular. Its primary cell wall component is cellulose, and it contains β-carotenes as well as chlorophyll a and b. In the form of starch and oils, the nutrients are preserved. Xanthophycophyta has branched filaments, can be either unicellular or coenocytic, and its cell wall contains pectin compounds. β-carotenes, xanthophylls, and chlorophyll a and c are present. Chrysolaminarin and oils are examples of storage materials of golden algae from the genus Bacillariophycophyta. Their cell wall components include silica SiO_2 and pectin, and the algal body is always unicellular (Gonçalves et al., 2020. The storage forms an approach of energy carrying and ass layers of sediment bury the organic

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matter, increased pressure and temperature lead to thermal maturation, converting it into hydrocarbons. This process ultimately results in the formation of crude oil and natural gas, highlighting the crucial role of algae in the development of fossil fuels that are vital energy sources today., Paniagua-Michel, J., & Banat, I. M. (2024). Chlorophyll a, c, β-carotenes, and fucoxanthin are all present. Among the storage items are oils and chrysolaminarin (Grubišić, M et al., 2024) *Phaeophycophyta* are morphologically complex and consist of several cells. Alginic acid and cellulose are the two main building blocks of the cell wall. Fucoxanthin, β-carotenes, and chlorophyll a and c are all present in them. Oils, laminarin, and soluble carbohydrates are examples of storage productsI gene editing tools such as RNAi, CRISPR/Cas9, ZNFs, and TALENs with gene banks are tools for obtaining varieties that would be most efficient in producing anti-obesity medicines against HIV or cancer treating (Mohamadnia et al., 2025) Rhodophycophyta have cellulose as a component of the cell wall in multicellular organisms that have either simple or complex thalli. They include zeaxanthin, β-carotenes, chlorophyll a, and d. Additionally, phycocyanin and phycoerythrin are present. Oils and floridean starch are among the storage items. The list of proteins is stored using special databases called molecular phylogenetic tree (Kato et al., 2025) .Khanra et al., (2023) observed that some lipids have anticorrosive properties and isolated environment environment-friendly metal protection emulsion. They can be applied as a detector of hazardous metabolites after drugs (Helou et al., 2018). They contain some antibacterial properties that are still being studied (Handayani et al, 2020). They have highest absorptivity of nitrogen making them suitable for cleaning that pollution (Khan et al., 2024)

Chrysophyta (Golden-brown algae): Members of this division are usually unicellular, possess flagellated cells, and lack a true cell wall. Their photosynthetic pigments include chlorophyll a and c, fucoxanthin, and lutein. They store energy in the form of oils and chrysolaminarin. heir vitamin content, particularly vitamins A, C, and E, contributes to health benefits, while the high protein levels make them an excellent alternative protein source. Additionally, algae can be used in green chemistry for producing biofuels, bioplastics, and other sustainable materials, aligning with eco-friendly practices and reducing reliance on fossil fuels. This versatility positions algae as a key player in

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promoting sustainability and innovation in various industries. Bohutskyi, P., & Bouwer, E. (2012). Additionally, golden brown algae can be a source of funori, a natural thickening agent derived from certain red algae. Funori is used in various applications, including as an adhesive, a conservation material for preserving artifacts, and in formulations for hygiene and cosmetics (Sousa et al., 2025). Its properties make it effective in stabilizing products, enhancing texture, and providing moisture retention. This versatility not only supports aquaculture but also contributes to sustainable practices in the food, cosmetic, and conservation industries, showcasing the multifaceted benefits of these algae.

***Euglena phycophyta* (Euglenoid flagellates):** These organisms are unicellular and motile, possessing one or more flagella. They lack a true cell wall but are surrounded by a flexible protein-rich layer called a pellicle, which allows them to change shape. Their pigments include chlorophyll a, chlorophyll b, and xanthophylls. They store reserve food material as paramylum and oils. These pigments are dark and compete with synthetic ones (Janse van Vuuren, S., & Levanets, A. 2021; Feng et al., 2023) They are rich in a wide spectrum of proteins and, according to Procházka et al. (2023), have the potential to serve as alternatives to pork and chicken meat, as well as certain plant-based foods such as pulses, grains, and peas

Cryptophycophyta (Cryptomonads): These unicellular, flagellated organisms exhibit a dorsoventrally compressed morphology with variable cell wall presence. When present, the cell wall contains cellulose as the primary structural component. The photosynthetic apparatus comprises chlorophylls a and c, supplemented by the accessory pigment alloxanthin. Phycobiliproteins, specifically phycocyanin and phycoerythrin, are characteristic features of this group. Energy storage occurs through the accumulation of starch and lipid reserves. Bounty (2025) found they are efficient source of ethanol by fermentation and promising biofuel. **Dinoflagellates (Pyrrophycophyta):** These unicellular organisms display variable cell wall architecture and possess two distinctive flagella that confer motility. The photosynthetic system contains chlorophylls a and c, along with the characteristic accessory pigments peridinin and dinoxanthin. Many species feature cellulose plates arranged in a distinctive armored theca. Primary metabolic storage products include starch and lipid compounds. They are effective food supplement enabling starting of dark fermentation and microbial electrolysis for hydrogen production with production of lactic acid (Khandelwal et al., 2023. Ngamnurak et al., 2025).

Applications and uses of beneficial algae:

Organic seaweed fertilizers are produced by processing marine plant seaweed as a raw material, with the organic core material derived from kelp. Seaweed has been used as a fertilizer for more than a century, with references to driftweed appearing in George Owen's sixteenth-century writings (Sleeman, 2025). Today, algae are widely applied in soil conditioners, animal feed, and fertilizers, reflecting their long-standing agricultural and economic importance. Although seaweed fertilizers are properly prepared, their absorption in the soil is further enhanced. These organic systems naturally interact with plants and soil to increase the activity of beneficial microbes, which function as agents or catalysts to improve plant and soil efficiency.

The most effective approach to reducing pollution is through the use of algae. Algae can be employed to remediate toxic substances generated during waste disposal. The most efficient method to remove toxins from ponds is by employing a lawn scrubber, also known as an algae scrubber. Agriculture researchers have discovered that manure effluents can be used with an algal grass scrubber to detect the majority of nitrogen and phosphorus runoff.

Algae have been utilized by numerous businesses to create polymers used in various items, such as flip-flops and surfboards. Bio-polyethylene, polylactic acid and cellulose-based plastics are among the several polymers produced by algae.

Algae, like seaweed, are a vital source of nutrients. People use supplements like spirulina, which is derived from the cultivation of cyanobacteria and microalgae. Rich in calcium, magnesium, iron, potassium, and iodine, algae are a significant source of nutrients and biomolecules, including vitamin A, B1, B2, B6, niacin, and others.

For several countries, including China, Japan, and Korea, algae have long been considered a national cuisine. More than 70 spices that include cyanobacteria are utilized in China, with laver being particularly used to make laver bread. Biofuel has been produced using environmentally benign methods, such as using algae, due to the global decline in petroleum products and environmental health concerns. Consequently, the usage of algae fuel as a substitute for traditional fossil fuels has increased. While it shares similarities with other corn and sugarcane-based biofuels, its production process differs

Threats to Beneficial Endangered Species of marine Macrolgae

According to the evidence and data presented so far, algal species are at risk of extinction. Macroalgae appear to be threatened by habitat destruction, community modification, and gravel mining (Gibson et al., 2007). Eutrophication of plateau lakes due to phosphorus contamination has led to harmful cyanobacterial blooms, as observed in Hongfeng Lake. These blooms initially proliferate rapidly, but eventually cause oxygen depletion, resulting in mass mortality of aquatic organisms. Following this collapse, the cyanobacteria themselves also decline, leading to a sharp disruption of the lake's ecological balance (Yuan et al., 2025). Algal species are particularly vulnerable to major environmental hazards, especially pollution and nutrient enrichment from fertilizer runoff. Such inputs accelerate eutrophication processes, disrupt natural aquatic ecosystems, and can trigger harmful algal blooms that pose risks to biodiversity and water quality. (Abdel-Raouf et al.,2012). Additional factors influence algal physiology and may present future clinical implications that require further investigation. Environmental stressors, including temperature fluctuations and climate variability, have been demonstrated to alter the genomic expression patterns of endosymbiotic dinoflagellates, potentially affecting host-symbiont relationships.

Light intensity represents a critical limiting factor in algal cultivation and metabolism. Photosynthetic efficiency, growth rates, and biomass accumulation are directly correlated with both light duration and intensity parameters (Vo et al., 2024). However, species-specific light requirements create variable responses in biomass production and cellular metabolism across different algal taxa.

Algal growth ceases at suboptimal light concentrations, particularly at the compensation point where photosynthetic carbon fixation equals respiratory carbon release, resulting in net zero growth. Conversely, increased light intensities generally enhance growth rates, though optimal thresholds vary

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among species and may be constrained by photoinhibition at excessive intensities (Rada-Ariza et al., 2023).

This revision eliminates redundancy, employs precise scientific terminology, and structures the content in a manner consistent with peer-reviewed medical literature

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Acidification of Oceans: Ocean acidification is primarily driven by human activities, particularly the anthropogenic emission of carbon dioxide (CO_2) and other harmful gases. When CO_2 dissolves in seawater, it forms carbonic acid, which lowers the ocean's pH and disrupts marine ecosystems. (Mostofa et al.,2016). Anthropogenic environmental degradation presents significant threats to macroalgae and coralline algae populations (Zuo et al., 2025), particularly species within the red algal lineage (*Rhodophyta*) that exhibit characteristic red-pink pigmentation due to phycoerythrin content.. On the other hand, some algae can overcome hazardous contamination cleaning wastewater and cleaning environment (Palomar et al., 2023)

Mesocosm investigations, which are experimental systems designed to study natural habitats, have shown that elevated CO_2 levels adversely affect marine life, particularly by inhibiting the growth of crustose coralline alga**e**(Dutra et al.,2016). hese algae play a crucial role in benthic ecosystems, which are the lowest surfaces of seas, lakes, and oceans. Ocean acidification, a direct consequence of elevated CO_2 levels, poses serious threats to marine ecosystems. Crustose coralline algae, which serve as vital structural and biological components, play a key role in forming habitats such as maerl beds (De et al. 2024). Their decline could therefore disrupt biodiversity and ecosystem stability. The decline of these algae can disrupt the entire benthic community, affecting biodiversity and the overall health of marine environments.

Temperature: Temperature exerts substantial influence on algal cellular metabolism and photosynthetic efficiency, with effects that are interdependent with light intensity parameters. Species-specific thermal optima for photosynthetic function vary considerably, though most algal taxa exhibit optimal growth within the 20-30°C range (Cassidy et al., 2011). Thermophilic species represent notable exceptions, demonstrating tolerance to elevated temperatures that would be lethal to mesophilic strains. Cultivation at suboptimal temperatures results in significant reductions in biomass yield and metabolic efficiency..

Conservation

Algae encompass prokaryotic cyanobacteria, which are ubiquitous, and eukaryotic species, such microalgae. (Larkum et al.,2020).Despite being widely distributed, they are most frequently seen in terrestrial areas. (Grenyer et al.,2006). Even so, many distinct species can tolerate the environmental conditions to varying degrees. Some strains can withstand even the most extreme environmental stressors, as the endolithic cyanobacteria known as "desert varnish," which thrive beneath stony surfaces. Some species, however, may form symbiotic relationships with water invertebrates, fungus, liverworts, and higher plants. (Stachowicz et al.,2001). Effective research methodologies and conservation strategies require access to authenticated biological specimens, as established for other taxonomic groups (De Klemm et al., 1993). Algal culture collections have emerged as essential repositories for the identification and preservation of endangered algal species, serving dual roles in biodiversity conservation and research applications.

These collections vary substantially in scope and specialization, ranging from specialized facilities focused on ecotoxicological assessment of environmental impacts to comprehensive repositories maintaining extensive taxonomic diversity. Notable examples include smaller collections housed within aquaculture and ecotoxicity research centers, and major institutional repositories such as the Pasteur Culture Collection of Cyanobacteria (PCC), which has maintained diverse strains of blue-green algae under Pasteur Institute auspices since 1971.

Current estimates indicate over 50,000 described microalgal species exist, with approximately 2.5% represented in established culture collections (Mata et al., 2010). Escalating anthropogenic pressures on natural ecosystems and mounting biodiversity concerns have necessitated the development of advanced isolation methodologies for algal species preservation (Barra et al., 2014). The integration of molecular systematics and genetic conservation approaches promises enhanced taxonomic resolution and improved species preservation outcomes.

Conservation protocols for algae remain less comprehensively studied compared to other major microbial groups (Nowicka-Krawczyk et al., 2022). The majority of algal species exhibit photoautotrophic metabolism, though some demonstrate mixotrophic capabilities utilizing organic substrates. Obligate heterotrophic species lack photosynthetic apparatus and chlorophyll content entirely. This metabolic diversity, coupled with the extensive range of ecological niches occupied by algal taxa, has necessitated the development of varied cultivation protocols and preservation strategies.

Contemporary preservation challenges, including specialized environmental requirements, genetic conservation needs, and resource constraints, have driven innovation in long-term algal preservation technologies (Bull et al., 2000). Conventional preservation methods, including air drying and lyophilization—a dehydration process designed to extend material shelf life—have demonstrated inadequate viability maintenance, with significant viability decline observed within one year.

Culture Collections used for the conservation of algae:

Given the practical limitations of in situ habitat preservation for endangered ecosystems, alternative conservation strategies require implementation (Ferraro et al., 2001). Ex situ cultivation represents a viable approach for ecosystem preservation beyond natural environmental contexts, with initial applications focusing on macroalgae conservation.

This methodology was pioneered in Japan approximately fifteen years prior for charophyte preservation, with subsequent adaptation by research groups for red algae and additional charophyte species conservation. These conservation efforts have enabled the National Institute for Environmental Sciences' Microbial Culture Collection to maintain extensive taxonomic diversity across multiple genera and species, providing repository facilities for taxa that have experienced local or regional extinctions (National Research Council et al., 1995).

Ex Situ Conservation/ Off-site Conservation:

Protecting the natural habitats of endangered species is essential for fostering dynamic evolutionary processes, making it preferable to conserve these species in their native environments (Grime et al., 2012). However, due to the rapid destruction of habitats worldwide, ex situ cultivation has emerged as a valuable

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method for preserving threatened species (Zegeye et al., 2017). Zoos and aquariums, which attract around 500 million visitors annually, play a significant role in raising public awareness about biodiversity issues through their marketing efforts, helping to change behaviors and promote a positive outlook toward conservation (Frost et al., 2011). Their primary purpose is to educate the public about the challenges faced by various species (Carr et al., 2011). Additionally, nature can aid in forensic investigations, as demonstrated by the use of **diatoms** in drowning cases. By comparing diatoms found in a deceased individual's bone marrow with those in the water sample from the recovery site, investigators can determine the ante-mortem nature of drowning, showcasing the intersection of ecology and forensic science.(Lockyer et al.,2021)

Conclusion

The taxonomic classification of algae underwent substantial revision following advances in electron microscopy from the 1960s onwards, which revealed fundamental ultra structural differences between algae, fungi, and protozoa, prompting new phylogenetic frameworks based on cellular architecture rather than gross morphology. Major taxonomic groups exhibit distinct characteristics: Cryptophycophyta display unicellular, flagellated morphology with chlorophylls a and c plus characteristic phycobiliproteins, while Dinoflagellates feature distinctive dual flagella and accessory pigments including peridinin and dinoxanthin. Environmental stressors significantly influence algal physiology, with light intensity and temperature representing critical limiting factors—most taxa exhibit optimal growth within 20-30°C, though thermophilic species demonstrate exceptional tolerance. Photosynthetic efficiency and biomass accumulation correlate directly with illumination parameters, with growth ceasing at suboptimal light concentrations where respiratory carbon release equals photosynthetic fixation. Anthropogenic environmental degradation poses substantial threats to macroalgae and coralline algae populations, particularly affecting Rhodophyta lineages. Conservation challenges are significant: over 50,000 microalgal species exist, yet only 2.5% are maintained in culture collections. Traditional preservation methods, including lyophilization, demonstrate inadequate long-term viability maintenance. Ex situ cultivation has emerged as a viable conservation strategy, successfully applied to macroalgae and charophyte preservation, with major repositories like the Pasteur Culture Collection of Cyanobacteria maintaining extensive taxonomic diversity. The majority of algal species exhibit photoautotrophic metabolism, though metabolic diversity necessitates varied cultivation protocols. Future conservation efforts increasingly rely on genetic sequence repositories such as GenBank, which provide essential infrastructure for monitoring genetic diversity and enhancing preservation strategies, ensuring continued availability of algal ecological services and biotechnological applications for future generations through integration of molecular systematics with conservation approaches

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