Application of Algae Biomarkers in Water Quality Monitoring

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Abstract

The research focuses on the broad use of algal bioindicators in water quality monitoring. Its use yields important insights for the future design of water quality monitoring systems in addition to a thorough knowledge of aquatic health. The practical implementation of algal bioindicators is supported by dependable data obtained from both field monitoring and laboratory study. Algae's versatility and adaptability in monitoring water quality are shown by the differences in how they are applied to different kinds of water. Artificial intelligence, big data, and technological advancements will shape the future of algal bioindicators in water quality monitoring. This paper provides a thorough explanation of the practical relevance and value of algae as bioindicators in water quality monitoring. The vital function that algae play in monitoring water quality is made clear by examining the reaction mechanisms of algae to pollutants, their uses in various kinds of water, and future directions. This improves the accuracy and thoroughness of monitoring by offering a broad viewpoint for comprehending changes in water quality.

Keywords: Algae, Biological Indicators, Ecological Adaptation, Monitoring Of Water Quality, Practical Use.

1. Introduction

Concerns over global water quality have led to serious worries about water quality monitoring on a global scale. The health of aquatic ecosystems is under unprecedented stress due to the ongoing environmental deterioration, especially the decline in benthic biodiversity. A worldwide agreement has emerged on the importance of this problem, which is propelling ongoing innovation and advancement in techniques for monitoring water quality. Algae are important for preserving the aquatic ecological balance since they are the principal producers in aquatic habitats. They provide the environment as a whole with energy by converting solar radiation into organic matter via photosynthesis. Algal species and abundance control vital water processes including oxygen generation and nitrogen cycling. The stability of the whole aquatic environment is directly impacted by the structure of algal populations in water. Algae of different kinds have different functions in the sea, such as releasing oxygen and providing food for benthic creatures (Hu, 2023).

Consequently, the variety and richness of algae act as crucial markers of the health of the aquatic environment. Algae react quickly to environmental changes and are very sensitive to variations in water quality. They are the perfect biological indicators because of their ecological richness and resilience, providing detailed data for monitoring water quality. Eutrophication and pollutant intake are two issues that researchers may identify in water bodies early on by observing the composition and organization of algal populations. Algae are among the main species in aquatic habitats and are essential to the general equilibrium of these ecosystems. Their place in the food chain and ability to control the cycle of nutrients make them suitable biological markers (Mohsenpour & Associates, 2021). It might be difficult to accurately and dynamically represent the state of waterbodies using traditional techniques of monitoring water quality because they often place an excessive amount of emphasis on certain indicators. Water industry experts urgently need more thorough and effective water quality monitoring technologies to effectively advise the sustainable use and conservation of water resources in the face of emerging environmental issues and the need for water management. Researchers may monitor algal populations to get insights into other biological communities and the aquatic ecosystem as a whole, as well as to obtain a more thorough knowledge of the health of water bodies.

This review aims to conduct in-depth research on the use of algae as biomarkers in water quality monitoring, offering more practical techniques and theoretical support for global water quality monitoring, and encouraging the preservation and restoration of water ecological balance in order to better address issues related to water quality worldwide. Researchers will further examine the shortcomings of current monitoring methods and advocate for the application of emerging technologies to meet the demand for more comprehensive water quality data by investigating the crucial ecological roles of algae in aquatic ecosystems, their potential value as biological indicators, and an analysis of the needs and challenges in current water quality monitoring.

2 Algal Biological Indicators: Classification and Features

2.1 Algae Classification

The ecological characteristics of algae are essential for their categorization. varying kinds of water bodies support the growth of algae with varying habitat adaptations. Using diatoms as an example, silicates are used to create their outer shells, which explains why they are comparatively common in silicate-rich seas. While Dunaliella salina, a kind of salt algae, may be more prevalent in salty lakes, green algae (Chlorophyta) may predominate in freshwater systems. Functional group studies provide light on the distinct ecological functions that various algae play in ecosystems, such as the pivotal part that diatoms play in the silicon cycle. The two primary pillars supporting the taxonomy of algae are morphology and genetics. Algae may be categorized morphologically according to the size, shape, and structure of their cells. For example, dinoflagellates vary significantly from diatoms due to their flagellated cell structure (Figure 1). The use of DNA sequencing in particular has advanced molecular biology methods, allowing researchers to more precisely determine the evolutionary links among algae. For instance, researchers may establish the evolutionary links of certain microalgae and provide the groundwork for a more accurate taxonomy by comparing the sequences of particular genes.

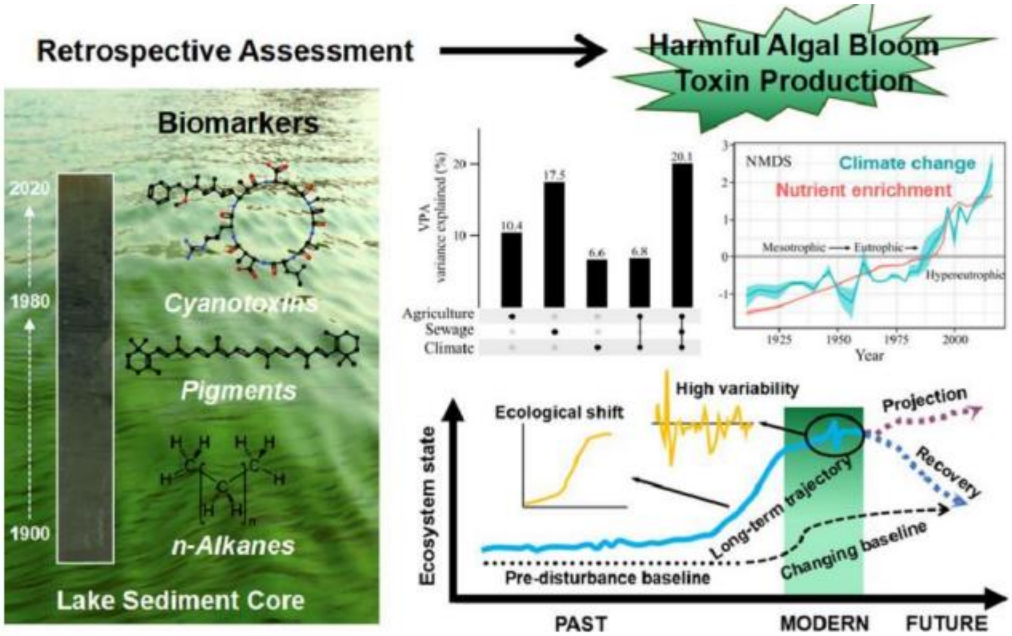

Figure 1 The hazards of algal blooms

Algal communities' spatiotemporal dynamics are essential for both ecological research and categorization. When it comes to seasonal fluctuations, certain algae, like diatoms, may greatly increase in the spring and gradually diminish in the summer. There is also a great deal of variation in the spatiotemporal distribution features of algae in various bodies of water. For instance, certain euglenoids could be scarce in clear lakes but more common in rivers with a lot of organic waste. Since different algae may show distinct adaptations to contaminants or temperature changes, the categorization also includes the response mechanisms of algal populations to external stresses.

2.2 Algal bioindicators' attributes

The relevance of algae in monitoring water quality is mostly determined by their biological adaptation to changes in the environment. Using diatoms as an example, this kind of algae can flourish in a variety of water environments and has strong flexibility. For example, the diatom Nitzschia palea is more prevalent in lakes and rivers with high amounts of silicate because it is better suited to surroundings rich in insilicate. Its oscillations in distribution and abundance reflect changes in the silicate content of the water, showing the level of eutrophication in the water and acting as environmental indicator organisms. Comprehensive data for water quality monitoring is also provided by the sensitivity of various algal groups to water health parameters. For instance, chlorophyta's sensitivity to nutrients like phosphorus and nitrogen in water quality may be linked to variations in the amount of eutrophication in the body of water. Algae's uses in monitoring water quality are closely related to its biological properties. One important metric that is directly connected to the amount of nutrients in the water is the growth rate of algae. Using cyanobacteria as an example, nutrients like phosphorus and nitrogen have a major impact on the growth rate of these bacteria. Thus, by keeping an eye on the development of cyanobacteria, scientists may quickly identify problems associated with an overabundance of nutrients in the water. Furthermore, there is a lot of focus on the indicator function of algal community structure in detecting water eutrophication. The drop in diatoms in freshwater lakes might be related to the water's phosphorus-rich conditions. Certain algae, such phytoplankton, may function as indicator species in water quality monitoring by reflecting changes in the organic composition of the water. Phytoplankton is particularly sensitive to organic loads. Algal bioindicators may be difficult to use in complicated water bodies, however. Accurately classifying and interpreting algal communities is challenging due to the variety of complicated ecological circumstances, physical and chemical characteristics, and the interplay of many algae species. Consequently, in real-world scenarios, staff members must take into account a variety of indications in order to fully evaluate the biological state of the water. 1.3 Algal communities and the health of aquatic ecosystems

Freshwater environments exhibit a complex and delicate interaction between the structure and composition of algal populations and the health of aquatic ecosystems. For efficient water quality monitoring and the preservation of aquatic ecosystems, comprehensive study into the ways in which various algal populations reflect the health of water bodies and their roles in preserving ecological balance and functioning is essential. Scientific water quality monitoring and water management are supported by this improved knowledge of the connection between algal populations and aquatic health. Transparency of water bodies is intimately related to the structure and composition of algae populations. The amount of light that can flow through water is referred to as transparency, and it is essential for the growth and development of aquatic plants. Certain diatoms, such those in the genus Tabellaria, are often linked to improved water quality circumstances. They are very effective in settling down suspended particles in the water, preserving its clarity and giving benthic plants a better place to flourish. Moreover, alterations in algal populations are a noteworthy symptom of eutrophication in water. According to Li et al. (2023), cyanobacteria often multiply excessively in nutrient-rich waters, generating cyanobacterial blooms. The algae in these blooms may create toxins that endanger the aquatic species and the ecological balance of water bodies (Figure 1). Problems with nutrient enrichment in aquatic bodies are often linked to elements like urban sewage discharge and agricultural runoff. It is thus possible to identify and prevent potential eutrophication issues in water bodies by keeping an eye on the composition of algal colonies. Algal communities also directly affect ecosystem functions as the generation of oxygen and the breakdown of organic materials in water bodies. Certain algae use photosynthesis to produce oxygen, which is what gives the aquatic environment its oxygen. In addition, various types of algae break down organic materials in water bodies, which helps with the cycling of organic waste. Alterations in the composition of distinct algal communities also demonstrate a mutually beneficial association with the well-being of aquatic bodies. For example, a steady rise in diatoms may signal enhanced water clarity and a rise in benthic plant richness throughout the ecosystem restoration stage. The stability and recovery of aquatic ecosystems are facilitated by this constructive interaction.

3. Algal Biomarkers' Ecological Adaptability

3.1 Algal response mechanism to contaminants

When exposed to contaminants, algae display a variety of reaction mechanisms that provide important hints for determining the degree of water contamination (Li et al., 2022). For instance, the structure of the cell walls of diatoms, a kind of siliceous shell algae, has a special function in the bioaccumulation of contaminants. Because diatoms' cell walls have a strong attraction for contaminants like heavy metals, diatoms may amass a significant quantity of these dangerous compounds in water polluted with heavy metals (Figure 2). Because of its bioaccumulation properties, it may be used as a biomarker to track heavy metal levels in aquatic bodies (Zheng et al., 2023).

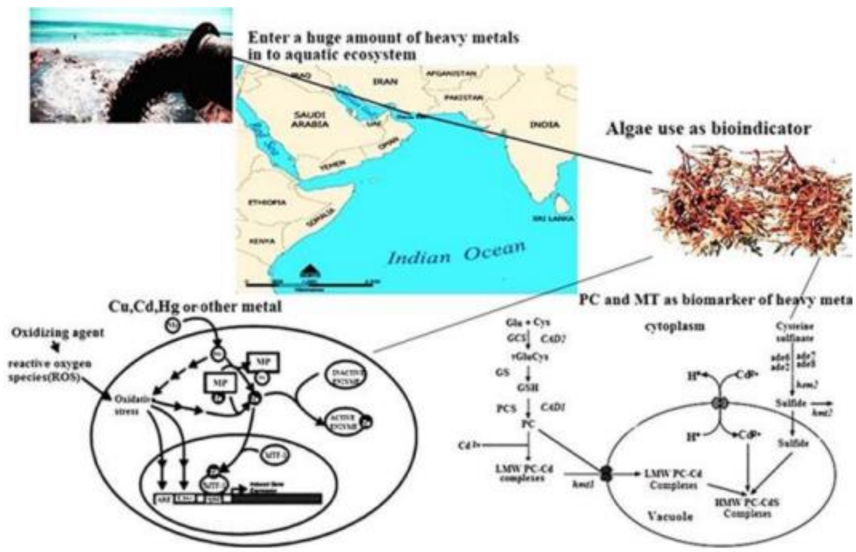

Figure 2 Accumulation of heavy metals inside algae

Furthermore, several algae show tolerance to toxins. Common algae called cyanobacteria may develop at comparatively faster rates in water bodies that are heavy in organic contaminants. The physiological traits of cyanobacteria, such as their capacity to acclimate to high temperatures, may be connected to this resistance. Cyanobacteria's increased ability to photosynthesize also helps them to withstand organic pollutants in the environment. Consequently, the diverse modes of reaction shown by different algae when exposed to toxins provide more thorough data for the monitoring of water quality.

3.2 Analysis of the features of the temporal and geographical distribution

The health of water bodies is intimately correlated with the temporal and geographical distribution features of algal populations. The spread of algae is significantly impacted by seasonal variations (Chen et al., 2023). Warm temperatures and plenty of sunshine in the spring provide the perfect conditions for algal growth. As a result, springtime water basins often have greater algal richness. Algal abundance in autumn may decline with decreasing temperatures, and the circumstances favorable for algal development steadily deteriorate. Seasonal variations are not the only significant variables affecting the spread of algal communities; water depth and geographic location also play a significant role. Because depth has an impact on how light and nutrients are distributed, algal colonies in water bodies with varying depths may display vertical stratification. Climate and kind of water body are two elements that affect geographic location and influence the regional features of algal communities in various places. For example, diatoms may predominate in eutrophic areas, whilst other species of algae may be more prevalent in waterways with a more balanced nutrient level.

3.3 Collaborative exchanges across varied algal communities

In watery conditions, diverse algal colonies may display intricate cooperative relationships. Through interactions including symbiosis, competition, and resource conversion, algae from various functional groups may affect one another and create a somewhat balanced ecosystem in the water. Algal communities include several forms of interaction, including as resource transformation, symbiotic connections, and competitive interactions. For example, diatoms and green algae have a symbiotic connection in some freshwater lakes. Through the process of photosynthesis, diatoms create oxygen, which raises the oxygen level in the water and creates a more favorable environment for green algae to survive. On the other hand, green algae encourage eutrophication in the water by absorbing carbon dioxide, which improves the life conditions for diatoms. These varied algae communities' cooperative relationships are essential to the stability and ecological equilibrium across aquatic environments. Researchers may get a better understanding of the workings of aquatic ecosystems by exploring the interactions between various algae species. This understanding can then be used to water management and ecological conservation. Knowing these cooperative relationships also helps to better preserve the health and sustainability of waterbodies by anticipating and reducing threats to aquatic ecosystems.

4 Using Algal Biomarkers to Monitor Water Quality

4.1 Combining outdoor observation with laboratory research

One of the key factors influencing the use of algal biomarkers in the area of water quality monitoring is the merging of lab research with field monitoring. Researchers have the opportunity to learn in-depth details about the physiological traits, ecological adaptation, and other aspects of algae via laboratory investigations. Researchers can determine the level of pollution in water bodies by observing the development of algae under the effect of various contaminants via laboratory culturing.

This lab research's practical applicability is important for creating water quality monitoring programs, determining the level of water contamination, and other tasks. In addition, data under actual water conditions are obtained by field monitoring, which include the observation and sampling of algal populations in their native habitats. Researchers may get a better understanding of the distribution of algae, community structure, and their link to environmental changes in naturally occurring water bodies by doing field monitoring. In order to verify the quality and comparability of monitoring data, researchers may verify the dependability of laboratory findings in real-world water conditions by combining field monitoring with laboratory research.

Modern technology is playing a more and bigger part in the monitoring of algae. Progressions in molecular biology methods, including DNA sequencing, have enabled quick and easy categorization and identification of algae. Concurrently, large-scale, high-frequency water monitoring has become feasible via the use of remote sensing technologies, making it easier to detect algal biomarkers in the field. By using these contemporary technologies, water quality monitoring may be done more thoroughly and effectively, which improves the usefulness of algal biomarkers in real-world monitoring initiatives.

4.2 Using algae biomarkers in various kinds of water bodies

Algal biomarkers show great adaptability in their use to water quality monitoring, since they are not restricted to any one kind of water body. The use of algae biomarkers in various water bodies, such as lakes, rivers, coastal regions, etc., reveals both parallels and differences. Due to the rapid water flow in rivers, the distribution of algae may show spatial heterogeneity, which may affect the efficacy of certain algae species that are sensitive to flow velocity (Yin and Li, 2023). Since lakes are relatively contained bodies of water, algal indicators are more likely to accumulate here (Huang et al., 2023), making the use of algae in lake water quality monitoring more crucial. The dynamic changes in algal populations are more complicated in coastal locations that are impacted by tides and currents. Seasons and tidal states may have a substantial impact on the makeup of algal communities, therefore monitoring must take both geographical and temporal factors into account. To best optimize monitoring systems, it is necessary to extensively research the effects of various water body parameters on algal biomarkers in particular habitats. To increase monitoring efficiency, algal biomarkers must be widely used in large-scale water quality monitoring. By verifying and contrasting the suitability of algal biomarkers in various water bodies, scientists may create universal monitoring indicators and techniques. This method makes it easier to quickly monitor a wider variety of aquatic bodies. This campaign offers broad technical help for managing water quality in various locations and kinds of water bodies, in addition to expanding the scope of monitoring.

4.3 Algal biomarkers' future directions for development

Algal biomarkers may be used in a variety of ways to improve and broaden the monitoring of water quality. In the future, technological innovation is anticipated to be a major factor in pushing breakthroughs in algae monitoring. Labs will have access to more accurate and efficient technological instruments for the identification and monitoring of algae as a result of ongoing advancements in molecular biology, remote sensing technology, and other domains. This will improve the accuracy and dependability of monitoring. It's also expected that the use of big data and artificial intelligence (AI) will lead to new developments in algae monitoring. Researchers may more quickly detect abnormalities, get a better understanding of the spatiotemporal distribution patterns of algae, and provide more intelligent assistance for the management of water quality by using deep learning and pattern recognition techniques to large amounts of monitoring data. Algal biomarkers have bright futures in the worldwide water quality monitoring network. Algal monitoring is set to become a crucial part of water quality monitoring as awareness of the value of protecting the environment via water grows. To better address global water quality concerns and protect humanity's common water resources, international collaboration should be strengthened, a worldwide water quality monitoring network can be established, and sharing and comparison of algal biomarkers made easier.

5 Conclusions

A crucial function that algae indicators play in evaluating water quality is their variety. In addition to reflecting the biological complexity of water bodies, the high variety of algae also offers more thorough information for monitoring. Different algae, ranging from Chlorophyta to Bacillariophyta and Phaeophyta, show notable variations in their environmental adaptation and response mechanisms. The ecological adaptability and prospective uses of algae as biological markers are important areas of study focus. Algae's reaction mechanisms to many environmental conditions, such as temperature, light, and pollution, include several facets of their growth and reproduction processes. Algae have a special potential for use in water quality monitoring because of their biological characteristics (Si et al., 2023). Researchers can interpret these features more precisely in aquatic ecosystems by having a thorough knowledge of how algae react to pollution, temperature fluctuations, and other conditions. This information strengthens the case for algae's biological indicator function. Algae play a crucial part in the aquatic food chain and are sensitive to contaminants, making them valuable for monitoring the overall health of aquatic ecosystems.

This makes algae a valuable tool for water health monitoring. The ongoing advancement of contemporary technology offers previously unheard-of possibilities for algal monitoring. More accurate algal identification and categorization are made possible by developments in molecular biology techniques, providing more effective methods of water monitoring (Bhatt et al., 2022). Large water bodies may be monitored simultaneously with the use of remote sensing technologies, giving monitoring activities a wider scope. Algal monitoring is changing as a result of this technology, moving from conventional field surveys to a multi-level system that integrates contemporary technical methods with laboratory research. Big data and artificial intelligence applications make it easier to handle vast amounts of data, which improves algal monitoring's ability to connect into the international water quality monitoring network. Even with the great advancements in focused research, the present studies still have several shortcomings. For example, techniques for precisely identifying algae in mixed communities are still in their infancy and need to be further refined and optimized.

Furthermore, the difficulties in gathering data must be addressed, particularly in intricate water bodies and challenging environmental settings. Future investigations need to concentrate on the dynamic analysis of algal communities, the use of algal biomarkers in the context of climate change, and the prospective use of algal monitoring in the management of ecosystems. The development of algae under various seasonal and hydric circumstances may be better understood via the dynamic study of algal communities, which serves as a foundation for more precise monitoring. Research on how algae react to climate change and the possible effects of this reaction on the health of water bodies may be conducted in the developing area of algal biomarkers in climate change. In addition, the integration of algal monitoring into prospective research on ecosystem management is expected to enhance the preservation of water bodies' biological equilibrium and provide more efficient approaches to safeguarding and regulating aquatic ecosystems.

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