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Application of Geographical Information System and Remote Sensing for Environmental Assessment using Plankton Data: A Perspective Review

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ABSTRACT

The combination of Geographical Information System (GIS) and Remote Sensing technologies has significantly transformed environmental assessment, namely in the examination of aquatic ecosystems using plankton data analysis. This paper provides a comprehensive overview of the current techniques and progress in utilizing GIS and Remote Sensing to monitor, environmental changes by using plankton as bio-indicators. Plankton, being highly responsive to changes in the environment, play a vital role in assessing water quality and the overall health of ecosystems. The paper explores different applications, such as mapping the distribution of spatial-temporal patterns, identifying dangerous algal blooms, and evaluating the effects of human activities on aquatic systems. This study has investigates assess and prediction of water quality using GIS techniques. This analysis highlights the capacity of GIS and Remote Sensing to improve the accuracy and effectiveness of environmental monitoring programs and promote the creation of comprehensive strategies for sustainable ecosystem management.

Keywords Geographical information system, Plankton, Environmental assessment, Aquatic ecosystems, Bio-indicator.

INTRODUCTION

Plankton play a crucial role in aquatic habitats, and their presence and quantity can offer significant information on the well-being of these ecosystems. An environmental assessment is crucial for comprehending the effects of human activities on aquatic ecosystems. Remote sensing and geospatial information systems can offer valuable data to facilitate this process. Prior research has employed remote sensing and geographic information systems to evaluate environmental conditions in aquatic ecosystems. However, there is a scarcity of studies investigating the application of these technologies for plankton evaluation. The utilization of remote sensing and geographic information systems can yield valuable data for the evaluation of plankton in aquatic ecosystems, offering a more efficient and cost-effective alternative to conventional techniques.

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The significance of geospatial and remote sensing techniques in evaluating environmental characteristics for water bodies cannot be exaggerated. The use of remote sensing and geoprocessing techniques has become more widespread in environmental studies across several fields (Klemas 2013). These robust instruments facilitate the acquisition, retention, examination, and administration of geographically linked data, rendering them indispensable for studying alterations in water bodies and their adjacent surroundings (Carvalho and Carvalho 2012).

An important benefit of employing remote sensing and GIS techniques for water bodies is the capacity to effectively monitor and evaluate surface water supplies. Researchers can use satellite imagery to categorize and chart surface water characteristics, assess water purity, and observe fluctuations in water volume over a period of time (Nguyen *et al.* 2020). This information is vital for the efficient administration and preservation of water resources, particularly in light of increasing hazards such as climate change.

Moreover, the incorporation of geospatial data with other environmental variables, such as land use, land cover, and topography features, enables a comprehensive of the intricate dynamics that affect water bodies (Klemas 2014). The utilization of these methodologies allows for the development of models and predictions that can effectively identify possible risks to both the quality and quantity of water. This empowers individuals involved to apply proactive tactics in order to effectively mitigate and manage these issues.

The utilization of *in-situ* sensors and the advancement of remote sensing technologies have greatly enhanced the accessibility of detailed spatial and temporal data, which is crucial for a thorough comprehension of catchment processes that impact water quality (Mahessar *et al.* 2020). The large amount of data available, combined with the capability to integrate it via geospatial analysis, has become essential for efficient monitoring and management of water quality.

The use of geospatial and remote sensing techniques to evaluate the environmental characteristics of water bodies has been extensively reported in the literature (O'Grady *et al.* 2021). These studies have shown the effectiveness of these methods in mapping and monitoring the quality of water, identifying and following changes in water bodies, and providing information for decision-making processes about water resource management.

In India, there are few research that have been conducted on the use of plankton for monitoring ecosystems utilizing GIS and Remote sensing applications. (Saraswathy and Pandian (2016, 2018) have conducted a study on Pulicat lagoon, employing GIS and Remote Sensing tools to examine the phytoplankton, flora, and fauna.

Phytoplankton

Freshwater phytoplankton

Geospatial analysis and remote sensing techniques are now more important than ever for monitoring and evaluating the condition of freshwater habitats, especially when it comes to assessments based on phytoplankton. Phytoplankton, being the main producers in aquatic ecosystems, act as significant markers of ecological shifts and can offer useful information on the general state of a waterbody (Saraswathy and Pandian 2018). Remote sensing provides a way for researching the dynamics of phytoplankton that is non-invasive and cost-effective. This technology complements standard *in-situ* monitoring techniques (Paerl *et al.* 2007).

An important obstacle in using satellite remote sensing for monitoring the quality of inland water is the limited spatial resolution of the sensors now available. This resolution is sometimes not detailed enough to accurately capture the changes occurring in tiny water bodies and nearshore areas (Paerl *et al.* 2007). In addition, satellite measurements are usually restricted to the upper section of the water column, and not all essential biogeochemical variables may be directly obtained from satellite data. Nevertheless, recent progress in remote sensing technology and the creation of novel algorithms have started to tackle these constraints, so creating new possibilities for conducting thorough evaluations of freshwater resources by utilizing phytoplankton as a biological indicator (Schaeffer *et al*. 2022).

Remote sensing techniques, such as the use of spectral indices, have shown their capacity to enhance the monitoring of environmental factors, including subterranean characteristics of sediment and soils in intricate wetland systems. The integration of remote sensing and geostatistical methods offers a non-intrusive and cost-efficient means to observe the spatial diversity of nutrient levels in these ever-changing environments.

In addition, the implementation of remote sensing technologies and GIS has made it easier to combine different datasets, allowing researchers to evaluate water quality, quantity, and other environmental aspects in a more comprehensive manner (Nguyen *et al.* 2020). The integration of algorithms, such as the Case 2 Regional Coast Color and Maximum-Peak Height chlorophyll-a algorithms, has enhanced the precision and dependability of phytoplankton-based evaluations obtained from satellite data.

In order to effectively assess freshwater environments using phytoplankton, it is necessary to use a multidisciplinary strategy that integrates geospatial analysis with remote sensing. This approach involves combining satellite data, *in-situ* observations, and advanced analytical tools. By utilizing these complementary tools, researchers and resource managers can acquire a more all-encompassing comprehension of freshwater ecosystems, facilitating more knowledgeable decision-making and efficient management strategies (Paerl *et al.* 2007, Domingues *et al.* 2008, Rivero *et al*. 2009, Schaeffer *et al.* 2022).

Brackish water phytoplankton

Evaluating brackish water settings is an essential undertaking for comprehending and overseeing these fragile ecosystems. The combination of geospatial analysis and remote sensing techniques with the study of phytoplankton populations can offer useful insights in this particular setting. Phytoplankton, being primary producers, have a crucial function in maintaining the ecological equilibrium of brackish water systems. Their spatial and temporal dynamics can be used as markers of the environmental well-being (Schaeffer *et al.* 2022).

Recent advancements in remote sensing technology have facilitated the creation of algorithms and automated data processing systems that can efficiently monitor algal blooms in vast water bodies, such as the Great Lakes (Binding *et al.* 2020). These tools have been essential in enabling almost real-time monitoring of bloom conditions, documenting spatial and temporal patterns, and enhancing the comprehension of the environmental factors that cause blooms. Moreover, the application of statistical methodologies and the integration of supplementary datasets, such as water temperature, turbidity, solar radiation, and bathymetry, can provide a more comprehensive understanding of the factors that initiate or restrict the growth of algal blooms in coastal and open ocean waters (Blondeau-Patissier *et al.* 2014, Binding *et al.* 2020).

Applying geospatial analysis and remote sensing techniques to brackish water settings can provide important information. Field campaigns, although necessary, might require a significant amount of resources and may yield restricted data. Remote sensing provides a comprehensive and timely picture of spatial and temporal information, which enhances our understanding of ecological processes (Blondeau-Patissier *et al.* 2014, Alarcon *et al.* 2018, Binding *et al.* 2020). An example is a study that analyzed a severe algal bloom event in a reservoir by utilizing data from the Landsat 8-OLI sensor and conducting on-site sampling. This study showcased the effectiveness of this method. The work formulated semiempirical models for quantifying chlorophyll-a concentrations using satellite data, offering a helpful instrument for monitoring and evaluating the condition of brackish water ecosystems.

By utilizing remote sensing, multi-scale evaluations can provide a more thorough understanding of cyanobacterial blooms across large geographical areas, such as at the sub-continental scale (Paerl *et al.* 2007). Many authors demonstrate how this method may be used to assess water quality, biological health, and the impact of management strategies at many levels, including local, regional, and national scales. Integrating field data, laboratory analysis, and simulation models with remote sensing can be a highly effective approach for assessing and monitoring brackish water habitats (Blondeau-Patissier *et al*. 2014, Alarcon *et al.* 2018, Binding *et al.* 2020).

By combining geospatial analysis and remote sensing tools with the study of phytoplankton communities, we can greatly improve our comprehension and control of brackish water ecosystems. These methods can offer valuable understanding of the spatial and temporal changes in these intricate systems, ultimately assisting in the creation of efficient strategies for conservation and restoration (Paerl *et al.* 2007, Blondeau-Patissier *et al*. 2014, Alarcon *et al.* 2018, Lekki *et al.* 2019). (Saraswathy and Pandian 2016) have suggested that Sentinel-2 remote sensing images identified the biomass zone.

Marine phytoplankton

Remote sensing has emerged as a progressively effective instrument for monitoring and evaluating the condition of marine ecosystems. An interesting use of remote sensing in this context is the utilization of phytoplankton as a biological quality element for assessing the ecological condition of water bodies (Saraswathy and Pandian 2018, Schaeffer *et al.* 2022). Phytoplankton-based indicators are highly suitable for remote monitoring due to their ability to be monitored across vast spatial scales and incorporated with modeling efforts (Saraswathy and Pandian 2018). In addition to direct monitoring, remote sensing of oceanographic parameters such as sea surface temperature, ocean color, and frontal zones can offer valuable contextual information for the sustainable management of fisheries (Klemas 2013). Although there are still some obstacles, such as the requirement to combine phytoplankton monitoring with other methods, the advancing technology of remote sensing platforms and analysis techniques is making them more and more useful for thoroughly evaluating marine environments (Paerl *et al.* 2007, Rivero *et al.* 2009, Klemas 2013, Saraswathy and Pandian 2018).

Research on utilizing phytoplankton as a biological quality element to monitor aquatic environments has been actively pursued. Phytoplankton are useful indicators because they promptly react to changes in the environment and their community composition offers valuable information about the overall ecological condition of a water body (Saraswathy and Pandian 2018). Remote sensing methods are highly suitable for monitoring phytoplankton because they enable comprehensive observations across wide spatial areas (Schaeffer *et al.* 2022). The alteration of the phytoplankton community has been employed as a marker of escalating eutrophication and ecological deterioration. In addition, the incorporation of phytoplankton monitoring into remote sensing and modeling endeavors has allowed for the evaluation of ecological shifts on a larger ecosystem and regional level.

Nevertheless, there are several inherent difficulties associated with utilizing satellite remote sensing for the purpose of monitoring the quality of inland and coastal waters. Initially, it is worth noting that the spatial resolution of numerous satellite sensors may not be sufficient to accurately depict smaller water bodies and areas close to the shore. Furthermore, satellite measurements solely provide information about the upper water column and may not accurately represent the dynamics occurring beneath the surface. Furthermore, it should be noted that satellite data alone is insufficient for directly assessing all pertinent biogeochemical factors (Paerl *et al.* 2007). In order to overcome these constraints, it is beneficial to integrate remote sensing with in situ monitoring, advanced modeling approaches, and multi-sensor data fusion. This approach allows for a more thorough comprehension of coastal and inland aquatic ecosystems (Rivero *et al.* 2009).

In addition to monitoring phytoplankton, remote sensing is increasingly employed to bolster sustainable fisheries management. Observing crucial oceanographic parameters such as sea surface temperature, ocean color, and frontal zones might assist in identifying regions with abundant resources that are preferred by particular fish species. Subsequently, this data can be incorporated into predictive models and conveyed to fishing fleets in order to direct them towards the most fruitful fishing zones, thus enhancing efficiency and diminishing fuel usage (Klemas 2013).

Despite certain remaining challenges, the ongoing progress of remote sensing technology and analytical methodologies is transforming them into an increasingly effective instrument for complete assessment and management of marine environments. The combination of remote sensing data, *in situ* monitoring, and modeling can create a robust framework for assessing the ecological condition of aquatic ecosystems, monitoring changes over time, and guiding sustainable management strategies (Paerl *et al.* 2007, Rivero *et al.* 2009, Klemas 2013, Mouw *et al.* 2015, Dierssen *et al.* 2021).

Zooplankton

Fresh water zooplankton

Freshwater ecosystems are crucial for supporting life, as they offer key resources and ecosystem services that are vital for human well-being and the conservation of biodiversity (Meaden and Aguilar-Manjarrez 2013). Nevertheless, these essential habitats face escalating peril from various human-induced stressors, including alterations in land use, pollution, and extraction of resources (Nguyen *et al.* 2020). Evaluating the condition and patterns of freshwater habitats is essential for successful preservation and administration (Abhilash and Mahadevaswamy 2021).

An effective method to address this difficulty involves utilizing geospatial analysis and remote sensing technology. These methodologies provide thorough and methodical mapping and monitoring of freshwater ecosystems and their corresponding biodiversity on a regional to global level. Remote sensing can be employed to categorize alterations in land-cover and land-use, which are significant factors contributing to the deterioration of freshwater quality. Furthermore, GIS have the capability to combine different data sources in order to evaluate both the quality and amount of water, as well as simulate the effects of human activities (Bastiaanssen *et al.* 2000).

The composition and quantity of zooplankton communities are a highly valuable indication of the health of freshwater ecosystems. Zooplankton are susceptible to environmental stressors, and their community structure can offer valuable information on the ecological processes occurring in a water body (Mahessar *et al.* 2020, Nguyen *et al.* 2020, Al-Fawzy *et al.* 2021). Hence, the incorporation of zooplankton-centered bioassessments along side geospatial and remote sensing technologies exhibits significant promise for all-encompassing freshwater monitoring and conservation.

Recently, a number of studies have shown the effectiveness of these integrated techniques (Mahessar *et al.* 2020, Nguyen *et al.* 2020, Al-Fawzy *et al.* 2021). Satellite imagery and GIS have been employed to accurately delineate and assess the size and condition of freshwater habitats, while also identifying possible risks and consequences (McManamay *et al.* 2018, Al-Fawzy *et al.* 2021). In addition, remote sensing has been investigated as a method to indirectly assess chlorophyll-a levels, which are frequently linked to zooplankton biomass and community composition (Paerl *et al.* 2007). These technological breakthroughs have the potential to significantly improve our comprehension of freshwater ecosystems and provide valuable insights for the development of more efficient management techniques.

Zooplankton, which are tiny animals that live in water, have a significant impact on aquatic ecosystems. They are essential for the food chain and have a direct effect on the overall well-being and productivity of these habitats (Lu *et al.* 2021). GIS and remote sensing technologies are effective tools for monitoring and evaluating the spatial distribution, population size, and seasonal fluctuations of zooplankton communities. These tools are especially valuable in the field of environmental management and conservation efforts (Chakraborty and Mallick 2020).

The variety and composition of zooplankton populations are shaped by an intricate interaction of physical, chemical, and biological elements, such as climatic conditions, water quality, and predator-prey dynamics (Sun 2019, Chakraborty and Mallick 2020). Various aquatic habitats have shown seasonal fluctuations in different zooplankton functional groups, including Protozoa, Rotifera, Cladocera, and Copepoda. These variations indicate that these groups are responsive to environmental changes (Pandit *et al.* 2020). Geospatial techniques, such as remote sensing and GIS, can be used to map and analyze the spatial and temporal patterns of zooplankton communities. This allows us to gain valuable insights into their relationship with environmental factors and the overall ecological condition of the ecosystem (Sun 2019, Chakraborty and Mallick 2020, Lu *et al.* 2021).

Through the integration of geospatial data and *in-situ* measurements of water quality, habitat characteristics, and zooplankton community structure, researchers can create prediction models and decision-support systems to assist in environmental assessment and management. Changes in the patterns of zooplankton diversity and the prevalence of particular functional categories can be used as bioindicators to assess water quality, nutrient enrichment, and other environmental stresses (Chakraborty and Mallick 2020, Lu *et al.* 2021).

In addition, the utilization of remote sensing technologies, such as satellite imagery and aerial photography, can offer comprehensive, wide-ranging information on water body properties, chlorophyll-a levels, and other factors that impact zooplankton dynamics (Chakraborty and Mallick 2020, Pandit *et al.* 2020). By combining remote sensing data with focused field surveys and laboratory investigations, we may improve our comprehension of the intricate relationships between zooplankton communities and their surroundings. This, in turn, allows for the development of more knowledgeable and efficient environmental management methods.

The combination of geographical information systems and remote sensing with the analysis of zooplankton communities provides a robust method for evaluating and tracking environmental conditions. By utilizing these technologies, scientists and managers can acquire a thorough comprehension of the spatial and temporal distribution of zooplankton, their correlation with environmental factors, and the overall ecological condition of aquatic ecosystems (Sun 2019, Chakraborty and Mallick 2020, Lu *et al.* 2021).

Brackish water zooplankton

Brackish water ecosystems, characterized by the mixing of freshwater and seawater, are intricate and ever-changing settings that support a wide variety of zooplankton species. Zooplankton, which are microscopic organisms that drift in aquatic settings, have a vital function in the food chain and can act as highly responsive sensors of environmental shifts. Geospatial analysis and remote sensing techniques provide effective tools for studying the distribution, abundance, and diversity of brackish water zooplankton. These tools give essential insights for conducting thorough environmental assessments and managing the environment.

The composition of zooplankton communities in brackish water habitats is affected by various interconnected physical, chemical, and biological elements, which can differ greatly depending on the season and location (Sun 2019). Multiple studies have emphasized the significance of comprehending the correlation between zooplankton and their surroundings. This is because the variety of species and the richness of the zooplankton community can indicate the ecological well-being and potential fisheries resources of a body of water (Pandit *et al*. 2020). Researchers have discovered that the biomass of different types of zooplankton, such as filter feeders, grazers, and predators, can vary throughout the year in response to changes in environmental factors like pH, water temperature, salinity, and nutrient levels (Sun 2019).

Utilizing geospatial analysis and remote sensing techniques can significantly improve our comprehension of the spatial and temporal changes in brackish water zooplankton groups. These sophisticated tools enable the mapping and monitoring of zooplankton distribution, abundance, and diversity patterns at different scales, ranging from local to regional. They can also assist in identifying the primary environmental factors that influence these patterns. Researchers can obtain a comprehensive understanding of the intricate relationships between zooplankton and their environment by combining field-based zooplankton surveys with satellite-derived data on water quality, habitat characteristics, and other relevant environmental factors (Sun 2019, Chakraborty and Mallick 2020, Pandit *et al.* 2020, Lu *et al.* 2021).

An important advantage of utilizing geospatial analysis and remote sensing for evaluating brackish water zooplankton is the capacity to encompass larger geographical areas and identify trends that may not be evident through localized field observations. This method is especially valuable for detecting areas with high levels of zooplankton diversity, tracking changes in community composition over time, and evaluating the effects of human activities or natural disruptions on the overall health of the ecosystem. The combination of geospatial analysis and remote sensing techniques with traditional field-based zooplankton investigations provides a robust method for evaluating and managing the environment in brackish water habitats. The integration of these complementary methods allows for a thorough comprehension of the intricate connections between zooplankton and their surroundings. This understanding can be utilized to make informed decisions and aid in the creation of successful conservation and restoration strategies for these dynamic and ecologically significant ecosystems.

Marine zooplankton

Human activities are causing a rise in challenges for the marine environment, resulting in concerns regarding marine pollution and harm to ecosystems (Chen *et al.* 2021). Geospatial analysis and remote sensing techniques have become effective tools for tackling these difficulties, providing the capability to observe and evaluate marine ecosystems on a bigger scale and with greater detail than traditional *in-situ* methods. An especially auspicious utilization of these technologies involves employing zooplankton as bioindicators for evaluating the maritime environment.

Zooplankton, the minuscule organisms that float in water and serve as the basis of marine food chains, exhibit great sensitivity to alterations in their surroundings and can offer valuable observations into the overall well-being of marine ecosystems. Scientists have employed diverse remote sensing data, such as satellite imaging, sensors mounted on aircraft, and monitoring systems located on the shore, to investigate the spatial distribution, population size, and composition of zooplankton communities (Chen *et al.* 2021). These data can be integrated with geospatial analysis tools to create maps and models that illustrate the connections between zooplankton and different environmental parameters, such as water temperature, salinity, and nutrient levels.

The field of remote sensing of coastal ecosystems and environments has experienced rapid progress, thanks to the development of new sensors and data analysis techniques. These advancements have made it possible to map important habitats such as marshes, seagrass beds, and coral reefs, as well as detect water quality parameters such as suspended sediments and algal blooms (Rivero *et al*. 2009). By incorporating these data with zooplankton information, a comprehensive comprehension of the general well-being and operation of marine ecosystems may be achieved, enabling the implementation of more focused and efficient management measures.

Developing models and making accurate predictions about how marine ecosystems will react to environmental changes is a significant obstacle in the study of marine ecology. Geospatial analysis and remote sensing techniques are essential tools that can help tackle this difficulty effectively. The progress in artificial intelligence and automated monitoring methods, such as deep learning algorithms for analyzing substantial amounts of image-based data, are improving the capability of these instruments for marine conservation and management (Ditria *et al.* 2022).

The integration of geospatial analysis, remote sensing, and the utilization of zooplankton as bioindicators presents a robust method for evaluating and tracking the well-being of marine ecosystems. By utilizing these technologies, scientists and administrators can acquire a more thorough comprehension of the intricate relationships between marine organisms and their surroundings, ultimately guiding more efficient and fact-based decision-making for the conservation and sustainable utilization of our marine resources.

There is a discrepancy in the current understanding of the application of remote sensing and Geospatial Information System in environmental assessment utilizing plankton. Some research indicates its promise, while others identify limitations. This study is important because it contributes to the current understanding of how remote sensing and Geospatial Information System may be used to analyze the environment using plankton. It also gives additional data to support their potential. The review highlights the necessity for additional research in order to gain a comprehensive understanding of the capabilities and constraints of remote sensing and Geospatial Information System in the context of environmental assessment involving plankton.

Plankton, which play a vital role in aquatic ecosystems, have been the subject of many studies that utilize geospatial and remote sensing technology. These techniques provide a thorough and economical strategy to monitoring and evaluating environmental conditions, especially in locations that are challenging to reach or observe using traditional methods. Remote sensing can offer comprehensive, wide-ranging information on several aspects of the aquatic environment (Klemas 2013), including water quality, phytoplankton biomass, and plankton dispersal.

An important use of geospatial and remote sensing methods in the study of plankton is to evaluate the quality of water. Phytoplankton, being primary producers, act as highly responsive indicators of ecological shifts in aquatic environments. Satellite remote sensing can offer vital information regarding the levels of chlorophyll-a, which serves as an indicator of the amount of phytoplankton present. This data can be utilized to monitor the general condition and nutrient levels of water bodies. Nevertheless, the capacity of satellite sensors to precisely evaluate water quality in smaller inland water bodies may be constrained by their spatial resolution. Additionally, these sensors usually only measure the surface layer, thus failing to capture the complete vertical dynamics of the ecosystem.

However, by combining remote sensing data with other monitoring techniques like *in-situ* measurements and modeling, a more comprehensive understanding of plankton dynamics and their correlation with environmental conditions can be achieved (Klemas 2013, Saraswathy and Pandian 2016). Chemotaxonomic analysis, which detects distinct phytoplankton hues, can complement remote sensing data to provide additional information about the taxonomic makeup and progression of plankton communities. In addition to evaluating water quality, GIS and remote sensing technologies have also demonstrated their usefulness in fisheries management. Remote sensing can aid in the sustainable management of marine resources by monitoring oceanographic factors that impact the distribution and abundance of fish stocks, such as sea surface temperature and ocean color. Similarly, the identification of detrimental algal blooms, frequently linked to specific phytoplankton species, can provide valuable insights for fisheries management and safeguard the well-being of marine organisms and human health.

The progress of remote sensing capabilities, including the creation of new sensors and analytical methodologies, is anticipated to enhance the integration of these technologies into plankton research and environmental assessment. Acquiring high-resolution, nearly instantaneous data on the movement and behavior of plankton and how they are influenced by environmental factors will be essential for tackling urgent environmental issues and developing efficient management plans.

Overall, the incorporation of remote sensing and GIS technology in the evaluation of plankton environments has shown considerable promise in enhancing our comprehension of aquatic ecosystems. Subsequent investigations in this domain could investigate the capacity of nascent technologies, such as machine learning and artificial intelligence, to augment the precision and efficacy of plankton environmental evaluations. In addition, future research could explore the utilization of remote sensing and Geographic Information Systems (GIS) in studying different aquatic ecosystems outside from plankton.

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