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Sustainable Exploitation of Freshwater and Marine Bioresources for Biotechnology Applications

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ABSTRACT
This study investigates the sustainable exploitation of freshwater and marine bioresources for biotechnology applications, with a focus on ecosystems in Nembe and Brass within the Niger Delta, Nigeria. Aquatic ecosystems are recognized as highly productive and biologically diverse, supporting food security, livelihoods, and industrial development. However, increasing anthropogenic pressures such as pollution, overfishing, and climate change threaten their sustainability. A combination of field sampling and laboratory analyses was employed to evaluate bioresources and environmental conditions. Samples of microalgae, macroalgae, fish, and microorganisms were collected from freshwater and marine environments. Physicochemical parameters, including temperature, pH, dissolved oxygen, biochemical oxygen demand, and salinity, were analyzed to assess water quality. Biochemical analyses using Kjeldahl, Soxhlet, and spectrophotometric methods determined protein, lipid, and carbohydrate contents, while chromatographic techniques (HPLC and GC-MS) identified bioactive compounds. Microbial analyses were conducted to evaluate abundance and bioremediation potential. Results revealed moderate water quality variations, with signs of organic pollution in Nembe indicated by lower dissolved oxygen and higher biochemical oxygen demand. Microbial loads were relatively high, with the presence of hydrocarbon-utilizing bacteria suggesting adaptation to oil pollution. Phytoplankton diversity showed dominance of Chlorophyceae and diatoms, while marine environments exhibited greater macroalgal diversity. Biochemical analysis indicated high protein content in fish and microalgae, and high carbohydrate levels in macroalgae, highlighting their industrial and nutritional potential. Bioactive compounds such as carotenoids, phenolics, and fatty acids were identified, demonstrating significant pharmaceutical and nutraceutical value. The study concludes that aquatic bioresources possess substantial potential for biotechnology applications. However, sustainable management strategies, including pollution control, conservation practices, and responsible resource utilization, are essential to ensure long-term availability and environmental protection.

Keywords: Marine, Bioresources, Water quality, Biochemical Oxygen Demand

INTRODUCTION
Aquatic ecosystems including freshwater systems such as rivers, lakes, and wetlands, as well as marine environments like oceans and coastal regions—are among the most diverse and productive ecosystems on Earth. They support a wide range of bioresources, including fish, algae, aquatic plants, invertebrates, and microorganisms. These resources are essential not only for maintaining ecological balance but also for supporting human livelihoods and industrial development. Globally, aquatic resources play a major role in food security, providing a vital source of protein for billions of people and serving as a key source of income, especially in developing countries. In recent years, the importance of aquatic bioresources in biotechnology has become increasingly evident. Biotechnology, which

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involves using living organisms or their components to develop useful products and processes, has expanded its focus to include aquatic systems. For example, microalgae are now widely studied for their potential in producing biofuels, pharmaceuticals, and nutraceuticals due to their rapid growth and rich biochemical composition. Likewise, aquatic microorganisms have proven valuable as sources of enzymes, antibiotics, and other bioactive compounds with industrial and medical applications. As a result, aquatic biodiversity is now recognized as a critical resource base for modern biotechnology. Aquatic bioresources also contribute significantly to renewable energy development. Algae-based biofuels, in particular, offer a promising alternative to fossil fuels, aligning with global sustainability goals aimed at reducing carbon emissions and combating climate change. Additionally, aquatic organisms are increasingly used in environmental management, especially in bioremediation, where microorganisms and plants help remove pollutants from water bodies, improving water quality and restoring ecosystem health.

Despite these benefits, the exploitation of aquatic bioresources is often unsustainable. Activities such as overfishing, pollution, habitat destruction, and climate change have severely impacted aquatic ecosystems. Many fish stocks are now overexploited, and water bodies are declining in quality. This threatens biodiversity and limits the long-term availability of resources needed for both human use and technological innovation. There is therefore an urgent need to adopt sustainable approaches that balance resource use with conservation. Sustainable exploitation ensures that current needs are met without compromising future generations. Integrating ecological principles with biotechnology offers a practical pathway to achieving this balance. Understanding both the opportunities and challenges associated with aquatic bioresources is essential for advancing biotechnology, ensuring food security, and supporting national development.

This study focuses on the role of aquatic biotechnology in national development. It highlights how applications in pharmaceuticals, bioenergy, and environmental management can drive economic growth, create jobs, and promote industrial progress. It also emphasizes environmentally friendly technologies such as bioremediation and wastewater treatment using aquatic organisms. By examining freshwater and marine bioresources and their applications, this study aims to propose sustainable solutions to current challenges and strategies for responsible resource use.

MATERIALS AND METHODS

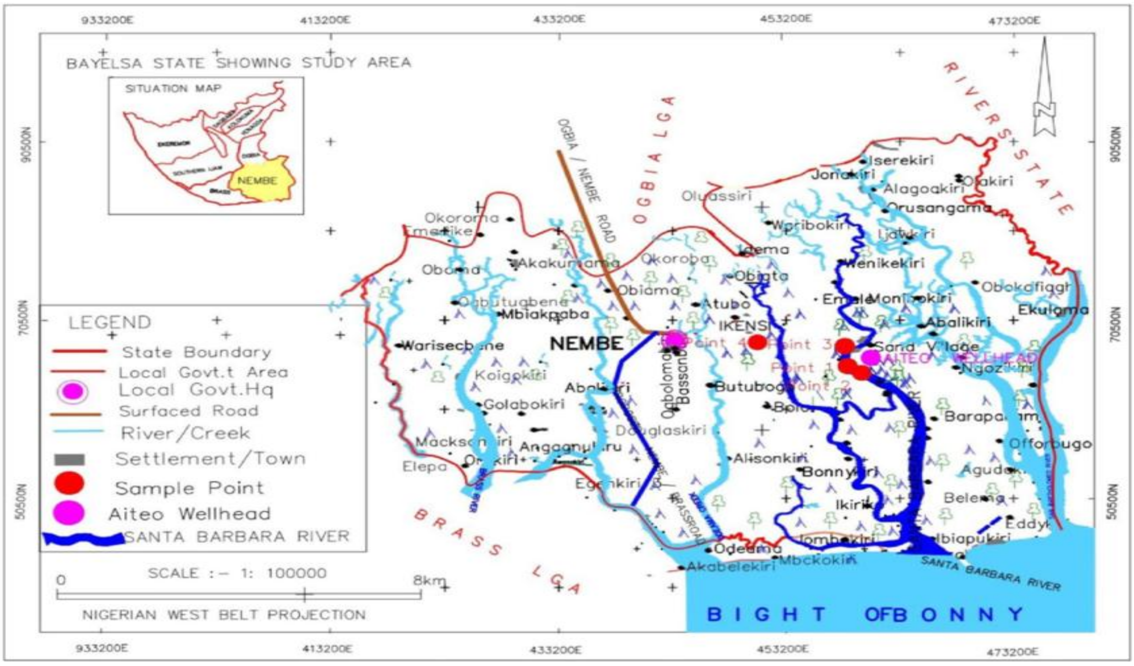
Study Area The study was carried out in Nembe, located in the Niger Delta region of southern Nigeria. This area is characterized by a complex network of creeks, mangrove swamps, and tidal waterways connected to the Atlantic Ocean. Nembe lies between latitudes 4°30′–4°45′ N and longitudes 6°15′–6°30′ E. The region experiences a tropical monsoon climate, with high rainfall ranging from 2,500 to 4,000 mm annually, high humidity, and temperatures between 25-32°C. The aquatic environment includes freshwater systems during peak rainfall and brackish to marine conditions due to tidal influences. These conditions support rich biodiversity, including phytoplankton, fish, shellfish, mangroves, and diverse microbial communities with biotechnological potential. However, the area is also affected by human activities such as oil exploration, fishing, and waste disposal, making it an ideal location for studying sustainability challenges.

Sample Collection: Samples were collected from both freshwater and marine environments. Microalgae and phytoplankton were collected using plankton nets, while macroalgae were handpicked during low tide. Fish and shellfish were obtained from local fishermen. Water samples were collected using sterile bottles, and sediment samples were taken for microbial analysis. All biological samples were preserved in ice and transported to the laboratory for further analysis, including microscopic examination and taxonomic identification.

Physicochemical Analysis Water quality parameters such as temperature, pH, dissolved oxygen, biochemical oxygen demand, and salinity were measured using standard methods and instruments.

Biological and Microbial Analysis: Phytoplankton were identified using light microscopy and taxonomic keys. Microorganisms were isolated using culture techniques, and their abundance was estimated through colony counts.

Data were analyzed using descriptive statistics, and comparisons were made between freshwater and marine environments.



Map showing sampling stations, water bodies, and surrounding settlements.

RESULTS

Table 1: Physicochemical parameters of water samples from Freshwater and Marine

Parameter	Freshwater (Mean±SD)	Marine (Mean ± SD)	WHO Standard
Temperature (°C)	28.5 ± 1.2	27.8 ± 1.0	25–30
pH	6.8 ± 0.3	7.2 ± 0.2	6.5–8.5
Dissolved Oxygen (mg/L)	4.2 ± 0.5	5.6 ± 0.6	≥5
BOD (mg/L)	6.5 ± 1.1	4.3 ± 0.9	≤5
Salinity (‰)	8.5 ± 1.3	15.2 ± 2.0	–
Nitrate (mg/L)	3.2 ± 0.7	2.1 ± 0.5	≤10
Phosphate (mg/L)	1.8 ± 0.4	1.2 ± 0.3	≤5

Table 1 shows the following physiochemical parameter of freshwater and marine Temperature 28.5 **±** 1.2 and 27.8 ± 1.0, pH 6.8 ± 0.3 and7.2 ± 0.2, Dissolved Oxygen 4.2 ±

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0.5 and 5.6 ± 0.6, Biochemical Oxygen Demand 6.5 ± 1.1and 4.3 ± 0.9, Salinity 8.5 ± 1.3 and 15.2 ± 2.0 Nitrate 3.2 ± 0.7 and 2.1 ± 0.5 Phosphate 1.8 ± 0.4 and1.2 ± 0.3The results showed clear differences between freshwater and marine environments, Marine water had better quality overall, especially in terms of dissolved oxygen. Freshwater showed higher biochemical oxygen demand, indicating more pollution.

Table 2: Identification of Freshwater and Marine Bioresources

Category	Freshwater	Marine
Microalgae	*Chlorella vulgaris*, *Scenedesmus spp.*	*Dunaliella salina*, *Chaetoceros spp.*
Macroalgae	*Spirogyra spp.*	*Sargassum spp.*, *Ulva lactuca*
Fish species	*Tilapia spp.*, *Clarias gariepinus*	*Sardinella spp.*, *Penaeus monodon*
Microorganisms	Cyanobacteria	Marine bacteria

Table 2 of Freshwater and Marine Bioresources shows that *Chlorella vulgaris*, *Scenedesmus spp and Dunaliella salina*, *Chaetoceros spp.* (Microalgae) *Spirogyra spp.Sargassum spp.*, and *Ulva lactuca (Macroalgae)Tilapia spp, Clarias gariepinus and Sardinella spp.*, *Penaeus monodon (Fish species).*

Other Microorganisms, Cyanobacteria and Marine bacteria showed that the marine environments have higher diversity of macroalgae, while freshwater systems had more abundant microalgae populations. Microalgae are rich in protein and lipids, making them useful for food and biofuel production. Macroalgae also contain high carbohydrates, suitable for industrial processes

Table 3: Proximate Composition of Biochemical Selected Bioresources

Sample	Protein (%)	Lipid (%)	Carbohydrate (%)
Chlorella vulgaris	52.4 ± 1.2	18.6 ± 0.8	20.3 ± 0.9
Dunaliella salina	45.7 ± 1.0	22.1 ± 0.7	25.4 ± 1.1
Sargassum spp.	18.3 ± 0.5	5.6 ± 0.3	48.7 ± 1.5
Tilapia spp.	60.2 ± 1.3	12.4 ± 0.6	0.0
Penaeus monodon	55.8 ± 1.1	15.2 ± 0.5	0.0

Table 3 Proximate Composition of Biochemical Selected Bioresources of protein, Lipid and Carbohydrate shows *Chlorella vulgaris have* 52.4 ± 1.2*,* 18.6 ± 0.8 and 20.3 ± 0.9 *Dunaliella salina* 45.7 ± 1.0, 22.1 ± 0.7 and 25.4 ± 1.1 *Sargassum spp.* 18.3 ± 0.5, 5.6 ± 0.3 and 48.7 ± 1.5 *Tilapia spp.* 60.2 ± 1.3, 12.4 ± 0.6 No carbohydrate *Penaeus monodon* 55.8 ± 1, 15.2 ± 0.5 also No Carbohydrate this shows Microalgae exhibited high protein and lipid content, indicating suitability for food and biofuel applications and Macroalgae also showed high carbohydrate content, useful for industrial fermentation. Fish and shellfish are excellent protein sources.

Table 4 shows the Bioactive Compounds which was detected for potential function, *Chlorella vulgaris* Chlorophyll and carotenoids (Antioxidant) *Dunaliella salina* Beta-carotene (Nutraceutical) *Sargassum spp.* Phenolic compounds (Antimicrobial) Marine bacteria Fatty acids and hydrocarbons (Industrial use) this is an indications that, Bioactive compounds with pharmaceutical and nutraceutical value were abundant, especially in marine microalgae. Marine environments also had greater macroalgal diversity than Freshwater

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which contained more microalgae and microbial activity. In biochemical analysis revealed that; Bioactive compounds such as antioxidants and antimicrobial substances were also identified, highlighting their pharmaceutical potential.

Table 4: Bioactive Compounds Identified (HPLC and GC-MS)

Sample	Compounds Detected	Potential Function
Chlorella vulgaris	Chlorophyll, carotenoids	Antioxidant
Dunaliella salina	Beta-carotene	Nutraceutical
Sargassum spp.	Phenolic compounds	Antimicrobial
Marine bacteria	Fatty acids, hydrocarbons	Industrial use

DISCUSSION

The study highlights important differences between freshwater and marine ecosystems. Marine environments generally showed better water quality, while freshwater systems exhibited signs of pollution, likely due to human activities such as oil exploration. The comparative analysis of freshwater and marine ecosystems reveals significant differences in environmental quality, biodiversity, and biotechnological potential. Physicochemical parameters show that Marine exhibited relatively better water quality than freshwater. Dissolved oxygen (DO) levels in marine (5.6 mg/L) met recommended standards, while freshwater (4.2 mg/L) fell below optimal levels, indicating possible organic pollution. This observation is supported by the higher biochemical oxygen demand (BOD) in freshwater (6.5 mg/L) compared to Marine (4.3 mg/L), suggesting increased microbial decomposition of organic matter (APHA, 2017). Salinity differences further reflect ecological variation, with marine exhibiting higher salinity due to marine influence, while freshwater represents a more brackish system. Microbial analysis indicated higher total heterotrophic and hydrocarbon utilizing bacteria in freshwater, suggesting greater pollution stress, likely from oil-related activities in the Niger Delta. The presence of hydrocarbon degrading bacteria highlights the adaptive capacity of microbial communities and their importance in bioremediation processes (UNEP, 2021). Phytoplankton composition varied between the two environments, with Chlorophyceae dominating in freshwater and Bacillariophyceae (diatoms) in marine. This aligns with established ecological patterns where freshwater systems favour green algae, while marine ecosystems support diatom abundance due to nutrient and salinity conditions (Borowitzka, 2018). Additionally, marine environments showed greater macroalgal diversity, indicating higher ecological complexity.

Biochemical analysis demonstrated that microalgae possess high protein and lipid content, supporting their application in food and biofuel production. Macroalgae such as *Sargassum* exhibited high carbohydrate content, making them suitable for industrial fermentation processes (Borowitzka, 2018). Fish and shellfish from both environments showed high protein levels, reinforcing their importance in global nutrition and food security (FAO, 2022). Furthermore, bioactive compound analysis revealed that marine organisms contain valuable compounds such as carotenoids and phenolics with antioxidant and antimicrobial properties. These findings highlight the growing importance of aquatic bioresources in pharmaceutical and nutraceutical industries. Overall, while marine demonstrates better environmental quality and biodiversity, freshwater shows higher microbial activity and bioremediation potential, emphasizing the need for sustainable and location-specific resource management strategies (UNEP, 2021; FAO, 2022)

CONCLUSION

Sustainable exploitation of freshwater and marine bioresources is not just an environmental necessity—it is also critical for food security, livelihoods, and economic resilience, especially

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in coastal and riverine regions such as the Niger Delta. These ecosystems support fisheries, aquaculture, transportation, and biodiversity that millions of people depend on directly and indirectly. However, increasing population pressure, pollution, overfishing, habitat degradation, and climate change are placing severe stress on these resources. While biotechnology offers innovative tools to improve productivity, disease control, and resource efficiency, its application must be carefully managed to avoid unintended ecological consequences. Therefore, sustainability must remain the guiding principle through strong governance, scientific research, and active stakeholder participation. Achieving sustainable exploitation of freshwater and marine bioresources requires a balanced approach that integrates biotechnology, environmental protection, governance, and community participation. When these recommendations below are effectively implemented, they will not only conserve biodiversity but also strengthen food security, support economic growth, and ensure the long-term resilience of aquatic ecosystems

RECOMMENDATIONS

Promote sustainable aquaculture practices: Sustainable aquaculture should prioritize environmentally friendly production systems that minimize pollution, habitat destruction, and overuse of wild broodstock.

Invest in research on aquatic biotechnology: Governments and institutions should increase funding for research in areas such as the genetic improvement of aquatic species, the development of disease-resistant strains, bioremediation using microorganisms, and the extraction of bioactive compounds from aquatic organisms.

Implement strict environmental policies: Effective regulatory frameworks must be established and enforced to control pollution, overfishing, habitat degradation, and unsustainable harvesting practices.

Encourage community participation in resource management: Local communities play a crucial role in the sustainable use of aquatic resources. Participatory management approaches, such as community-based fisheries management, should be promoted to empower local stakeholders in decision-making processes.

Develop eco-friendly technologies: the development and adoption of environmentally sustainable technologies are essential for reducing the ecological footprint of aquatic resource utilization. Innovations such as biodegradable fishing gear, low-impact harvesting equipment, renewable energy-powered aquaculture systems, and waste-to-resource technologies (e.g., converting fish waste into biofertilizers or biogas should be supported.

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