Aspects of the Plankton Community from Sauípe Port Estuary, Bahia, Brazil

Letícia Nayara Barreto dos Santos[1*], Maria Dolores Ribeiro Orge[1], Diogo Silva Bezerra[1]
[1]State University of Bahia; Alagoinhas, Bahia, Brazil

The estuary forms at the meeting of the river and the sea. It houses a fundamental microbiological community of plankton, which plays a role in the trophic network and the decomposition of organic matter. The uncontrolled expansion of human occupation in areas near mangroves has led to degradation, with alterations in physical, chemical, and biological characteristics. The present study investigates the ecological aspects of planktonic communities in the estuary waters and the identification of species that indicate the water quality of the Port of Sauípe estuary, state of Bahia, Brazil. Estuary water samples were collected to identify plankton, with random releases of a conical plankton net with a screw cup and stored in plastic containers with Transeau solution. The water samples were filtered, and the material retained in the filter was analyzed. All samples were examined under an optical microscope to identify phytoplankton, zooplankton, parasites, and other microinvertebrate species. Cyanobacteria predominated in the phytoplankton, while Copepoda was the most common in the zooplankton. Among the parasites, *Ascaris lumbricoides* had been recorded six years earlier, but *Schistosoma haematobium* and *Entamoeba coli* are being recorded for the first time in the area. The plankton data indicate poor environmental quality in the estuary, with toxin-producing species and sanitary hazard parasites used for fishing, shellfish harvesting, recreation, and tourism in a reference place on the North Coast of Bahia, Brazil.
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Mangroves and estuaries are coastal aquatic ecosystems that serve as transition zones between land and sea, distributed in the intertropical zone of the planet. They provide a habitat for protection, feeding, mating, and reproduction for native or transient species [1]. The biodiversity in these ecosystems is characteristic and adapted to the saline stress, making them highly productive environments and a source of nutrients for the continental shelf. These ecosystems also have a significant socioeconomic impact on the people who live directly in these areas. In the interstitial water of the mangrove and estuary, microorganisms such as plankton and bacteria are found, playing diverse ecosystemic roles that support niches in the mangrove and coastal regions with their characteristic productivity [2].

Phytoplankton organisms are responsible for most oxygen released into the water and atmosphere, turning these ecosystems into natural nurseries for many animal species, mainly fish and crustaceans, which complete their life cycles in these environments [3].

The plankton community's diversity and species predominance depends on temperature, light, nutrients, competition, and predation factors. It is an important component in the dynamics of an aquatic environment and can influence various ecological processes in nutrient cycling [4]. Currents move diatoms and bacteria and disperse widely, while environmental conditions regulate survival [5].

Phytoplankton comprises euglenophytes and dinoflagellates, which perform photosynthetic activity in the euphotic zone. Zooplankton includes rotifers, microcrustaceans, cnidarians, flatworms, and protozoa. This group is further divided into holoplankton, which remains in the plankton throughout its entire life cycle in the water column, and meroplankton (temporary plankton), characterized by the eggs and larvae of invertebrates and vertebrates that disperse species and colonize new environments [6].

Among the phytoplankton organisms, there is a wide variation in forms and sizes. In terms of shape, they can be spherical, ellipsoid, short

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Address for correspondence: Letícia Nayara Barreto dos Santos. Rodovia Alagoinhas / Salvador, BR110, Km 03. Zipcode: 48.000-000. Alagoinhas, Bahia, Brazil. E-mail: leticiabarreto728@gmail.com.

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cylindrical, flattened, or elongated. In terms of size, they range from unicellular cyanobacteria to mucilaginous colonies. These factors determine their adaptation to aquatic environments. They can reproduce asexually and sexually, in the latter case increasing genetic variability and the species' chances of adapting to a transforming environment influenced by tides and anthropogenic actions [7].

Phytoplankton organisms are of great ecological importance as primary producers in the food web. Despite their short life cycle, they serve as bioindicators and provide insight into environmental conditions.

Analysis of phytoplankton fluctuations reflects environmental changes and makes it a suitable bioindicator due to its sensitivity to respond quickly to various environmental alterations and variations [8]. The composition and abundance of phytoplankton communities are good models for understanding the dynamics of continental aquatic ecosystems, as they are found in almost all coastal ecosystems, including species sensitive to pollution and tolerant to tidal variations.

Among the environmental factors that limit phytoplankton development are light, temperature, pH, and predation by zooplankton. Therefore, zooplankton is associated with the dynamics of coastal ecosystems and is an indicator of environmental quality due to its short life cycle, responding quickly to changes caused by anthropogenic actions. Zooplankton can be considered extremely important as the primary consumers in estuaries and oceans, transferring energy retained by microalgae to other trophic levels. They are organisms easily carried by currents due to their limited mobility, making them more susceptible to biological influences, which alters their distribution in the water column.

The zooplankton community has been used as a bioindicator to assess various environmental changes, such as pollution from pesticides and/or toxins from algae, acidification, and eutrophication, which affect water quality. This evaluation can be mainly made by studying their feeding behavior, as they consume bacteria, microalgae, protozoa, and organic matter, contributing to the clarification of effluent and playing a role in environmental bioremediation [9].

Thus, this study aimed to investigate the ecological aspects of the planktonic community in the waters of the Sauípe Port estuary and identify potential species as indicators of environmental quality for the estuary, which serves as a reference for the North Coast of Bahia, Brazil.

Materials and Methods

The study area was in the Sauípe Port estuary, located at the mouth of the Sauípe River, in the municipality of Entre Rios, on the North Coast of Bahia (Brazil) (12º24'S, 37º53'W) [10]. Two sampling points were selected in the estuary channel for plankton analysis: Point 1, in front of the beach huts, and Point 2, in front of the mangrove forest (Figure 1).

The local community uses the estuary and mangrove for fishing, shellfish gathering, leisure, and tourism. Beach huts are located on the left bank of the estuary. Sample collection was not conducted on the preserved right bank of the channel due to its difficulty in access without the aid of a canoe. Estuary water samples were collected during low tide in the morning (10:00), at the start of the incoming tide in the early afternoon (13:00), and during high tide in the mid-afternoon (15:00) in 2022. A conical plankton net with a 20 cm screwable cup was used for surface tows in the middle of the channel, following the methods by Magalhães (2011) [8]. Each 100 mL sample was stored in pre-labeled plastic bottles with approximately 20 mL of a Transeau solution (6 parts distilled water: 3 parts 95% ethyl alcohol: 1 part formaldehyde) for proper plankton preservation. At the Soil Laboratory of UNEB (DCET II, Alagoinhas), the collected material was filtered through filter paper and concentrated into appropriately labeled glass bottles. The samples were analyzed under an optical microscope (Bioval brand) for photographic documentation and specimen identification [5]. The data were used to calculate diversity, evenness,

Figure 1. Study area at the Porto of Sauípe estuary (up right and down), North Coast of Bahia state (Brazil) (up left).

Source: José Gabriel Ferreira dos Santos, 2023; authoral, 2023; Passeios & Viagens, 2017.

and richness indices through PAST version 4.17 [11], an open-source software, to estimate the ecological status of the plankton community in the estuary.

Results and Discussion

The plankton community of Sauípe Port was characterized by low diversity, a common feature in degraded tropical environments. At the same sampling points, several plankton representatives were identified in this study in 2022 and 12 in 2016. This comparison of results allowed us to infer the deterioration of environmental quality over the past six years.

In the phytoplankton community, the most representative group was Cyanobacteria, with the occurrence of *Pseudanabaena* sp. at both study points, dominating at point 2 (N=105). Additionally, *Demonostoc punense* comb. nov. (formerly *Nostoc punensis*) was found at Point 1 (N=1), and *Cylindrospermopsis raciborskii* was found at Point 2. These species are producers like microalgae, represented by *Fragilaria* sp.

(Stramenopila), *Euglena* sp. (Euglenophyta), *Ceratium* sp. (Dinoflagellata), and photosynthetic diatoms (Bacillariophyta), such as *Nitzschia acicularis* and *Thalassionema* sp. (Kingdom Protista) (Table 1, Figure 2).

Shellfish and fish can consume dominant populations of cyanobacteria and toxin-producing microalgae, affecting the local food web. Although cooking kills the microorganisms present in fish and shellfish, their toxins can cause severe food poisoning for humans.

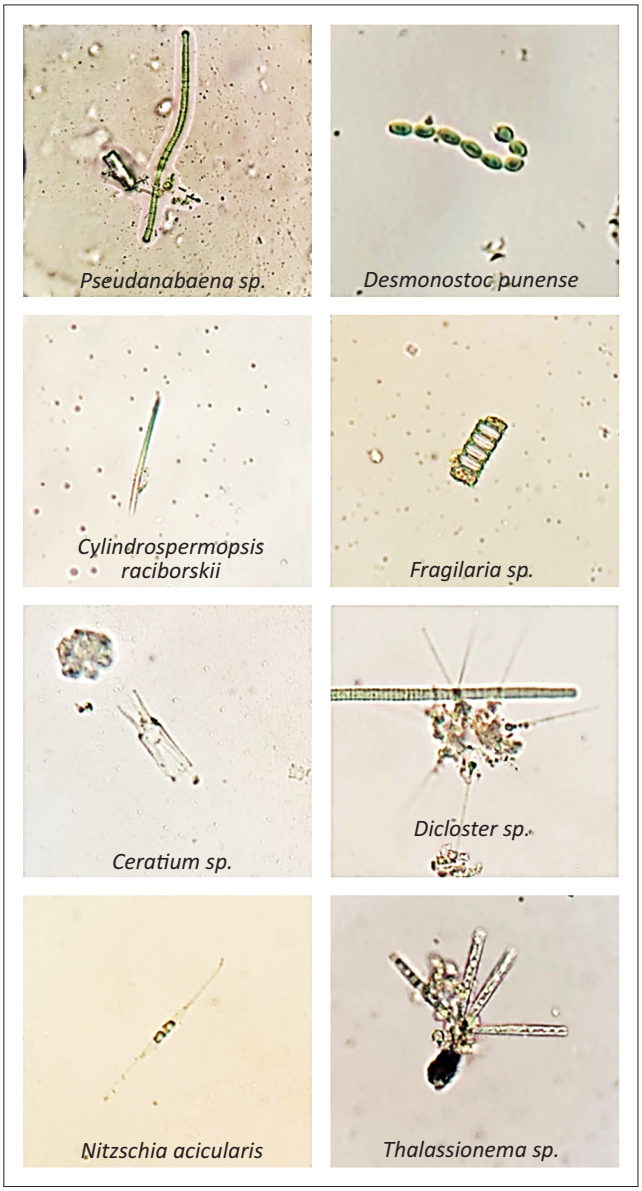
According to Kling and colleagues [12], the presence of Cyanobacteria in the phytoplankton community is not favorable, as some genera can be toxic to aquatic organisms and their consumers. Although they perform photosynthesis and often nitrogen fixation, cyanobacteria can pose a significant public health risk due to the occurrence of blooms of species potentially producing cyanotoxins.

Specimens of the genus Pseudanabaena (Pseudanabaenales, Synechococcophycideae) have elongated cells and are widely distributed in eutrophic aquatic environments, with their toxicity potential being poorly understood. Some species are producers of microcystins, which can

Table 1. Brief checklist of plankton collected in the Sauípe Port Estuary, Bahia, Brazil, 2023.

Species	Point 1	Point 2
Pseudanabaena sp.	2	105
Demonostoc punense	1	0
Cylindrospermopsis raciborskii	0	1
Fragilaria sp.	0	2
Euglena sp.	1	0
Ceratium sp.	1	0
Dicloster sp.	0	1
Nitzschia acicularis	1	0
Thalassionema sp.	0	1
Hyperia macrocephala	1	0
Copepoda (Harpacticoida)	2	0
Copepoda (Cyclopoida)	0	1
Euchlanis sp.	0	1
Ascaris lumbricoides	1	0
Schistosoma haematobium	1	0
Entamoeba coli	0	1

Figure 2. Individuals of the phytoplankton community from the Sauípe River estuary. Entre Rios, Bahia, Brazil, 2022.



be toxic to aquatic organisms and their consumers. The degree of intoxication depends on the amount ingested; no weight loss or lesions were observed in animals that received the extract via intraperitoneal injection, but weight loss and lesions in the kidneys, spleen, intestines, and liver were observed when administered orally [13].

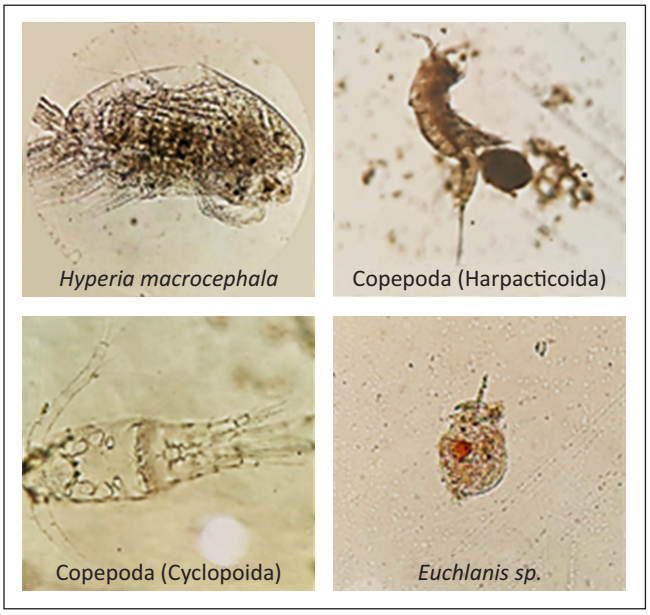
The abundance of benthic diatoms such as *Actinoptychus* sp. confirms the contribution of microphytobenthos present in the water column due to tidal currents that favor the suspension of sediments from shallow areas. The chain-like organization of the taxon *Thalassionema* sp. may indicate its adaptation to the coastal environment, as it favors continuity in the water column, minimizing sedimentation in regions with intense water mixing, especially related to river discharges [14]. There was higher zooplankton abundance during high tide, and copepods were the most representative individuals. In the zooplankton group, the following were recorded: human parasitic worms such as *Ascaris lumbricoides* (Nematoda) and *Schistosoma haematobium* (Platyhelminthes, Trematoda), the commensal amoeba *Entamoeba coli* (Amoebozoa), and microinvertebrates such as *Euchlanis* sp. (Rotifera), Hyperiamacrocephala, Harpacticoida, and Cyclopoida (Copepoda, Crustacea) from the Animalia kingdom (Figures 3 and 4).

The cosmopolitan parasitic species *Ascaris lumbricoides* and *Schistosoma haematobium* cannot be considered isolated cases in the area, as the likelihood of them being randomly collected with the tide movement is very low. These resistant enteric pathogens are considered parasitological indicators of organic pollution, either due to waste from bathers or sewage discharge from the stalls installed on the left bank of the estuary. *Ascaris lumbricoides* had already been recorded [4]; however, the record of *Schistosoma haematobium* is new and concerning due to sanitary risks. While the commensal amoeba *Entamoeba coli* is non-pathogenic and can inhabit the human colon, *Schistosoma haematobium* is a parasite of humans that causes hematobium schistosomiasis or bilharzia, which is associated with urinary schistosomiasis. It causes complications such as bacterial urinary tract infections, renal failure, and more severe cases such as urothelial cancer. The severity of the disease's sequelae depends on the worm and egg load and the duration of infection, as these eggs cause pathogenicity in the infected individual [15].

Zooplankton moves with the tides regularly twice a day, causing variations in salinity, temperature, and oxygen in the water column [16]. The density and species composition of zooplankton were studied by Srichandan and colleagues [17] in response to tidal fluctuations in an estuary in India. Abundance and diversity were higher during high tide, with records of taxa belonging to the groups. Migration of Copepoda, Cladocera, and larvae was also observed at night. Variation in abundance among species highlighted the need for collection along the tidal cycle and its relation to salinity. The Copepoda group contributes significantly to the total zooplankton biomass (Figure 3). In addition to being the primary

Figure 3. Parasitic and commensal species of zooplankton from the Sauípe River estuary. Entre Rios, Bahia, Brazil, 2022.

Figure 4. Predatory species of zooplankton from the Sauípe River estuary. Entre Rios, Bahia, Brazil, 2022.



food source for various fish species, they serve as a link between producers and consumers in the trophic web. Zooplankton organisms are sensitive to environmental changes and respond immediately to environmental quality. The appearance of Copepoda in different developmental stages may represent an adaptation of the group, as in early stages, organisms can occupy different niches compared to their adult phase [18].

In marine zooplankton, more groups are found among protozoa, microcrustaceans, and rotifers, primarily of the genus Brachionus. The latter is the most resistant to extreme conditions and indicates a negative effect on water quality, reflecting an increase in ammonia, soluble orthophosphate, nitrites, and nitrates [19].

Plankton analysis showed low diversity and richness, which is characteristic of degraded tropical environments. Dominance, diversity, equitability, and richness indices were considered. At point 2 near the mangrove, the cyanobacterium *Pseudanabaena* sp. (N=105) and toxin-producing microalgae dominated (Table 2).

The high dominance of these groups suggests an imbalance in the plankton community, likely reflecting an increase in pollution and environmental degradation over the last six years. The Shannon index, which measures diversity, shows that diversity is relatively low despite the abundance. This is indicated by the predominance of a few species and a smaller variety of taxa, which is common in eutrophic environments.

The Simpson index, which assesses the probability that two random samples will be of the same species, reinforces this observation, indicating a high probability of dominance by a few species over a more balanced diversity. Equitability, which reflects the uniformity in species distribution, confirms that low diversity is accompanied by an uneven distribution, where some species, such as cyanobacteria and microalgae, dominate others. This set of indicators reveals an aquatic environment suffering from ecological imbalance and degradation of environmental quality, evidenced by the dominance of potentially toxic species and the presence of parasites at alarming levels. This situation underscores the need for continuous monitoring and interventions to improve the region's environmental health. In the cluster analysis, *Pseudanabaena* sp. stood out

Table 2. Diversity and richness index of plankton from Sauípe Port estuary, Bahia, Brazil, 2023.

Index	Point 1	Point 2
Tax_S	9	8
Individuals	11	113
Dominance_D	0.0364	0.8630
Simpson_1-D	0.9636	0.1370
Shannon_H	2.5090	0.4216
Margalef	3.3360	1.4810
Equitability_1	1.1420	0.2028
Fisher-alpha	23.1500	1.9660
Chao-1	15.36	15.43
iChao-1	20.14	25.84
ACE	24.75	29.00

from the other species due to its abundance (N=105) at point 2 through the dissimilarity index (Euclidean distance), an effective tool for understanding general differences in the community. The samples are grouped based on the relative abundance data of species, indicating correlation patterns in the structure of the plankton community [19]. Based on the presence and absence of species, the correlation coefficient and the Jaccard evenness index allow for the grouping of similar samples, facilitating the understanding of which areas or conditions share similar biodiversity patterns (Figure 5).

The sampling points 1 and 2 did not differ (F=0.95 df=31, p=0.34) in their means in the variance analysis, raising a public health alert due to the presence of human parasites indicating environmental degradation in the Sauípe Port estuary caused by sewage, which contraindicates its use for tourism purposes.

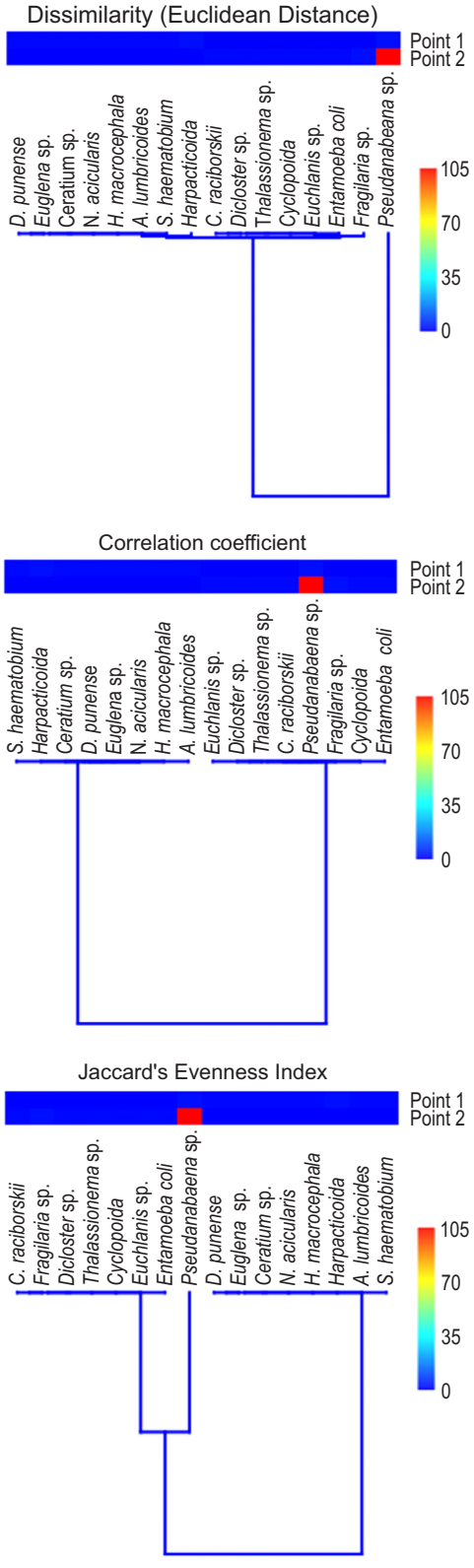
Conclusions

The evaluation of phytoplankton species biodiversity is not straightforward, despite many species being relatively well-known, due to the scarcity of taxonomic studies on this large group, which plays a significant role in aquatic ecosystems by interfering and serving as a bioremediation. The occurrence of potentially toxic Cyanobacteria species, such as *Pseudanabaena catenate*, highlights the need for proper site management to avoid harmful blooms in this community. These blooms could negatively affect aquatic organisms captured by the fishing community for human consumption. The release of cyanotoxins, which are risks to public health, requires continuous monitoring of water quality in the estuary.

There was a higher representation of microcrustaceans, particularly copepods, one of the most important zooplankton in the trophic chain.

The sampling points 1 and 2 did not differ ($p<0.05$). The presence of eggs from the parasite Ascaris lumbricoides and the worm Schistosoma haematobium, even in low occurrence, indicates contamination of the Sauípe Port estuary by sewage,

Figure 5. Cluster analysis of zooplankton species from the Sauípe River Estuary. Entre Rios, Bahia, Brazil, 2023.



raising a public health alert and contraindicating its use for tourism.

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